# MRAM commercialization potential evaluation Research Based on the Chinese Market

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**September 2017**

Abstract

Regarding the Chinese data storage industries, there is an urgent need for a national strategy and new investments as there are new technologies emerging in the global markets. The storage technology commercialization activities are becoming a widespread concern for the Chinese government and their strategic enterprises. The promotion of storage technology commercialization has become a common goal for enterprise and national government strategies. How the potential for commercialization of a storage technology can be assessed, what evaluation index should be used, and what the factors affect the storage technology are the important issues that must be addressed.

This study investigates and evaluate the technical and commercialization potentials of a new data storage technology, Magnetic Random-Access Memory (MRAM), with the aim to provide a systematic technology optimization and decision-making tool for the government and enterprise. This paper systematically reviews the theoretical literatures regarding the commercialization potential of storage technology and the theory of the data analysis method used. Building an original index system for storage technology commercialization potential.

According to this index system, a pre-research questionnaire is designed regarding the storage technology commercialization potential evaluation index system. Combining the index system and the weight of each index, the expert investigation method is used to demonstrate the commercialization potential evaluation of magnetic storage technology.

Key words: storage technologies; commercialization potential; assessment indexes; index weighting; comprehensive assessment

# Acknowledgements

I would like to acknowledge and thank the supervisions of Professor Yongbing Xu, of the Electronics Department and Dr. Dong Li of the Management School. Their continuous guidance, encouragement and support enable me to finish this PhD thesis.

I would like to thank many others have been of great help to me during my studies at York: Mr. Xianyang Lu, Dr. Cong Lu, Mr. Nikolaos Barmpatsalos, Dr. Iain Will from Electronics Department, University of York.

I also appreciate my colleague in Electronics Department, my friends and my girlfriend who support me over the period of my PhD study.

Finally, I would like to thank my parents. It would have been the great difficult for me to reach this stage if I'm without their support.

# Glossary

AHP – Analytic Hierarchy Process

GDP – Gross Domestic Product

GMR – giant magnetoresistance

HR – Information Technology

MRAM – magnetic random-access memory

MTJ – magnetic tunnel junction

MR – magnetoresistance

NP – Net Profit

R&D – Research and Development

RBV – Resource-based View

SPSS – Statistical Package for Social Science

TMR – tunneling magnetoresistance

AMR – anisotropic magnetoresistance

DOS – density of states

STT – spin-transfer torque

SOT – spin-orbit torque

TAS – thermally assisted switching

UMA – uniaxial magnetic anisotropy

PMA – perpendicular magnetic anisotropy

FL – free layer

RL – reference layer

TB – tunnel barrier

SAF – synthetic antiferromagnet

IP – in plane

PP – perpendicular to plane

PVD – physical vapor deposition

MOKE – magneto-optical Kerr effect

PCM – phase-change memory

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# Declaration

I declare that this thesis titled, "MRAM commercialization potential evaluation Research Based on the Chinese Market", and the work presented in it are my own.

I confirm that this work was done wholly or mainly while in candidature for a research at this university and has not been submitted previously for a degree at this or any other university.

I confirm where I have quoted from the work of others, the source is always given. Except for such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Lingyu Yan

# Contents

# Chapter 1 Introduction

This Chapter introduces subject selection background and research significance of this project, the research content and research framework. Moreover, the research objectives will also be presented.

## 1.1 Research background

To research emerging magnetic storage technologies, we start with the broad concept of research emerging technologies. This new technology (ET) is different from ordinary technology, and it can create an emerging industry or changing industries with significant influences on economic structure. The widespread appearance of emerging technologies offers great opportunities to developing countries, to the development of China. Like any other technology, after successful research and development, the new technology must be launched in the market and converted into productivity to realize commercial value, generate profit for enterprises and create wealth for society.

The most essential feature in the commercialization of new technology is the high degree of uncertainty, which has the possibility of giving rise to an emerging industry, or result in failure due to uncertainty in technology, market, competition and other aspects.

For new technology is based on progress of fundamental science or integration of existing technologies, it is inherently complex and difficult to realize, and requires relatively strong fundamental research and development capability and technical integration capacity. Therefore, new technology is often born out of scientific research institutes and universities with high concentration of talents, technologies, information and advanced equipment. However, scientific research institutes and universities are isolated from society to a certain extent, which hampers the conversion of scientific and technological achievements, and results in extreme waste of resources.

Fully and extensively identifying dynamic features of the market, and selecting the right application market that can sufficiently develop and realize commercial values of new technology, will not only yield fantastic returns for the technology owner, but also cause significant impacts on industrial structures brought by the features of new technology or create brand new industries that will fuel national socio-economic growth.

In respect to China, the huge market capacity is the most outstanding feature that distinguishes it from other countries. The scale of many industries in western countries are limited or might not even reach any large scale at all, but Chinese markets have tremendous prospects because of the potential customer base which is massive enough to cultivate a whole batch of enterprises or to allow a new enterprise to grow into a large or extra-large enterprise, as well as providing sufficient space for the realization of commercial values. Taking for example the chips market, China imports more than USD 200 billion in products from the United States and other countries and regions every year. If these products were to be produced in China, the size of the market would be staggering.

McKinsey, a world-renowned consultancy, was the first to come up with the ‘big data era’, saying data has become an important production factor which has infiltrated every industry and business function area today.

The arrival of the big data area is undoubtedly another historic changing. Every major change will bring a rare opportunity to the society, but also a huge impact on some areas. For the memory industry, it is facing unprecedented challenges. Storage and calculation of many data rely on high-performance and high memory as guarantee. Traditional memory, including flash memory, is changing, and new memories are emerging. The development trend of the new type of memory represented by the MRAM which is: super-large capacity, ultra-fast information transmission speed and ultra-high reliability and environmental adaptability.

However, the MRAM’s commercialization is still in its infancy due to the technic issue in the worldwide. Especially in the Chinese market, many experts believe that MRAM has a promising prospect for commercialization as an emerging technology, but there is nobody truly studying the commercialization of MRAM.

This study investigates and evaluate the commercialization potentials of MRAM in the Chinese market.

## 1.2 Research objectives

Breaking through the study in Chinese MRAM market, this dissertation aims to provide further insights into the potential of MRAM’s commercialization in Chinese market. Assessment on commercialization potential of magnetic storage technology provides scientific basis for investment and decision-making related to magnetic storage technology. Magnetic storage technology commercialization potential assessment results would be beneficial to enterprises looking to invest in and convert scientific research achievements by directing them to specific target, and contributive to improve utilization efficiency of corporate resources.

This is a preliminary study of an on-going research project through comparing MRAM's commercialization potential with DRAM and Flash memory. We hope that this study may provide some insights into the way of analyzing the MRAM commercialization potentials for government and enterprise.

# 1.3 Research method

(1) Documentation research approach. Through referencing to relevant documentation on the research domestically and abroad, classifying and re-organizing, conclude the research basis and starting point of this paper.

(2) Theory integration approach. In combination of magnetic storage technology commercialization connotation, technology commercialization process model and risk types, technology commercialization connotation and relevant knowledge, explore and analyze influential factors of the commercialization potential of magnetic storage, and preliminarily establish assessment index system of the commercialization potential of magnetic storage technology.

(3) Questionnaire survey approach. This paper adopts the questionnaire survey approach. Firstly, to determine the assessment index system of the commercialization potential of magnetic storage through experts' survey; then, to determine the index weighting by issuing the consultation questionnaire; and finally, the experts' survey is used to assess the commercialization potential of magnetic storage technology.

(4) Data analysis approach. Firstly, by use of reliability analysis and factor analysis of SPSS software, the reliability and effect of scale of questionnaire A are analyzed; statistics of analysis results is made with the basic description, and

the assessment index system of the commercialization potential of magnetic storage technology. Secondly, the analytical hierarchy process (AHP) with EXCEL function is used to weigh the assessment indexes of the technology commercialization of magnetic storage. Application of the data analysis approach makes the research more empirical.

(5) Instance analysis approach. This paper uses assessing the commercialization potential with the DRAM storage technology as case study.

## 1.4 Contributions

Innovation of the paper is expressed in two fields:

(1) The research discusses influential factors of the commercialization potential of magnetic storage technology in technology dimension, market dimension, support dimension, conformance dimension and validity dimension, and determines assessment index system of the commercialization potential of magnetic storage technology.

(2) The research adopts AHP to weigh assessment index of the commercialization potential of magnetic storage technology, and researches assessment instances of the commercialization potential of magnetic storage technology.

In summary, the research describes the full process of assessment for the commercial potential of magnetic storage technology completely, and helps fill the theoretical gap in the research field.

# Chapter 2 Literature Review

To provide new technology commercialization potential evaluation research strategy, this chapter's literature review focuses on the connotation of new technology commercialization potential, new technology commercialization potential evaluation index, new technology commercialization potential evaluation research method related research, these three aspects. This chapter also expounds the theory of new technology commercialization potential and theory of data analysis method, which provides theoretical support and research foundation for subsequent chapters.

## 2.1.1 Research on the connotation of the new technology commercialization potential

New technology commercialization process follows the general technology commercialization process, which is from the basic knowledge of theoretical research to the product before the industrialization production process and also includes the technology transfer, technology licensing, including the process of creating profit [1]. The theoretical circles bot h at home and abroad have different idea about steps on technology commercialization. Vijay K.Jolly thinks technology commercialization process includes basic research, applied research and development, product development and engineering, production and sales as well as the further research and development [2]. Joseph P. Martino pointed out that the technology change track tends to follow the five stages: theory put forward the feasible, scientific discovery, laboratory, test production and commercialization [3]. Chinese scholar Meng Yan thinks new technology commercialization involves 7 stages: social demand (market), project demonstration (or preparatory exploration test), test development (research and development), middle test, design and manufacture, industrial test (promotion demonstration and technical service), industrial production (application), and influx market [4]. Chinese scholars Yang Renfei and Tong Yunhuan point out the general process of technology commercialization includes 6 stages: technology research, technology development, technology transfer, product concept development, product production and sales and technical commercial success [5].

In conclusion, although the division method is not the same, but from the operation trajectory, technology commercialization is not only a process from idea to technology and product, but also the process from laboratory to market.

The definition of the new technology commercialization potential mainly refers to the potential form of power, energy or function [6].

Magnetic storage technology commercialization potential be the potential of function and energy when the magnetic storage technology commercial has not been developed before. It is a possibility which is a storage technology (products) from the laboratory to the market and realizing the economic profit and social benefit.

In view of the new technology commercialization potential, Chinese scholar Wang Jiwu defined it as a new technology (including product, hardware and software, and process) to realize mass production (application) and the possibility of business profits [7]. This profit potential possibility depends on the sustainable development of the technology itself, and utility of the market potential, conditions of technology commercialization potential, social development suitability, potential social utility, and so on [8]. On this basis, wen-guang lu also points out that the conformity importance factors in the evaluation of new technology is far higher than that of importance in the evaluation of the traditional technology, and used the paired sample *t* test method to verify it.

Based on analysis of the literature on international, determine whether a new technology with commercial potential, should not only consider the technology itself, but also have to realize the mass production of the basic conditions, degree of coincidence of social development plan, the expected economic effects and social effects, etc.

The commercial potential evaluation of magnetic storage technology can use these as the standard to design index system.

### 2.1.2 New technology commercialization potential evaluation index related research

**(1) Worldwide research**

Although the academic study of magnetic storage technology business potential is rare, but foreign scholars conducted many studies from different angles on how to judge the commercial value of a new technology product, which has great reference value. However, the realization of the technical and economic value influenced by many non-technical factors, and economic value only can be realized after the commercialization. Due to the lack of historical data, we can't use the new product output ratio, net present value, payback period, internal rate of return and other traditional economic indicators to evaluate the new technology commercialization potential [9]. Geroge S. Day and Paul J.H. Schoemaker emphasized, evaluating a new technology, managers have to shift focus from the technology itself to determine the potential demand and the research of the main user [10]. The Joint Research Centre of European Commission developed a new technology market potential assessment software (IPTS -TIM) in 1999 [11]. The most important two modules of the software are technology and market evaluation module and economic and financial assessment module. Technology and market evaluation module is mainly from four aspects, including the level of technological development, market potential, the innovation potential, social, and economic and strategic importance. And the economic and financial assessment module mainly analyze technology commercialization and technology transfer may bring economic outlook. F.T.S.Chan, M.H.Chan and N.K.H.Tang put forward technology selection by establishing a subjective criterion (flexibility and quality, etc.) and the objective metric. The objective metric main economic indicator is new technology commercialization net present value estimated respectively in three situations, including pessimism, general and optimal, and comparing technical economy [12]. So Young, Sohn and Tae Hee Moon study the elements of new technology commercialization success from the three aspects (technology itself, the recipient and technology providers) [13, 14].

**(2) Research in China**

In terms of research on potential index assessment of new technology in China, Zhu Ji pointed out that key elements such as technical achievements and human resources, supporting elements such as funding, policy, equipment and facilities, dynamic elements such as science and technology requirements, market-driven forces, government leadership and information interaction, and control elements such as system, rules and regulations, systems and administration ability constitute the four fundamental elements in commercialization [15]. Through collating relevant domestic and overseas documentations, he concluded that the assessment indexes of commercialization potential of new technology include aspects such as technical performance, market requirements, profitability, potential values for users and society, market competitive force, corporate ability equal to the product, consistency in operation objectives, and economic and legal environment. He also designed new technology commercialization potential assessment index system in terms of adaptation to overall industrial development, technical success potential, market and demand forecast and main entities carrying out the commercialization. Lu Wenguang, Huang Lucheng, Wang Jiwu and other scholars concluded that the crux behind the potentials in new technology involves the three aspects of technology potential, market potential (economic benefits potential and social benefits potential), and commercialization conditions potential (potential for satisfying basic requirements and conformity potential). They also designed 25 second-tier indexes based on standards of technical factors, market factors, condition factors, conformity factors and effect factors [16, 17]. Upon this foundation, Lu Wenguang also pointed out that the role of the conformity factor in new technology assessment is much more important than that in conventional technology assessment, and the matching sample t inspection was used to verify this claim [18].

Based on analysis of the literature, determining a new technology whether has commercial potential, not only consider the technology itself, but also whether have the basis conditions to realize mass production, and degree of coincidence about social development plan and the resulting economic effects and social effects, etc.

### 2.1.3 New technology commercialization potential evaluation research method related research

Although looking up many documents, there is no research paper officially assessing the commercialization potential of magnetic storage technology at home and abroad. By reorganizing similar documentation - the documentation related to the commercialization potential of magnetic storage technology - provides reference philosophy for research on the commercialization potential of magnetic storage technology.

**(1) Worldwide research**

Globally, there is no exclusive approach available for assessment on new technology, and the assessment method of other disciplines and subjects is used for reference. In selection of an assessment approach for the commercialization potential of new technology, overseas scholars have adopted the Technology Future Analysis, such as scenario analysis approach and technology roadmap drawing. Discerned from data of these models, the Technology Future Analysis is summarized into subject assessment based on experts' knowledge and objective analysis based on documentation and data, as shown in Table 1. Typical documentation applying the approach includes: Laura M. Meade and Adrien Presley apply analytic network process (ANP) to perform empirical research on selection of R&D projects [19]. Torsten Fleischer et.al. apply the technology roadmap chart to analyze and assess space and aviation technology [9]. Ronald N. Kostoff analyzes electrochemical technology with the bibliometric approach [20]. Jin woo Lee and other scholars propose the comprehensive integration approach of the Delphi survey, ANP and target planning process to select the information system and handle interrelation of the indexes [21]. Through use of the bibliometric approach and the patent analysis approach, and combined with systematic dynamic model, Tugrul U. Daim forecasts fuel, food safety and optical storage technology [22].

Table 1 Classification of Subjective and Objective of Technology Future Analysis

| | |
|---|---|
| Subjective analysis approach | DELPHI survey approach, brainstorm approach, scenario analysis approach, technology roadmap chart, analytical hierarchy process (AHP), analytic network process (ANP), cross-impact method, future wheel process, morphological approach, fuzzy comprehensive judgment method etc. |
| Objective analysis approach | Trend extrapolation, relevant trend analysis, growth limit approach, envelop curve analysis approach (DEA), Fisher-Pry substitution model, Gompertz model, patent analysis approach, text exploration, bibliometric approach etc. |

### (2) Research in China

There are several relevant domestic documentations in China. Through the Delphi survey method, Huang Lucheng, Wang Jiwu and Lu Wenguang established an assessment index system of the commercialization potential of emerging technology into five classes such as technology factor, market factor, commercialization conditions factor, conformance factor and validity factor, but they also conducted empirical analysis with the ANP approach [23]. The research philosophy of both was to establish the index system first, score relevant indexes by experts, and get the final judgment results through data processing. The scoring by experts is subjective and the qualified judgment method is also limited by its use of subjective knowledge and the experience of experts. It is for this reason, in view of objective judgment, Wang Jiwu et.al. comprehensively measured the commercialization potential of emerging technology in fields of maturity, technology opportunity and technology standing with objective data, beneficially supplemented the subjective data, and improved the science and reliability of the technology assessment [24]. Yang Dongsheng described necessity of combination of subjective and objective assessment on the commercialization potential of technology, and established an assessment model of the commercialization potential of emerging technology with combination of subjective and objective assessment [25]. Based on the above, Huang Lucheng further described basic procedures of the approach [26]. Subsequently, Wang Jiwu built the assessment framework on the commercialization potential of emerging technology with the combination of subjective and objective assessments, and conducted empirical research. The assessment framework was composed of preliminary screening by laboratory staff, further screening by senior experts, subjective assessment funnel model finely screened by ANP and the objective assessment model comprised of technology maturity, technology opportunity and technology standing [27]. Ji-Yi Zhou and Yue-Jin Lv used the Grey Clustering Model of AHP to evaluate the commercial potential of emerging technology. They aim at the uncertainty and complexity of emerging technology, a gray clustering evaluation model based on AHP is positioned to obtain the evaluation grade of all commercial potentials of emerging technologies.[80]

Although the above assessment approaches are used to research the commercialization potential of emerging technologies or any selection among them, they are of great reference value for research assessment of the commercialization potential of magnetic storage technology.

Through documentation review and re-organizing, although research of magnetic storage has become a hot topic by industrial scholars, the research on magnetic storage technology is not developed, to research assessment on the commercialization potential. The following is the summary of disadvantages of the research:

(1) Most research on magnetic storage technology remains at the stage of qualified existing technology conditions and prospect forecast. The only research is related to influential factors of magnetic storage technology or the commercialization potential, even without the special research assessment on the commercialization potential of magnetic storage technology; therefore, the decision-makers cannot be guided to select storage technology optimally in view of technology development.

(2) Even relevant research assessments on the commercialization potential of new technology misses' optimization of the assessment flow. Multi-round questionnaires for the same batch of experts increase fatigue and antipathy of the experts, and cannot guarantee the scientificalness and effectiveness of the survey and research data. The scientific experts' survey flow shall follow the screening process from "rough" to "fine", the first-round screening by the root staff to remove interferential items and remove subsequent workload, and shall be finely screened by the experts.

In summary, gaps and disadvantages of the research provide the opportunity for improvement to the paper.

# 2.2 Theory of commercialization potential of new technology

The section describes the theory of the commercialization potential of new technology of magnetic storage in three aspects, including connotation of the new technology, new technology commercialization process model and risk categories, new technology commercialization potential theory

## 2.2.1 Connotation of commercialization of new technology

The new technology commercialization is classified into broad sense and narrow sense. The technology commercialization in broad sense refers to the process starting from fundamental knowledge research until industrial production of the products, the technology commercialization in narrow sense refers to the process of technology transfer and profit creation in shaping products and technologies, and the technology transfer is at the core stage of commercialization in broad sense.

Before the birth of the commercialization philosophy, domestic scholars in China had called for a process to transform technology into realistic productive force as transformation of technology achievements (or transformation of science and technology achievements). According to definition of transformation of science and technology achievements in the Law of the People’s Republic of China on Promotion of Transformation of Science and Technology Achievements [28]: follow-up testing, development and promotion for science and technology achievements of use values from scientific research and technology until birth of new products, new processes and new materials. Zhu Ji figures out that [6], the technology commercialization refers to the process of launching the new products, new products or new technology service into market and obtaining economic benefits through research and development of technology. Obviously, technology commercialization includes transformation of technology achievements.

Meanwhile, technology commercialization and technology industrialization are two different concepts. According to comments by Chen Yongzhong [29], the technology commercialization refers to the process of making technology achievements practical and commercial through scientific research and technology development. It includes six programs such as fundamental research, application research, development research, production, marketing and consumption and the corresponding five transformation programs, and the five transformation programs are classified into the two transformation process from technology achievements to products (including technology development, pilot plant test, production preparation and trial production), and the transformation process from products to commodities; and the technology industrialization refers to the process of making technology commodities manufactured in scale through production, development, business and management and shape an industry. It relates to industrial expansion and industrial penetration. The technology industrialization has 2 layers of definitions [6]:

(1) After technology realizes commercialization application, shape industries (enterprise groups) led by scaling products (or technology services), create (or satisfy) market requirements and obtain scale benefits; (2) The technology results are applied on relevant industries or upgrade or reconstruct other industrial technologies through industrial penetration. Therefore, the core of industrialization is to expand the business scale, with highlights of technology penetrating into new fields.

### 2.2.2 New technology commercialization process models and risk identifications

**(1) Technology commercialization process model**

Technology commercialization is a continuous, complicated and long-term process. Scholars from worldwide, according to the needs of their research, divided technology commercialization process into different stages, as shown in table 20. Although scholars' phase division methods are not the same, but the main phase line is same, which is technology development → product development→ capacity development → market development.

A. Technology development stage, namely the testing and invention stages. In the laboratory, research and develop the scientific research achievements, shape technology and product idea, prepare technical documentation and demonstrate technology feasibility.

B. Product development stage: namely the product rudiment and pilot testing stage. Complete materialization of technology achievements, and obtain prototype design of the products; conduct pilot testing for preliminary technical appraisal or the science & technology achievements in laboratory, determine and perfect technical specifications (namely product standards and product process codes), obtain technology and process for production or the products for manufacturing and finish production of the technology.

C. Production capacity development stage, namely the production capacity shaping stage. If both the pilot testing goes well and the product prospers, the production line is created, re-built or expanded to produce in large quantities, so that it may enter the market and start Internet sales.

D. Market development stage, namely the commercialization application promotion stage. Perform large-scale marketing, perfecting and stabilizing of the marketing network, increase market share, obtain considerable investment payback, and achieve original intention of the technology commercialization.

The process covers the process from technology development to market, including the entire process of the technology from birth to maturity. The four processes are sequential and are not isolated but are dependent upon one another.

In consideration of research objects and contents of the paper, the research focuses on production capacity development and marketing development after shaping of product prototype, and analyzes main factors influencing the commercialization potential of magnetic storage technology.

Table 20.Technology commercialization theory and process

| Presenter | Theory | Process |
|---|---|---|
| Bright(1984)[81] | Bright's stage | 1. Scientific proposal, discovery, identification of needs and opportunities.<br>2. Proposals for theoretical or conceptual design.<br>3. Experimental verification of theory or design concept.<br>4. Laboratory verification of the application.<br>5. Pre-production<br>6. Commercial introduction or first trial.<br>7. Wide acceptance of a large range of profits, extensive applications, and significant impact<br>8. Mass production |

| | | |
|---|---|---|
| Howrd&Guile,1993[82] | Professional engineer international union's engineering process | 1. The concept<br>2. Technical feasibility<br>3. Development<br>4. Commercial confirmation and preparation of products.<br>5. Mass production<br>6. Product service |
| Ruiqing Xu(1997)[83] | Secondary innovation model | 1. Technical selection<br>2. Technology import<br>3. Digestion and absorption<br>4. Improvement<br>5. Technological innovation.<br>6. Technical services |
| Zhennan Sui, Zhenping Wang(1998)[84] | The theory of scientific research achievements transformation process. | 1. Laboratory stage (technical document, prototype or sample)<br>2. Transition stage (commercialized technology or process, products that can be put into production)<br>3. Commercialization stage (mass production enters the market, technological innovation results diffusion) |
| Yan Meng(2000)[4] | New technology transformation stage theory. | 1. Social needs (market forecast)<br>2. Program demonstration (exploration test or pre-research)<br>3. Experimental development (research and development)<br>4. Pilot test (design and trial)<br>5. Industrial test (promotion demonstration and technical service)<br>6. Industrial production |

| | | |
|---|---|---|
| | | (promotion and application)<br>7. Into the market |
| Jolly(2001)[2] | Linear theory of technology commercialization process | 1. Basic research<br>2. Applied research and development.<br>3. Product development and engineering.<br>4. Production and sales.<br>5. Further research and development. |
| Tong Chen, Hongpo Tian(2001)[85] | The industrialization path of new technology | 1. Research and development of scientific research achievements.<br>2. Conducted pilot production of the obtained technical form products<br>3. Technology entrepreneurship<br>4. Marketization of technology |
| Martino(2003)[86] | Trajectory of technological change | 1. The theory put forward<br>2. Scientific discovery<br>3. Laboratory feasibility<br>4. Trial production<br>5. commercialization |
| Yunheng Tong(2011)[87] | Theory of new technology commercialization | 1. Technology research<br>2. Technology development<br>3. Technology transfer<br>4. Product concept development<br>5. Product production and sales.<br>6. Commercialization of technology is successful. |

### (2) **Types of commercialization risks of new technology**

Transformation of technological achievements is risky. Such risks originate from the dynamics of technology development, piloting of strategy, substantial investment of funds and competition of market. According to Wang Jiwu [17], ordinary risks in technology commercialization include: technology risks (uncertainty of success of technology research and development, uncertainty of technology prospects, uncertainty of technology effects, uncertainty of technology service life), market risks (uncertainty of market capacity, uncertainty of market penetration time, and market price risks), capital risks, management risks and environment risks (talents, intellectual property rights and policy etc.). And according to Xu Xuebin and Gu Jianfei, the technology commercialization risks are classified into strategy hierarchy risks, operation hierarchy risks and root hierarchy risks [30], which are shown in Figure 1 after organizing.

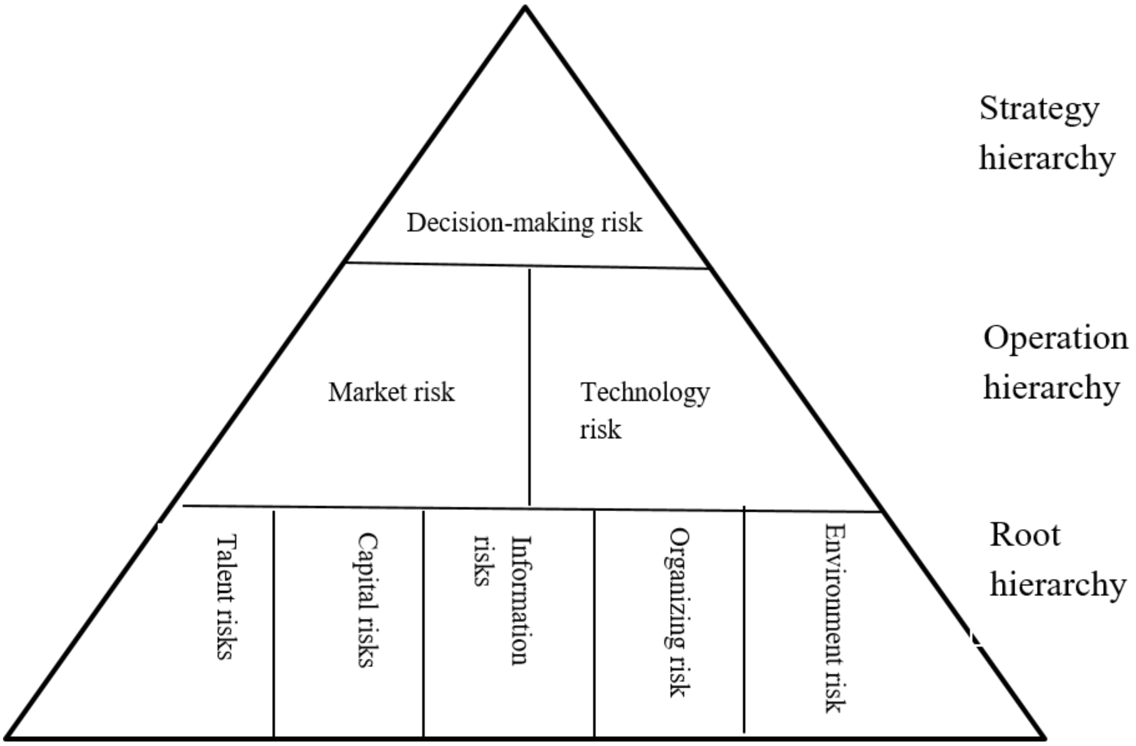


Figure 1 Pyramid Model of Technology Commercialization Risks

i. **Strategy hierarchy risks**.

The strategy hierarchy risks are the management and decision-making risks. The decision-making risks are of amplification effects, regardless of market opportunity and traps, business profits or losses will be multiple. The technology commercialization decision-making involves overall activities. If it is of overall philosophy or strategy awareness, incorrect decisions will be made. For example, ignoring environmental protection industry policy, missing strategy opportunity or incorrect technology market positioning may result in great economic losses.

ii. **Operations level risk**.

A. Market risks. Main sources of market risks include: (1) The market technology is not developed, although the product idea has been deeply impressed upon people, and specific uses cannot be found due to high price or other factors; (2) The market may reject or delay accepting technology achievements. Time lag between the achievements launched to market and the customers' effective requirements results in difficulty in recovering investment;(3) Too many uncertain factors of the market technology, without relevant data history to make quantified analysis of the market technology, difficult forecast of market scale and unforeseeable market growth rate;(4) Unforeseeable competition between new technology market and the conventional market.

B. Technology risks. Main sources of the technology risks include:(1) Immature technology, many problems are found when implemented; (2) The existing production equipment, production system, talent structure are incompatible with the new technology; (3) Not clear technology prospect, the investor is not confident in continuing investment; (4) Difficult or failing technology transaction and technology transfer; (5) The technology talents' lack of innovation, difficulty in transformation of technology achievements; (6) The technology effects (including economic and social issues) are hard to estimate; (7) Low technology level, low science & technology content, easily simulated by competitors or replaced by other technologies.

### iii. Root hierarchy risks.

A. Talent risks. The technology commercialization needs many management talents and technology talents with professional knowledge and skill; otherwise, technology commercialization cannot succeed.

B. Fund risks. All stages of the technology commercialization cannot be developed without support from fund chain. Insufficient funds results in rejection of the technology program, program abortion or project progress obstacle.

C. Information risks. Insufficient information collection and processing capacity, and ineffective collecting, analyzing and organizing of customers' requirements and other external information lead to incorrect technology commercialization decision making and subsequent economic losses.

D. Organizing risks. Transformation of technology achievements establishes the corresponding organizing structure. The organizing system optimizes resources required for technology commercialization, and improper organizing structure results in serious internal losses, imbalance of resource allocation and failing commercialization.

E. Environment risks. The environmental risks include policy risks and social risks. Restrictions by environmental protection laws may prevent production of some technology achievements and may result in failure to transform the technology achievements into tangible assets; consumers may reject emerging technologies and new products.

The above commercialization risk factors and knowledge will be considered in discussing influential factors of the commercialization potential of magnetic storage technology and building original index system of the commercialization potential assessment of magnetic storage technology.

