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2023

Global Quantum Precision Measurement Industry Development Prospect

Quantum Annual Series Report

February 2023

Foreword

Sensor technology is at the forefront of modern technology. Many countries have regarded sensor technology, along with communication and computer technology, as equally important and referred to them as the three pillars of information technology. Quantum sensors, in particular, represent a disruptive and revolutionary technology in the field of sensing. They have been hailed as a "multiplier" for industrial production and a "pathfinder" for scientific research.

Earlier this year, our organization, in conjunction with Photon Box, released the "Global Quantum Metrology and Sensing Industry Development Report for 2022," which gained widespread attention due to the wide-ranging application of quantum precision measurement. The report was compiled based on the research framework of quantum computing and quantum communication and is currently the industrys first comprehensive industrial research report on quantum precision measurement. It has drawn considerable attention within the quantum sensor industry, and as a result, we have decided to continue our annual updates to the quantum precision measurement industry report to further contribute to the field.

This year, our research team has continued to conduct in-depth research on the quantum precision measurement industry, and we have achieved excellent results. We will change our focus on quantum sensors that have already been realized. Our main industry chain analysis will focus on more mature areas such as time measurement, gravity measurement, and magnetic field measurement. These areas mainly include atomic clocks, cold atom interferometry gravity meters, and optical magnetometers. Other quantum sensors that are not yet mature or currently receive less attention will be categorized as "others," such as quantum optical devices, quantum radar, and atomic antennas.

ICV Frontier Technology Consulting Director, Senior Vice President

Jude Green

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Global Quantum precision measurement WG
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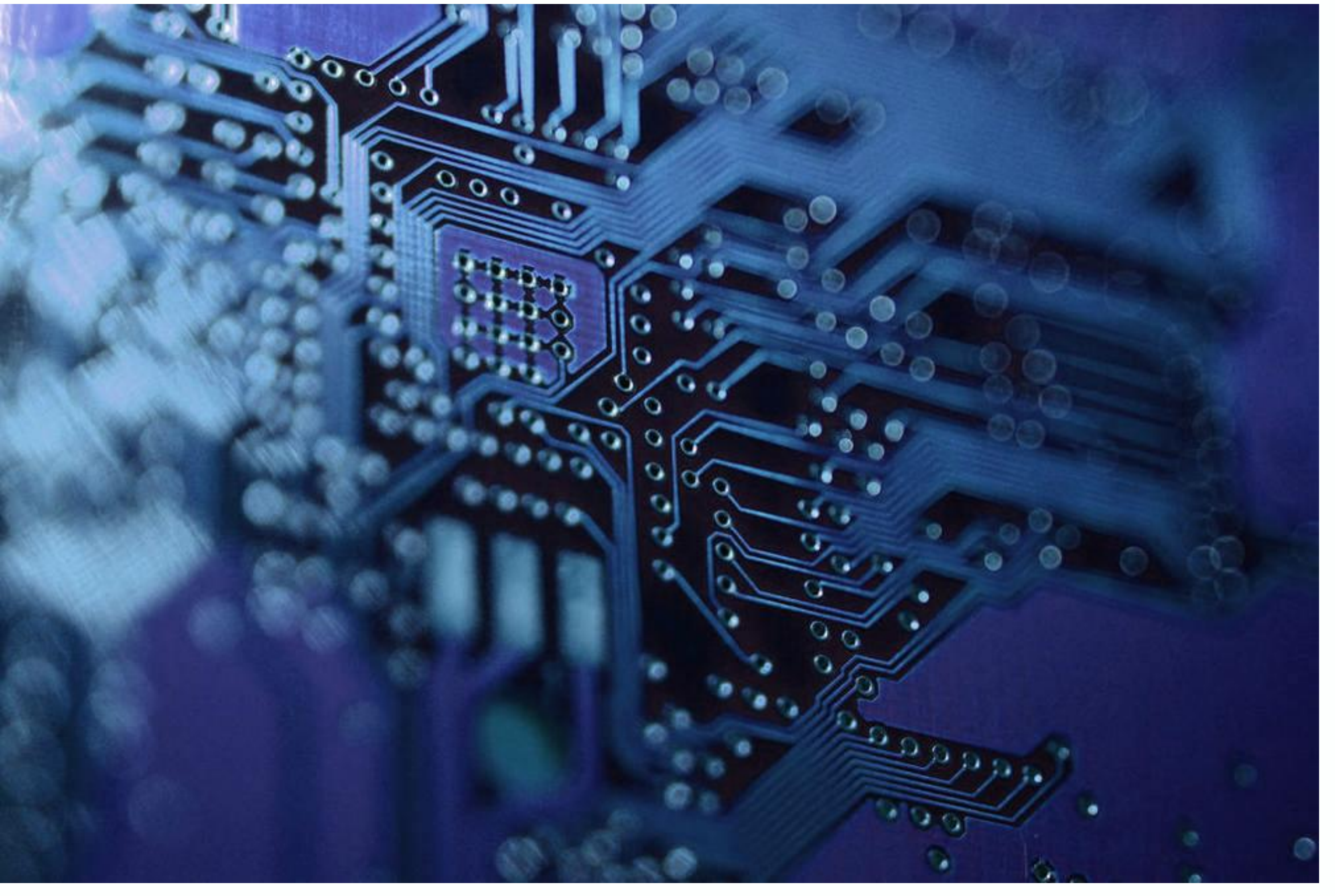