### 2.2.3 Theory of the commercialization potential of new technology

**(1) Connotation of the technical commercial potential**

The technology commercialization potential is regarded as the functions not developed before technology commercialization and reflects the possibility of technology achievement transformation, large-scale production, economic benefits and social benefits. Such possibility can be expressed as follows [8] [24]:(1)sustainable development potential of technology, including technology advancement, technology maturity, potential for preparing technical standards and the possibility of acquiring intellectual property rights etc.;(2)economy and market utility, not only including economic benefit potential for controlling investment risks and guaranteeing investment proceeds, but also including potential for value increasing and use convenience etc.; (3)commercialization resource guarantee, including accessibility of infrastructure, capital, talent and other basic conditions and supplementary assets; (4)potential adaptable to social development, including adaptation to market requirements and conformity of science and technology policy, technology foreseeing and social development planning; (5) potential for social utility, including potential for raising the living standard, increased employment and environmental protection.

Technology transformation with the commercialization potential is expressed in 2 points: I. Mass production; II. After mass production, yield economic benefits and social benefits. Both are required. Only when both conditions are available, technology commercialization can succeed and the potential of technology value can be yielded.

In summary, the assessment on the commercialization potential of technology is to select the technology with relatively higher comprehensive effects in technology potential, market potential, conformance conditions potential and social effects, and lay a foundation for subsequent research.

**(2) Features of the technology commercialization potential**

In combination with domestic and foreign documentation, the technology commercialization potential has the following features:

Firstly, the dynamics of the technology commercialization potential. The technology commercialization potential refers to the possibility of realizing economic profits and social benefits in the future. If the potential is larger, the possibility is larger, the opportunity of accessing funds is more likely, and the probability of commercialization is larger; otherwise, if the potential is smaller, the probability of commercialization is smaller. Whether one technology is developed from laboratory to market and brings economic and/or social benefits is related to many factors, such as technological conditions (like technology advancement, maturity and operability), market conditions (acceptability of market to new products, public consumption habits and consumption culture), policy support trends and support of fundamental market conditions. These factors change dynamically; therefore, the potential of the same technology is different in different periods.

Secondly, future sense of the technology commercialization potential. The technology commercialization potential is a concept of future tense and has the meaning of future. Before commercialization, the technology cannot realize its economic and social values, and assessment on the commercialization potential depends on experts' experience and relevant history data. The magnitude of the potential cannot be explained and can only be verified after realization of technology values after commercialization. So, the technology commercialization potential has the feature of future tense.

Thirdly, the relativity of the technology commercialization potential. The technology commercialization potential is a relatively comparative concept, and is not an absolute concept. Simply speaking, the score of 5 is an ideal value, however a score of 4.90 technology commercialization potential, does not mean commercialization prospect of the technology is 4.90, it only indicates that the commercialization prospect ranks high when compared within the same kind of technology, or the ranking is distinguished in accordance with fuzzy judgment by experts. Compared with different technologies, the potential score may be changed. Even for the same technology, the influential factors vary in different countries and are dynamic, the potential remains the same, so the technology commercialization potential is foreseeable.

Fourthly, the foreseeability of the technology commercialization potential. Original intention of “technology foreseeability” is to help maximize the technology interests of the economy and society through research science, technology, economy and long-term development of society in the future. The objective of technology foreseeing is the “general new technology”, namely the technology of pre-competitive stage [31].

## 2.3 Theory of data analysis approach

The data analysis approaches involved the research include reliability analysis approach, validity analysis approach and analytic hierarchy process etc. The reliability analysis approach is used to measure reliability of measurement scaling; the validity analysis approach is used to measure validity of measurement scaling; and the analytic hierarchy process is used to solve index weighting.

### 2.3.1 Reliability analysis method

Reliability is used to measure precision, consistency and stability of scale, and reflect extent of the measurement tool (scale or questionnaire) measures the tested issues stably. The usual reliability indexes include test-retest reliability, inter-scorer reliability, equivalent-form reliability, split-half reliability and internal consistent reliability.One questionnaire is surveyed by identical person for the same group at different time twice, and the extent of consistency of the scoring in twice is called test-retest reliability; one questionnaire is surveyed by different surveyors for the same group, and the consistency between scorers is called inter-scorer reliability; the same group of surveyed persons are invited to fill two equivalent questionnaires (expressed in different forms), relevancy between results of the two questionnaires is called equivalent-form reliability; the questionnaire (scale) is split into half, and relevancy of score of the split questionnaire is called split-half reliability (the split-half reliability is applicable to scale with many issues, and the split-half scale is of homogeneity of variance); the inter-scorer reliability is an expansion of split-half reliability, reflects relevancy of issues in the scale, tests whether the scale checks one idea, namely the issues composing the scale are of relatively higher consistency [32].

Basic principle of inter-scorer consistency reliability (hereinafter referred to as reliability analysis) is that firstly, describe and make statistics of the issues, compute simple relevancy factor of the issues, relevancy factor of the remaining issues after removal of one issue, then analyze internal reliability preliminarily, and judge validity of the scale in combination with the reliability factor [33].

Cronbach's $a$ coefficient is a common method used to measure internal reliability of measurement scale. The calculation formula is $a = \frac{K\overline{r_{ij}}}{1+(K-1)\overline{r_{ij}}}$ .

In the formula $r_{xy} = \frac{\varepsilon(x-\bar{x})(y-\bar{y})}{\sqrt{\varepsilon(x-\bar{x})^2(y-\bar{y})^2}}$ , $K$ is the number of items that constitute the scale. $\overline{r_{ij}}$ is the mean value of the correlation coefficient $r_{ij}$. Cronbach's $a$ coefficient is between 0 and 1. The higher a coefficient is , the higher the reliability of the scale is. On the other hand, the lower a coefficient is, the lower the scale reliability is.

In experience, if $a \geq 0.9$, the scale is excellent. If $0.8 \leq a < 0.9$, the scale reliability is good. If $0.7 \leq a < 0.8$, the scale reliability is acceptable. If $0.6 \leq a < 0.7$, the scale design has few problems, but it still has some reference value. If $a < 0.6$, The scale design has a lot of problems and should be redesigned. [88]

## 2.3.2 Validity analysis method

Validity is used to measure precision, reasonability and effectiveness of the scale, and is the extent of reflecting whether the measurement tool measures the tested issues. The ordinary validity indexes include face validity, content validity, criterion validity, and construct validity, etc.

The face validity refers to the extent on the issue description whether describes contents of the tested precisely and is usually judged by experts; the content validity reflects character of the issues to be measured, and highlights breadth, coverage and richness of the scales, and the following shall be taken into account in assessment on content validity:(1)whether the issue philosophy is of the fields to be tested;(2)whether the issues included in the scale cover all aspects of the fields to be tested, and the content validity analysis is to test the empirical deduction from concept to index matches process; the criterion validity is based on the widely accepted scale to test consistency of the new scale and the benchmark scale; the construct validity to check whether the testing tool reflects internal structure of concept and topics, reflect the scale structure matches the tabulation philosophy, and the internal composition is consistent with fields of pre-measurement.

Factor analysis is the commonly used method for testing the structure validity. Reliability is the necessary condition for validity, but is not sufficient condition. Validity is low due to the lower reliability, but high reliability can't make validity higher. The reliability is high due to high validity, but low validity can't make reliability lower. So, only the reliability and stability inspection of scale must be making reliability analysis and validity analysis at the same time can guarantee the reliability of the survey data and scientific of the analysis conclusion

### 2.3.3 Analytic hierarchy process

Analytical Hierarchy Process (hereinafter referred to as AHP) is a multi-criteria decision-making process proposed by the famous American operation research experts Thomas L Saaty in the 1970s. The process features building one hierarchy structure model after deeply analyzing essence of complicated decision-making issues, influential factors and the intrinsic relationship, less quantitative data mathematizes decision-making and thinking process and provides simple solutions for solving complicated decision-making issues with multiple targets, multiple codes or without structural features. The AHP is particular applicable to situations that human's qualifying judgment in dominant and the decision-making achievements not directly measured easily [34].

As a kind of systematic and hierarchical analysis process with combination of qualification and quantification, it is practical and valid in handling complicated decision-making issues; therefore, it is extensively used in social, economic and scientific management fields.

Implementation procedures of the analytic hierarchy process are detailed as follows:

(1) Build structure model of hierarchical structure;

(2) Establish judgment matrix group

(3) Solve weighting vector of single judged matrix;

(4) Judge consistency inspection of matrix;

(5) Solve weighting vector of matrix group by many people with the same code;

(6) Solve composite weighting vector.

## 2.4 Conclusion

This chapter has studied various methods to study commercial potential about the new technology. During this study, we chose the analytic hierarchy process (AHP) for magnetic storage technology commercialization potential evaluation index empowerment. This thesis will use the expert investigation method for the evaluation of the magnetic storage technology commercialization potentials.

# Chapter 3 MRAM Technology

## 3.1 Overview

Magneto resistive random-access memory (MRAM) is a non-volatile technology that has been in development since the 1990s. The memory chip is now ubiquitous in computers, mobile phones, music players, digital cameras and other devices. However, the various memory products have different advantages and disadvantages that determine their application. While existing memory technologies (notably flash RAM and DRAM) continue to increase in density and retain a niche role in the market, the advantages of MRAM are so overwhelming that this technology is expected to eventually become dominant for all applications [35].

Based on the integration of Magnetic Tunnel Junction (MTJ) and CMOS, MRAM technology has the potential to be competitive with existing semiconductor memories. The key superiorities of MRAM are non-volatility, unlimited reading times and high write endurance. In addition, it is anticipated that MRAM could operate at high speeds and low voltages, with comparable densities. Technical challenges for successful implementation of this new technology include control of resistance uniformity, switching behavior of magnetic bits and integration of MTJ with CMOS [36, 37].

### 3.1.1 The TMR effect

The TMR (Tunnel Magnetoresistance) effect is used in the STT-MRAM "reading" process. The first step towards realizing the STT-MRAM technology was taken by Julliere in 1975. In his acclaimed paper [38], he first predicted the TMR effect by studying the conductance of a Fe/Ge/Co junction when the mean magnetizations of ferromagnetic films (i.e. Fe and Co) are parallel and anti-parallel. These measurements of conductance were used to gain insight into the spin polarizations of the conducting electrons. His prediction was observed independently for the first time in 1994 by Miyazaki [39] and Moodera [40]. Miyazaki observed the TMR effect in Fe/Al2O3/Fe MTJ, and Moodera observed the effect in CoFe/Al2O3/X (X = Co, NiFe) MTJ. TMR values of 18% and 11.8% were independently achieved at room temperature (300 K).

An important breakthrough in 2001 attracted the attention of the data storage industry. Butler [41] predicted that a symmetry-based spin filter effect in the MgO barrier would induce a huge TMR effect. This exciting phenomenon was later demonstrated independently by Parkin [42] and Yuasa [43]. Using the sputtering method, Parker fabricated a polycrystalline MTJ device on an amorphous underlayer of highly aligned (100) MgO between two CoFe electrodes, achieving a TMR ratio of 220% at room temperature. Yuasa studied MTJ devices fabricated with single crystal multi-layer thin films Fe/MgO/Fe MTJs, achieving up to 180% TMR at room temperature. This represented a breakthrough for both science and industry; at this scale, the TMR effect could now be used in standard electronics and in the data storage industry.

### 3.1.2 The STT phenomenon

The MRAM "writing" process is facilitated by the STT effect, a mechanism that manipulates the magnetic state of a ferromagnet as first predicted in 1996 by Slonczewski and Berger [44]. As Slonczewski explained, "we predict that a transfer of vectorial spin accompanies an electric current flowing perpendicular to two parallel magnetic films connected by a normal metallic spacer. This spin transfer drives motions of the two magnetization vectors within their instantaneously common place" [45]. In other words, spin-polarized current arises from passing unpolarized current through a magnetic layer. If this spin-polarized current is then passed through a second magnetic layer, its angular momentum will change the orientation of that layer. The phenomenon was first demonstrated in 1999 by Katine [46]. Spin-transfer switching was accomplished using pillars of 100 nm diameter comprising two Co layers separated by a Cu spacer. Based on those findings, the first commercial STT-MRAM products were introduced to the market.

# 3.2 MRAM Technology

## 3.2.1 Giant Magnetoresistance (GMR)

Since 1986, a German research team led by Grünberg has employed nanotechnology to research Fe/Cr/Fe three-fold membrane systems. They found that two iron (Fe) layers exhibit antiferromagnetic coupling when the chromium (Cr) layer thickness is adjusted to a certain value. For different film thicknesses in a certain magnetic field at room temperature, the observed range of material resistance can reach 4.1%. The results of the experiment are shown in Fig.2.

In France, Fert’s research group was independently investigating a Fe/Cr multiple-fold membrane system. Overlapped by ferromagnetic and nonferromagnetic films grown by molecular beam epitaxy (MBE) or by sputtering, this superlattice can contain dozens of Fe/Cr multiple-fold membranes as shown in Fig. 3.

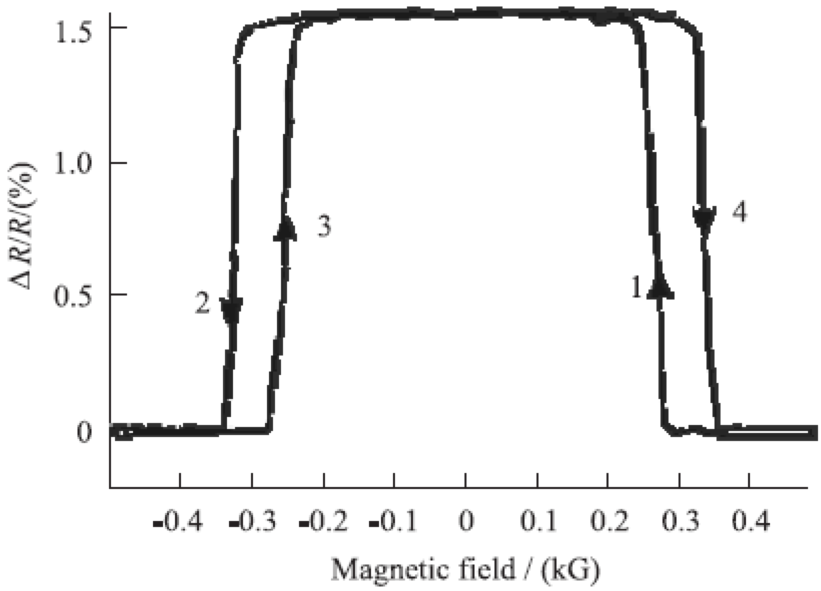


Figure 2. Magnetoresistance changes according to external magnetic field in the Fe/Cr multiple-fold membrane system.

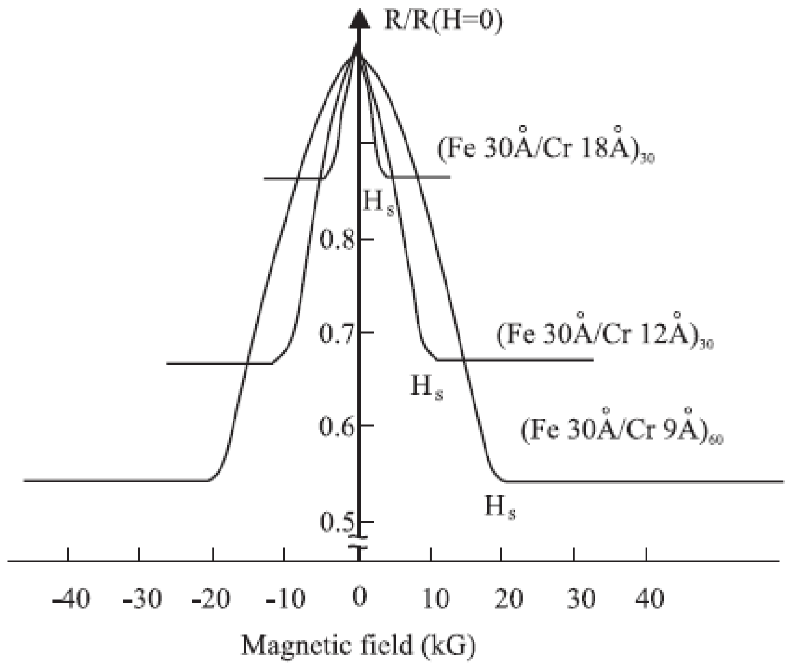


Figure 3. Magnetoresistance changes according to external magnetic field in the Fe/Cr multiple-fold membrane system.

This large magnetoresistance effect, which had never previously been observed in any material, was independently discovered by the two teams. To distinguish it from general magnetoresistance, Fert named this effect (observed only in magnetic multilayer film and granular film structures) the "Giant magnetoresistance effect" (GMR).

**The two-current model**

The two-current model [47] provides a simpler approach to the GMR phenomenon. It states that electrons whose spin is parallel to the magnetization of the metal have a lower resistance than those with antiparallel spin. GMR material exhibits high resistance when the magnetic layers are magnetized antiparallel—that is, when they are antiferromagnetically coupled. In this way, both electronics (spin up and spin down) are strongly scattered at the interface (as noted in the section on Energy Band Dependence), and the structure's net resistance is high. When the layers are parallel-magnetized—that is, ferromagnetically aligned—only one kind of electronic (depending on spin polarization at the Fermi level) is strongly scattered. It follows that the structure's net resistance is less than in the parallel state. The GMR effect is illustrated in Fig. 4.

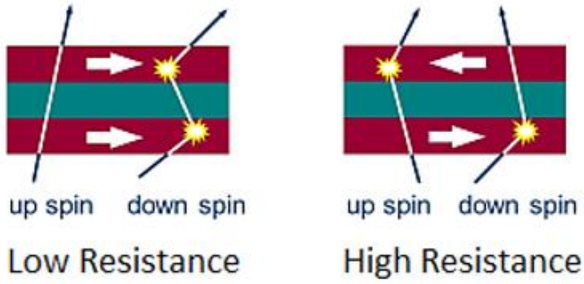


Figure 4. Two-current model. (a) Parallel magnetized layers (b) Antiparallel magnetized layers [47]

The Mott model is used to explain the origins of GMR in qualitative terms. The model involves two main points. First, electrical conductivity in metals is divided into two independent conducting channels: spin up and spin down, which differ in their projection along the quantization axis. Spin-flip scattering in metals is unlikely in respect to the probability of scattering when spin is conserved.

### 3.2.2 The Spin Valve

A spin valve is a device consisting of two or more conducting magnetic materials, whose electrical resistance can change between two values depending on the relative alignment of magnetization in the layers. The change in resistance is induced by the GMR effect as the device's magnetic layers align "up" or "down", depending on the external magnetic field. In the simplest case, a spin valve consists of a non-magnetic material sandwiched between two ferromagnets; one of these is fixed (pinned) by an antiferromagnet that increases its magnetic coercivity and behaves as a "hard" layer while the other is free (unpinned) and behaves as a "soft" layer. Because of the difference in coercivity, the soft layer changes polarity at a lower applied magnetic field strength. On application of a magnetic field of appropriate strength, the soft layer switches polarity, producing two distinct states: parallel low-resistance and antiparallel high-resistance. In 1991, Dieny identified "the ferromagnetic layer/nonmagnetic isolation layer/ferromagnetic/antiferromagnetic layer" spin valve structure and found a low saturation GMR effect, primarily in the "NiFe/Cu/NiFe/FeMn" spin valve [48]. The spin valve structure is shown in Fig. 5.

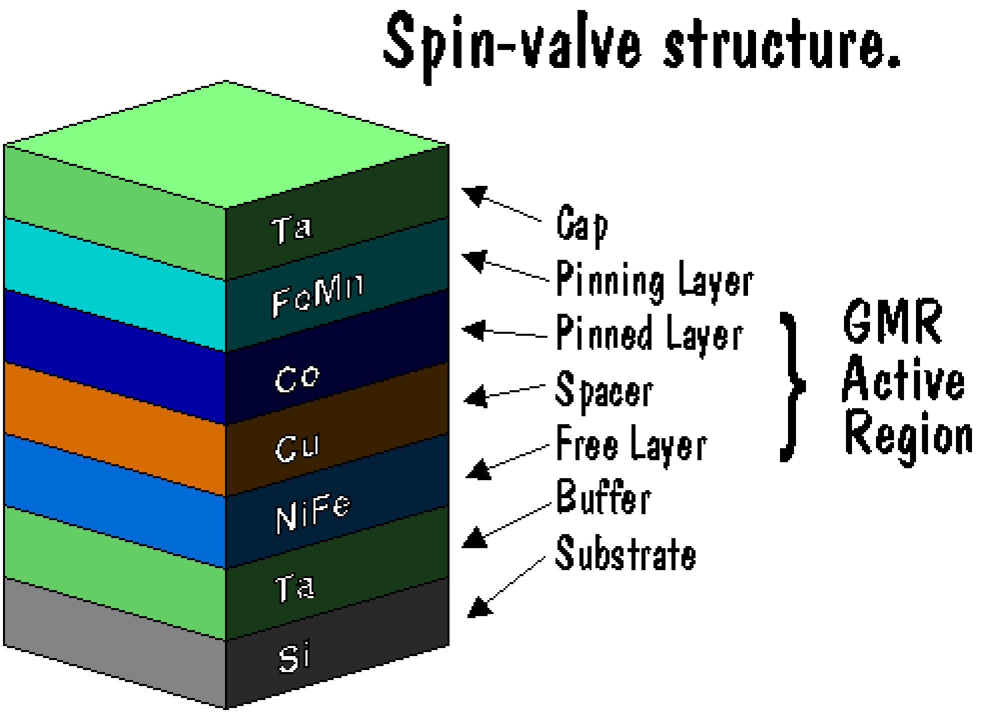


Figure 5. Spin valve structure (from [49]).

## 3.2.3 Tunneling Magnetoresistance (TMR)

Tunneling magnetoresistance (TMR) is an MR effect that occurs in a magnetic tunnel junction (MTJ), which consists of two ferromagnets separated by a thin insulating layer. Magnetic tunnel junctions are manufactured using thin film technology. At industrial scale, film deposition employs magnetron sputter deposition; at laboratory scale, molecular beam epitaxy, pulsed laser deposition and electron beam physical vapor deposition are also utilized. The junction devices are prepared using photolithography. If the insulating layer is thin enough (typically a few nanometers), electrons can tunnel from one ferromagnet to the other. As this process is forbidden in classical physics, TMR is strictly a quantum mechanical phenomenon.

The TMR effect (illustrated in Fig. 6) was originally discovered in 1975 by Jullière (University of Rennes, France) in Fe/Ge-O/Co-junctions at 4.2 K. The relative change of resistance was around 14% and attracted little attention. In 1991, Miyazaki (Tohoku University, Japan) observed an effect of 2.7% at room temperature. Then, in 1994, Miyazaki found an 18% effect in junctions of iron separated by an amorphous aluminum oxide insulator [39], and Jagadeesh Moodera found an 11.8% effect in junctions with electrodes made of CoFe and Co [40]. To date, the highest observed effects (with aluminum oxide insulators) are around 70% at room temperature.

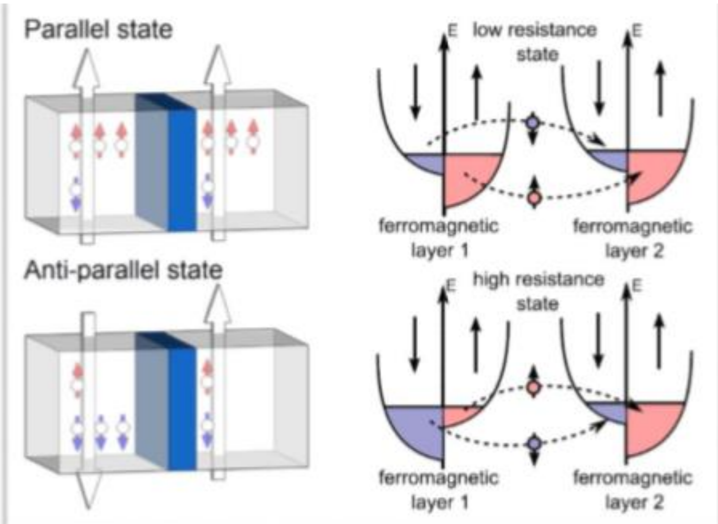


Figure 6. Schematic illustration of the TMR effect. The right-hand image illustrates tunnel ling's dependence on spin. The left-hand image explains this spin-dependent tunneling in terms of DOS [50].

Tunnel barriers made of crystalline magnesium oxide (MgO) have been under development since 2000. In 2001, Butler and Mathon made the independent theoretical prediction that tunnel magnetoresistance can reach several thousand percent by using iron as the ferromagnet and MgO as the insulator [41, 51]. In the same year, Bowen et al. were the first to report experiments demonstrating significant TMR in an MgO-based magnetic tunnel junction [Fe/MgO/FeCo(001)] [52]. In 2004, Parkin and Yuasa succeeded in making Fe/MgO/Fe junctions that exceeded 200% TMR at room temperature [42, 43]. In 2009, effects of up to 600% at room temperature and more than 1100% at 4.2 K were observed in junctions of CoFeB/MgO/CoFeB [53].

Because of its unique advantages, including large magnetoresistance and high magnetic field sensitivity, TMR has significant application potential. TMR materials are used mainly in computer hard disk read heads, MRAM and magnetic sensors. As a head material, TMR's advantages include greater magnetic resistance and magnetic field sensitivity than GMR heads. Its geometric structure means that current runs perpendicular to the membrane surface, making it suitable for thin gaps.

Parallel and antiparallel conductance are expressed mathematically by the following equations.

$$G_p = G^{\uparrow\uparrow} + G^{\downarrow\downarrow} \qquad (6)$$

$$G_{Ap} = G^{\uparrow\downarrow} + G^{\uparrow\downarrow} \qquad (7)$$

Given that conductance is proportional to the density of states (DOS) at the two ferromagnetic layers,

$$G^{\uparrow\uparrow} \propto N_L^{\uparrow} N_R^{\uparrow}, \quad G^{\downarrow\downarrow} \propto N_L^{\downarrow} N_R^{\downarrow}, \quad G^{\uparrow\downarrow} \propto N_L^{\uparrow} N_R^{\downarrow} \qquad G^{\downarrow\uparrow} \propto N_L^{\downarrow} N_R^{\uparrow} \qquad (8)$$

As shown in Eq. (9), TMR ratio is defined as the ratio of change in conductance to minimum conductance.

$$\mathrm{TMR} = \frac{G_P - G_{AP}}{G_{AP}} = \frac{N_{\mathrm{L}}^{\uparrow}N_{\mathrm{R}}^{\uparrow} + N_{\mathrm{L}}^{\downarrow}N_{\mathrm{R}}^{\downarrow} - N_{\mathrm{L}}^{\uparrow}N_{\mathrm{R}}^{\downarrow} - N_{\mathrm{L}}^{\downarrow}N_{\mathrm{R}}^{\uparrow}}{N_{\mathrm{L}}^{\uparrow}N_{\mathrm{R}}^{\downarrow} + N_{\mathrm{L}}^{\downarrow}N_{\mathrm{R}}^{\uparrow}} \quad (9)$$

Polarization at the left and right electrodes is defined as

$$P_{\mathrm{L,R}} = \frac{N_{\mathrm{L,R}}^{\uparrow} - N_{L,\mathrm{R}}^{\downarrow}}{N_{\mathrm{L,R}}^{\uparrow} + N_{L,\mathrm{R}}^{\downarrow}} = \frac{\Delta N_{\mathrm{L,R}}}{N_{\mathrm{L,R}}} \quad (10)$$

It follows that the final TMR ratio is

$$\mathrm{TMR} = \frac{\Delta N_{\mathrm{L}}\Delta N_{\mathrm{R}}}{(1/2)(N_{\mathrm{L}}N_{\mathrm{R}} - \Delta N_{\mathrm{L}}\Delta N_{\mathrm{R}})} = \frac{2P_{\mathrm{L}}P_{\mathrm{R}}}{(1 - P_{\mathrm{L}}P_{\mathrm{R}})} \quad (11)$$

This is how TMR relates to the ‘polarization’ of right and left electrodes (PR and PL). The relation between $P_{L,R}$ polarization and magnetic tunnel junction (MTJ) band structure is, however, not frivolous, as polarization ($P_{L,R)}$ is not necessarily the polarization of the two electrodes’ electronic DOS.

### 3.2.4 Spin-Transfer Torque (STT)

Spin-transfer torque switching on all-metallic stacks was discovered in 2000 by Katine [46]. Its potential was realized early, leading to commercial development of the $AlO_x$-based STT-MRAM cell in 2004 and the MgO-based cell in 2005. Today, most of the biggest memory producers have their own STT-MRAM development programmers.

Spin-transfer torque occurs whenever the stream of spin angular momentum has sources or sinks (i.e. is not constant throughout the sample). The phenomenon can be demonstrated in magnetic tunnel junctions when a spin current created by spin filtering from one magnetic layer is again filtered by another magnetic layer whose direction of magnetization is not collinear. In other words, the stream of spin angular momentum fluctuates when spin-polarized electrons pass through a non-uniform magnetization distribution. While spin filtering, the second magnetic thin film absorbs a fragment of the spin angular momentum carried by the electron spins. The magnetization of the ferromagnetic layer alters the flow of spin angular momentum by exerting a torque on the electron spins, reorienting them to the ferromagnet. In attempting to oppose disturbance of their state, the flowing electrons exert an equal and opposite torque on the ferromagnet. As administered to a ferromagnet by the non-equilibrium conduction electrons, this torque is known as spin-transfer torque [54], as illustrated in Fig. 7.

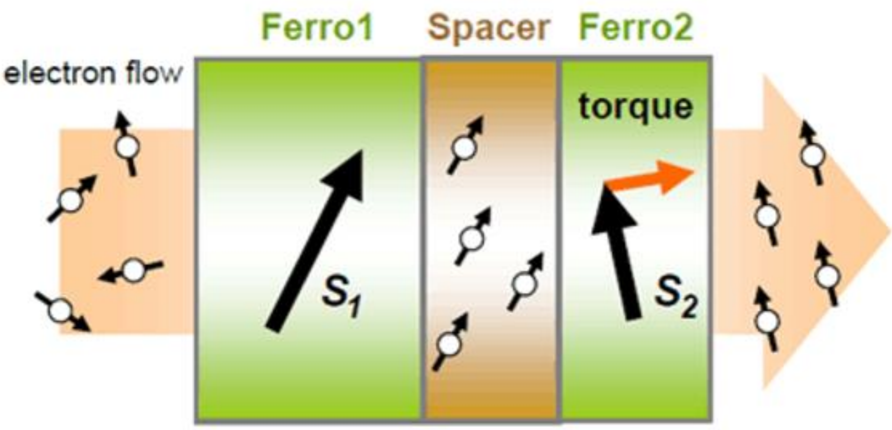


Figure 7. Schematic illustration of spin-transfer torque. The red arrow indicates the direction of the resultant torque on the second layer [55].

### 3.3.1 Categories of MRAM

Since 1996, various categories of MRAM have been developed. These reflect progress in spintronics research, notably the giant TMR of MgO tunnel junctions and the STT phenomenon (Fig. 9). These categories of MRAM use MTJs as elementary storage cells. MTJs essentially comprise two ferromagnetic layers (typically 1–2.5 nm thick) separated by a thin insulating barrier (typically 1–1.5 nm thick). The MTJ's resistance perpendicular to the plane of the layers depends on the relative orientation of magnetization in these two ferromagnetic layers. The amplitude of resistance change between the antiparallel magnetic configuration (high-resistance state) and the parallel magnetic configuration (low-resistance state) defines TMR amplitude.