Chapter 1
Industry Research Definition

1.1 The origin of quantum precision measurement

"Can we discover a promising real-world application of quantum mechanics that utilizes its most counterintuitive features? Since the development of quantum theory in the early 20th century, physicists have been captivated by this question.

Quantum computing and quantum communication are widely regarded as the most promising applications of quantum technology. However, slow progress in technology development is attributed in part to the core weakness of quantum systems - their strong sensitivity to external interference. Quantum metrology takes advantage of this core weakness to achieve the measurement of certain physical quantities from the external environment, and has become a new emerging application in quantum information technology in recent years.

In recent years, quantum metrology has become a unique and rapidly growing research branch in the field of quantum information science and technology. It utilizes quantum mechanical systems to measure various physical quantities, from magnetic fields and electric fields to time and frequency, from rotation to temperature and pressure.

Exhibit 1-1 Quantum technology revolution and industrial revolution are emerging

Early 20th century The first quantum revolution	The first quantum revolution overturned classical mechanics measurements at the microscopic level. Classical mechanics believed that an objects state could be measured, and that the measurement behavior could be ignored when considering the objects properties. The classical measurement system held a perception that all matter had a definite value, perhaps even predetermined before measurement, that is unaffected by the measuring tools and the measurer, regardless of whether the system was material or non-material (velocity, position, volume, direction, etc.). However, this understanding of measurement changed drastically due to the advent of quantum mechanics and relativity in the early 20th century. The revolutionary new theory of quantum mechanics upended everything that had been considered certain and unchanging in physics.
1970s The second quantum revolution	Quantum control, represented by quantum information technology, generates a "second revolution" by manipulating the micro-quantum behavior of quantum systems (such as electrons and photons) through active control and manipulation. As the main development direction of quantum information technology, quantum precision measurement technology leads the transformation of measurement by utilizing the laws of quantum mechanics. Measurement, observation, and attention can have an impact on the measured quantum system, such as changing the state of the measured quantum system. after measurement, quantum systems in the same state may yield completely different results. In the pursuit of higher precision measurement, in recent years, with the advancement of quantum technology and the arrival of the second quantum revolution, quantum precision measurement is expected to lead the transformation of a new generation of sensors, measuring matter with unprecedented precision.

Although quantum precision measurement is a relatively new and unique research area in the field of quantum science and engineering, many of its definitions and concepts include theoretical technologies that have long existed in the physics community. These can be divided into two categories based on their historical development.

Old

Although quantum precision measurement is a relatively new and unique research area in the field of quantum science and engineering, many of its definitions and concepts include theoretical technologies that have long existed in the physics community. These can be divided into two categories based on their historical development.