In most forms of MRAM, the magnetization of one ferromagnetic layers is fixed to provide a reference direction for the spin of the electrons; this layer is called the reference layer. The magnetization of the other layer (known as the storage layer) can be switched between two stable states, parallel or antiparallel to that of the reference layer. As illustrated in Fig. 9, the magnetization of the ferromagnetic electrodes can lie in the plane of the layers or perpendicular to the plane, depending on the choice of materials. For small devices, typically below 50 nm, MTJs with perpendicular magnetization are preferred because their higher magnetic anisotropy provides better information stability. However, these perpendicular-to-the-plane magnetized materials are generally more difficult to grow than in-plane magnetized materials.

In most embodiments, each MTJ is connected in series, using a selection transistor as a switch to control the current through the MTJ. During read, a moderate current is passed through the MTJ (corresponding to a bias voltage across the MTJ in the order of 0.1–0.2 V). The change of resistance between parallel and antiparallel magnetic configurations enables sensing of the storage layer's magnetic state, allowing the stored information to be read.

The various families of MRAM displayed in Fig. 9 differ in terms of how the information is written into memory. Between 1996 and 2004, research and development focused on MRAM written by field (Fig. 9a). Until the discovery of STT switching and its gradual implementation in MTJs after 2004, the only known way of manipulating the magnetization of a magnetic nanostructure (here, the MTJ storage layer) was by means of a magnetic field created by pulses of current flowing in conducting lines below and above the MTJ. This approach led to the commercialization of the first MRAM products (1, 4, 8 and 16 Mbit MRAM chips) by Freescale Semiconductor (and its spinoff Everspin Technologies) in 2006.

Thermally-assisted MRAM (TA-MRAM), developed mainly by Crocus Technology, is an extension of field-written MRAM. In this case, write selectivity is achieved by a combination of temporary heating of the selected cell (produced by the tunneling current flowing through the cell) and a single magnetic field pulse. By using lower magnetic fields and sharing each field pulse among several cells to write several bits at once, the power needed to write these memory elements is significantly less than for conventional field-written MRAM.

Field-written technology is robust and is already used in a range of applications that require reliability, endurance and resistance to radiation, such as automotive and space applications. However, because of electro migration in the conducting lines used to generate the field, the downsize scalability of field-writing in conventional technology is confined to MTJ dimensions of the order 60 nm × 120 nm. In addition, the write field extends along the conducting line where it is produced and diminishes gradually in space in inverse proportion to distance from this line. As a result, unselected bits adjacent to selected bits may sense a significant fraction of the write field, yielding accidental switching of these unselected bits. TA-MRAM allows smaller dimensions to be reached by the field sharing approach, the lower required amplitude of the write field and the alternative write selectivity mechanism.

Since STT-induced switching in GMR metallic spin-valve pillars was first observed (3), interest has increased in using STT as a new MRAM write approach, motivated by the much better downsize scalability offered by STT writing (Fig. 9b). This is because the critical current required to write using STT decreases in proportion to cell area while, in the case of field-writing, it tends to increase. Additionally, STT provides very good write selectivity as current flows only through the selected cells. Interest in STT-MRAM is now focused on out-of-plane magnetized STT-MRAM, which requires significantly less write current than its in-plane counterparts for a given memory retention criterion.

Thermal assistance can also be combined with the STT write approach, exploiting the Joule heating produced by the current flowing through the MTJ tunnel barrier to facilitate magnetization switching. This overcomes a classic difficulty in data storage: the trade-off between memory write ability and retention. Fig. 9c refers to a third category of MRAM in research and development. The purpose of three-terminal MRAM cells is to separate write and read current paths, so increasing memory reliability. These offer new possibilities for the design of memory architecture and for logic applications, with writing based on current-induced domain wall propagation or spin-orbit torque. The next two sections discuss two common functions of the categories of MTJ-based MRAM shown in Fig. 8: storage and read.

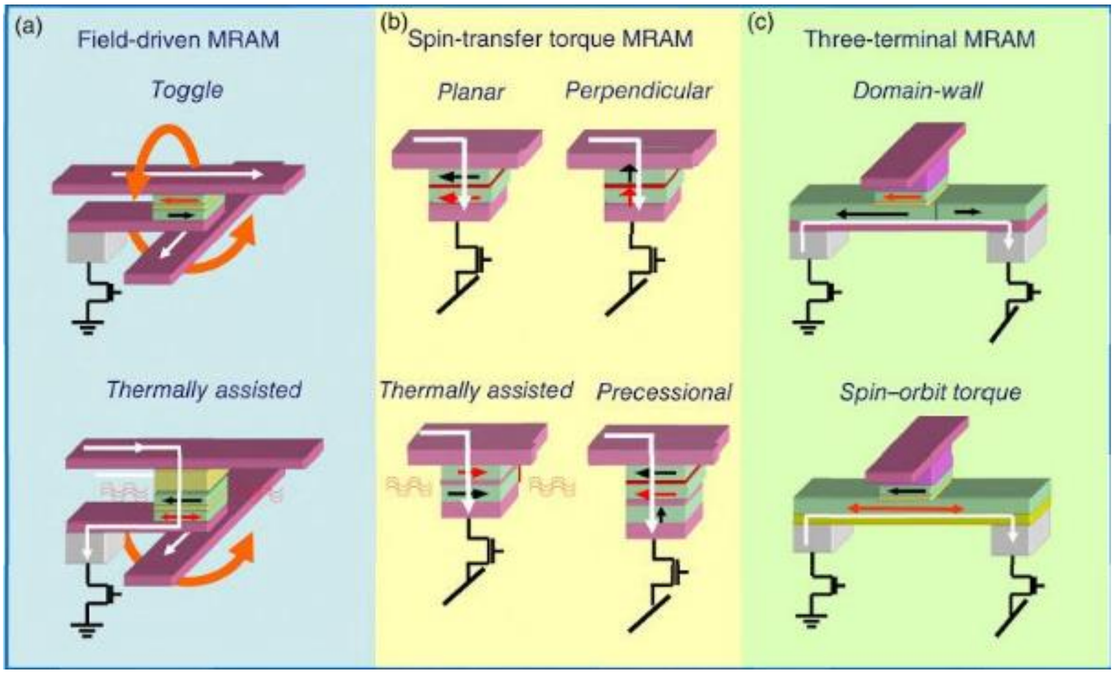


Figure 8. Categories of MRAM developed since 1996: (a) MRAM written by magnetic fields; (b) MRAM based on STT writing; (c) three-terminal MRAM based on domain wall propagation or spin-orbit torque switching.

## 3.3.2 STT-MRAM architectures

As mentioned in the STT-MRAM Technology section, the architecture of the basic STT-MRAM cell comprises a single MTJ with just one tunnel barrier: FL, RL and tunneling barrier layer. Numerous alternative architectures have been proposed to improve the performance of the memory cell. These include alternative two-terminal structures, multi-terminal structures and structures that use alternate physics to improve the fundamental characteristics of the MRAM memory cell. These designs have different structures or use different physical phenomena, or both; two are described below.

### 3.3.2.1 Alternative two-terminal devices

(1) Dual MTJ (DMTJ)

DMTJ consists of two MTJ structures that share the same FL (Fig. 9; an SAF is often used as the RF.

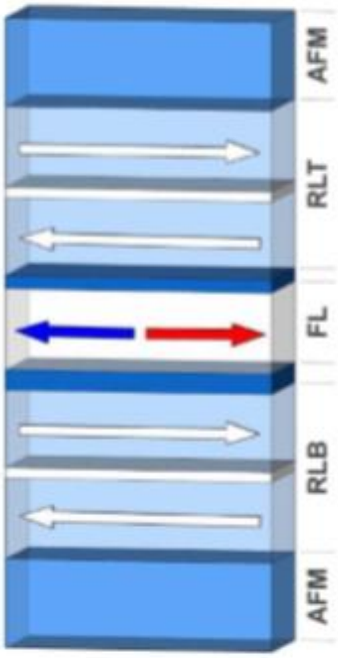


Figure 9. Dual magnetic tunnel junction design: two symmetrical MTJs using the same FL. SAF is used for the RL [50].

(2) Orthogonal MTJ (OMTJ)

The orthogonal MTJ is a two-terminal stack that can potentially reduce the critical current IC without hindering read ability. The unique characteristic of the OMTJ is that, just like DMTJ, it contains two RLs but with perpendicular magnetization (i.e. one IP RF and one PP RF) (Fig. 10).

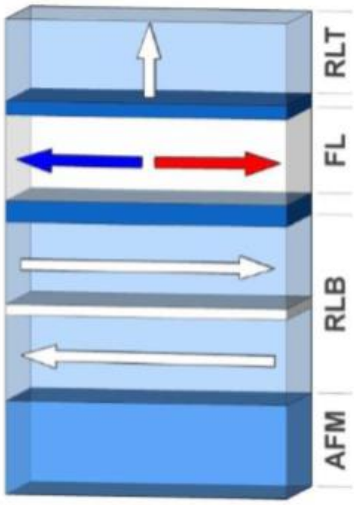


Figure 10. Processional magnetic tunnel junction design [50].

(3) Tilted magnetic anisotropy MTJ (T-MTJ)

It has been experimentally observed that the switching delay of the STT-MRAM cell in the precession regime relates directly to the initial angle due to thermal fluctuation [56]. Aside from the magnetization of the FL, the structure of the T-MTJ cell is the same as the conventional MTJ design. As depicted in Fig. 11 the easy axis of the RL is tilted at angle θ. As a result, the initial torque exerted on the FL is significantly diminished, and the power required for the write operation is also reduced.

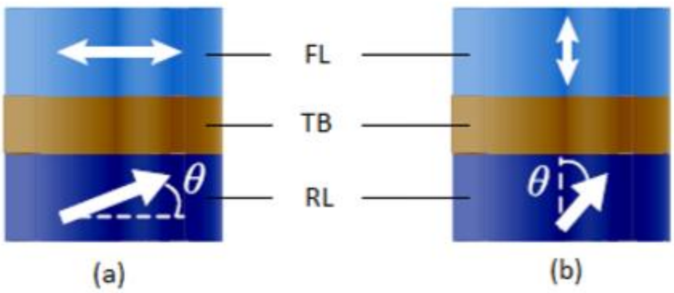


Figure 11. T-MTJ structure for (a) in-plane magnetization and (b) perpendicular magnetization.

### 3.3.2.2 Multi-terminal devices

Domain wall MTJ (DWMTJ)

While the RL and tunneling barrier of the DWMTJ are the same as in the basic MTJ, the FL is quite different. As shown in Fig. 12, it is divided into three distinct parts. The regions on the two edges of the layer have fixed magnetizations that are antiparallel to each other. The magnetization of the central region is free, and the domain wall moves according to the write process. The speed of domain wall motion can reach 50 m/s, making it suitable for high-speed write operation; this is also referred to as 'domain wall stripe'. Perpendicular magnetization is used in both FL and RL because of the low critical current required as compared to enplane magnetization. The physical size of the three-terminal device structure requires more space than conventional MRAMs and so exhibits low area density, with a scalability limit of 12F2 [57].

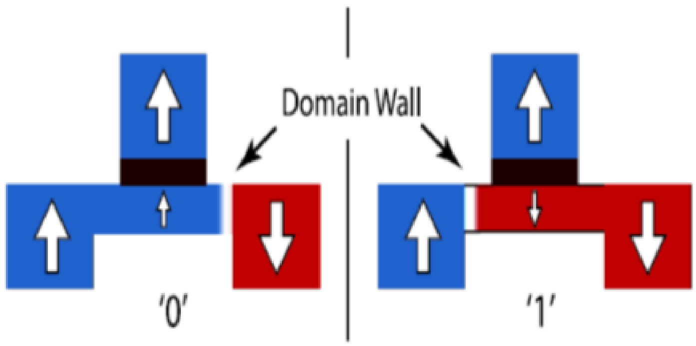


Figure 12. DWMTJ: possible magnetizations. The memory cell state (i.e. data stored) is represented by the magnetic orientation of the central region, right below the spacer layer [58].

# 3.4 The current memory device

## 3.4.1 Dynamic random-access memory (DRAM)

Dynamic random-access memory (DRAM) is the memory type most commonly used in desktop and larger computers. Each elementary DRAM cell comprises a single MOS transistor and a storage capacitor (see Fig. 13). Each storage cell contains one bit of information. However, this charge leaks off the capacitor because of the sub-threshold current of the cell transistor and must be refreshed several times each second.

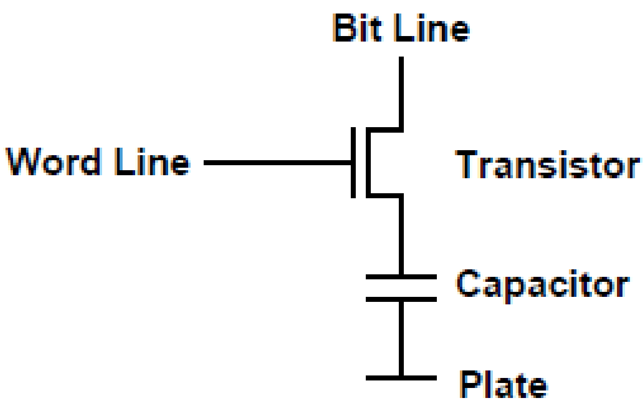


Figure 13. Dynamics random access memory (DRAM) cell.

DRAM works by sending a charge through the appropriate column (CAS) to activate the transistor at each bit in the column. When writing, the row lines specify the state the capacitor should take on. When reading, the sense amplifier determines the level of charge in the capacitor; if this is more than 50%, it is read as a 1; otherwise it is read as a 0. The counter tracks the refresh sequence based on which rows have been accessed in what order. The total length of time this takes is so short that it is expressed in nanoseconds. Fig.14 shows a simplified DRAM diagram.

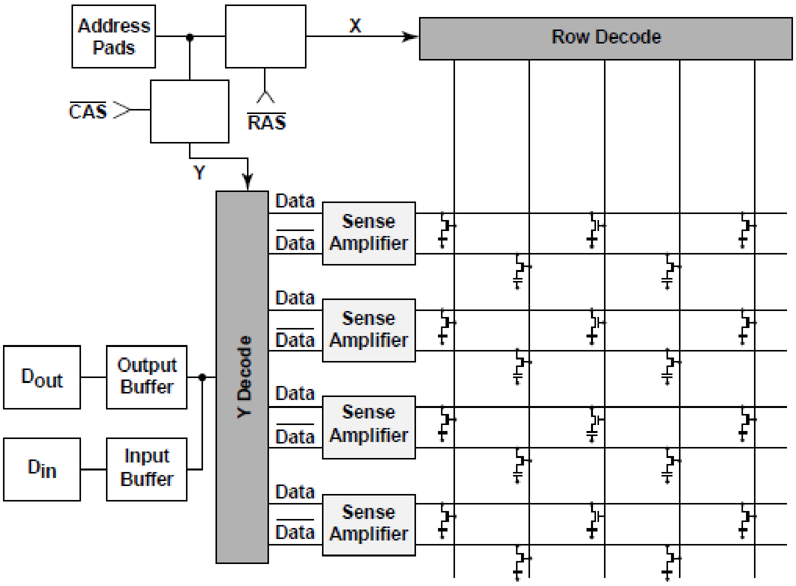


Figure 14. Simplified DRAM diagram (from [59]).

### 3.4.2 Ferroelectric random-access memory (FRAM)

Ferroelectric random-access memory (FRAM) is a high-performance, low-power, non-volatile memory type that combines the benefits of conventional non-volatile memory types (Flash, EEPROM) and high-speed RAM (SRAM, DRAM). This universal memory outperforms existing types like EEPROM and Flash, consumes less power, is many times faster and exhibits greater endurance in multiple read-and-write operations. While the maximum number of read/write cycles for Flash and EEPROM is about 100,000, the lifetime of FRAM memory is essentially unlimited, with more than 1 trillion ($10^{13}$) read/write cycles.

FRAM stores information using polarized ferroelectric film material placed between two electrodes. The FRAM cell structure is like the transistor and capacitor structure of a DRAM cell but does not require the same high programming voltages as Flash or EEPROM. This means that FRAM offers non-volatile data storage but is significantly more energy-efficient than other conventional non-volatile memories. Specifically, FRAM uses ferroelectric film as a capacitor for storing data and commonly uses PZT ($Pb[ZrTi]O_3$), which has a perovskite-type structure ($ABO_3$) (Fig. 15. When an electric field is applied, the Zr/Ti atom shifts up or down, and this polarization remains when the electric field is removed. This is the property that provides non-volatility and reduces the power requirement for data storage.

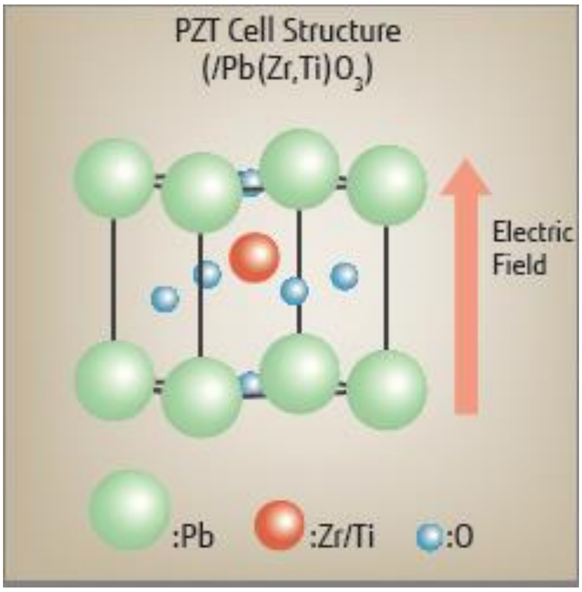


Figure 15. PZT cell structure.

### 3.4.3 Static random-access memory (SRAM)

Static random-access memory has stationary and access functions that can save data without refresh. Although SRAM exhibits high performance, it also has some disadvantages, including low integration level, large volume and large power consumption. Because SRAM is a static memory cell, it has more parts and takes up more space than a dynamic memory cell. That means less memory per chip, making SRAM more expensive.

The SRAM cell consists of a bi-stable flip-flop connected to the internal circuitry by two access transistors (Fig. 16. When the cell is not addressed, the two access transistors are closed, and the data is kept in a stable state, latched within the flip-flop. The flip-flop needs the power supply to retain the information. While the data in an SRAM cell are volatile (i.e. are lost when power is removed), the data do not “leak away” as in DRAM, and no refresh cycle is needed.

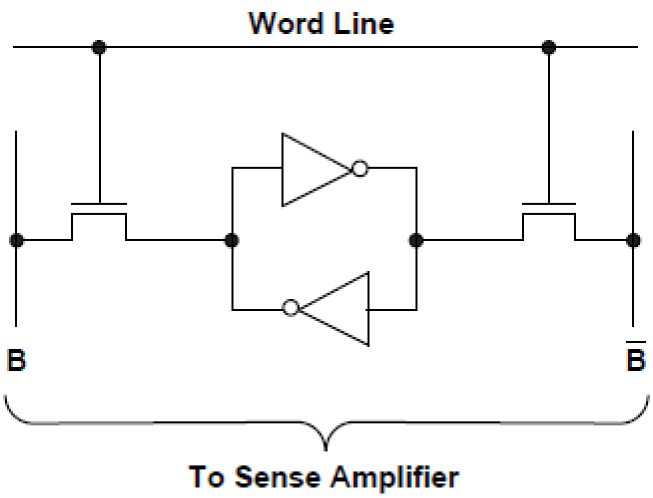


Figure 16. SRAM Cell (from [60]).

### 3.4.4 Flash memory

Flash memory technology is a mix of EPROM and EEPROM technologies. The term “flash” refers to how a large chunk of memory can be erased at one time. This distinguishes flash devices from EEPROMs, where each byte is erased individually. Flash is now a mature memory technology and competes strongly against other non-volatile memory types such as EPROMs and EEPROMs, as well as some DRAM applications. There are two forms of flash memory: NOR (not or) and NAND (not and). These names refer to the type of logic gate used in each storage cell. Flash memory wears out after multiple erases, with oxidation due to wear on the insulating oxide layer around the charge storage mechanism used to store data.

### 3.4.5 Comparison of MRAM and Redox RAM

Redox RAM combines good potential for scaling below 10 nm generation with fast read and write times (<10 ns) and relatively low write current (in the microampere range). It is stackable in three-dimensional cross-bar architectures and offers multilevel capabilities by controlling the growth or dissolution of conducting filaments, which determines cell resistance. However, the underlying physical mechanisms are based on statistical phenomena that are difficult to control at dot scale, leading to relatively large dot-to-dot variability. Predictive models of reliability are more difficult to establish for this technology, and their endurance (∼108 cycles) is sufficient for flash-type applications but not for working memory in microprocessors, which require > 1015 cycles. Because it allows continuous variation of resistance between a minimum and maximum value in hysteretic fashion, redox RAM seems best suited to intermediate storage class memory applications that fall between hard disk drives, solid-state drives (SSD) and DRAM and memristor applications.

Today, STT-MRAM seems the most credible candidate for embedded flash and SRAM replacement, combining CMOS compatibility, high retention time (10 years), endurance (> 1015 cycles), and fast write/read time (1–30 ns, depending on embodiments). A further goal is DRAM replacement, although the technology is not yet mature enough for this high-density application. The main difficulty relates to the etching of MTJ stacks at small pitch (sub-20 nm) and the associated cell-to-cell variability. This variability is caused mainly by edge defects generated during patterning of the cells. Whenever the MgO barrier is damaged by patterning, this yields local changes in barrier resistance, tunnel magnetoresistance, magnetic anisotropy and, correlatively, cell retention. Redeposition on the MTJ sidewalls during etching also contributes to variability. As the number of laboratories (including major equipment suppliers) working on this technology has increased substantially, technological progress is much faster. Table 2 compares various non-volatile memory types.

Table 2 Performance comparison of various non-volatile memories [61]

| | SRAM | eDRAM | DRAM | eFlash (NOR) | Flash (NAND) | FRAM | PCM | STT-MRAM | RRAM |
|---|---|---|---|---|---|---|---|---|---|
| Endurance (cycles) | Unlimited | Unlimited | Unlimited | $10^5$ | $10^5$ | $10^{14}$ | $10^9$ | Unlimited | $10^9$ |
| Read/ write access time(ns) | < 1 | 1-2 | 30 | $10/10^3$ | $100/10^6$ | 30 | 10/100 | 2-30 | 1-100 |
| Density | 18.4 | | 20.3 | | 0.8 | | | 0.0021 | |
| Write power | 0.6 | | 1.8 | | 0.025 | | | 0.08 | |

## 3.5 Main Applications of MRAM

According to recent market research reports, solid-state memory constitutes a market of over $50 billion, while the nonvolatile memory (NVM) segment is much smaller. Most laptops nowadays use NVMs, which retain data when the power is off, in the form of a solid-state drive in place of an HDD. The now ubiquitous smart cell (mobile) phones and other handheld devices also use NVM, but there is a trade-off between cost and performance. The cheapest NVM is Flash memory, which, among other uses, is the basis of small, portable Flash memory sticks. Flash memory, however, is slow and has a limited cyclability of 105 cycles, sufficient for many storage applications ranging from memory sticks to digital camera memory to SSDs, but much lower than that of redox RAM or STT-MRAM.

Besides computers, today's portable electronics have become intensively computational devices as the user interface has migrated to a full multimedia experience. To provide the performance required for these applications, the portable electronics designer uses multiple types of memory: a medium-speed random-access memory for continuously changing data, a high-speed memory for caching instructions to the CPU, and a slower NVM for long-term information storage when the power is removed. Combining these memory types into a single memory has been a long-standing goal of the semiconductor industry. With such a memory, computing devices would become much simpler and smaller, more reliable, faster, and less energy-consuming.

As a result, advanced NVM chips are expected to see phenomenal growth in the next few years, with the global market increasing from $209 million in 2012 to

$2,028 million by 2018 [62]. This will occur in many applications: embedded system- on-chip (SOC) cards; radio-frequency identification (RFID) tags used in goods transported by high-speed detection conveyors; smart airbags used in automobiles; radiation-hardened memory in aerospace and nuclear installations; printed memory platforms (such as smart cards, games, sensors, display, storage-class memory network); and high-end smart mobile phones.

MRAM has the potential to become a "universal" memory device applicable to a wide variety of functions. As a matter of fact, MRAM can have similar performance to SRAM Cache 3 (switching time ~5 ns) but is nonvolatile. It has also similar density to DRAM but at lower power consumption since there is no need to refresh and with reduced leakage since MRAM can be powered off on standby. Besides, it is nonvolatile as Flash memory but much faster and suffers no degradation over time. It is this combination of features that makes it so attractive. Some suggest that it could replace SRAM, e-FLASH, DRAM, in embedded and standalone forms, some storage class memories, resulting in instant-on nonvolatile computers and tiny, super-fast and reliable portable devices.

In cell phones, handheld tablet computers, notebooks, personal digital assistants (PDAs), and other forms of mobile computing, MRAM is an attractive alternative to deploy both Flash and DRAM since it can save money and space. With software applications residing in memory, mobile devices could be instantaneously repowered up to the same state in which they were when they were turned off. In general computing and networking, MRAM can be used to avoid boot-up delays and to provide faster access to hard drives and nonvolatile backup capabilities. At present, BIOS tend to use high-cost, low-density EEPROM or battery-backed-up SRAM— and volatile memory is used to alleviate I/O bottlenecks. In such applications, MRAM could prove much more economical.

In factory automation systems, microcontrollers and robots typically employ both RAM and PROMs/Flash. Lower costs will be achieved by replacing these two chips with one MRAM device. RFID tags need low-cost NVM, and a price point that makes MRAM economically viable for RFID applications will almost certainly push MRAM into other cost-sensitive areas. For aerospace use, MRAMs are radiation hard, meaning that they can withstand ionizing radiation in contrast to most of semiconductor memories based on capacitor charge. This makes them suitable for use in airplanes (already in Airbus flight controllers), satellites and spacecraft.

Table 3. The performance of STT-MRAM in recent year.

| *Year* | *Group* | *Capacity* | *CMOS(nm)* | *Cell (μm$^2$ ), die/chip (mm$^2$ )* | *Speed (ns)* | *Power or current* |
|---|---|---|---|---|---|---|
| *2010* | Uni Toronto/Fujitsu Lab[3] | 16 Kbit | 130 | cell: 5.525 | R: 9, W: 9–10 | W: 0.4–0.87 mA |
| *2010* | Toshiba[63] | 64 Mbit | 65 | cell: 0.3584, Die: 47.124 | 30 | R: 10 μA, W: 49 μA |
| *2010* | Hynix/Grandis[64] | 64 Mbit | 54 | Cell: 0.041 | R: <2 | W: 140 μA |
| *2010* | Hitachi/Uni Tohoku[65] | 32 Mbit | 150 | cell: 1, chip: 94.83 | R: 32, W: 40 | W: 300 μA |
| *2013* | Toshiba[66] | 512 Kbit | 65 | cell: 0.504 | 8 | R: 4 mW, W: 15 mW |
| *2013* | Toshiba[67] | 1 Mbit | 65 | cell: 0.45 | R: 4, W: 4 | R: 0.142 nJ, W: 0.372 nJ |
| *2013* | Infineon/TUM[62] | 8 Mbit | 40 | - | R: 23 | - |
| *2014* | TDK-Headway[68] | 8 Mbit | 90 | cell: 0.4 | W:<5,R:4 | - |
| *2015* | Qualcomm/TDK-Headway[69] | 1 Mbit | 40 | cell: 0.065 | R: 20, W: 20–100 | 3.2 μW/Mbps |
| *2015* | Toshiba[70] | 1 Mbit | 65 | cell: 0.11 | R: 3.3, W: 3.0 | R: 71.2 μJ/MHz, W: 166.2 μJ/MHz |
| | Toshiba/Uni Tokyo [121] | 4 Mbit | 65 | cell: 0.11 | R: 3.3 | W: 92.4 μJ/MHz |

# 3.6 Current MRAM Companies

**1. Avalanche Technology**

California-based Avalanche Technology is a startup company founded in 2006, which develops patented Spin Programmable perpendicular STT-MRAM (SPMEM) memory that uses a revolutionary proprietary spin current and voltage switching technology which enables lower write current, smaller cell size, higher density and excellent scalability.

Avalanche Technology currently offers STT-MRAM chips up to 64Mb in size, in both discrete and embedded forms.

**2. Everspin Technologies, Inc**

Headquartered in Chandler, Arizona, Everspin Technologies, Inc. is the worldwide leader in designing, manufacturing, and commercially shipping discrete and embedded Magneto resistive RAM (MRAM) and Spin-Torque MRAM (ST-MRAM) into markets and applications where data persistence and integrity, low latency, and security are paramount. With over 50 Million MRAM and ST-MRAM products deployed in data center, cloud storage, energy, industrial, automotive, and transportation market, Everspin has built the strongest and fastest growing foundation of MRAM users in the world.

**3. Crocus Technology**

Crocus, headquartered in Grenoble (France) with operations in the US and France, develops spintronics-based sensors and memory solutions. The MRAM technology that is the foundation on which Crocus is built was developed in the Grenoble-based Spintec research center and Crocus has formal joint development programs with Spintec and other leading European laboratories. Crocus's MRAM chips are produced by Israeli's Tower Jazz (130nm process). The company embedded MRAM chips are available in densities ranging from 256 bytes to 4 Kb. In 2011 Crocus established a joint-venture with Rusnano called Crocus Nanoelectronics (CNE) -with an aim to mass produce MLU devices on 300-mm wafers (90 nm and 65 nm) in Russia.

**4. Crocus Nanoelectronics**

Established in 2011, Crocus Nano Electronics LLC (CNE) is the world's first and only 300 mm fabrication facility. Located in Russia, the fab was created to provide unique foundry solutions for BEOL (back-end-of-line) and MRAM (Magneto resistive Random-Access Memory) processing. CNE provides foundry services with our state.

**5. Shanghai Ciyu Information Technologies Co., Ltd.**

Shanghai Ciyu Information Technologies Co., Ltd. is a high-tech sino-foreign joint venture with the latest MRAM manufacturing technologies, located in Shanghai Zhangjiang High Tech Industrial Zone, Jiading Park. Ciyu has been invested by several well-known VCs, private firms and Shanghai local government-guided foundations. Ciyu is the first and the only Chinese company fully dedicated to developing and delivering revolutionary products with disruptive STT-MRAM technologies and beyond. These new generations of memory chips have combined excellent properties of DRAM density/SRAM speed/better-than-Flash non-volatility, and further comprise ultra-low power consumption and superb reliability. With the platform of Shanghai Industrial μ Technology Research Institute (SITRI) and local government, Ciyu will develop and manufacture 3rd and 4th Gen MRAM products from a fully equipped back-end pilot line. The incoming commercial products include standalone memory, embedded memory and modular chips

# Chapter 4 MRAM commercialization potential influencing factors analysis

After successful research and development, the storage technology must be launched to the market and transformed into productive force, realize commercial values and social values, bring economic benefits to the investors, and create benefits for the public. How to select storage technology suitable for commercialization is the key to economic layout adjustment and economic boosting, and is a complicated systematic project. The first to be clarified is influential factors of commercialization of storage technology. The Chapter analyzes and researches influential factors of the commercialization potential for the storage technology itself in public views, and lays a research basis for the commercialization potential assessment index system and model building of storage technology in following text.

In combination with theory knowledge of the commercialization potential of storage technology and referring to exiting research achievements, the paper holds the opinions that, influential factors of the commercialization potential of storage technology include: technology factor, market factor, support factor, conformance factor and effectiveness factor.

# 4.1 Technical factor

The object of commercialization is storage technology (or storage product), so value of the storage technology is the preferred consideration factor for commercialization of storage technology. The potential of value of the storage technology depends on technology advancement, technology maturity, technology feasibility, technology standing and protected extent etc.

## 4.1.1 Technical advancement

The technology advanced refers that, the technology (and its products) is advanced compared with average level of the technology during the same period and in the same industry, and is obviously practical and advanced compared with the existing technology. If the technology is more advanced, it cannot be easily simulated and replaced; if the commodity monopoly is stronger, the market price is higher, the profitability is superior and the technology commercialization potential is larger. The technology with advancement and relatively higher complicacy achieves differentiation of products and services and become advantageous on market, and the investors can obtain more profits. The possibility of the more advanced storage technology replaced by other technologies becomes lower, relatively higher technological barrier is established, and the technology-based commodities makes profit continuously to lower investment risks. Therefore, the technology advancement is the precondition of investment values of magnetic storage technology.

### 4.1.2 Technical maturity

The technology maturity refers to evolution of the technology. Maturity of each technology must undergo stages of R& D-sample-sample test-pilot plant test-production- commercialization (marketing). The same technology at different stages is of varying maturity. On the development chain, if the position is near the front more, transforming into commodity is more difficult and risk factor is higher; otherwise, if the position is near the back more, the technology achievement transforming risks are lower and commercialization possibility is higher. Namely the technology maturity is improved with the technology commercialization progress. Therefore, the technology maturity can be measured with the index of the stages which the technology is located and is expressed at S curve of technology evolution. The curve is classified into five stages such as incubation period, generation period, growth period, maturity period and degenerating period. With extension of S curve, the technology maturity is increased.

Risk investors are inclined to storage technology with quick returns and avoid storage technology with large investment and long return period to increase circulation rate of fund. Therefore, the storage technology with relatively higher maturity becomes the preferred choice of risk investment. Immature storage technology cannot be commercialized, for complicacy and uncertainty of the technology cannot make investors judge the time required for pilot plant test of the storage technology and the probability of success rate of pilot plant test. Generally, the storage technology achievements after pilot plant test are almost matured. The body in charge of commercialization has obtained design, technology and process parameters for production and the probability of technology adjustment and change is low, and commercialization risks are also low [71]. According to statistics, after pilot plant test of the science and technology achievements, the success rate of commercialization reaches 80%; without pilot plant testing, the success rate of commercialization is only 30%. However, when all conditions of the storage technology are mature and science and technology achievement transformation is involved, severe competition pressure must be challenged. Foresight investors select the storage technology at the quick development and approaching the maturity stage of the technology development track (S curve), and reject the storage technology at the stage of slow development or technology quitting for commercialization operation.

### 4.1.3 Technical feasibility

To commercialize storage technology, the feasibility is the factor which must be considered. The technology feasibility refers to operability of the technology in research and development, implementation and continuous development, and relates to the reality from product concept to materialized products, from commercial blueprint to production, and from material technology to commodity transforming. It does no not only relate to technology development, achievement transforming and transaction difficulty, but also relates to technology standing and protected extent.

The technology protection extent is expressed in two aspects: (1) Independent intellectual property rights. One technology is patented and is free of other ownership disputes, and the technical barrier is high. The patented technology is of great exclusiveness, and commercialization of storage technology plays a role of protection; (2) difficult replacement. The magnetic storage technology with relatively higher science and technology level cannot be easily replaced by other technologies, the risk of sustainable profiting of the technology is low, and the commercialization potential is large.

### 4.1.4 Technical costs

No investors will invest on one outdated technology with more technical disputes, large investment and long return period, which is based on fund security. The technology cost forecast is also necessary. The technology costs are composed of technology acquisition costs, technology absorption costs and adaptation costs and technology carrier operation costs [71]. Of them, the technology acquisition costs refer to technology research and development (independent research and development, joint research and development or consigned research and development) costs or technology introduction costs, and the technology introduction costs are related to accessibility, acquisition convenience and other factors of the technology transfer resources; the technology absorption and adaptation costs include the technology pilot plan test, industrial testing costs and learning costs, or absorption, renovation and coupling costs of the introduced costs; and the technology carrier operation costs are composed of costs of mass production, technology diffusion and market promotion. The storage technology with higher investment requirements involves higher commercialization costs, and the investment potential cannot be forecast difficultly.

In summary, the storage technology is more advanced with longer service life, better profitability, and larger technology commercialization values. With patent right protection, the possibility of being replaced is low, the possibility of becoming leading technology or technical standard is larger, the research, development and application difficulty is low, practical operation is stronger, and the storage technology with low transforming costs results in higher investment return and larger possibility of commercialization success. Therefore, technical risks of the storage technology commercialization can be measured with the following indexes, as shown in Fig. 17. Besides, the storage technology commercialization potential is related to the time required for successful research and development, technology complicacy, technology stability, technology knowing, technology update speed and continuous profitability after technology application.

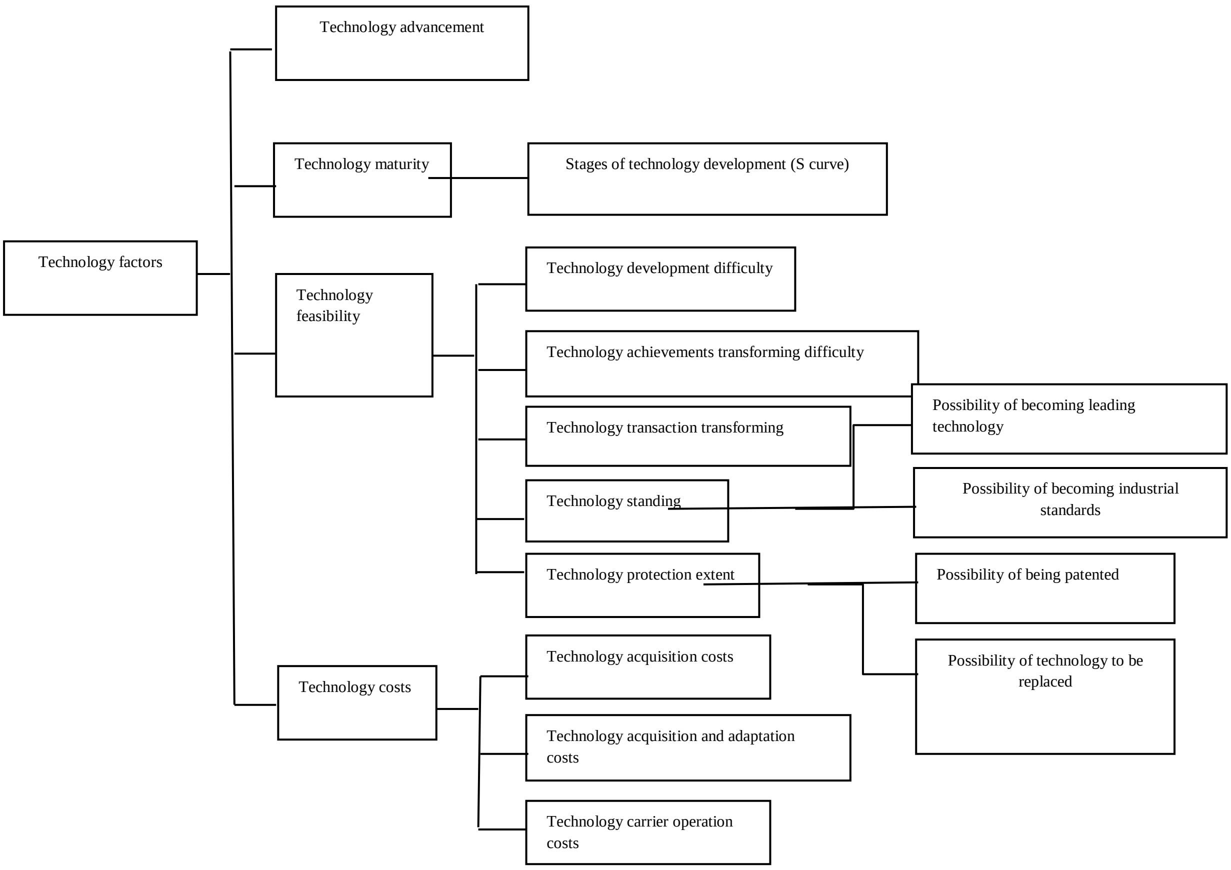


Figure 17. Technical Factors Affecting the Commercialization Potential of Low Carbon Technologies.

## 4.2 Market factors

The storage technology commercialization is a process pushed by technology and driven by market, and the storage technology achievements are commercialized after being launched to market successfully. Whether the storage technology achievements can be successfully transformed is subject to consumers. Only the products satisfying consumers' requirements can occupy market, obtain commercial profits and realize economic values of storage technology. The consumers' spending delivers back much needed funds and provides a valid guarantee for smooth operation of re-production. Meanwhile, new market requirement information promotes transforming of the next round of storage technology. Therefore, the goal of the storage technology commercialization is to be accepted by consumers and markets to obtain economic benefits. Therefore, market factors play a decisive role in storage technology commercialization, and whether one technology is to be accepted by market or not is the key to success or failure of commercialization.

The magnetic storage technology is of specific features. Firstly, the magnetic storage technology is well compatible with high technology, and is of features of high technology: strong sense of knowledge, high technology contents; difficult development, and large investment on research and development; high operation uncertainty, more serious competition and high investment risks. Secondly, the market of magnetic storage technology is foreseeable, and the features of high product stability and technical requirements may not be the same. Seen from the development of storage field in the future, the possibility of magnetic storage technology to be accepted by market is high, and market requirements are outburst. Seen from another angle, if the technology and process cannot satisfy requirements of the products, the costs cannot be lowered below the storage technology which is mature and extensively applied, and such technology cannot be easily commercialized. Therefore, the magnetic storage technology is of great uncertainty. Whether the magnetic storage technology is successfully commercialized is subject to market types, market scale, market return and other factors.

### 4.2.1 Market types

Market is the sum of exchange relations between enterprises, and enterprises and customers. After commercialization of magnetic storage technology, if the provider of the same technology exists in the target market, such market is assumed as existing market (also called current market or known market); otherwise, it is an unknown market.

At the existing market, the magnetic storage technology also faces competition pressure from the same kind of technology. At this moment, the main considerations are squeezing and replacement of mainstream technologies at the existing markets, for the potential customers are also covered by existing market. For the existing markets are relatively stable, the customers are not willing to use new magnetic storage technology due to high transforming costs; the provider of the same kind of technology will not abandon the acquired market shares and inherent interests to engage in research, development and production of storage technology of the same kind; otherwise, it will bear huge sunk costs of proprietorship assets and costs and risks of new technology development and application. They are more inclined to improving the existing technology, and building higher technical barrier to squeeze out the magnetic storage technology to be born.

At the unknown market, the commercialization stage of magnetic storage technology bears the mission of creating and fostering new customers and exploring new markets. Innovation modes of the magnetic storage technology are classified into two types. Firstly, market-driven innovation mode. In terms of the magnetic storage technology with such mode innovation, during the marketing stage, the target markets shall be segmented and positioned, the customers' requirements are explored and forecasted, the customers' satisfying products with high added value are created, and the market is penetrated and explored. Secondly, technology-driven innovation mode. Such magnetic storage technology is originated from technology development and technology progress. Under the situations, the technical functions and advantages on satisfying customers' requirements shall be considered compared with the old technology to replace mainstream technology on market.

### 4.2.2 Market size

Market scale, namely market capacity, refers to the sum of consumers who buy or consume some products (or labors) with some period not taking product prices or suppliers' strategies into account, and reflects the size of market potential. The market capacity is the objective prime of economic development, and is decisive for success or failure of the Project. It is decided by consumers' acceptability level and effective requirements.

The magnetic storage technology and the products are profitable only after being accepted by market. To achieve successful commercialization, the magnetic storage technology focuses on creating customers' values, engages in lowering product costs, increases product performance price ratio, increases added value of the products, enhances customers' satisfaction, obtains market recognition and guides consumers' behaviors. With maturity of magnetic storage technology, market potential of replacing the existing technology is larger, the price flexibility is low, analyzed and discovered from development trend and speed of the electronic industry, the commercialization may succeed easily.

The market requirements refer to the quantities that certain consumers will and are able to buy some commodities (or services) under specific time and areas, and specific marketing environment and marketing plans, and gather all consumers' effective requirements. The effective requirements refer to total social requirements of profits expected to enterprises, and are composed of two elements: I. The consumers' willing to buy, namely the desire of buying; II; The consumers' capable of buying, namely the payment capability (or purchasing capacity), and both are required. Fast development of the global electronic industry leads to the revolution of information technology, such trend requires substances or products with the corresponding storage capacity, the original storage technology cannot meet the requirements of development, and consumers have willing to buy such new storage technology products. Matching of technology and market, and buying of market are considered for commercialization of magnetic storage technology. When consumers have sufficient paying capability and the technology matches market well, the magnetic storage technology has been effectively demanded. When the effective demand reaches specific level, the magnetic storage technology can realize scaled production, scaled economic and obtain investment return.

### 4.2.3 Market return

Whether the magnetic storage technology can be commercialized depends on investment by institutions (government or enterprise). The investors' judging whether one magnetic storage technology worthy of investment, except for the capability of creating values by the technology, market acceptability extent and market scale etc., the most concern is commercial values of technology (including technology market proceeds and technology carrier sales proceeds), and whether the investment can be paid back by technology commercialization. In consideration of fund security, investors are more prone to the storage technology with high circulation rate of capital, short investment recovery period and proper risks after commercialization of the investment. The technology requires relatively higher expected profit rate and specific customer growth rate after commercialization. If the expected profit level is higher, the break-even point can be attained more easily, the investment is recovered faster, the investment risk is low, and the customer growth rate reflects market growth rate and market prospect. If the customer growth rate is higher, the technology market is more promising, and commercialization succeeds more easily.

In summary, the values created for customers are larger, the customers' satisfaction is higher, the market acceptability is higher, consumption possibility is high, and estimated market scale is larger; if the technology matches the market better, and consumers have sufficient payment capability, effective requirements are more and market potential is larger; if the customer growth rate is high, market space is larger, and technology market is promising; if the expected profit level is higher, the investment return is faster, and it is more easily favored by investors; compared with the same kind of technology, it has more market advantages, satisfies customers' requirements more, and achieves lower transforming cost for customers compared with the same kind of vendors, competitive strength of the storage technology is stronger, market standing of the technology is higher, and success rate of commercialization is higher. Therefore, market risks of commercialization of storage technology are measured by the following indexes, as shown in Fig. 18. In addition, the commercialization potential of storage technology is related to price flexibility of products in the future, market development and market penetration rate.

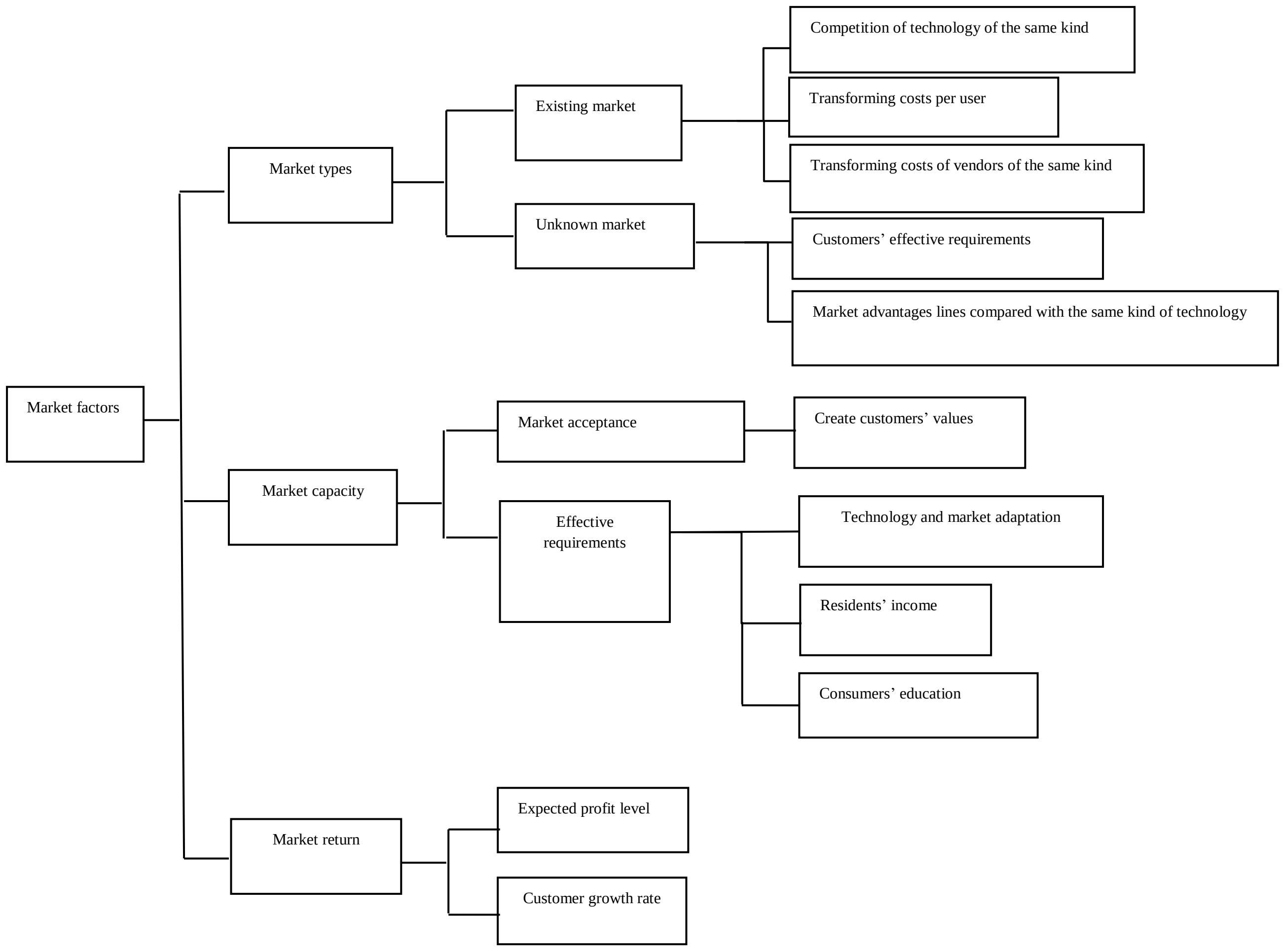


Figure 18. Market Factors Influencing the Commercialization Potential of Storage Technology

# 4.3 Support factors

To transform magnetic storage technology achievements into productive force successfully, except for technology feasibility, market acceptability and investors' will, the magnetic storage technology must be completed with the supporting environment for commercialized operation, and specific resource conditions. The commercial of magnetic storage technology is smooth under proper environment and with completed commercialization support conditions, and can be guaranteed. According to commercial operation flow, significant support factors influencing commercialization of magnetic storage technology are classified into resource support factors, transfer support factors, government support factors, etc.

## 4.3.1 Resource support factors

The resource support factor is the basis of commercialization activities of storage technology. It includes infrastructures, technology and management talents, sufficient funds, supporting technology, and supply of materials in the upper and lower reaches during the commercialization stage.

(1) Infrastructures

The infrastructures refer to material engineering facilities providing public services for social production and residents' life, and are the generic terms of engineering infrastructures and social infrastructures required for social survival and development and conducting universe economic activities and social activities. The infrastructures usually refer to engineering infrastructures, including six systems such as energy supply, water supply and drain, traffic and transporting, post and telecommunication, environmental protection and sanitation and defense and disaster prevention. Representative bases providing infrastructures (such as workshops, supporting equipment) for innovation of magnetic storage technology include: Productive Force Promotion Center, Scientific Research Pilot Plant Test Base, Technology Development Center, Incubation Base and Hi-tech Industrial Park, and they provide test site, equipment, tools and consultations for innovation and commercialization of magnetic storage technology, and are beneficial for transforming science and technology achievements and increasing achievement transforming efficiency and opportunity. The infrastructures are necessary elements for commercialization of magnetic storage technology, the infrastructures with perfect facilities advance sufficient commercialization of magnetic storage technology; otherwise, the commercialization is impeded. Taking the power system as example, the imperfect power system may be faulted, to the situations without double loop system, and interruption of test and production, failure of the test and stop of the production cannot satisfy market requirements.

(2) Human resources

Knowledge of electronic science and material science are necessary elements for magnetic storage technology, innovation of storage technology is application of magnetic materials and electronic knowledge, and electronic science experts, materials experts and relevant technical experts are carrier of knowledge, and storage technology and its products are materialization of knowledge. In terms of fundamental research and development, the magnetic storage technology is based on fundamental science progress or based on integration of existing technology, is of relatively higher complicacy and difficulty, and relatively powerful fundamental research and development capability and technology integration are required; in terms of technology absorption, relatively technology absorption is required, including technology absorption capability, technology operation capability, market forecast and exploration capabilities etc. Therefore, commercialization of the magnetic storage technology needs high-quality talents of knowledge of systematic electronic information engineering, material engineering knowledge and storage apparatus production process, and the commercialization subjects need cooperation by management talents and technical talents (including technology, operation and inspectors) with relevant professional knowledge and skills. The commercialization of magnetic storage technical cannot succeed without the professional talents, and will face great risks of failure.

(3) Financial conditions

The magnetic storage technology development, small-scaled pilot manufacturing, large-scaled manufacturing and other commercialization stages support from fund chain, and research and development, equipment adjustment and bulk production cannot be developed without fund. Nevertheless, the fund investment strength must be adaptable to scale of commercialization of magnetic storage technology. The fund condition is the material foundation for technology reconstruction and technology updating, insufficient fund may lead to impeding or suspension of the magnetic storage project, and the commercial subjects are unable to absorb magnetic storage technology and develop magnetic storage technology as they hope to do. Fund for commercialization of magnetic storage technology is originated from interior and exterior of the commercialization subjects, and whether to absorb large risk investment or whether the financing channel is smooth is the key to successful commercialization. Consideration indexes of financing difficulties include financing qualification limitation, financing amount, financing term and terms and conditions limitation.

(4) Technology, equipment and material guarantee

The magnetic storage science and technology achievements shape a combination system of application significance with various technologies. Relevant technologies required for commercialization of magnetic storage technology which is not well matched and immature have influences on integrity, feasibility and reliability of the magnetic storage technology, and result in technical risks. For example, the magnetic storage testing technology, for the testing means is outdated, quality and reliability of the magnetic storage products cannot be assured. Except for relevant supporting technologies, perfect facilities and equipment conditions are also crucial. Specific testing equipment, instruments and machines for producing product prototypes are required for commercialization of magnetic storage. If the facilities and equipment are not perfect, practice and reliability of magnetic storage technology, and stability of magnetic storage product quality are affected, thus risks of commercialization are increased. Therefore, the efficiently coordinated technology equipment and system solve technology coupling and other barriers, and the supporting technology and equipment system with high relevancy can make the magnetic storage technology and process more reasonable, beneficial for scale economy and lower production costs. Meanwhile, timely, continuous and effective supply of materials and energy required for transforming of magnetic storage achievements is the factor which must be considered. Low material quality, insufficient quantity or untimely supply affects continuity of production of magnetic storage products. So, auxiliary technology level, equipment supporting level and materials acquired timely and efficiently restrict commercialization of the magnetic storage technical achievements.

### 4.3.2 Transfer support factors

The transfer support factor acts as core element of commercialization operation of high technology, and plays a key role in efficient operation for guarantee high technology transforming. The transfer support factor involves technology innovation system, social intermediary service, relevant policies and rules, etc.

(1) Technological innovation system

The technological achievements commercialization is classified into 4 parts, such as fundamental research, application research, technology development and market promotion, and realization of each part is supported by social carrier. These carriers include colleges, scientific research institutions, enterprises and markets.

Higher education institutions have rich high-quality science and technology talents, powerful scientific research strength, own great advantages in tracking and acquiring the latest knowledge and technology and information, and provide scientific research guarantee for fundamental research of storage technology; the scientific research institutions own professional scientific research talents, advanced experimental instruments and complete equipment, and act as main research force for technology innovation, usually leading in the research field; the enterprises approach the market in closest distance, respond requirements of magnetic storage technology acutely and truly, and give feedback to technology innovation timely based on market requirements to ensure that innovation of magnetic storage technology is led by market; through drafting policies and laws, building fair competition environment and slack innovation culture atmosphere and national strategy development planning, the government provides environment guarantee for technology innovation, and realizes marketing of technological achievements of magnetic storage technology with powerful purchasing capability and expanding market requirements; the social risk capital is one of the fund sources for innovation of storage technology with high risks and high investment, and provides fund chain support for scientific research, pilot test plan and marketing of the magnetic storage technology; the special government fund is a key guarantee for marketing of magnetic storage technology, which needs huge fund and cannot succeed without support and advancement by the national strategy.

Therefore, establish the "government, enterprise, university, research and capital" technology with government as the leader, market as the guide, higher education institutions and scientific research institutions as support, and risk capital and government development fund as dependence, reinforce effective cohesion and interaction among government, enterprise, university, research and capital", and promote absorption, acquisition, re-innovation, transferring and spreading effective combination of production elements, which are fundamental approaches to innovation and achievement transformation of the magnetic storage technology. For the "government, university, higher education institutions, research and capital" cover several innovation subjects, collaboration among the subjects relates to maximum operation of the innovation system; if combination of the government, enterprise, higher education institutions, research and capital is slack, collaboration multiplier effect of the technology innovation system cannot be fully yielded. The innovation subject functions are complementary and shape an orderly, closely connecting and interactive organic integrity to fully yield complete efficiency of the technology innovation system, increase achievement transforming efficiency and accelerate commercialization of the magnetic storage technology.

(2) Social intermediary services

Technology transfer, technology consultation, technology service and technology transfer are beneficial for launching technological achievements to market; in technology transaction, technology transfer activities are very hard, and transaction difficulty and risks are large. Main barriers from technology transfer are originated from two aspects [72]: A. The technology transferor does not familiarize the process from successful putting into operation to the market, overestimates maturity, application and commodity of the technology at hand, and proposes transfer prices beyond the technology and the transferee cannot accept it; B. Due to features of the intangible assets, economic benefits in the future are of uncertainty (in particular to electronic storage project with long-term economic benefits), and the transferee's recognition of the technical values is difficult. The transferee intrinsically concerns about economic benefits after putting into production, plus insufficient recognition of the transfer technology, and underestimates the technology values. To coordinate interests of supplier and buyer of technology, promote technology transfer, increase volume of technology transfer contract and increase transaction rate, a third party's involvement is required. The science and technology intermediary service (hereinafter referred to as intermediary) serves regional science and technology innovation, acts as bridge and link among government, enterprise, scientific research institute and colleges, and plays in the role of entity providing all-round and entire process science and technology service transforming science and technology achievements into productive force. The main business includes: new science and technology inquiry, science and technology information network service, science and technology appraisal, science and technology tendering and bidding, science and technology project acceptance, science and technology project supervision and acceptance, science and technology innovation fund application, technology service, consultation and training, undertaking seminars, exhibition and negotiation conferences, technology contract certification and registration, and achievements transforming, investment and financing. In terms of the intermediary (such as technology transfer center, technology transfer institute, technology trading institute and technology property trading institute etc.), it knows more about the transferee and the market advantages compared with the transferee, and knows more about advantages of technological achievements, with sufficient cohesion between the transferor and the transferee, and the intermediary provides commercialization shortcut between technological achievements and market. Otherwise, if the intermediary does not know much about it, does not have extensive liaison, does not know much about technology, cannot grasp the production and cannot control market, its function is only limited to “acting as a go-between”, then the standing and equity cannot be guaranteed, and the transfer results must be affected [73].

The intermediary renders a broad service, except for the above-mentioned science and technology intermediary, including investment and financing guarantee institution, accounting firm and lawyer firm etc. These institutions organize social forces to provide technical assistance, technology promotion, technical consultation and information service for commercialization of technology, assists them in HR development, business management and training and plays a key role in increasing transforming rate of science& technology achievements.

(3) Policies and laws

Proper policy laws and environments are fertile soil for encouraging storage innovation and promoting commercialization of storage technology. In China, there are Law of Progress of Science and Technology, Law of Promoting Transforming of Science and Technology, Law of Technology Contract, Law of Protection of Intellectual Property Rights, Law of Patent and Code for Awarding of Science and Technology Achievements etc., which create a sound environment for commercialization of the magnetic storage technical achievements. The perfect technology intermediary laws, rules and supervision systems standardize orderly development of intermediary service, highlights functions of intermediary service in achievement development and innovation incubation, optimizes combination and maximize utilization of social science and technology resources. It aims to promote the policy of technology innovation spreading. The policy tool is a key means for the government's involving technology innovation process, optimizing configuration of technology innovation resources, and effectively protecting the technology innovation achievements. Follow the technology commercialization chain, and summarize the policy tool as follows [74]: during the fundamental research stage, reinforce support for fundamental research, and introduce leading scientific research talents; during the application research stage, build the innovation technology platform system, and perform joint development for key technology; during the technology development stage, perfect the enterprise financing channel, and enterprise service system building; during the market access stage, the finance, taxation, purchasing and industrial policy for independent innovation; during the technology upgrading stage, encourage enterprises to establish research and development stage, build university science and technology park, support the science and technology intermediary service, implement intellectual property right strategy, and encourage enterprise, university and research cooperation and overseas cooperation etc. Therefore, the government plays a key role in the entire process of commercialization of the magnetic storage technology, and the government drafts laws and systems encouraging innovation and reducing commercialization barriers, beneficial for prosperous development of technology commercialization.

In summary, commercialization of the magnetic storage technology needs powerful support by infrastructures, fund, talents and technology, needs support by the technology innovation system, needs assistance by neutral and professional science and technology intermediary service, and needs perfect law systems, financial and taxation policies, government industry guide and support by financial organizations. Optimal commercialization support conditions facilitate quick commercialization of the magnetic storage technology, and firm commercialization foundation becomes preconditions for commercialization of the magnetic storage technology. Therefore, the environmental support conditions of the magnetic storage technology can be surveyed by the following factors, as shown in Fig. 19. Besides, the regional economic foundation, cooperation modes between technology innovation subjects and information interaction capability, and richness of knowledge, technology, talent, capital, information and other elements required for commercialization of the magnetic storage technology, acquisition costs and quick fluidity are factors to be considered. Whether to gather these factors and shape transforming capability within a very short time according to market needs directly have influences on efficiency and achievements of commercialization of the magnetic storage technology.