New

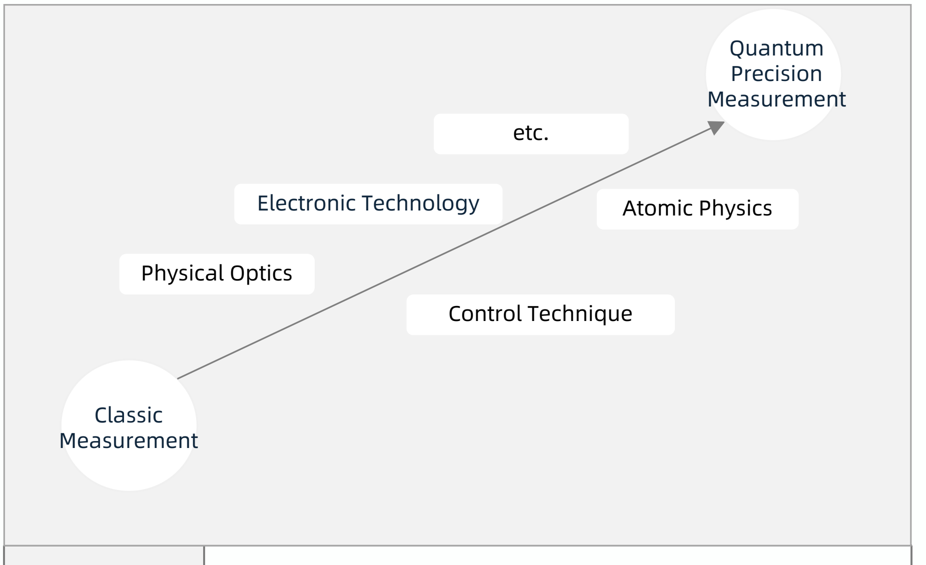
As research on quantum systems at the single-atom level has matured, new technologies have emerged. For example, quantum entanglement is used to enhance sensitivity and is designed specifically for sensing purposes. For instance, there are magnetometers based on NV center technology and atomic clocks based on ion trap technology.

With breakthroughs in fundamental research in quantum mechanics and the development of experimental techniques, people are constantly improving their ability to manipulate and measure quantum states, allowing for the use of quantum states for information processing, communication, and sensing, as well as for high-precision and high-sensitivity measurements of some key physical quantities. For example, unprecedented measurement accuracy can be achieved in physical quantities such as time, frequency, acceleration, and electromagnetic fields. The entire modern natural science and material civilization have developed in tandem with the continuous improvement of measurement precision, and quantum precision measurement can be understood as an upgraded iteration of classical precision measurement under the condition of progress in fundamental research. Taking time measurement as an example, from ancient sundials and water clocks, to modern mechanical clocks, and then to quartz and atomic clocks, with the continuous improvement of time measurement accuracy, communication, navigation, and other technologies have been able to develop.

1.2 Introduction of Quantum Precision Measurement

Quantum precision measurement aims to use quantum resources and effects to achieve measurement accuracy beyond classical methods. It is a comprehensive technology that integrates atomic physics, physical optics, electronic technology, control technology and other disciplines. Basic principle : The external electromagnetic field, temperature, pressure and other physical quantity factors will change the quantum states of microscopic particles such as electrons, photons and phonons. The quantum states after these changes are measured to realize the measurement of external physical quantities.

Exhibit 1-2 Principle and Definition



Tool	Atoms, molecules, ions, photons (single photons, entangled photon pairs), electrons, phonons.
Indicator	sensitivity (signal with unit signal-to-noise ratio given after 1 second of integration time) . Dynamic range (minimum and maximum detectable signal) . sampling rate (signal sampling frequency) . working temperature, etc.
Purpose	Magnetic field and electric field, rotation, time, force, temperature and photon counting, etc.

At present, various national policies, reports and other documents have different names due to different fields of technical expertise and different languages. This paper will refer to this technology and application field with quantum precision measurement . In particular, it refers to the five application fields of quantum time measurement, quantum magnetic field measurement, quantum gravity measurement, quantum inertial measurement and quantum target recognition in product classification in the following analysis framework. It is divided according to the different physical quantities measured. The main application scenarios cover many fields such as aerospace, defense equipment, geological resource survey, basic scientific research and biomedicine, and the application and industry development prospects are broad.

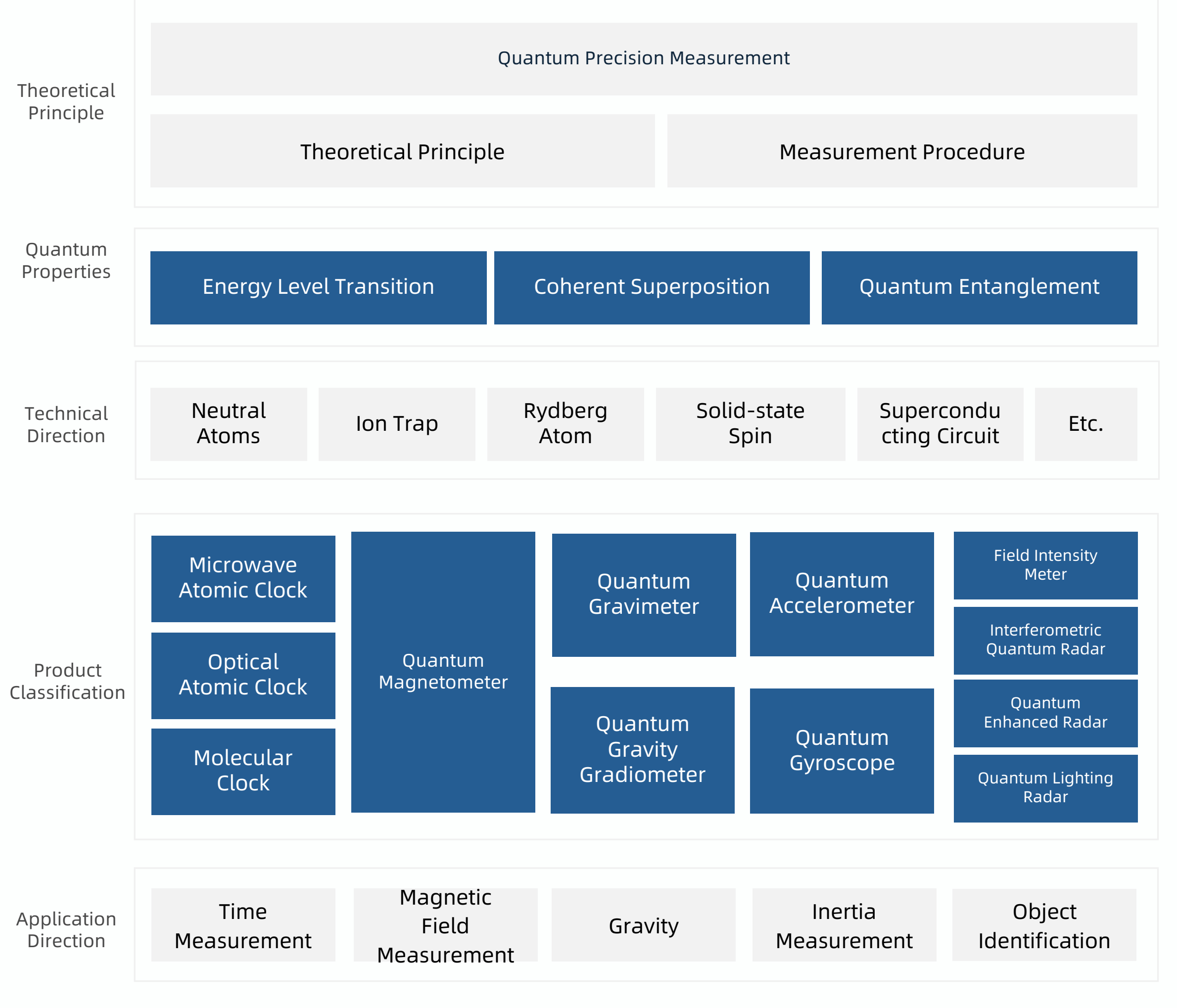
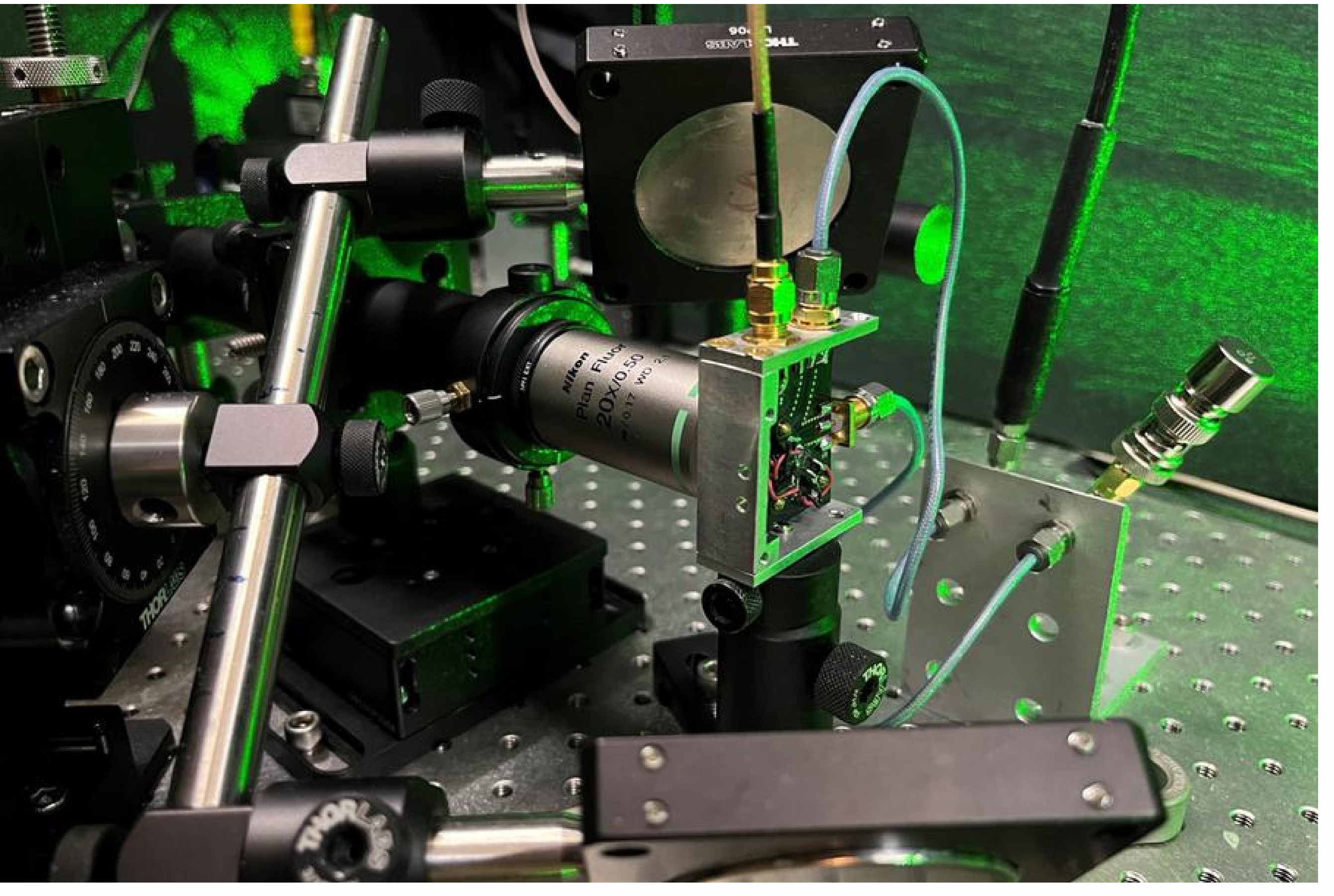