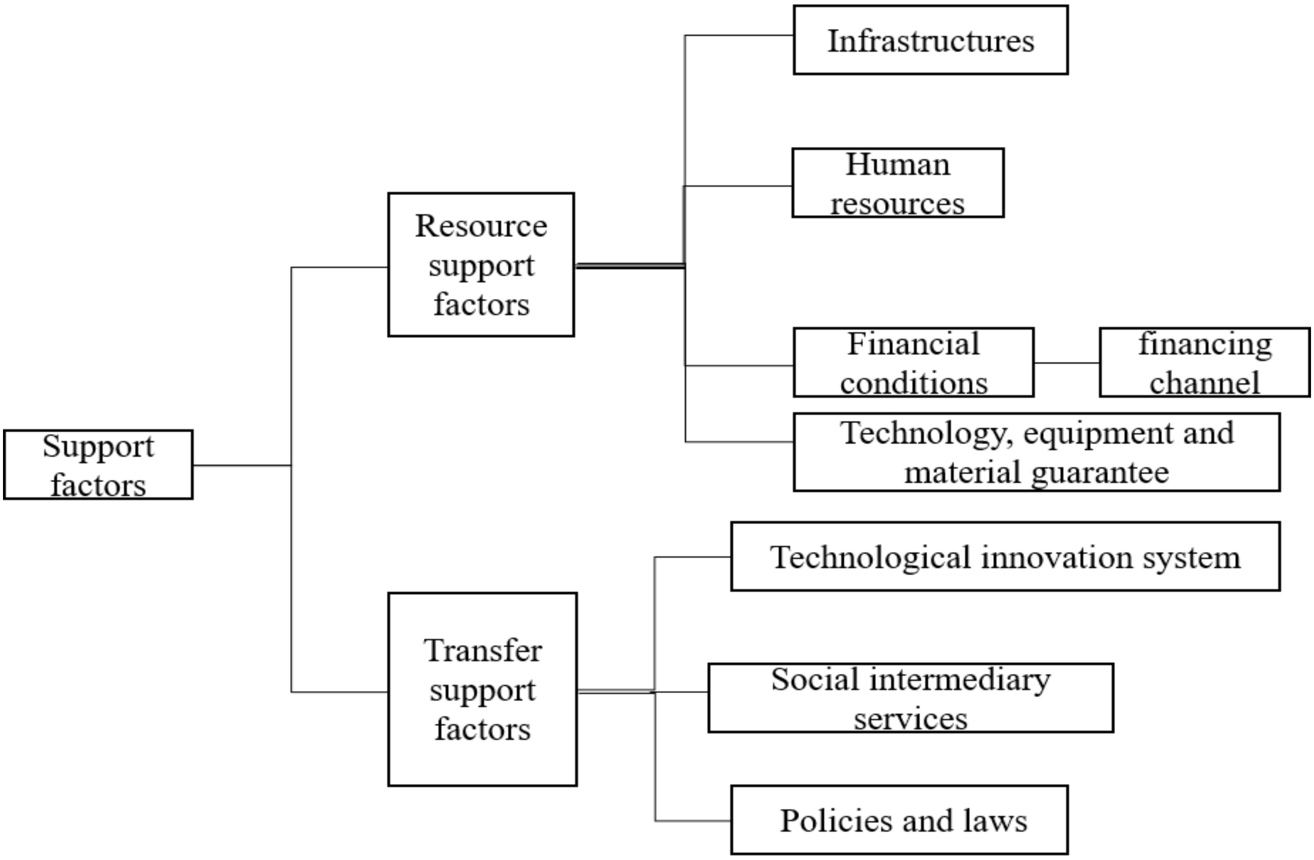


Figure 19. Support Factors Influencing the Commercialization Potential of Storage Technology

## 4.4 Compliance factors

Commercialization promotion of the magnetic storage technology must be adaptable to science& technology development and social development planning, and be consistent with key technology selection and technology foreseeability results in relevant countries and regions. Firstly, support in industrial policy, science& technology policy, and social development planning must bring opportunities to development of the magnetic storage technology. These opportunities include both policy approval, and infrastructure construction, financial subsidy, tax discount and financial loan. The Government offers convenience for commercialization of the magnetic storage technology with matching conformance, and adds dynamics to commercialization of the magnetic storage technology. Therefore, during commercialization of the magnetic storage technology, actively control the science and technology development trend, and track the national policy trend timely. China takes developing electronic information industry as the national strategy, and the technology is well conformed. Secondly, the foreseeable results of key technology in the country or region represent the development trend in the future. If one technology is closer to the field to be developed in near-term, it must be more favored by the fund, staff and technology, the commercialization prospect is easily controlled, and the possibility of commercialization is large.

Therefore, conformance indexes of commercialization of magnetic storage technology include conformance with science and technology, industrial policy, social development planning and technology foreseeability etc., as shown in Fig. 20.

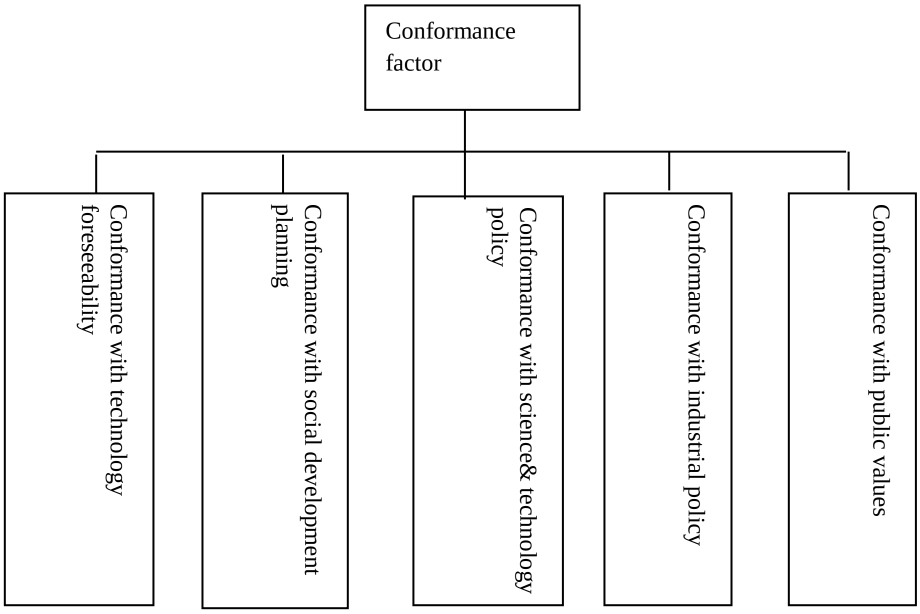


Figure 20. Influences on Conformance of the Commercialization Potential of Storage Technology

## 4.5 Effectiveness factors

The goal of commercialization of the magnetic storage technology is to create economic benefits and social benefits for society. In terms of commercialization of the magnetic storage technology, both estimated level of commercialization and contribution to GDP, and social influences of commercialization of the magnetic storage technology on resource saving, environment improvement, living quality, science and technology development, industrial driving and employment creating etc. Meanwhile, these factors react the magnetic storage technology. The magnetic storage technology with outstanding contribution to and influences on efficient energy saving, science and technology promotion and industrial development, and employment creation will be greatly supported by the government and favored by risk investors. Increasing of continuous capacity leads the electronic information industry to high efficiency and low consumption to expand market requirements and accelerate commercialization of the magnetic storage technological achievements. Therefore, effectiveness indexes of commercialization of the magnetic storage technology include: estimated profit level, resource saving extent, living standard improvement, science& technology development promotion, relevant industrial driving extent, and employment opportunities etc., as shown in Fig. 21.

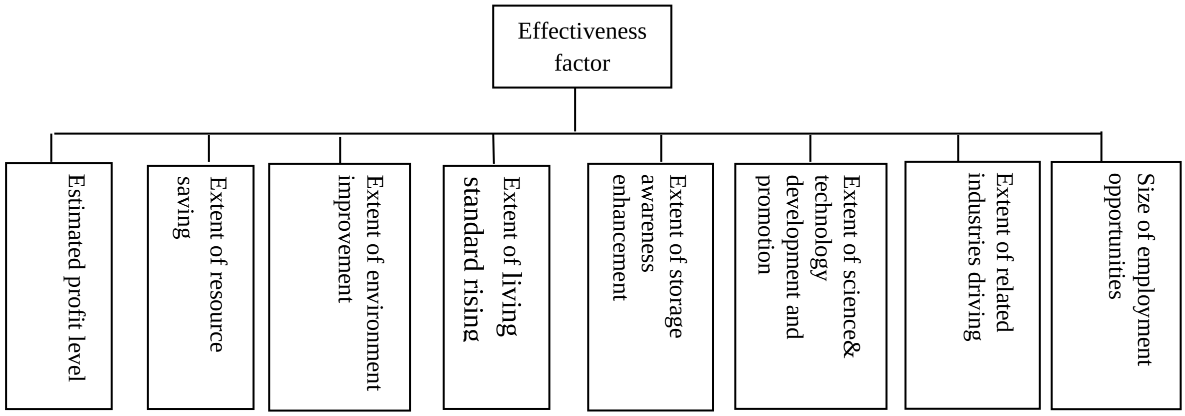


Figure 21. Effectiveness Influencing the Commercialization Potential of Magnetic Storage Technology

In summary, commercialization of the magnetic storage technology is influenced by many factors, such as technology factor, market factor, support factor, conformance factor and effectiveness factor. If the five factors of one magnetic storage technology perform well, commercialization in the future must be prosperous, and the commercialization potential must be great. Commercialized potential indexes of the magnetic storage technology shall be tested with the above factors.

# Chapter 5 Storage technology commercialization potential evaluation index empowerment

Each evaluation index is a kind of characteristic of the object from different aspects, and the relative importance of evaluation index is different relative to the evaluation goal. The relative importance of the evaluation index can be characterized by weight coefficient. This chapter will combine the Delphi method with group hierarchy process (AHP) to empower the potential evaluation index of storage technology commercialization. The specific thinking is: firstly, analyze the reasons of the hierarchy process for the empowerment of indicators; then, the operation flow of analytic hierarchy process is clarified; finally, the paper uses AHP to deal with the empowerment of commercial potential evaluation index of storage technology.

## 5.1 Selection of indicators empowerment methods

Modern comprehensive evaluation methods: analytic hierarchy process (AHP) and FUZZY comprehensive evaluation method (FUZZY), data envelopment analysis (DEA) evaluation method, artificial neural network (BP) neural network, GRAY comprehensive evaluation method (GRAY), etc. Choosing AHP is not the simplest and most useful. There are two reasons: 1, because of the lack of relevant historical data, so data envelopment analysis (DEA) method requires the input and output variable values and artificial neural network evaluation method (BP neural network training set and test set). 2, Comprehensive evaluation method (FUZZY) and grey comprehensive evaluation (GRAY), no matter which method is adopted, the index weight must be determined firstly. The AHP method is a kind of multi-criterion index weighting method which combines good quality and quantity.

There are many methods to determine index weight, such as AHP method and expert comprehensive scoring method. There are two reasons why using group decision AHP: First, group decision is better than individual decision making, and it can avoid the influence of individual decision preference. Second, the AHP method is superior to other weight determination methods. The calculation of least squares is cumbersome and difficult to operate. This study designed a "building block" algorithm, namely the single logarithm least squares method and a single criterion of people under the single criterion of weight vector (weighted geometric averaging) synthesis combined instead of many under the single criterion of outreach logarithm least squares method.

# 5.2 Operation process of AHP and its application

## 5.2.1 Operation process of analytic hierarchy process

Analytic hierarchy process (AHP) can be divided into the following steps [34, 76, 77], as shown in Fig 22

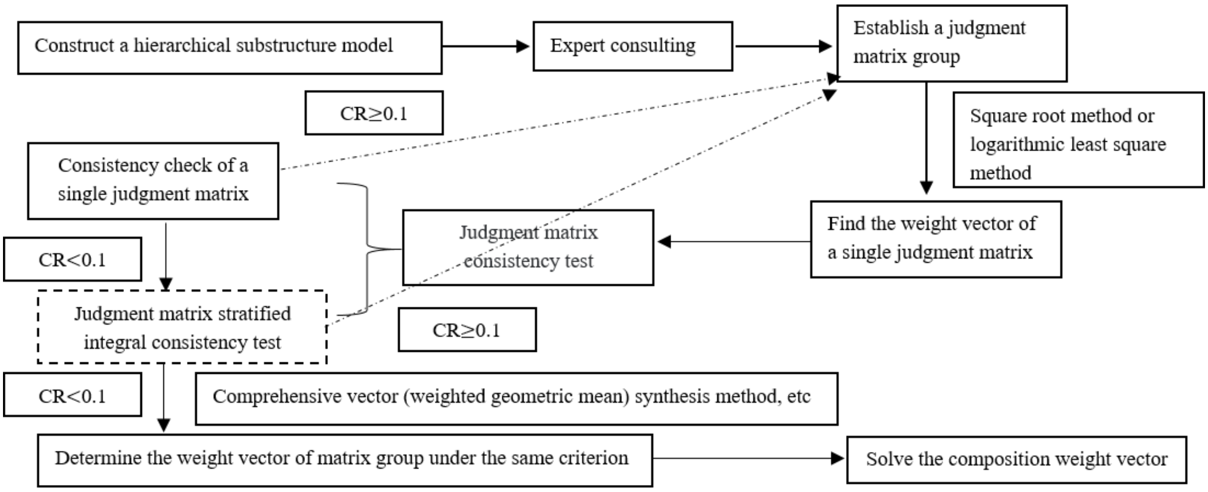


Figure 22. The operation process of AHP method

### (1) Construct the hierarchical substructure model

When using AHP method to analyze complex problems, the first thing is putting the question to be methodical, hierarchical. According to the essence of the problem, the problem is decomposed into different components. This dominant relationship from top to bottom forms a recursive level. The highest level is called the target layer, and there is usually only one element that represents the intended target of the decision maker. The middle layer is called the criterion layer, and the criterion layer may have more than one layer. The bottom layer is called the scheme layer, which arranges various options. Level is completely different, it does not dominate the next layer of all or part of the elements. And each element (except the target layer) is at least a layer of an element. A typical hierarchy can be shown in Fig. 23

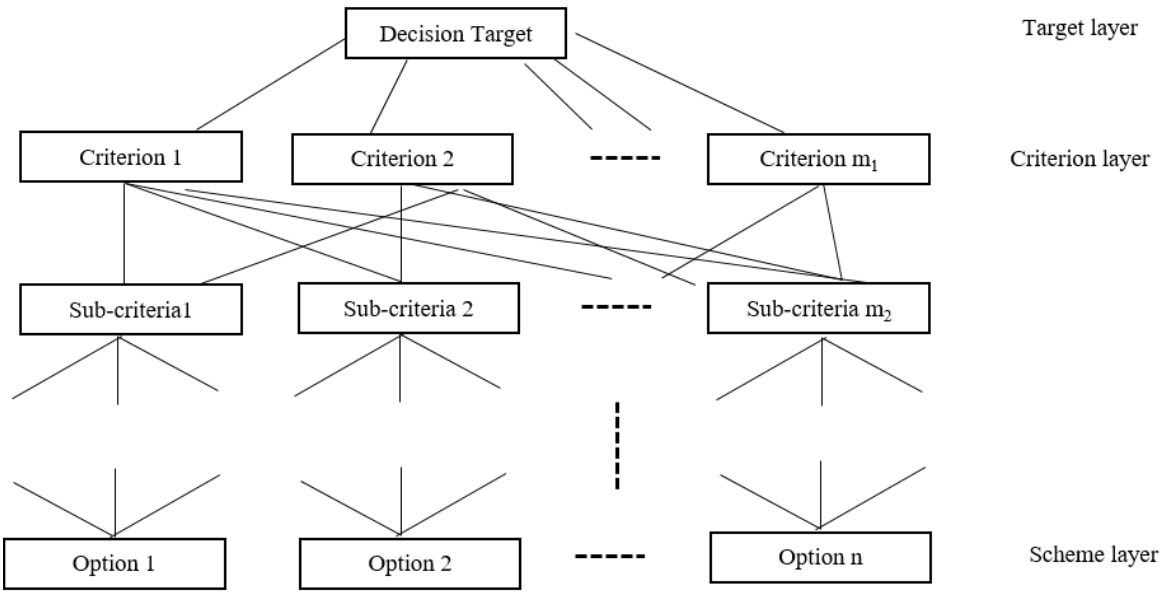


Figure 23. Hierarchical structure schematic diagram

### (2) Expert consultation

To determine the hierarchical model of hierarchical structure model, it is necessary to consult the experts to obtain the importance level of the two comparisons.

A. Enacting expert consultation books. The expert consultation book should include the following contents:1. The purpose of the consultation. 2.The hierarchical structure of the index system. 3.The expert consultation table should stratify the index of importance of the index. 4.Contents of consulting and filling table method. 5.Note: the choice of importance level should be in line with the "transitivity principle". If A is more important than B, B is more important than C, and A must be more important than C. 6. Other. Comments on confusing or unusual nouns that appear in the indicator system.

B. Selecting experts. When choosing an expert, consider the expert qualities (such as moral character, business ability or academic attainments) and the expert structure (including subject structure and professional structure). Discipline institutions should focus on systems science and management science subjects and consider the experts of relevant disciplines. Professional composition should include academic institutions and enterprises and institutions and other experts, striving for expert group to become a broad-minded.

Expert consultation is usually conducted two rounds. After the first round, the experts will get the feedback by the results of the calculation and the main questions of consultation.

**(3) Establishing judgment matrix group**

After establishing the hierarchical model, we can compare the importance of the same factors and construct a comparison judgment matrix. The judgment matrix represents the relative importance of the factors related to the previous level. Judgment matrix is the basic information of analytic hierarchy process, and it is also an important basis for calculation of relative importance.

In the analytic hierarchy process, to determine quantization of decision making, a numerical judgment matrix should be formed, which should be quantified according to certain ratio scale. The usual method is the 1-9 scale method proposed by Saaty, as shown in table 12.

Table 12. Scale and meaning of judgment matrix

| No. | Grade of importance | $a_{ij}$ assignment |
|---|---|---|
| 1 | i， j two elements are equally important | 1 |
| 2 | i element is moderate important than the j element | 3 |
| 3 | i element is significantly important than the j element | 5 |
| 4 | i element is mightiness important than the j element | 7 |
| 5 | i element is extremely important than the j element | 9 |
| 6 | i element is moderate unimportant than the j element | 1/3 |
| 7 | i element is significantly unimportant than the j element | 1/5 |
| 8 | i element is mightiness unimportant than the j element | 1/7 |
| 9 | i element is extremely important than the j element | 1/9 |

Note: $a_{ij} = [2,4,6,8,1/2,1/4,1/6,1/8]$ represents the assignment of the importance level between the corresponding values of $a_{ij}$ = {1,3,5,7,9,1/3,1/5,1/7,1/9}

According to the comparison results of two matrices A=$(a_{\overline{\imath\imath}})_{n\times n}$ (as shown in figure 5-3), referred to as the judgment matrix. Obviously, $a_{ij} > 0$， $a_{ii}$=1 and$a_{ij}$ij=1/ $a_{ji}$, which is A positive inverse matrix.

| A | A1 | A2 | …… | An |
|---|---|---|---|---|
| A1 | $a_{11}$ | $a_{\bar{i}\bar{j}}$ | …… | $a_{\bar{i}\bar{j}}$ |
| A2 | $a_{\bar{i}\bar{j}}$ | $a_{\bar{i}\bar{j}}$ | …… | $a_{\bar{i}\bar{j}}$ |
| ⋮ | ⋮ | ⋮ | | ⋮ |
| An | $a_{\bar{i}\bar{j}}$ | $a_{\bar{i}\bar{j}}$ | …… | $a_{\bar{i}\bar{j}}$ |

Figure 24. general judgment matrix form

In fact, the judgment matrix group is formed after many experts from different occupations have filled out the consultation form. If the number of experts is *m*, the same type of judgment matrix group will be generated.

**(4) Solving the weight vector of a single judgment matrix**

Assumes that the judgment matrix A=$\left(\boldsymbol{a_{\bar{i}\bar{j}}}\right)_{\boldsymbol{n\times n}}$ , if for ∀ij, k= 1, 2, n, equation $\boldsymbol{a_{ik}}=\boldsymbol{a_{ij}a_{jk}}$ is correct, matrix A is consistency matrix. It's obvious that the element A can be represented as $\boldsymbol{a_{ij}=w_i/w_j}$. In practical problem solving, judgment matrix A is not necessarily consistent, but the nature of the reference consistency matrix (all the consistency of matrix A column for each component of the geometric average, after normalization of vector is the weight vector), can put forward to solve the weight vector of the square root method, steps as follows:

(1) Calculate the product of each row element of the matrix $M_i$: $M_i=\prod_{j=1}^{n} a_{ij}$ (i, i=1,2…, n)

(2) Compute the nth root of $\mathbf{M}_i$, $\overline{\boldsymbol{W}_i}$ :$\overline{\boldsymbol{W}_i}=\sqrt[n]{\boldsymbol{M_i}}$

(3) Normalization for vector $\overline{\boldsymbol{W}}=[\overline{\boldsymbol{W_1}}, \overline{\boldsymbol{W_2}}, \ldots \overline{\boldsymbol{W_n}}]^r$

$$\boldsymbol{W_i}=\frac{\overline{\boldsymbol{W_i}}}{\sum_{i=1}^{n}\overline{\boldsymbol{W_i}}}=\frac{\sqrt[n]{\boldsymbol{M_i}}}{\sum_{i=1}^{n}\boldsymbol{M_i}}=\frac{\sqrt[n]{\prod_{j=1}^{n}\boldsymbol{a_{ij}}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n}\boldsymbol{a_{ij}}}} \quad (i,j=1,2\ldots, n) \qquad (5\text{-}1)$$

(4) Calculate the maximum characteristic root of matrix $\boldsymbol{\lambda_{max}}$

$$\lambda_{max}=\sum_{i=1}^{n}\frac{(AW)_i}{nW_i} \qquad (5\text{-}2)$$

$(\boldsymbol{AW})_{\boldsymbol{i}}$represents the *ith* element of AW.

Therefore, the weight vector of the individual judgment matrix can be summed up as the maximum characteristic root of the calculation judgment matrix and its corresponding eigenvector. In fact, in addition to the square root method, single weight vector algorithm under single criterion and method of characteristic root method, least square method and logarithmic least-squares method (using the method and the W equals the formula (5-1). Namely, the method and root method equivalent).

(5) **Judgment matrix consistency test**

In order to ensure the conclusion of the AHP method, it is necessary to verify the judgment matrix of the structure. The consistency test includes the consistency check of the single judgment matrix and the stratified integral consistency test of the judgment matrix.

First, the consistency of the single judgment matrix is shown as follows:

1. Calculate the consistency index *CI*, *CI*=$\frac{\boldsymbol{\lambda_{max}-n}}{\boldsymbol{n-1}}$, n is order of judgment matrix.
2. The average random consistency index *RI* is calculated and the arithmetic average is obtained by the calculation of the eigenvalue of the random judgment matrix. For the 1~9 judgment matrix, *RI* values are listed in table 13.

Table 13. Average random consistency index

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

3. Calculate the random consistency ratio *CR*， $CR=\frac{CI}{RI}$

When CR< 0.10, the judgment matrix has satisfactory consistency, otherwise it is necessary to adjust the judgment matrix.

Second, the overall hierarchical judgment matrix consistency test known to the k-1 layer of j elements as the criterion of the $CI_j^{(k)}$， $RI_j^{(k)}$ and $CI_j^{(k)}$， j=1, 2…,$n_{k-1}$. Then the overall consistency test of the judgment matrix group above level K can be calculated according to the following formula.

$CI^{(k)}= (CI_1^{(k)},CI_2^{(k)}, \dots， CI_{n_{k-1}}^{(k)})w^{(k-1)}$ (5-3)

$RI^{(k)}= (RI_1^{(k)},RI_2^{(k)}, \dots， RI_{n_{k-1}}^{(k)})w^{(k-1)}$ (5-4)

$CR^{(k)}=\frac{CI^{(k)}}{RI^{(k)}}$ k=3,4…, s (5-5)

If the $CR^{(k)}$<0.1, believes that the hierarchical structure model in the k layer above all meet the overall consistency of the judgment matrix.

In practical applications, the overall consistency test can often be omitted. Because experts in constructing judgment matrix under the single criterion, it is difficult for the overall consideration; furthermore, when the overall consistency is not satisfied, but also more difficult to adjust. Therefore, most of the actual operations have not tested the overall consistency, and we need to explore further.

(6) **Solving the weight vectors of the judgment matrix group under the same criterion**

If it is a single decision, one can go directly to the next step to solve the composite weight vector. But in the face of complex decision-making problems, many experts (m bits) are needed for group decision making, which produces m groups of judgment matrices of the same type. The algorithms for determining weight vectors of decision matrices in multi person decision making generally include: extension optimization algorithm, judgment matrix synthesis method and weight vector synthesis method.

Assume $A_l$=$[aij, l]_{n\times n}$, ($l$=1, 2…, m) ($l$=1, 2…, m) is the judgement of matrix groups, m is the number of experts.

$D$= $\{w\in R_+^n \mid \sum_{\mathrm{i}=1}^{\mathrm{n}} w_i$=1,$w_i > 0, i = 1,2, \ldots, n\}$ is Weight vector set.

$\Omega$=$\{\lambda\in R_+^m \mid \sum_{\mathrm{i}=1}^{\mathrm{m}} \lambda_i$=1,$\lambda_i$>0, $l$ =1,2, …, $m\}$ is Weighted vector set.

The weight vector (weighted geometric average) synthesis method is used to solve the weight vector of the judgment matrix group as following:

The weight vector of the judgment matrix $\boldsymbol{A_l}$ is$(\boldsymbol{w_{l1}}, \boldsymbol{w_{l2}}, \ldots, \boldsymbol{w_{ln}})^{\boldsymbol{T}}$, $\boldsymbol{l}$=1,2, …, $\boldsymbol{m}$, and the weighted geometric mean of the corresponding components of each weight vector is calculated

$$\overline{w_i}=\prod_{l=1}^{m} w_{li}^{\boldsymbol{\lambda}_l} \quad (\mathrm{i}=1,2,\ldots, n)\lambda\in\Omega \qquad (5\text{-}6)$$

When the weight of the vector is equal, that is, $\lambda_l$=$\frac{1}{m}$, the formula (5-6) can be converted into

$$\overline{w_i}=\left(\prod_{l=1}^{m} w_{li}\right)^{\frac{1}{m}} \quad (\mathrm{i}=1,2,\ldots, n)\lambda\in\Omega \qquad (5\text{-}7)$$

Normalized

$$w_i=\frac{\overline{w_i}}{\sum_{j=1}^{n}\overline{w_j}} \qquad (i=1,2,\ldots,n) \tag{5-8}$$

Obtained Synthetic weight vector $W=(w_1, w_2, \ldots, w_n)^T$.

**(7) Solving composite weight vectors**

The weight vector of each judgment matrix under the single criterion of many people is known. The total number of layers of the hierarchical structure model is s, and the number of the elements in layer k is $\boldsymbol{n_k(k=1,2,\ldots,s)}$. Obviously, the weight vector of the second layers of $\boldsymbol{n_2}$ elements on the first-floor total target is $\boldsymbol{w^{(2)}}=\left(\boldsymbol{w_1^{(2)}}, \boldsymbol{w_2^{(2)}}, \ldots, \boldsymbol{w_{n_2}^{(2)}}\right)^{\boldsymbol{T}}$.

Suppose that $\boldsymbol{n_{k-1}}$ element on layer $\boldsymbol{k-1}$ is known to be the weight vector of the total target $\boldsymbol{w^{(k-1)}}=\left(\boldsymbol{w_1^{(k-1)}}, \boldsymbol{w_2^{(k-1)}}, \ldots, \boldsymbol{w_{n_{k-1}}^{(k-1)}}\right)^{\boldsymbol{T}}$, and $\boldsymbol{n_k}$ element on layer k, layer k-1with the first element（$\boldsymbol{j}$=1,2,…,$\boldsymbol{n_{k-1}}$）is the weight vector of the criterion $\boldsymbol{p_j^{(k)}}=\left(\boldsymbol{p_{1j}^{(k)}}, \boldsymbol{p_{2j}^{(k)}}, \ldots, \boldsymbol{p_{n_kj}^{(k)}}\right)^{\boldsymbol{T}}$(Elements are not governed by J and whose weights are zero.). Construct the weight matrix of the $\boldsymbol{n_k}$elements of layer K for $\boldsymbol{n_{k-1}}$ elements on layer $\boldsymbol{k-1}$.

$$P^{(k)}=\left[P_1^{(k)}, P_2^{(k)}, \ldots, P_{n_{k-1}}^{(k)}\right]_{n_k\times n_{k-1}}$$

$$\left(p_{i1}^{(k)}, p_{i2}^{(k)}, \ldots, p_{in_{k-1}}^{(k)}\right)\left(w_1^{(k-1)}, w_2^{(k-1)}, \ldots, w_{n_{k-1}}^{(k-1)}\right)^T=\sum_{j=1}^{n_{k-1}} p_{ij}^{(k)} w_j^{(k-1)}$$

Thus, the weight vectors of the n_k k (please check?) elements on the total target can be represented as

$$w^{(k)}=P^{(s)}P^{(s-1)}\ldots P^{(s3)}w^{(2)}k=3,4,\ldots,s \tag{5-10}$$

### 5.2.2 AHP method in the application of the storage technology commercialization potential index weighting

(1) Build hierarchy model

Reasonability of Hierarchy structure is directly related to the quality of the analytic hierarchy process (AHP) to calculate the results. Therefore, this section is based on the evaluation of the reliability and validity, which finally establishes the evaluation index system of the commercialization potential of storage technology in chapter 5. Design a hierarchical structure model for evaluating the commercialization potential of storage technology.

(2) Expert consultation work

To avoid the existence of collective discussion to authority and blind obedience to most of the problems, this study adopts communication mode prediction back-to-back consult member of the expert group, that is the Delph method (Delphi) investigation. Delphi method requires specialists are under best control between 10 to 15 people. Concrete implementation steps are as follows:

1. First round expert consultation table. Experts were given the "MRAM technology commercial potential evaluation index weight" consultation table, and the relevant information was attached as a reference.

2. First round of survey data for analysis and processing. The first round of the survey issued a total of 24 expert consultation, back to 19 copies, of which the number of effective copies of 15 (rejection criteria: judgment matrix consistency test), that is, the efficiency of 62.5% analysis of the expert process, the upper judgment error ratio. The impact of judgments under the greater impact of this study uses AHP method for the second layer of indicators for processing.

Analysis of the expert group on the five secondary indicators (technical dimension B1, market dimension B2, support dimension B3, compliance dimension B4, the effect of dimension B5) weight value, you can find a significant difference, that is, five experts (W> 0.35), and 8 other experts (professional composition: 3 academic researchers, 5 corporate staff) are optimistic about the "technical staff of the two" Market size B2 "(w> 0.35) 1/3 of the experts optimistic about the" technical dimension ", about 1/2 of the experts are optimistic about the" market dimension ", which is a significant difference in value orientation, thus it is necessary to conduct a second round of experts advisory. The feedback from the first round of the survey was given to each expert and brought to their attention in the second round. A total of 19 expert consultation lists were issued for the second round, with 16 valid copies, of which the effective rate was 57.9%. The results of the consultation are summarized in Schedule 4 as a basis for the empowerment of the storage technology commercialization potential indicators.

(3) Establish the judgment matrix group and find its weight vector

According to the second round of the Delphi method of effective expert consultation table, it can produce 11 the same type of judgment matrix group.

First, the judgment matrix and the weight vector in the criterion layer

| A | B1 | B2 | B3 | B4 | B5 |
|---|---|---|---|---|---|
| B1 | 1 | 1 | 5 | 5 | 3 |
| B2 | 1 | 1 | 7 | 7 | 3 |
| B3 | 1/5 | 1/7 | 1 | 1 | 1/5 |
| B4 | 1/5 | 1/7 | 1 | 1 | 1/4 |

| B5 | 1/3 | 1/3 | 5 | 4 | 1 |
|---|---|---|---|---|---|
| Single weight$w_i$ | 0.3395 | 0.3884 | 0.0510 | 0.0533 | 0.1679 |

$w_A^1$=)( 0.3395 , 0.3884 , 0.0510 , 0.0533 , 0.1679) $^T$is the eigenvector of the judgment matrix A of the expert 1.

Second, sub - criterion layer judgment matrix group and weight vector

1. Technical dimensions is the eigenvector of the judgment matrix B1 of the expert 1

| B1 | B11 | B12 | B13 | B14 | B15 | B16 | B17 |
|---|---|---|---|---|---|---|---|
| B11 | 1 | 5 | 1/3 | 1/7 | 1/5 | 1/9 | 1/7 |
| B12 | 1/5 | 1 | 1/3 | 1/5 | 1/4 | 1/8 | 1/5 |
| B13 | 3 | 3 | 1 | 1/5 | 1/3 | 1/7 | 1/5 |
| B14 | 7 | 5 | 5 | 1 | 3 | 1/5 | 1 |
| B15 | 5 | 4 | 3 | 1/3 | 1 | 1/3 | 1/2 |
| B16 | 9 | 8 | 7 | 5 | 3 | 1 | 3 |
| B17 | 9 | 8 | 7 | 5 | 3 | 1 | 3 |
| Single weigh$w_i$ | 0.0342 | 0.0250 | 0.0534 | 0.1856 | 0.1134 | 0.4000 | 0.1884 |

$w_{B1}^1 = ( 0.0342 , 0.0250, 0.0534 , 0.1856, 0.1134, 0.4000, 0.1884 )^T$

is the eigenvector of the judgment matrix B1 of the expert 1.

2. Market dimension

| B2 | B21 | B22 | B23 | B24 | B25 |
|---|---|---|---|---|---|
| B21 | 1 | 1 | 1/5 | 1/7 | 5 |
| B22 | 1 | 1 | 1/5 | 1/7 | 5 |
| B23 | 5 | 5 | 1 | 1/3 | 7 |
| B24 | 7 | 7 | 3 | 1 | 8 |
| B25 | 1/5 | 1/5 | 1/7 | 1/8 | 1 |
| Single weight$w_i$ | 0.0852 | 0.0852 | 0.2834 | 0.5168 | 0.0295 |

$w_{B2}^{1}$=( 0.0852 , 0.0852 , 0.2834, 0.5168, 0.0295$)^T$ is the eigenvector of the judgment matrix B2 of the expert 1.

3.Support dimension

| B3 | B31 | B32 | B33 | B34 | B35 | B36 | B37 |
|---|---|---|---|---|---|---|---|
| B31 | 1 | 1/3 | 1/3 | 1 | 3 | 5 | 1/5 |
| B32 | 3 | 1 | 1 | 3 | 5 | 7 | 1/2 |
| | 3 | 1 | 1 | 3 | 5 | 6 | 1/3 |
| B34 | 1 | 1/3 | 1/3 | 1 | 3 | 5 | 1/3 |
| B35 | 1/3 | 1/5 | 1/5 | 1/3 | 1 | 2 | 1/5 |
| B36 | 1/5 | 1/7 | 1/6 | 1/5 | 1/2 | 1 | 1/5 |
| B37 | 5 | 2 | 1 | 3 | 5 | 5 | 1 |
| Single weight$w_i$ | 0.0919 | 0.2214 | 0.2391 | 0.0998 | 0.0435 | 0.0286 | 0.2767 |

$w_{B3}^{1}$

$= (0.0919, 0.2214, 0.2391, 0.0988, 0.0435, 0.0286, 0.2767)^T$

is the eigenvector of the judgment matrix B3 of the expert 1

4. Conformance dimension

| B4 | B41 | B42 | B43 | B44 | B45 |
|---|---|---|---|---|---|
| B41 | 1 | 1 | 1/3 | 1/3 | 3 |
| B42 | 1 | 1 | 1/3 | 1/3 | 3 |
| B43 | 3 | 3 | 1 | 1 | 3 |
| B44 | 3 | 3 | 1 | 1 | 3 |
| B45 | 1/3 | 1/3 | 1/3 | 1/3 | 1 |
| Single weight $w_i$ | 0.1364 | 0.1364 | 0.3284 | 0.3284 | 0.0705 |

$w_{B4}^{1}=(0.1364, 0.1364, 0.3284, 0.3284, 0.0705)^T$ is the eigenvector of the judgment matrix B4 of the expert 1

5. Effect dimension

| B5 | B51 | B52 | B53 | B54 | B55 | B56 | B57 | B58 |
|---|---|---|---|---|---|---|---|---|
| B51 | 1 | 2 | 7 | 9 | 3 | 4 | 5 | 1/3 |
| B52 | 1/2 | 1 | 7 | 8 | 3 | 3 | 4 | 1/5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| B53 | 1/7 | 1/7 | 1 | 1 | 1/6 | 1/5 | 1/4 | 1/7 |
| B54 | 1/9 | 1/8 | 1 | 1 | 1/6 | 1/6 | 1/3 | 1/9 |
| B55 | 1/3 | 1/3 | 6 | 6 | 1 | 3 | 4 | 1/6 |
| B56 | 1/4 | 1/3 | 5 | 6 | 1/3 | 1 | 3 | 1/6 |
| B57 | 1/5 | 1/4 | 4 | 3 | 1/4 | 1/3 | 1 | 1/8 |
| B58 | 3 | 5 | 7 | 9 | 6 | 7 | 8 | 1 |
| Single weight $w_i$ | 0. 2097 | 0. 1529 | 0. 0209 | 0. 0195 | 0. 1022 | 0. 0693 | 0. 0418 | 0. 3838 |

$w_{B4}^{1}$=( 0.2097 , 0.1529 , 0.0209 , 0.0195 , 0.1022, 0.0693, 0.0418, 0.3838$)^T$ is the eigenvector of the judgment matrix B5 of the expert 1.

Summarize the weight vector of all expert judgment matrix groups, as shown in appendix table B. The table shows that the experts' views tend to be consistent and only a few experts have different ideas.

(4) Consistency check

First, the consistency test of a single judgment matrix combines the formula (5-2) to solve the maximum characteristic root $\lambda_{max}$ of the judgment matrix and perform the consistency check. The first expert judgment matrix is taken as an example to test the consistency of the single judgment matrix.

$$AW_A^1=\begin{bmatrix} 1 & 1 & 55 & 3 \\ 1 & 1 & 77 & 3 \\ 1/5 & 1/7 & 11 & 1/5 \\ 1/5 & 1/7 & 11 & 1/4 \\ 1/3 & 1/3 & 54 & 1 \end{bmatrix}\begin{bmatrix} 0.3395 \\ 0.3884 \\ 0.0510 \\ 0.0533 \\ 0.1679 \end{bmatrix}$$

$(AW_A^1)_1$=1. 7528 $(AW_A^1)_2$ =1. 9613 $(AW_A^1)_3$ =0. 2612

$(AW_A^1)_4$=0. 2696

$(AW_A^1)_5$=0. 8784

A- $\lambda^1_{max}$=$\frac{1.7528}{5\times0.3395}+\frac{1.9613}{5\times0.3884}+\frac{0.2612}{5\times0.051}+\frac{0.2696}{5\times0.0533}+\frac{0.8784}{5\times0.1679}=5.1261$

By $CI=\frac{5.1261-5}{5-1}+0.0315$，$RI$=1. 12，$CR$=$\frac{CI}{RI}=0.0281<0.1$, we can seethe judgment matrix A of expert 1 has a satisfactory consistency.

Similarly, the consistency test of the sub-criterion layer judgment matrix can be obtained:

B1: the largest eigenvalue $\lambda_{max}=7.7695$，$CI=0.1283$，$RI=1.32$，$CR=0.0972<0.1$， we can see that the judgment matrix B1 of expert 1 has satisfactory consistency;

B2: the largest eigenvalue $\lambda_{max}=5.3992$，$CI=0.0998$，$RI=1.12$，$CR=0.0891<0.1$， we can see that the judgment matrix B2 of expert 1 has satisfactory consistency;

B3: t the largest eigenvalue λ_max = 7.2830, CI = 0.0472, RI = 1.32, CR = 0.0357 <0.1, we can see that the judgment matrix B3 of expert 1 has satisfactory consistency;

B4: the largest eigenvalue $\lambda_{max}=7.2830$，$CI=0.0472$，$RI=1.32$，$CR=0.0357<0.1$，we can see that the judgment matrix B4 of expert 1 has satisfactory consistency;

B5 :the largest eigenvalue $\lambda_{max}=8.7621$，$CI=0.1089$，$RI=1.41$，$CR=0.0772<0.1$ ,we can see that the judgment matrix B5 of

$CR^{(3)}=\frac{CI^{(3)}}{RI^{(3)}}$=0. 0847<0. 1 indicating that the stratification of the judgment matrix is well consistent.

The results of the consistency test of all expert judgment matrix groups are summarized in Table 5-3. According to both the $CR^{(2)}$ and the $CR^{(3)}$ values, it is known that the judgment matrix of the 11 experts has satisfactory consistency, so the next step can be performed.

Table 5-3 The results of the consistency test of the judgment matrix of the experts(a)

| | A- $\lambda_{max}$ | B1- $\lambda_{max}$ | B2- $\lambda_{max}$ | B3- $\lambda_{max}$ | B4- $\lambda_{max}$ | B5- $\lambda_{max}$ | $CI^{(2)}$ | $RI^{(2)}$ | $CR^{(2)}$ |
|---|---|---|---|---|---|---|---|---|---|
| Expert 1 | 5. 1261 | 7. 7695 | 5. 3992 | 7. 2830 | 5. 1958 | 8. 7621 | 0. 0315 | 1. 12 | 0. 0281 |
| Expert 2 | 5. 1265 | 7. 3337 | 5. 1497 | 7. 6705 | 5. 2581 | 8. 6633 | 0. 0316 | 1. 12 | 0. 0282 |
| Expert 3 | 5. 2641 | 7. 7458 | 5. 3667 | 7. 6974 | 5. 0553 | 8. 8628 | 0. 0660 | 1. 12 | 0. 0589 |
| Expert 4 | 5. 2502 | 7. 6579 | 5. 4386 | 7. 7570 | 5. 2184 | 8. 7093 | 0. 0646 | 1. 12 | 0. 0559 |

expert 1 has satisfactory consistency.

Second, the stratification of the judgment matrix as a whole consistency test. The same is true with the first expert as an example to test the stratification of the judgment matrix as a whole.

$$CI^{(3)} = \left(\mathrm{CI}_1^{(3)}, \mathrm{CI}_2^{(3)}, \mathrm{CI}_3^{(3)}, \mathrm{CI}_4^{(3)}, \mathrm{CI}_5^{(3)}\right) w^{(2)} =$$

$$(0.1283,0.0998,0.0472,0.0489,0.1089)(0.3395,0.3884,0.0510,0.0533,0.1679)^T$$

=0. 1056

$$RI^{(3)} = (\mathrm{RI}_1^{(3)}, \mathrm{RI}_2^{(3)}, \mathrm{RI}_3^{(3)}, \mathrm{RI}_4^{(3)}, \mathrm{RI}_5^{(3)})\ \mathrm{w}^{(2)} =$$

$(1.32,1.12,1.32,1.12,1.41)(0.3395,0.3884,0.0510,0.0533,0.1679)^T$ =1. 2469

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Expert 5 | 5.2564 | 7.5116 | 5.1849 | 7.6742 | 5.1212 | 8.8997 | 0.0641 | 1.12 | 0.0572 |
| Expert 6 | 5.0582 | 7.5067 | 5.2183 | 7.3009 | 5.3713 | 8.6154 | 0.0145 | 1.12 | 0.0130 |
| Expert 7 | 5.3395 | 7.7439 | 5.3327 | 7.6291 | 5.2207 | 8.6371 | 0,0849 | 1.12 | 0.0758 |
| Expert 8 | 5.2482 | 7.5195 | 5.1131 | 7.4932 | 5.2972 | 8.8363 | 0.0620 | 1.12 | 0.0554 |
| Expert 9 | 5.1214 | 7.5948 | 5.2327 | 7.6801 | 5.2856 | 8.5771 | 0.0304 | 1.12 | 0.0271 |
| Expert 10 | 5.3651 | 7.5087 | 5.2836 | 7.6351 | 5.2163 | 8.6709 | 0.0913 | 1.12 | 0.0815 |
| Expert 11 | 5.2021 | 7.4774 | 5.1991 | 7.2596 | 5.1945 | 8.7641 | 0.0505 | 1.12 | 0.0451 |

Table 5-3 The results of the consistency test of the judgment matrix of the experts (b)

| | $CI^{(3)}$, B1 | $CI^{(3)}, B2$ | $CI^{(3)}$, B3 | $CI^{(3)}$, B4 | $CI^{(3)}$, B5 | $CI^{(3)}$ |
|---|---|---|---|---|---|---|
| Expert 1 | 0.1283 | 0.0998 | 0.0472 | 0.0489 | 0.1089 | 0.1056 |
| Expert 2 | 0.0556 | 0.0374 | 0.1118 | 0.0645 | 0.0948 | 0.0743 |
| Expert 3 | 0.1243 | 0.0917 | 0.1162 | 0.0138 | 0.1233 | 0.1023 |
| Expert 4 | 0.1097 | 0.1097 | 0.1262 | 0.0546 | 0.1013 | 0.1057 |
| Expert 5 | 0.0853 | 0.0462 | 0.1124 | 0.0303 | 0.1285 | 0.0630 |
| Expert 6 | 0.0845 | 0.0501 | 0.0501 | 0.0928 | 0.0879 | 0.0781 |
| Expert 7 | 0.1240 | 0.1048 | 0.1048 | 0.0552 | 0.0910 | 0.0920 |
| Expert 8 | 0.0866 | 0.0822 | 0.0822 | 0.0743 | 0.1195 | 0.0895 |
| Expert 9 | 0.0991 | 0.1133 | 0.1133 | 0.0714 | 0.0824 | 0.0791 |
| Expert 10 | 0.0848 | 0.1058 | 0.1058 | 0.0541 | 0.0958 | 0.0786 |
| Expert 11 | 0.0796 | 0.0433 | 0.0433 | 0.0486 | 0.1092 | 0.0619 |

Table 5-3 The results of the consistency test of the judgment matrix of the experts (c)

| | $RI^{(3)}$, B1 | $RI^{(3)}$, B2 | $RI^{(3)}$, B3 | $RI^{(3)}$, B4 | $RI^{(3)}$ | $RI^{(3)}$ |
|---|---|---|---|---|---|---|
| Expert 1 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2469 |
| Expert 2 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.3104 |
| Expert 3 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2120 |
| Expert 4 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2193 |
| Expert 5 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.1969 |
| Expert 6 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2826 |
| Expert 7 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2239 |
| Expert 8 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.3074 |
| Expert 9 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2524 |
| Expert 10 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2070 |
| Expert 11 | 1.32 | 1.12 | 1.32 | 1.12 | 1.41 | 1.2380 |

Table 5-3 The results of the consistency test of the judgment matrix of the experts (d)

| | $CR^{(3)}$, B1 | $CR^{(3)}$, B2 | $CR^{(3)}$, B3 | $CR^{(3)}$, B4 | $CR^{(3)}$, B5 | $CR^{(3)}$ |
|---|---|---|---|---|---|---|
| Expert 1 | 0.0972 | 0.0891 | 0.0357 | 0.0437 | 0.0772 | 0.0847 |
| Expert 2 | 0.0421 | 0.0334 | 0.0847 | 0.0576 | 0.0672 | 0.0567 |
| Expert 3 | 0.0942 | 0.0819 | 0.0881 | 0.0124 | 0.0874 | 0.0844 |
| Expert 4 | 0.0831 | 0.0979 | 0.0956 | 0.0488 | 0.0719 | 0.0867 |
| Expert 5 | 0.0646 | 0.0413 | 0.0851 | 0.0271 | 0.0912 | 0.0527 |
| Expert 6 | 0.0640 | 0.0487 | 0.0380 | 0.0829 | 0.0624 | 0.0609 |
| Expert 7 | 0.0939 | 0.0743 | 0.0794 | 0.0493 | 0.0645 | 0.0752 |
| Expert 8 | 0.0656 | 0.0252 | 0.0623 | 0.0663 | 0.0847 | 0.0685 |
| Expert 9 | 0.0751 | 0.0519 | 0.0859 | 0.0637 | 0.0585 | 0.0632 |
| Expert 10 | 0.0642 | 0.0633 | 0.0802 | 0.0483 | 0.0680 | 0.0651 |
| Expert 11 | 0.0603 | 0.0444 | 0.0328 | 0.0434 | 0.0774 | 0.0500 |

(5) Find the weight vector of the matrix group under the criteria

Combined with the formula (5-7) and (5-8), we use the weight vector (weighted geometric mean) synthesis method to find the weight vector of the judgment matrix under the same criterion,

$$W_A = (0.3316\ ,0.3870\ ,0.0927\ ,0.0701\ ,0.1186\ )^T,$$

$W_{B1} =$

$(0.0603\ ,0.0532\ ,0.0938\ ,0.1919\ ,0.1078\ ,0.3822\ ,0.1108\ )^T,$

$W_{B2}=(0.1075\ ,0.0902\ ,0.2768\ ,\ 0.3986\ ,\ 0.1269\ )^T,$

$W_{B3} = (0.0941\ ,\ 0.1542\ ,\ 0.1301\ ,\ 0.1015\ ,\ 0.1483\ ,$

$0.1119\ ,0.2599\ )^T,$

$W_{B4}=(0.2086\ ,\ 0.1404\ ,\ 0.1902\ ,\ 0.2951\ ,\ 0.1658)^T,$

$W_{B5} = (0.2247\ ,$

$0.0774\ ,0.0235\ ,0.0260\ ,0.0734\ ,0.1148\ ,0.0805\ ,0.3798)^T,$

The important criterion layer indicators are: market factors> technical factors> efficiency factors> support factors> compliance factors; technical dimension of the importance of indicators of the order: the profitability of technology after application-B16> the formation of industry technology. The possibility of the standard -B14> the cost of commercial technology-B17> the possibility of patent-B15> become the possibility of leading technology-B13> advanced level of technology-B11> technical maturity-B12; market dimension of the importance of the order of indicators. For the value of the customer to create -B24> compared with similar technology more market advantage -B23> customer growth rate-B25> customer conversion costs -B21> similar technology manufacturers conversion costs-B22; support the importance of the index order : Policy and regulation support - B37> Human resources situation -B32> Technical innovation system coordination level -B35> Financing situation -B33> Social intermediary service quality -B36> Technology, equipment and material protection -B34> Infrastructure conditions -B31; The importance of the index of the dimensionality of the dimension is: conformance with the industrial policy - B44> conformance with the technical foresight - B41> conformance with the science and technology policy - B43> compliance with the public values -B45> Compliance with social development planning -B42; Indicators of importance of indicators of efficiency dimensions: expected profit level -B58> Resource savings level -B51> Relevant industry-driven level -B56> Job creation size -B57> Environmental improvement Level-B52> Science and technology to promote the development process-B55> Storage of new technology awareness-B54> Quality of life improvement - B53. However, it can be seen from Table 14 that the weights of the index before and after the single order are in the range of 1-3, which indicates that the previous index in each dimension is only slightly important to the latter index.

Table 14 Ranking of index weights in each dimension

| Hierarchical single order | index | weight | Ratio of weights |
|---|---|---|---|
| 1 | Market dimensions -B2 | 0.3870 | --- |
| 2 | Technological dimensions-B1 | 0.3316 | 1.17 |
| 3 | Effect dimensions -B5 | 0.1186 | 2.80 |
| 4 | Support dimensions -B3 | 0.0927 | 1.28 |
| 5 | Conformance dimensions -B4 | 0.0701 | 1.32 |
| Hierarchical single order | index | weight | Ratio of weights |
| 1 | Continuity of profiting after technology application -B16 | 0.3822 | --- |
| 2 | Possibility of becoming industrial technological standards -B14 | 0.1919 | 1.99 |
| 3 | Technology commercialization costs -B17 | 0.1108 | 1.73 |
| 4 | Possibility of being patented -B15 | 0.1078 | 1.03 |
| 5 | Possibility of becoming leading technology -B13 | 0.0938 | 1.15 |

| | | | |
|---|---|---|---|
| 6 | Technology advancement level -B11 | 0.0603 | 1.56 |
| 7 | Technical maturity -B12 | 0.0532 | 1.13 |
| Hierarchical single order | index | weight | Ratio of weights |
| 1 | Values created for customers -B24 | 0.3986 | --- |
| 2 | More market advantages compared with the same kind of technology -B23 | 0.2768 | 1.44 |
| 3 | Expected customer growth rate -B25 | 0.1269 | 2.18 |
| 4 | Customers' transforming costs -B21 | 0.1075 | 1.18 |
| 5 | similar technology manufacturers conversion costs -B22 | 0.0902 | 1.19 |
| Hierarchical single order | index | weight | Ratio of weights |
| 1 | Policy and law support strength -B37 | 0.2599 | --- |
| 2 | HR conditions -B32 | 0.1542 | 1.69 |
| 3 | Technology innovation system coordination extent -B5 | 0.1483 | 1.04 |
| 4 | Financing conditions -B33 | 0.1301 | 1.14 |
| 5 | Social intermediary service quality -B36 | 0.1119 | 1.16 |
| 6 | Technology, equipment and material guarantee -B3 | 0.1015 | 1.10 |
| 7 | Infrastructure conditions -B31 | 0.0941 | 1.08 |
| Hierarchical single order | index | weight | Ratio of weights |
| 1 | Conformance with industrial policy -B44 | 0.2951 | --- |
| 2 | Conformance with technology foreseeability -B41 | 0.2086 | 1.41 |
| 3 | Conformance with science and technology policy -B43 | 0.1902 | 1.10 |
| 4 | Conformance with public values -B45 | 0.1658 | 1.15 |

| | | | |
|---|---|---|---|
| 5 | Conformance with social development planning -B42 | 0.1404 | 1.18 |
| Hierarchical single order | index | weight | Ratio of weights |
| 1 | expected profit leve-B58 | 0.3798 | --- |
| 2 | Resource saving extent -B51 | 0.2247 | 1.69 |
| 3 | Related industries driving extent -B56 | 0.1148 | 1.96 |
| 4 | Employment opportunities -B57 | 0.0805 | 1.43 |
| 5 | Environment improvement extent -B52 | 0.0774 | 1.04 |
| 6 | Science and technology development promotion extent -B55 | 0.0734 | 1.05 |
| 7 | New storage technology awareness improvement -B54 | 0.026 | 2.82 |
| 8 | Living standard improvement extent -B53 | 0.0235 | 1.11 |

(6) Solving composite weight vectors

Combining formula (5-9) and (5-10) solving synthetic weight vector, table 15 is obtained. From the fifth column of table (*Wij*) shows that the weight of each index were 0.0200, 0.0176, 0.0311, 0.0636, 0.0357, 0.1267, 0.0367, 0.0416, 0.0349, 0.1071, 0.1543, 0.0491, 0.0087, 0.0143, 0.0121, 0.0094, 0.0137, 0.0104, 0.0241, 0.0146, 0.0098, 0.0133, 0.0207, 0.0092, 0.01160.0266 0.0028, 0.0031, 0.0087, 0.0136, 0.0095, 0.0450.

Table 15. Evaluation index system of storage technology commercialization potential

| index | weight $WB_I$ | index | weight $WB_{Ij}$ | $W_{Ij}$ |
|---|---|---|---|---|
| | | Technology advancement level -B11 | 0.0603 | 0.0200 |
| | | Technical maturity -B12 | 0.0532 | 0.0176 |
| | 0.3316 | Possibility of becoming leading technology -B13 | 0.0938 | 0.0311 |

| | | | | |
|---|---|---|---|---|
| Technological dimensions- | | Possibility of becoming industrial technological standards -B14 | 0.1919 | 0.0636 |
| | | Possibility of being patented -B15 | 0.1078 | 0.0357 |
| | | Continuity of profiting after technology application -B16 | 0.3822 | 0.1267 |
| | | Technology commercialization costs -B17 | 0.1108 | 0.0367 |
| Market dimensions | 0.387 | Customers' transforming costs -B21 | 0.1075 | 0.0416 |
| | | Transforming costs of vendors of the same kind -B22 | 0.0902 | 0.0349 |
| | | More market advantages compared with the same kind of technology -B23 | 0.2768 | 0.1071 |
| | | Values created for customers -B24 | 0.3986 | 0.1543 |
| | | Expected customer growth rate -B25 | 0.1269 | 0.0491 |
| Support dimensions | 0.0927 | Infrastructure conditions -B31 | 0.0941 | 0.0087 |
| | | HR conditions -B32 | 0.1542 | 0.0143 |
| | | Financing conditions -B33 | 0.1301 | 0.0121 |
| | | Technology, equipment and material guarantee -B34 | 0.1015 | 0.0094 |
| | | Technology innovation system coordination extent -B35 | 0.1483 | 0.0137 |
| | | Social intermediary service quality -B36 | 0.1119 | 0.0104 |
| | | Policy and law support strength -B37 | 0.2599 | 0.0241 |
| Conformance dimensions | 0.0701 | Conformance with technology foreseeability -B41 | 0.02086 | 0.0146 |
| | | Conformance with social development planning -B42 | 0.1404 | 0.0098 |
| | | Conformance with science and technology policy -B43 | 0.1902 | 0.0133 |

| | | | | |
|---|---|---|---|---|
| | | Conformance with science and technology policy-B44 | 0.2951 | 0.0207 |
| | | Conformance with industrial policy -B45 | 0.1658 | 0.0116 |
| Effect dimensions | 0.1186 | Resource saving extent -B51 | 0.2247 | 0.0266 |
| | | Environment improvement extent -B52 | 0.0774 | 0.0092 |
| | | Living standard improvement extent -B53 | 0.0235 | 0.0028 |
| | | New storage technology awareness improvement -B54 | 0.026 | 0.0031 |
| | | Science and technology development promotion extent -B55 | 0.0734 | 0.0087 |
| | | Related industries driving extent -B56 | 0.1148 | 0.0136 |
| | | Employment opportunities -B57 | 0.0805 | 0.0095 |
| | | Expected profit level -B58 | 0.3798 | 0.0450 |

# Chapter 6 Example analysis of commercial potential of magnetic storage technology

## 6.1 Introduction of evaluation process and comprehensive evaluation method

### 6.1.1 Evaluation process

Because some storage technology itself is still not perfect, the market is not mature enough, commercial infrastructure, supporting technology, human resources and other conditions are not well matched, and resources are limited, investment decision makers may not be able to make commercial operation for storage. This requires the selected key storage technology with commercial potential investment or policy guidance. However, when the project storage technology requires huge amounts of money in R & D and production experiments, if one begins with expert selection, it will increase workload of experts. Also, redundant questionnaires and numerous expert judgments will inevitably lead to fatigue and even cause resentment from experts, so it would be hard to guarantee the high quality of data. To improve the scientific and accuracy of expert investigation, the multi round expert survey should follow the selection process from "rough" to "fine". First of all, inviting the general professionals (such as personnel and basic laboratory professional masters) is preliminary screening for storage alternative project "surface", which was excluded interference technology without any commercial value Then, a senior expert in the field is invited to reevaluate the commercial potential of the storage technology filtered out of the first round [78]. Only by following such an evaluation process can the scientific and rigorous research be improved.

### 6.1.2 Comprehensive evaluation method

Comprehensive evaluation of the commercialization potential of MRAM technology can be carried out in three steps:

(1) Determining each index score

According to the expert's technical familiarity and expert scoring, the arithmetic weighted comprehensive evaluation method was used to calculate the index scores.

$$x = \frac{\sum_{i=1}^{m} x_i w_i}{\sum_{i=1}^{m} w_i} \quad (i=1,2, \ \ldots, m) \qquad (6\text{-}1)$$

Among them, $m$representsing the number of experts, $x$ means comprehensive index score, $x_i$indicates the expert $i$index scoring, and $w_i$represents the weight of expert $i$. The expert weight is determined according to the expert's familiarity with the new storage technology project (corresponding weights of 1, 0.75, 0.5, 0.25).

(2) Uniform processing of index data

Suppose there are $n$ indexes, $m$ new storage technology solutions, then evaluation index matrix is X=$\left(x_{ij}\right)_{m\times n}$). $x_{ij}$ represents the new storage technology in the index score. Taking the evaluation index of commercial potential of new storage technology into account, it can be divided into different types (positive index, reverse index and moderate index), cannot spend index, so in the comprehensive evaluation should be the index relationship in a certain function consistent processing, keep the index with the trends to ensure the comparability [79].

Design: $\max_{1\le i\le m} x_{ij}$=$a_j$, $a_j$ for the j index score maximum value. $\min_{1\le i\le m} x_{ij}$=$b_j$, which is the minimum value of $b_j$ of j index score.

For positive indicators, it’s the better when the index value becoming greater.

$$y_{ij}=\frac{x_{ij}-b_j}{a_j-b_j} \qquad (6\text{-}2)$$

For reverse indicators, t’s the better when the indicator becoming smaller.

$y_{ij}=\frac{a_j-x_{ij}}{a_i-b_j}$ (6-3)

For moderate indicators, that is, the index value to stabilize at a fixed value for the best indicators.

$y_{ij}=\frac{1}{1+|q-x_{\overline{ij}}|}$ (6-4)

Among them, $q$ is the most appropriate value of this index.

(3) Calculating the new storage technology commercialization potential comprehensive score

$R = W \times Y$ (6-5)

Among them, $R$=($r_1$ ,$r_2$ ,…,$r_m$) a comprehensive evaluation result vector for the commercialization potential of the $m$ new storage technology. $W$=($w_1$,$w_1$， …,$w_n$)for the weight vector of each index. $Y=\left(y_{ij}\right)_{m\times n}$ for consistent data matrix commercial potential evaluation index $m$ of new storage technology.

Finally, sort the low carbon technology by the size of the $r_j$ (when $r_j$ is greater, the commercial potential of the storage technology is greater).

# 6.2 Magnetic storage technology commercial potential evaluation case study

## 6.2.1 Survey designing

We chose 3 storage technologies.

(1) Research purposes. Evaluate the commercial potential of magnetic storage (MRAM), semiconductor storage (DARM), and flash memory.

(2) Questionnaire designing. Using five levels of Likert scaling method to design an expert questionnaire for evaluating the commercial potential of storage technology, as shown in schedule 7.

(3) Investigation Object. This paper will research the staff in the electronic storage industry and professor in the University

## 6.2.2 Data analysis and processing

A total of 45 questionnaires were issued and 36 were recovered with 80%effective rate. First, according to the data collected by experts, combining formula (6-1) to calculate the storage technology in each index score. The arrangement is shown in table 16 below.

Table 16. Summary of storage technology commercialization potential indicators

| First level index | Second level index | MRAM | DRAM | Flash |
|---|---|---|---|---|
| Technological dimensions | Technology advancement level | 4 | 3. 33 | 5 |
| | Technical maturity | 4 | 4. 33 | 1. 67 |
| | Possibility of becoming leading technology | 4. 33 | 4. 33 | 1 |
| | Possibility of becoming industrial technological standards | 4 | 4. 33 | 1. 33 |

| | | | | |
|---|---|---|---|---|
| | Possibility of being patented | 4.33 | 4.67 | 2 |
| | Continuity of profiting after technology application | 3.67 | 4.33 | 2 |
| | Technology commercialization costs | 3.33 | 4.33 | 1.67 |
| Market dimensions | Customers' transforming costs | 3.67 | 4.33 | 1.67 |
| | Transforming costs of vendors of the same kind | 3.33 | 4.33 | 1.67 |
| | More market advantages compared with the same kind of technology | 4.33 | 4.67 | 2 |
| | Values created for customers | 4.67 | 3.33 | 4 |
| | Expected customer growth rate | 4.33 | 4.33 | 3 |
| Support dimensions | Infrastructure conditions | 3.67 | 4.67 | 2.33 |
| | HR conditions | 4.33 | 4.67 | 3.33 |
| | Financing conditions | 4.33 | 4.67 | 3.67 |
| | Technology, equipment and material guarantee | 4.33 | 4.67 | 2.33 |
| | Technology innovation system coordination extent | 3.67 | 4.67 | 2.33 |
| | Social intermediary service quality | 4 | 4 | 3.67 |
| | Policy and law support strength | 4.33 | 4 | 5 |
| Conformance dimensions | Conformance with technology foreseeability | 4.67 | 3.33 | 5 |
| | Conformance with social development planning | 5 | 5 | 4 |
| | Conformance with science and technology policy | 5 | 4 | 5 |
| | Conformance with industrial policy | 5 | 4.67 | 4.67 |
| | Conformance with public values | 3.67 | 3.67 | 3.33 |
| | Resource saving extent | 4.33 | 3.33 | 4.67 |
| | Environment improvement extent | 4.33 | 3 | 5 |

| | | | | |
|---|---|---|---|---|
| Effect dimensions | Living standard improvement extent | 4. 67 | 3 | 3. 33 |
| | New storage technology awareness improvement | 4. 67 | 3. 33 | 5 |
| | Science and technology development promotion extent | 4 | 4 | 4. 33 |
| | Related industries driving extent | 4. 67 | 4. 33 | 2. 67 |
| | Employment opportunities | 3. 67 | 4. 33 | 2 |
| | Expected profit level | 4 | 4. 67 | 2. 33 |

Secondly, we use the formula (6-2) and (6-4) to do the data consistency processing of the forward and the moderate indexes respectively. Among them, $a_{ij}$=5， $b_{ij}$=0， $q$=3. The data consistency processing results are shown in table 17.

Table 17 Summary of data reconciliation processing

| First level index | Second level index | MRAM | DRAM | Flash |
|---|---|---|---|---|
| Technological dimensions | Technology advancement level | 0. 5 | 0. 752 | 0. 333 |
| | Technical maturity | 0. 5 | 0. 429 | 0. 429 |
| | Possibility of becoming leading technology | 0. 866 | 0. 866 | 0. 2 |
| | Possibility of becoming industrial technological standards | 0. 8 | 0. 866 | 0. 266 |
| | Possibility of being patented | 0. 866 | 0. 934 | 0. 4 |
| | Continuity of profiting after technology application | 0. 734 | 0. 866 | 0. 4 |
| | Technology commercialization costs | 0. 666 | 0. 866 | 0. 334 |
| | Customers’ transforming costs | 0. 734 | 0. 866 | 0. 334 |
| | Transforming costs of vendors of the same kind | 0. 666 | 0. 866 | 0. 334 |

| | | | | |
|---|---|---|---|---|
| Market dimensions | More market advantages compared with the same kind of technology | 0. 866 | 0. 934 | 0. 4 |
| | Values created for customers | 0. 934 | 0. 666 | 0. 8 |
| | Expected customer growth rate | 0. 866 | 0. 866 | 0. 6 |
| Support dimensions | Infrastructure conditions | 0. 734 | 0. 934 | 0. 466 |
| | HR conditions | 0. 866 | 0. 934 | 0. 666 |
| | Financing conditions | 0. 866 | 0. 934 | 0. 734 |
| | Technology, equipment and material guarantee | 0. 866 | 0. 934 | 0. 466 |
| | Technology innovation system coordination extent | 0. 734 | 0. 934 | 0. 466 |
| | Social intermediary service quality | 0. 8 | 0. 8 | 0. 734 |
| | Policy and law support strength | 0. 866 | 0. 8 | 1 |
| Conformance dimensions | Conformance with technology foreseeability | 0. 934 | 0. 666 | 1 |
| | Conformance with social development planning | 1 | 1 | 0. 8 |
| | Conformance with science and technology policy | 1 | 0. 8 | 1 |
| | Conformance with industrial policy | 1 | 0. 934 | 0. 934 |
| | Conformance with public values | 0. 734 | 0. 734 | 0. 666 |
| Effect dimensions | Resource saving extent | 0. 866 | 0. 666 | 0. 934 |
| | Environment improvement extent | 0. 866 | 0. 6 | 1 |
| | Living standard improvement extent | 0. 934 | 0. 6 | 0. 666 |
| | New storage technology awareness improvement | 0. 934 | 0. 666 | 1 |
| | Science and technology development promotion extent | 0. 8 | 0. 8 | 0. 866 |
| | Related industries driving extent | 0. 934 | 0. 866 | 0. 534 |

| | | | | |
|---|---|---|---|---|
| | Employment opportunities | 0. 734 | 0. 866 | 0. 4 |
| | Expected profit level | 0. 8 | 0. 934 | 0. 466 |

Finally, using formula (6-5), the composite scores of commercial potentials of each storage technology are obtained, as shown in table 18.

Table 18 Comprehensive commercialization potential of storage technologies

| | $R_{BEV}$ | $R_{HEV}$ | $R_{FCEV}$ | $R^*_{BEV}$ | $R^*_{HEV}$ | $R^*_{FCEV}$ |
|---|---|---|---|---|---|---|
| Technological dimensions | 0.245 | 0.279 | 0.115 | 0.739 | 0.843 | 0.345 |
| Market dimensions | 0.333 | 0.312 | 0.221 | 0.861 | 0.805 | 0.573 |
| Support dimensions | 0.077 | 0.082 | 0.065 | 0.827 | 0.884 | 0.701 |
| Conformance dimensions | 0.066 | 0.058 | 0.063 | 0.941 | 0.828 | 0.896 |
| Effect dimensions | 0.099 | 0.096 | 0.079 | 0.836 | 0.809 | 0.663 |
| Comprehensive dimension | 0.820 | 0.827 | 0.542 | --- | --- | --- |

Note：BEV, HEV and FCEV represent MRAM, DRAM and Flash respectively.

$R^*_{BEV}$=$R_{BEV}$/the corresponding dimension weights

$R^*_{HEV}$=$R_{HEV}$/the corresponding dimension weights

$R^*_{FCEV}$=$R_{FCEV}$/the corresponding dimension weights/

# 6.3 Research conclusion

As you can see from table 6-3, different storage technologies have different commercial potentials. MRAM technology and DRAM technology both have high commercial potential (R values are greater than 0.8). And both have considerable commercial potential, while Flash technology has less potential for further commercialization. The commercialization potential of storage technology depends on five aspects: technical dimension, market dimension, support dimension, conformance dimensions and effect dimension.

MRAM technology and DRAM technology in each dimension are better than flash. So, the potential of both commercial potential is high. Flash in effect dimension has more advantages (potential compliance score is 0.896, close to 0.9, in table 6-1 conformance dimension score also shows Flash's technology foresight and social development planning, science and technology policy and industrial policy of high consistency). Although the degree of commercialization relatively high, it lacks further commercial potential basis in the two aspects of technology and market.

In any dimension, MRAM has an absolute advantage over Flash in implementing commercial operations. In the market, DRAM is inferior to MRAM in the aspects of conformance and effect. But the commercial potential of DRAM is a little higher than MRAM. The reasons (the existing infrastructure conditions, human resources, financial status, technology, equipment and material security and technology innovation system terms) are more conducive to promoting the further commercialization than DRAM. And integrated advanced technology, maturity, profitability and business costs and other factors are beneficial to promotion the commercialization of DRAM. The above analysis shows that, besides technical factors and market factors, the supporting factors are also the key factors to implement the commercialization of storage technology.

# Chapter 7 Conclusion and future work

## 7.1 Research summary

Storage technology commercialization potential evaluation provides the basis for commercial investment decisions, according to the results merit investment in storage technology, which helps reduce blindness in technology development and transfer. And it not only helps improve the targeting of Government policy support, but also helps improve allocation of limited resources.

This thesis reviews relevant literature from the aspects of the connotation of the commercialization potential of storage technology, the evaluation index of the commercial potential of storage technology, and the evaluation method of the commercial potential of storage technology. Results found that most of the storage technology have remained at the technology present situation and outlook of the qualitative description stage, the research content rarely involve storage technology commercialization factors or commercial potential. There are few special studies on the commercial potential evaluation of storage technology.

In this context, this paper attempts to explore the commercialization potential evaluation of storage technology to guide the practical activity about storage technology commercialization potential.

This paper based on the clear connotation storage technology and technology commercialization, technology commercialization process, risk and potential. At meantime, based on the previous researches, discussing the influence factors of the commercialization potential from the public perspective to extracted and purified five main factors. They are technical factors, market factors, supporting factors, conformance factors and effect factors. Then, designing storage technology commercialization potential to evaluate the original index system from these five aspects.

To ensure the scientific and reasonable of the index system, this paper designed questionnaire A (see schedule A) for expert investigation, and analyzed the reliability and validity of expert data. The results (see table 5 to table 9) show that the scale (questionnaire A) has good reliability and validity, that is, the original index system is reasonable. On this basis, according to the description of statistical results (see table 10) and expert consultation, adjusting the index structure and the noun expression to obtain the more generally accepted commercial potential measurement index system of storage technology (see table 11).

Then, based on the understood the analytical hierarchy process(AHP)operation process, this paper using AHP method to determine weight coefficient of each evaluation index ( see table 15). Finally, the commercialization potentials of t h e magnetic storage technology have been systemically evaluated. This study presents the whole process of the evaluation of the commercialization potential of storage technology, and achieves the expected goal of this research.

This paper discusses storage technology commercialization potential evaluation, and fills the blank theory in the field of the project. Also, it contributes to guiding the commercialization potential of storage technology evaluation practice. For Chinese companies, this paper can be a guide book to start MRAM investment and also can be an important data information for storage technology companies which want industrial transformation. For government, this paper provides many fields which government can give support for the local emerging companies.

## 7.2 Limitations and prospects

Nevertheless, there are still many shortcomings in this study.

Firstly, it lacks the existing research methods. First, for the evaluation of storage technology commercialization potential indicators of empowerment, its original data consists of experts based on the experience obtained. Although experts' evaluation is based on the reality, there is still possibility that their evaluation might be subjective. As for the application of the analytic hierarchy process, although the method of strict logic to determine the "weight" for "filtering" and "repair" process was designed to achieve objectivity, it is hard to completely achieve the goal. Second, level analysis method can reflect the evaluation index on evaluation target of importance size, but its analysis process in the only on sibling with dimension degrees.

Secondly, it's sample questions, expert evaluation of accuracy depending on the expert's experience, as well as the breadth and depth of knowledge. This requires experts involved in the research of high academic level and practical experience. At the time of sample collection, i considered the professional of study characteristics and research is made mainly from related fields. Experts selected level can be further improved.

For future research, the author would like to propose two recommendations:

First, there should be evaluation of the commercial potential of storage technology and a deeper discussion of data collection.

Second, the current study mainly focused on public perspective. This study discussed new storage technology commercial potential evaluation in the intermediate level. The study didn't consider the influencing factors of technology transferor and technology receiver

Further research can consider factors about the deep development of technology and the strategic connection of purchase from micro angle, and combine with its internal capacity for systematic research.

# Questionnaire

## Questionnaire 1

New storage Technology commercialization potential evaluation index system questionnaire

Note:

1 The purpose of the investigation: through experts scoring, screening storage technology commercialization potential evaluation index

2 Numerical meaning: 5- is very important; 4- is more important; 3- is generally important; 2- is less important; 1- is very unimportant. Please according to the degree of importance of each index, tick " √ " in the corresponding figures.

| Target layer | Benchmark indexes | Sub-factor layer index | Importance score (Very important→generally→very unimportant) | | | | |
|---|---|---|---|---|---|---|---|
| Assessment index system of commercialization indexes of MRAM technology | Technology dimension | Technology advancement level | 5 | 4 | 3 | 2 | 1 |
| | | Technology development stage (S curve) | 5 | 4 | 3 | 2 | 1 |
| | | Technology development difficulty | 5 | 4 | 3 | 2 | 1 |
| | | Technology achievement transformation difficulty | 5 | 4 | 3 | 2 | 1 |
| | | Technology transaction difficulty | 5 | 4 | 3 | 2 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Possibility of becoming leading technology | 5 | 4 | 3 | 2 | 1 |
| | | Possibility of shaping industrial technological standards | 5 | 4 | 3 | 2 | 1 |
| | | Possibility of being patented | 5 | 4 | 3 | 2 | 1 |
| | | Possibility of technology to be replaced | 5 | 4 | 3 | 2 | 1 |
| | | Continuity of profiting after technology application | 5 | 4 | 3 | 2 | 1 |
| | | Costs of technology commercialization | 5 | 4 | 3 | 2 | 1 |
| | Market dimension | Competitive strength of the same kind of technology | 5 | 4 | 3 | 2 | 1 |
| | | Customers transforming costs | 5 | 4 | 3 | 2 | 1 |
| | | Transforming costs of vendors of the same kind of technology | 5 | 4 | 3 | 2 | 1 |
| | | More market advantages compared with the same kind of technology | 5 | 4 | 3 | 2 | 1 |
| | | Values created for customers | 5 | 4 | 3 | 2 | 1 |
| | | Matching of technology and market | 5 | 4 | 3 | 2 | 1 |
| | | Residents’ income | 5 | 4 | 3 | 2 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Consumers’ education | 5 | 4 | 3 | 2 | 1 |
| | | Expected profit level | 5 | 4 | 3 | 2 | 1 |
| | | Customer growth rate | 5 | 4 | 3 | 2 | 1 |
| | Support dimension | Infrastructure conditions | 5 | 4 | 3 | 2 | 1 |
| | | HR conditions | 5 | 4 | 3 | 2 | 1 |
| | | Financial conditions | 5 | 4 | 3 | 2 | 1 |
| | | Technology, guarantee and material guarantee | 5 | 4 | 3 | 2 | 1 |
| | | Technology innovation system coordination | 5 | 4 | 3 | 2 | 1 |
| | | Social intermediary service quality | 5 | 4 | 3 | 2 | 1 |
| | | Policy and law support strength | 5 | 4 | 3 | 2 | 1 |
| | Conformance dimension | Conformance with technology | 5 | 4 | 3 | 2 | 1 |
| | | Conformance with social development planning | 5 | 4 | 3 | 2 | 1 |
| | | Conformance with science and technology policy | 5 | 4 | 3 | 2 | 1 |
| | | Conformance with industrial policy | 5 | 4 | 3 | 2 | 1 |
| | | Conformance with social values | 5 | 4 | 3 | 2 | 1 |
| | Effect dimension | Resource saving extent | 5 | 4 | 3 | 2 | 1 |
| | | Environment improvement extent | 5 | 4 | 3 | 2 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Living standard improvement extent | 5 | 4 | 3 | 2 | 1 |
| | | MRAM awareness enhancement | 5 | 4 | 3 | 2 | 1 |
| | | Science and technology development promotion | 5 | 4 | 3 | 2 | 1 |
| | | Related industries driving extent | 5 | 4 | 3 | 2 | 1 |
| | | Employment opportunities | 5 | 4 | 3 | 2 | 1 |

# Questionnaire 2

Expert consultation questionnaire about the evaluation index of commercialization potential of storage technology

Note:

1. The purpose of the consultation: Identify the relative importance of each index through expert scoring to empower the evaluation of new storage technology commercialization potential.
2. This table uses the 1~9 scale and reciprocal scaling method.

1-equally important. 3- moderate important. 5- significantly important. 7- mightiness important. 9- extremely important.

1/3- moderate unimportant. 1/5- significantly unimportant. 1/7- mightiness unimportant. 1/9- extremely important.

1. Benchmark indexes' importance comparison

| | Technology dimension | Market dimension | Support dimension | Conformance dimension | Effect dimension |
|---|---|---|---|---|---|
| Technology dimension | 1 | | | | |
| Market dimension | — | 1 | | | |
| Support dimension | — | — | 1 | | |
| Conformance dimension | — | — | — | 1 | |
| Effect dimension | — | — | — | — | 1 |

2. Sub-factor layer indexes' importance comparison

(1) Importance comparison in Technology dimension

| | Technology advancement level | Technical maturity | Possibility of becoming leading technology | Possibility of becoming industrial technological standards | Possibility of being patented | Continuity of profiting after technology application | Technology commercialization costs |
|---|---|---|---|---|---|---|---|
| Technology advancement level | 1 | | | | | | |
| Technical maturity | — | 1 | | | | | |
| Possibility of becoming leading technology | — | — | 1 | | | | |
| Possibility of becoming industrial technological standards | — | — | — | 1 | | | |
| Possibility of being patented | — | — | — | — | 1 | | |
| Continuity of profiting after technology application | — | — | — | — | — | 1 | |
| Technology commercialization costs | — | — | — | — | — | — | 1 |

## (2) Importance comparison in Market dimension

| | Customers' transforming costs | Customers' transforming costs | More market advantages compared with the same kind of technology | Values created for customers | Expected customer growth rate |
|---|---|---|---|---|---|
| Customers' transforming costs | 1 | | | | |
| Customers' transforming costs | — | 1 | | | |
| More market advantages compared with the same kind of technology | — | — | 1 | | |

| | | | | | |
|---|---|---|---|---|---|
| Values created for customers | — | — | — | 1 | |
| Expected customer growth rate | — | — | — | — | 1 |

## (3) Importance comparison in Support dimension

| | Infrastructure conditions | HR conditions | Financing conditions | Technology, equipment and material guarantee | Technology innovation system coordination extent | Social intermediary service quality |
|---|---|---|---|---|---|---|
| Infrastructure conditions | 1 | | | | | |
| HR conditions | — | 1 | | | | |
| Financing conditions | — | — | 1 | | | |
| Technology, equipment and material guarantee | — | — | — | 1 | | |
| Technology innovation system coordination extent | — | — | — | — | 1 | |
| Social intermediary service quality | — | — | — | — | — | 1 |

## (1) Importance comparison in Conformance dimension

| | Conformance with technology foreseeability | Conformance with social development planning | Conformance with science and technology policy | Conformance with industrial policy | Conformance with public values |
|---|---|---|---|---|---|
| Conformance with technology foreseeability | 1 | | | | |
| Conformance with social development planning | — | 1 | | | |
| Conformance with science and technology policy | — | — | 1 | | |

| | | | | | |
|---|---|---|---|---|---|
| Conformance with industrial policy | — | — | — | 1 | |
| Conformance with public values | — | — | — | — | 1 |

## (5) Importance comparison in Effect dimension

| | Resource saving extent | Environment improvement extent | Living standard improvement extent | New storage technology awareness improvement | Science and technology development promotion extent | Related industries driving extent | Employment opportunities | Expected profit level |
|---|---|---|---|---|---|---|---|---|
| Resource saving extent | 1 | | | | | | | |
| Environment improvement extent | — | 1 | | | | | | |
| Living standard improvement extent | — | — | 1 | | | | | |
| New storage technology awareness improvement | — | — | — | 1 | | | | |
| Science and technology development promotion extent | — | — | — | — | 1 | | | |
| Related industries driving extent | — | — | — | — | — | 1 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Employment opportunities | — | — | — | — | — | — | 1 | |
| Expected profit level | — | — | — | — | — | — | — | 1 |

# Questionnaire 3

Technical commercialization potential evaluation questionnaire

Part 1. Expert familiarity about new storage technology.

1. The familiarity about MRAM.
A. Very familiar B. More familiar C. General familiarity D. Less familiar

2. The familiarity about DRAM.
A. Very familiar B. More familiar C. General familiarity D. Less familiar

3. The familiarity about Flash.
A. Very familiar B. More familiar C. General familiarity D. Less familiar

Part 2. Technic factors

Scoring standards (5-Extremly advantages. 4-Obviously advantages. 3-Slightly advantages. 2- Lack of advantages .1- No advantages at all.)

1. For Technology advancement level,
MRAM_______ DRAM_______ Flash_______

2. For Technical maturity
MRAM_______ DRAM_______ Flash_______

3. For Possibility of becoming leading technology
MRAM_______ DRAM_______ Flash_______

4. For Possibility of becoming industrial technological standards
MRAM_______ DRAM_______ Flash_______
5. For Possibility of being patented
MRAM_______ DRAM_______ Flash_______
6. For Continuity of profiting after technology application
MRAM_______ DRAM_______ Flash_______
7. For Technology commercialization costs
MRAM_______ DRAM_______ Flash_______

Part 3 Market factors

Scoring standards (5-Extremly advantages. 4-Obviously advantages. 3-Slightly advantages. 2- Lack of advantages .1- No advantages at all.)

1. For Customers' transforming costs
   MRAM_______ DRAM_______ Flash_______
2. For Transforming costs of vendors of the same kind
   MRAM_______ DRAM_______ Flash______
3. For More market advantages compared with the same kind of technology
   MRAM_______ DRAM_______ Flash_______
4. For Values created for customers
   MRAM_______ DRAM_______ Flash_______
5. For Expected customer growth rate
   MRAM_______ DRAM_______ Flash_______

Part 4 Support factors

Scoring standards (5- Very high. 4- High. 3- Medium. 2- Low. 1- Very low)

1. For Infrastructure conditions
   MRAM_______ DRAM_______ Flash_______
2. For HR conditions
   MRAM_______ DRAM_______ Flash_______
3. For Financing conditions
   MRAM_______ DRAM_______ Flash_______
4. For Technology, equipment and material guarantee
   MRAM_______ DRAM_______ Flash_______
5. For Technology innovation system coordination extent
   MRAM_______ DRAM_______ Flash_______
6. For Social intermediary service quality
   MRAM_______ DRAM_______ Flash_______
7. For Policy and law support strength
   MRAM_______ DRAM_______ Flash_______

Part 5 Conformance factors

Scoring standards (5- Very high. 4- High. 3- Medium. 2- Low. 1- Very low)

1. For Conformance with technology foreseeability
   MRAM_______ DRAM_______ Flash_______
2. For Conformance with social development planning

MRAM_______ DRAM_______ Flash_______

3. For Conformance with science and technology policy
   MRAM_______ DRAM_______ Flash_______
4. For Conformance with industrial policy
   MRAM_______ DRAM_______ Flash_______
5. For Conformance with public values
   MRAM_______ DRAM_______ Flash_______

Part 6 Effect Factors

Scoring standards (5-Extremly advantages. 4-Obviously advantages. 3-Slightly advantages. 2- Lack of advantages .1- No advantages at all.)

1. For Resource saving extent
   MRAM_______ DRAM_______ Flash_______
2. For Environment improvement extent
   MRAM_______ DRAM_______ Flash_______
3. For Living standard improvement extent
   MRAM_______ DRAM_______ Flash_______
4. For New storage technology awareness improvement
   MRAM_______ DRAM_______ Flash_______
5. For Science and technology development promotion extent
   MRAM_______ DRAM_______ Flash_______
6. For Related industries driving extent
   MRAM_______ DRAM_______ Flash_______
7. For Employment opportunities
   MRAM_______ DRAM_______ Flash_______
8. For Expected profit level
   MRAM_______ DRAM_______ Flash_______

# Appendix

Table A. Summary of expert consultation results

| *Expert* | *B1/B2* | *B1/B3* | *B1/B4* | *B1/B5* | *B2/B3* | *B2/B4* | *B2/B5* | *B3/B4* | *B3/B5* | *B4/B5* | *B11/B12* | *B11/B13* | *B11/B14* | *B11/B15* | *B11/B16* | *B11/B17* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 1 | 5 | 5 | 3 | 7 | 7 | 3 | 1 | 1/5 | 1/4 | 5 | 1/3 | 1/7 | 1/5 | 1/9 | 1/7 |
| *2* | 3 | 3 | 4 | 1 | 1 | 4 | 1/3 | 3 | 1/2 | 1/5 | 1 | 1/3 | 1/5 | 1/5 | 1/7 | 1/7 |
| *3* | 1/3 | 5 | 7 | 5 | 7 | 9 | 8 | 5 | 2 | 1/2 | 1 | 1/3 | 1/4 | 1/5 | 1/7 | 1/6 |
| *4* | 1 | 4 | 5 | 7 | 7 | 5 | 9 | 1 | 5 | 5 | 3 | 1/5 | 1/6 | 1/7 | 1/9 | 2 |
| *5* | 1/4 | 5 | 5 | 6 | 7 | 7 | 9 | 1 | 3 | 3 | 3 | 1/5 | 1/7 | 1/3 | 1/5 | 1/5 |
| *6* | 3 | 7 | 5 | 2 | 5 | 3 | 1 | 1/2 | 1/5 | 1/3 | 1 | 1/5 | 1/7 | 1/3 | 1/7 | 1/3 |
| *7* | 1/5 | 4 | 4 | 1 | 7 | 7 | 3 | 3 | 1/5 | 1/3 | 3 | 1/4 | 1/5 | 1/4 | 1/5 | 1/3 |
| *8* | 2 | 5 | 4 | 1/2 | 4 | 3 | 1/4 | 1/3 | 1/5 | 1/4 | 3 | 1/5 | 1/7 | 1/3 | 1/9 | 1/5 |
| *9* | 1/2 | 5 | 7 | 1 | 5 | 7 | 2 | 3 | 1/3 | 1/5 | 4 | 5 | 3 | 5 | 2 | 7 |
| *10* | 1/3 | 3 | 5 | 7 | 5 | 7 | 9 | 3 | 5 | 5 | 1/5 | 4 | 3 | 4 | 2 | 7 |
| *11* | 1 | 3 | 4 | 6 | 3 | 4 | 5 | 3 | 5 | 3 | 1 | 1/3 | 1/5 | 1/4 | 1/7 | 1 |

| EXPERT | B12/B13 | B12/B14 | B12/B15 | B12/B16 | B12/B17 | B13/B14 | B13/B15 | B13/B16 | B13/B17 | B14/B15 | B14/B16 | B14/B17 | B15/B16 | B15/B17 | B16/B17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1/3 | 1/5 | 1/4 | 1/8 | 1/5 | 1/5 | 1/3 | 1/7 | 1/5 | 3 | 1/5 | 1 | 1/3 | 1/2 | 3 |
| **2** | 1/2 | 1/5 | 1/5 | 1/7 | 1/6 | 1/3 | 1/4 | 1/5 | 1/5 | 1 | 1/3 | 1/3 | 1/4 | 1/5 | 1 |
| **3** | 1/2 | 1/3 | 1/4 | 1/7 | 1/5 | 1/3 | 1/4 | 1/6 | 1/5 | 1/3 | 1/7 | 1/6 | 1/5 | 1/4 | 1/3 |
| **4** | 1/5 | 1/5 | 1/6 | 1/7 | 1/3 | 1 | 1/4 | 1/5 | 3 | 1/2 | 1/5 | 3 | 1/4 | 7 | 9 |
| **5** | 1/5 | 1/7 | 1/5 | 1/8 | 1/5 | 1/5 | 2 | 1/3 | 1/3 | 7 | 3 | 1 | 1/3 | 1/3 | 1 |
| **6** | 1/5 | 1/7 | 1/3 | 1/7 | 1/3 | 1/4 | 1 | 1/5 | 1 | 3 | 1/5 | 4 | 1/5 | 1/2 | 7 |
| **7** | 1/4 | 1/6 | 1/3 | 1/5 | 1/4 | 1/4 | 2 | 1/6 | 2 | 4 | 1/4 | 3 | 1/7 | 1 | 5 |
| **8** | 1/6 | 1/7 | 1/3 | 1/9 | 1/4 | 1/2 | 4 | 1/5 | 2 | 5 | 1/3 | 5 | 1/5 | 1/2 | 5 |
| **9** | 5 | 9 | 4 | 3 | 5 | 1 | 1 | 1/5 | 3 | 3 | 1/3 | 4 | 1/5 | 3 | 5 |
| **10** | 6 | 4 | 5 | 3 | 8 | 1/3 | 2 | 1/5 | 3 | 2 | 1/3 | 5 | 1/5 | 2 | 7 |
| **11** | 1/2 | 1/5 | 1/4 | 1/8 | 1 | 1/2 | 1/2 | 1/7 | 1 | 5 | 1/5 | 5 | 1/5 | 3 | 7 |

| *Expert* | *B21/B22* | *B21/B23* | *B21/B24* | *B21/B25* | *B22/B23* | *B22/B24* | *B22/B25* | *B23/B24* | *B23/B25* | *B24/B25* | *B31/B32* | *B31/B33* | *B31/B34* | *B31/B35* | *B31/B36* | *B31/B37* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 1 | 1/5 | 1/7 | 5 | 1/5 | 1/7 | 5 | 1/3 | 7 | 8 | 1/3 | 1/3 | 1 | 3 | 5 | 1/5 |
| *2* | 1 | 1/7 | 1/8 | 1/3 | 1/6 | 1/7 | 1/4 | 1 | 5 | 5 | 1/7 | 1/5 | 1 | 5 | 5 | 1/5 |
| *3* | 3 | 1/5 | 1/7 | 1/3 | 1/4 | 1/7 | 1/3 | 1/3 | 4 | 5 | 1/7 | 1/3 | 1/5 | 5 | 3 | 1/6 |
| *4* | 2 | 1/5 | 1/7 | 1/3 | 1/6 | 1/7 | 1/4 | 1/3 | 7 | 5 | 1/4 | 1/3 | 1/2 | 1/7 | 1/8 | 1/7 |
| *5* | 3 | 7 | 7 | 5 | 8 | 7 | 5 | 1 | 1 | 1 | 1/3 | 1/4 | 3 | 1/7 | 1/6 | 1/5 |
| *6* | 1/3 | 6 | 7 | 4 | 6 | 8 | 5 | 1 | 1/2 | 1/4 | 1/2 | 1/3 | 1/3 | 1/7 | 1/7 | 1/6 |
| *7* | 1 | 1/5 | 1/7 | 1/3 | 1/5 | 1/7 | 1/5 | 2 | 4 | 5 | 1/6 | 1/4 | 1 | 4 | 5 | 1/5 |
| *8* | 1 | 1/7 | 1/8 | 1/3 | 1/6 | 1/7 | 1/4 | 1/2 | 3 | 5 | 1/3 | 1/4 | 3 | 1/7 | 1/6 | 1/5 |
| *9* | 3 | 1/4 | 1/7 | 1/3 | 1/5 | 1/8 | 1/3 | 1/3 | 3 | 4 | 1/3 | 3 | 5 | 7 | 6 | 1/5 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *10* | 3 | 1/5 | 1/8 | 1/3 | 1/5 | 1/7 | 1/3 | 1/3 | 3 | 5 | 5 | 3 | 1/3 | 1/5 | 1/3 | 1 |
| *11* | 2 | 1/5 | 1/7 | 1/3 | 1/4 | 1/7 | 1/3 | 1/3 | 3 | 4 | 7 | 5 | 4 | 2 | 7 | 5 |

| *Expert* | *B32/B33* | *B32/B34* | *B32/B35* | *B32/B36* | *B32/B37* | *B33/B34* | *B33/B35* | *B33/B36* | *B33/B37* | *B34/B35* | *B34/B36* | *B34/B37* | *B35/B36* | *B35/B37* | *B36/B37* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 1 | 3 | 5 | 7 | 1/2 | 3 | 5 | 6 | 1 | 3 | 5 | 1/3 | 2 | 1/5 | 1/5 |
| *2* | 3 | 4 | 5 | 6 | 2 | 2 | 4 | 5 | 1/2 | 3 | 5 | 1/4 | 3 | 1/5 | 1/8 |
| *3* | 4 | 3 | 7 | 6 | 1/2 | 1/3 | 5 | 4 | 1/5 | 4 | 3 | 1/4 | 1/3 | 1/9 | 1/7 |
| *4* | 3 | 4 | 1/5 | 1/7 | 1/6 | 3 | 1/7 | 1/9 | 1/5 | 1/5 | 1/7 | 1/4 | 1/3 | 3 | 2 |
| *5* | 2 | 5 | 1/5 | 1/5 | 1/3 | 3 | 1/5 | 1/4 | 1/3 | 1/7 | 1/6 | 1/5 | 3 | 5 | 3 |
| *6* | 1/2 | 1/3 | 1/5 | 1/5 | 1/4 | 1 | 1/5 | 1/5 | 1/3 | 1/4 | 1/5 | 1/3 | 1 | 2 | 1/2 |
| *7* | 1 | 3 | 5 | 7 | 1 | 5 | 6 | 5 | 1 | 5 | 5 | 1/3 | 1/3 | 1/6 | 1/4 |
| *8* | 1/2 | 4 | 1/5 | 1/6 | 1/3 | 3 | 1/4 | 1/5 | 1/3 | 1/7 | 1/6 | 1/5 | 2 | 3 | 2 |
| *9* | 3 | 4 | 7 | 6 | 1/3 | 3 | 5 | 4 | 1/5 | 5 | 3 | 1/7 | 1/3 | 1/9 | 1/8 |
| *10* | 1 | 1/2 | 1/5 | 1/3 | 1/2 | 1/5 | 1/7 | 1/3 | 1/2 | 1/5 | 2 | 5 | 3 | 7 | 4 |
| *11* | 1/3 | 1/4 | 1/4 | 1 | 1/3 | 1/3 | 1/4 | 3 | 1 | 1/2 | 5 | 3 | 7 | 5 | 1/3 |

| *Expert* | *B41/B42* | *B41/B43* | *B41/B44* | *B41/B45* | *B42/B43* | *B42/B44* | *B42/B45* | *B43/B44* | *B43/B45* | *B44/B45* | *B51/B52* | *B51/B53* | *B51/B54* | *B51/B55* | *B51/B56* | *B51/B57* | *B51/B58* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 1 | 1/3 | 1/3 | 3 | 1/3 | 1/3 | 3 | 1 | 3 | 3 | 2 | 7 | 9 | 3 | 4 | 5 | 1/3 |
| *2* | 1/2 | 1/3 | 1/4 | 1/7 | 1/2 | 1/4 | 1/6 | 1/2 | 1/6 | 1/6 | 5 | 8 | 6 | 4 | 3 | 4 | 1/3 |
| *3* | 2 | 3 | 5 | 8 | 2 | 3 | 5 | 1 | 3 | 3 | 4 | 5 | 7 | 5 | 4 | 3 | 1/5 |
| *4* | 1 | 3 | 5 | 7 | 1 | 1 | 5 | 1 | 3 | 3 | 6 | 8 | 7 | 5 | 3 | 5 | 1/5 |
| *5* | 1/2 | 1/2 | 1/5 | 1/7 | 1 | 1/5 | 1/6 | 1/3 | 1/5 | 1/3 | 4 | 9 | 6 | 4 | 3 | 3 | 1/5 |
| *6* | 1/3 | 1/5 | 1/4 | 3 | 1/4 | 1/3 | 4 | 1/3 | 6 | 7 | 5 | 9 | 7 | 5 | 3 | 4 | 1 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *7* | 1 | 1/4 | 1/5 | 3 | 1/4 | 1/3 | 2 | 1 | 4 | 3 | 3 | 9 | 7 | 4 | 4 | 6 | 1/3 |
| *8* | 1/3 | 1/5 | 1/7 | 1/9 | 1/4 | 1/6 | 1/8 | 1/3 | 1/5 | 1/3 | 2 | 8 | 7 | 5 | 4 | 5 | 1/5 |
| *9* | 3 | 5 | 3 | 7 | 5 | 3 | 7 | 1/3 | 3 | 5 | 1 | 5 | 8 | 3 | 4 | 3 | 1/5 |
| *10* | 7 | 5 | 3 | 3 | 1/3 | 1/5 | 1/4 | 1/4 | 1/2 | 3 | 4 | 5 | 7 | 4 | 4 | 3 | 1/5 |
| *11* | 7 | /5 | 3 | 2 | 1/3 | 1/5 | 1/7 | 1/3 | 1/5 | 1/3 | 3 | 7 | 7 | 3 | 3 | 4 | 1/5 |

| *Expert* | *B52/B53* | *B52/B54* | *B52/B55* | *B52/B56* | *B52/B57* | *B52/B58* | *B53/B54* | *B53/B55* | *B53/B56* | *B53/B57* | *B53/B58* | *B54/B55* | *B54/B56* | *B54/B57* | *B54/B58* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 7 | 8 | 3 | 3 | 4 | 1/5 | 1 | 1/6 | 1/5 | 1/4 | 1/7 | 1/6 | 1/6 | 1/3 | 1/9 |
| *2* | 4 | 2 | 1/2 | 1/6 | 1/4 | 1/8 | 1/3 | 1/5 | 1/7 | 1/6 | 1/9 | 1/4 | 1/6 | 1/5 | 1/7 |
| *3* | 2 | 2 | 1/2 | 1/4 | 1/5 | 1/7 | 3 | 1/3 | 1/4/ | 1/5 | 1/8 | 1/4 | 1/5 | 1/6 | 1/7 |
| *4* | 5 | 3 | 1/2 | 1/4 | 1/2 | 1/7 | 1/2 | 1/5 | 1/6 | 1/5 | 1/9 | 1/3 | 1/5 | 1/3 | 1/7 |
| *5* | 4 | 2 | 1/3 | 1/6 | 1/5 | 1/9 | 1/3 | 1/5 | 1/7 | 1/7 | 1/9 | 1/5 | 1/7 | 1/5 | 1/7 |
| *6* | 3 | 1 | 1/3 | 1/7 | 1/5 | 1/8 | 1/3 | 14 | 1/7 | 1/5 | 1/7 | 1/3 | 1/6 | 1/5 | 1/7 |
| *7* | 8 | 6 | 4 | 1 | 3 | 1/4 | 1/2 | 1/4 | 1/5 | 1/3 | 1/9 | 1/4 | 1/5 | 1/3 | 1/7 |
| *8* | 7 | 6 | 5 | 4 | 5 | 1/5 | 1 | 1/4 | 1/5 | 1/3 | 1/7 | 1/3 | 1/4 | 1/3 | 1/7 |
| *9* | 5 | 7 | 2 | 3 | 4 | 1/5 | 3 | 1/5 | 1/3 | 1/3 | 1/7 | 1/5 | 1/4 | 1/4 | 1/9 |
| *10* | 1 | 3 | 1 | 1/4 | 1/6 | 1/8 | 1 | 1/3 | 1/5 | 1/7 | 1/9 | 1/5 | 1/5 | 1/7 | 1/9 |
| *11* | 7 | 7 | 4 | 4 | 3 | 1/5 | 1 | 1/5 | 1/4 | 1/3 | 1/9 | 1/5 | 1/5 | 1/3 | 1/7 |

| *Expert* | *B55/B56* | *B55/B57* | *B55/B58* | *B56/B57* | *B56/B58* | *B57/B58* |
|---|---|---|---|---|---|---|
| *1* | 3 | 4 | 1/6 | 3 | 1/7 | 1/8 |
| *2* | 1/3 | 1/2 | 1/7 | 3 | 1/3 | 1/4 |
| *3* | 1/4 | 1/3 | 1/7 | 1/3 | 1/5 | 1/4 |
| *4* | 1/3 | 1 | 1/5 | 3 | 1/5 | 1/6 |
| *5* | 1/3 | 1/3 | 1/7 | 3 | 1/3 | 1/4 |
| *6* | 1/5 | 1/2 | 1/5 | 3 | 1/3 | 1/5 |
| *7* | 1/3 | 3 | 1/5 | 4 | 1/3 | 1/5 |
| *8* | 1/2 | 3 | 1/5 | 3 | 1/4 | 1/7 |
| *9* | 2 | 1 | 1/5 | 1/2 | 1/5 | 1/4 |
| *10* | 1/3 | 1/3 | 1/7 | 1 | 1/5 | 1/3 |
| *11* | 1 | 1 | 1/5 | 3 | 1/3 | 1/5 |

# Table B. Weight vector aggregation of expert judgment matrix group

| | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | Expert 9 | Expert 10 | Expert 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Matrix A | $W_A^1 = \begin{bmatrix}0.3395\\0.3884\\0.0510\\0.0533\\0.1679\end{bmatrix}$ | $W_A^2 = \begin{bmatrix}0.3370\\0.1399\\0.1433\\0.0550\\0.3249\end{bmatrix}$ | $W_A^3 = \begin{bmatrix}0.2780\\0.5331\\0.0960\\0.0340\\0.0590\end{bmatrix}$ | $W_A^4 = \begin{bmatrix}0.3578\\0.4208\\0.0944\\0.0965\\0.0305\end{bmatrix}$ | $W_A^5 = \begin{bmatrix}0.2568\\0.5548\\0.0761\\0.0761\\0.0361\end{bmatrix}$ | $W_A^6 = \begin{bmatrix}0.4391\\0.2079\\0.0467\\0.0808\\0.2255\end{bmatrix}$ | $W_A^7 = \begin{bmatrix}0.1758\\0.5214\\0.0646\\0.0461\\0.1922\end{bmatrix}$ | $W_A^8 = \begin{bmatrix}0.2776\\0.1654\\0.0487\\0.0876\\0.4208\end{bmatrix}$ | $W_A^9 = \begin{bmatrix}0.2627\\0.3982\\0.0778\\0.0396\\0.2217\end{bmatrix}$ | $W_A^{10} = \begin{bmatrix}0.2629\\0.5082\\2.1291\\0.0702\\0.0296\end{bmatrix}$ | $W_A^{11} = \begin{bmatrix}0.3566\\0.3438\\.01679\\0.0871\\0.0447\end{bmatrix}$ |
| Matrix B1 | $W_{B1}^1 = \begin{bmatrix}0.0342\\0.0250\\0.0534\\0.1856\\0.1134\\0.4000\\0.1884\end{bmatrix}$ | $W_{B1}^2 = \begin{bmatrix}0.0306\\0.0331\\0.0565\\0.1338\\0.1244\\0.3093\\0.3123\end{bmatrix}$ | $W_{B1}^3 = \begin{bmatrix}0.0311\\0.0364\\0.0531\\0.0797\\0.1359\\0.3048\\0.3591\end{bmatrix}$ | $W_{B1}^4 = \begin{bmatrix}0.0400\\0.0246\\0.1100\\0.1247\\0.2265\\0.4351\\0.0390\end{bmatrix}$ | $W_{B1}^5 = \begin{bmatrix}0.0383\\0.0243\\0.1021\\0.3419\\0.0744\\0.1999\\0.2187\end{bmatrix}$ | $W_{B1}^6 = \begin{bmatrix}0.0318\\0.0318\\0.0985\\0.2299\\0.0804\\0.4380\\0.0896\end{bmatrix}$ | $W_{B1}^7 = \begin{bmatrix}0.0424\\0.0302\\0.1148\\0.2314\\0.0801\\0.4136\\0.0876\end{bmatrix}$ | $W_{B1}^8 = \begin{bmatrix}0.0324\\0.0238\\0.1463\\0.2421\\0.0596\\0.4058\\0.0900\end{bmatrix}$ | $W_{B1}^9 = \begin{bmatrix}0.3349\\0.2270\\0.0615\\0.0933\\0.0542\\0.1891\\0.0300\end{bmatrix}$ | $W_{B1}^{10} = \begin{bmatrix}0.1994\\0.3889\\0.0552\\0.0965\\0.0465\\0.1876\\0.0260\end{bmatrix}$ | $W_{B1}^{11} = \begin{bmatrix}0.0402\\0.0418\\0.0764\\0.2096\\0.1154\\0.4675\\0.0490\end{bmatrix}$ |
| Matrix B2 | $W_{B2}^1 = \begin{bmatrix}0.0852\\0.0852\\0.2834\\0.5168\\0.0295\end{bmatrix}$ | $W_{B2}^2 = \begin{bmatrix}0.0473\\0.0473\\0.3843\\0.4071\\0.1139\end{bmatrix}$ | $W_{B2}^3 = \begin{bmatrix}0.0669\\0.0450\\0.2625\\0.5096\\0.1160\end{bmatrix}$ | $W_{B2}^4 = \begin{bmatrix}0.0592\\0.0408\\0.3056\\0.4890\\0.1055\end{bmatrix}$ | $W_{B2}^5 = \begin{bmatrix}0.4892\\0.3238\\0.0584\\0.0660\\0.0686\end{bmatrix}$ | $W_{B2}^6 = \begin{bmatrix}0.2958\\0.4930\\0.0562\\0.0448\\0.1101\end{bmatrix}$ | $W_{B2}^7 = \begin{bmatrix}0.0548\\0.0495\\0.4010\\0.3635\\0.1312\end{bmatrix}$ | $W_{B2}^8 = \begin{bmatrix}0.0478\\0.0478\\0.3050\\0.4721\\0.1274\end{bmatrix}$ | $W_{B2}^9 = \begin{bmatrix}0.0707\\0.0424\\0.2507\\0.5062\\0.1300\end{bmatrix}$ | $W_{B2}^{10} = \begin{bmatrix}0.0642\\0.0425\\0.2557\\0.5163\\0.1213\end{bmatrix}$ | $W_{B2}^{11} = \begin{bmatrix}0.0633\\0.0501\\0.2544\\0.5002\\0.1319\end{bmatrix}$ |
| Matrix B3 | $W_{B3}^1 = \begin{bmatrix}0.0919\\0.2214\\0.2391\\0.0988\\0.0435\\0.0286\\0.2767\end{bmatrix}$ | $W_{B3}^2 = \begin{bmatrix}0.0762\\0.3400\\0.1660\\0.0903\\0.0414\\0.0248\\0.2614\end{bmatrix}$ | $W_{B3}^3 = \begin{bmatrix}0.0554\\0.2750\\0.0945\\0.1392\\0.0232\\0.0389\\0.3738\end{bmatrix}$ | $W_{B3}^4 = \begin{bmatrix}0.0248\\0.0742\\0.0471\\0.0350\\0.2530\\0.3802\\0.1856\end{bmatrix}$ | $W_{B3}^5 = \begin{bmatrix}0.0369\\0.0848\\0.0696\\0.0261\\0.3929\\0.2474\\0.1423\end{bmatrix}$ | $W_{B3}^6 = \begin{bmatrix}0.0308\\0.0464\\0.0730\\0.0799\\0.2947\\0.2496\\0.2257\end{bmatrix}$ | $W_{B3}^7 = \begin{bmatrix}0.0802\\0.2603\\0.2585\\0.0953\\0.0275\\0.0378\\0.2403\end{bmatrix}$ | $W_{B3}^8 = \begin{bmatrix}0.0380\\0.0675\\0.0872\\0.0277\\0.3433\\0.2685\\0.1668\end{bmatrix}$ | $W_{B3}^9 = \begin{bmatrix}0.1565\\0.2232\\0.0956\\0.0570\\0.0207\\0.0335\\0.4135\end{bmatrix}$ | $W_{B3}^{10} = \begin{bmatrix}0.0884\\0.0458\\0.0412\\0.1856\\0.4205\\0.1563\\0.0622\end{bmatrix}$ | $W_{B3}^{11} = \begin{bmatrix}0.3709\\0.0360\\0.0761\\0.1557\\0.2544\\0.0332\\0.0737\end{bmatrix}$ |
| Matrix B4 | $W_{B4}^1 = \begin{bmatrix}0.1364\\0.1364\\0.3284\\.03284\\0.0705\end{bmatrix}$ | $W_{B4}^2 = \begin{bmatrix}0.0486\\0.07408\\0.1164\\0.1868\\0.5780\end{bmatrix}$ | $W_{B4}^3 = \begin{bmatrix}0.4524\\0.2598\\0.1316\\0.1096\\0.0466\end{bmatrix}$ | $W_{B4}^4 = \begin{bmatrix}0.4134\\0.2249\\0.1630\\0.1472\\0.0516\end{bmatrix}$ | $W_{B4}^5 = \begin{bmatrix}0.0520\\0.0813\\0.0934\\0.2260\\0.5072\end{bmatrix}$ | $W_{B4}^6 = \begin{bmatrix}0.0790\\0.1439\\0.3009\\0.4348\\0.0414\end{bmatrix}$ | $W_{B4}^7 = \begin{bmatrix}0.1095\\0.1119\\0.3678\\0.3428\\0.0681\end{bmatrix}$ | $W_{B4}^8 = \begin{bmatrix}0.0321\\0.0051\\0.1340\\0.2672\\0.5115\end{bmatrix}$ | $W_{B4}^9 = \begin{bmatrix}0.4453\\0.2869\\0.0740\\0.1561\\0.0376\end{bmatrix}$ | $W_{B4}^{10} = \begin{bmatrix}0.4612\\0.0436\\0.0869\\0.2657\\0.1426\end{bmatrix}$ | $W_{B4}^{11} = \begin{bmatrix}0.44149\\0.0380\\0.0748\\0.1577\\0.3145\end{bmatrix}$ |
| Matrix B5 | $w_{B5}^1 = \begin{bmatrix}0.2097\\0.1529\\0.0209\\0.0195\\0.1022\\0.0693\\0.0418\\0.3838\end{bmatrix}$ | $w_{B5}^2 = \begin{bmatrix}0.2283\\0.0410\\0.0179\\0.0295\\0.0680\\0.1624\\0.0095\\0.3535\end{bmatrix}$ | $w_{B5}^3 = \begin{bmatrix}0.2072\\0.0405\\0.0326\\0.0221\\0.0573\\0.1009\\0.1478\\0.3917\end{bmatrix}$ | $w_{B5}^4 = \begin{bmatrix}0.2324\\0.0498\\0.0188\\0.0291\\0.0714\\0.1367\\0.0698\\0.3921\end{bmatrix}$ | $w_{B5}^5 = \begin{bmatrix}0.2000\\0.0377\\0.0170\\0.0276\\0.0686\\0.1624\\0.1116\\0.3751\end{bmatrix}$ | $w_{B5}^6 = \begin{bmatrix}0.2797\\0.0330\\0.0199\\0.0328\\0.0641\\0.1772\\0.0976\\0.2956\end{bmatrix}$ | $w_{B5}^7 = \begin{bmatrix}0.2485\\0.1358\\0.0205\\0.0269\\0.0684\\0.1251\\0.0460\\0.3288\end{bmatrix}$ | $w_{B5}^8 = \begin{bmatrix}0.2141\\0.1737\\0.0232\\0.0256\\0.0641\\0.0883\\0.0426\\0.3826\end{bmatrix}$ | $w_{B5}^9 = \begin{bmatrix}0.1740\\0.1626\\0.0320\\0.0198\\0.0914\\0.0589\\0.0786\\0.3826\end{bmatrix}$ | $w_{B5}^{10} = \begin{bmatrix}0.1989\\0.0404\\0.0281\\0.0220\\0.0568\\0.1134\\0.1433\\0.3971\end{bmatrix}$ | $w_{B5}^{11} = \begin{bmatrix}0.2026\\0.1596\\0.0238\\0.0238\\0.0761\\0.0904\\0.0583\\0.3653\end{bmatrix}$ |

Table C. Weight vector aggregation of judgment matrix groups by multi person criterion

| Matrix A | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | Expert 9 | Expert 10 | Expert 11 | Row element multiplication | m root | Normalized vector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB1** | 0.3395 | 0.337 | 0.278 | 0.3578 | 0.2568 | 0.4391 | 0.1758 | 0.2776 | 0.2627 | 0.2629 | 0.3566 | 1.54235E-06 | 0.2962464 | 0.3316 |
| **WB2** | 0.3384 | 0.1399 | 0.5331 | 0.4208 | 0.5548 | 0.2079 | 0.5214 | 0.1654 | 0.3982 | 0.5082 | 0.3438 | 8.43569E-06 | 0.3457309 | 0.3870 |
| **WB3** | 0.051 | 0.1433 | 0.096 | 0.0944 | 0.0761 | 0.0467 | 0.0646 | 0.0487 | 0.0778 | 0.1291 | 0.1679 | 1.24876E-12 | 0.0827679 | 0.0927 |
| **WB4** | 0.0533 | 0.055 | 0.034 | 0.0965 | 0.0761 | 0.0808 | 0.0461 | 0.0876 | 0.0396 | 0.0702 | 0.0871 | 5.78293E-14 | 0.0625978 | 0.0701 |
| **WB5** | 0.1679 | 0.3249 | 0.059 | 0.0305 | 0.0361 | 0.2255 | 0.1922 | 0.4208 | 0.2212 | 0.0296 | 0.0447 | 1.89583E-11 | 0.1059875 | 0.1186 |

| Matrix B1 | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | Expert 9 | Expert 10 | Expert 11 | Row element multiplication | m root | Normalized vector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB11** | 0.0342 | 0.0306 | 0.0311 | 0.04 | 0.0383 | 0.0318 | 0.0424 | 0.0324 | 0.3349 | 0.1994 | 0.0402 | 6.02212E-15 | 0.0509624 | 0.0603 |
| **WB12** | 0.025 | 0.0331 | 0.0364 | 0.0246 | 0.0243 | 0.0318 | 0.0302 | 0.0238 | 0.227 | 0.3889 | 0.0418 | 1.51866E-15 | 0.0449635 | 0.0532 |
| **WB13** | 0.0534 | 0.0565 | 0.0531 | 0.11 | 0.1024 | 0.0985 | 0.1148 | 0.1463 | 0.0615 | 0.0552 | 0.0764 | 7.74296E-13 | 0.0792486 | 0.0938 |
| **WB14** | 0.1856 | 0.1338 | 0.0797 | 0.1247 | 0.3419 | 0.2299 | 0.2314 | 0.2421 | 0.0933 | 0.0965 | 0.2096 | 2.05095E-09 | 0.1622474 | 0.1919 |
| **WB15** | 0.1134 | 0.1244 | 0.1359 | 0.2265 | 0.0744 | 0.0804 | 0.0801 | 0.0596 | 0.0542 | 0.0465 | 0.1154 | 3.60651E-12 | 0.0911455 | 0.1078 |
| **WB16** | 0.4 | 0.3093 | 0.3048 | 0.4351 | 0.1999 | 0.438 | 0.4136 | 0.4058 | 0.1891 | 0.1876 | 0.4675 | 3.9988E-06 | 0.3230474 | 0.3822 |
| **WB17** | 0.1184 | 0.3123 | 0.3591 | 0.039 | 0.2187 | 0.0896 | 0.0876 | 0.09 | 0.03 | 0.026 | 0.049 | 4.86549E-12 | 0.0936606 | 0.1108 |

| Matrix B2 | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | Expert 9 | Expert 10 | Expert 11 | Row element multiplication | m root | Normalized vector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB21** | 0.0852 | 0.0473 | 0.0669 | 0.0592 | 0.4892 | 0.2958 | 0.0548 | 0.0478 | 0.0707 | 0.0642 | 0.0633 | 1.738E-12 | 0.0852939 | 0.1075 |
| **WB22** | 0.0852 | 0.0473 | 0.045 | 0.0408 | 0.3238 | 0.493 | 0.0495 | 0.0478 | 0.0424 | 0.0425 | 0.0501 | 2.52303E-13 | 0.0715682 | 0.0902 |
| **WB23** | 0.2834 | 0.3843 | 0.2625 | 0.3056 | 0.0584 | 0.0562 | 0.401 | 0.305 | 0.2507 | 0.2557 | 0.2544 | 5.71937E-08 | 0.2195721 | 0.2768 |
| **WB24** | 0.5168 | 0.4071 | 0.5096 | 0.489 | 0.06 | 0.0448 | 0.3635 | 0.4721 | 0.5062 | 0.5163 | 0.5002 | 3.16153E-06 | 0.316221 | 0.3986 |
| **WB25** | 0.0295 | 0.1139 | 0.116 | 0.1055 | 0.0686 | 0.1101 | 0.1312 | 0.1274 | 0.13 | 0.1213 | 0.1319 | 1.07974E-11 | 0.1006999 | 0.1269 |

| Matrix B3 | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | Expert 9 | Expert 10 | Expert 11 | Row element multiplication | m root | Normalized vector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB31** | 0.0919 | 0.0762 | 0.0554 | 0.0248 | 0.03969 | 0.0308 | 0.0802 | 0.038 | 0.1565 | 0.0884 | 0.3709 | 1.70998E-13 | 0.0690817 | 0.0941 |
| **WB32** | 0.2214 | 0.34 | 0.275 | 0.0742 | 0.0848 | 0.0464 | 0.2603 | 0.0675 | 0.2232 | 0.0458 | 0.036 | 3.90793E-11 | 0.1131914 | 0.1542 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB33** | 0.2391 | 0.166 | 0.0945 | 0.0471 | 0.0696 | 0.073 | 0.2585 | 0.0872 | 0.0956 | 0.0412 | 0.0761 | 6.06442E-12 | 0.095555 | 0.1301 |
| **WB34** | 0.0988 | 0.0903 | 0.1392 | 0.035 | 0.0261 | 0.0799 | 0.0953 | 0.0277 | 0.057 | 0.1856 | 0.1557 | 3.94143E-13 | 0.0745302 | 0.1015 |
| **WB35** | 0.0435 | 0.0414 | 0.0232 | 0.253 | 0.3929 | 0.2947 | 0.0275 | 0.3433 | 0.3433 | 0.4205 | 0.2544 | 2.55871E-11 | 0.1089163 | 0.1483 |
| **WB36** | 0.0286 | 0.0248 | 0.0389 | 0.3802 | 0.2474 | 0.2496 | 0.0378 | 0.2695 | 0.2695 | 0.1563 | 0.0332 | 1.14714E-12 | 0.0821317 | 0.119 |
| **WB37** | 0.2767 | 0.2614 | 0.3738 | 0.1856 | 0.1423 | 0.2257 | 0.2403 | 0.1668 | 0.1668 | 0.0622 | 0.0737 | 1.22448E-08 | 0.1908635 | 0.2599 |

| **Matrix B4** | **Expert 1** | **Expert 2** | **Expert 3** | **Expert 4** | **Expert 5** | **Expert 6** | **Expert 7** | **Expert 8** | **Expert 9** | **Expert 10** | **Expert 11** | **Row element multiplication** | **m root** | **Normalized vector** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB41** | 0.1364 | 0.048 | 0.4524 | 0.4134 | 0.052 | 0.079 | 0.1095 | 0.0321 | 0.4453 | 0.4612 | 0.4149 | 1.50655E-09 | 0.1577606 | 0.2086 |
| **WB42** | 0.1364 | 0.0708 | 0.2598 | 0.2249 | 0.0813 | 0.1439 | 0.1119 | 0.0551 | 0.2869 | 0.0436 | 0.038 | 1.93568E-11 | 0.1061831 | 0.1404 |
| **WB43** | 0.3284 | 0.1164 | 0.1316 | 0.163 | 0.0934 | 0.3009 | 0.3678 | 0.134 | 0.074 | 0.0869 | 0.0748 | 5.46309E-10 | 0.1438629 | 0.1902 |
| **WB44** | 0.3284 | 0.1868 | 0.1096 | 0.1472 | 0.266 | 0.4348 | 0.4348 | 0.2672 | 0.1561 | 0.2657 | 0.1577 | 6.85761E-08 | 0.2232251 | 0.2951 |
| **WB45** | 0.0705 | 0.578 | 0.0466 | 0.0516 | 0.5072 | 0.0414 | 0.0414 | 0.5115 | 0.0376 | 0.1426 | 0.3145 | 1.20852E-10 | 0.1254257 | 0.1658 |

| **Matrix B5** | **Expert 1** | **Expert 2** | **Expert 3** | **Expert 4** | **Expert 5** | **Expert 6** | **Expert 7** | **Expert 8** | **Expert 9** | **Expert 10** | **Expert 11** | **Row element multiplication** | **m root** | **Normalized vector** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WB51** | 0.2097 | 0.2283 | 0.2072 | 0.2324 | 0.2 | 0.2797 | 0.2485 | 0.2141 | 0.174 | 0.1989 | 0.2026 | 4.81082E-08 | 0.216146 | 0.2247 |
| **WB52** | 0.1529 | 0.041 | 0.0405 | 0.0498 | 0.0377 | 0.033 | 0.135 | 0.1737 | 0.1626 | 0.0404 | 0.1596 | 3.89014E-13 | 0.0744415 | 0.0774 |
| **WB53** | 0.0209 | 0.0179 | 0.0326 | 0.0188 | 0.017 | 0.0199 | 0.0205 | 0.0232 | 0.032 | 0.0281 | 0.0238 | 7.895E-19 | 0.0226102 | 0.0235 |
| **WB54** | 0.0195 | 0.0295 | 0.0221 | 0.0291 | 0.0276 | 0.0328 | 0.0269 | 0.0256 | 0.0198 | 0.022 | 0.0238 | 2.39101E-18 | 0.0250065 | 0.0260 |
| **WB55** | 0.1022 | 0.068 | 0.0573 | 0.0714 | 0.0686 | 0.0641 | 0.0684 | 0.0641 | 0.0914 | 0.0568 | 0.0761 | 2.16565E-13 | 0.0705813 | 0.0734 |
| **WB56** | 0.0693 | 0.1624 | 0.1009 | 0.1367 | 0.1624 | 0.17772 | 0.1251 | 0.0883 | 0.0589 | 0.1134 | 0.0904 | 2.9795E-11 | 0.1104343 | 0.1148 |
| **WB57** | 0.0418 | 0.0995 | 0.1478 | 0.0698 | 0.1116 | 0.0976 | 0.046 | 0.0428 | 0.0786 | 0.1433 | 0.0583 | 6.04202E-13 | 0.0774816 | 0.0805 |
| **WB58** | 0.3838 | 0.3535 | 0.3719 | 0.3921 | 0.3751 | 0.2956 | 0.3228 | 0.3682 | 0.3826 | 0.3971 | 0.3653 | 1.55241E-05 | 0.3654423 | 0.3798 |

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