Exhibit 1-3 Report Analysis Framework



Chapter 2
Industry Development Status and Future Trends

2.1 Main Developments

By combing the industry progress and technological progress (see Appendix-1 & 2 for details), the progress that is of great significance to the future development of quantum precision measurement is listed. In 2022, the path of quantum precision measurement technology will blossom. With the continuous iteration of quantum precision measurement engineering prototypes, more and more prototypes are out of the laboratory and moving towards productization.

2.1.1 The United States released the first independent strategic plan report for the quantum precision measurement industry

The United States officially issued the first quantum precision measurement industry report. The attention of politicians in various countries to the quantum precision measurement industry continues to increase, which is different from the previous analysis that the quantum precision measurement industry was packaged by the quantum information technology industry.

In addition to the United States, major quantum precision measurement technology countries (such as Germany, China, the United Kingdom, Japan, etc.) have not yet released independent quantum precision measurement reports. However, the United States issued a quantum sensor strategy policy-Bringing Quantum Sensors Fruition in April 2022.This is the first time that a country has issued an independent strategic plan report in the field of quantum precision measurement. At present, China, the United Kingdom, Germany, France and other countries have increased their attention to the field of quantum precision measurement in different degrees and different technical fields. In the future, it is possible that countries will have a clear development path with technological progress. After careful evaluation, a separate plan will be issued to point out the future strategic development direction in more detail. The main development directions are as follows :

2.1.2 Breakthroughs and progress in quantum time measurement

Ye Jun s team produced the world s most accurate atomic clock, which can verify general relativity. The first high-performance optical clock sent into space by China Dream Laboratory

The team has developed the world s most accurate atomic clock. At a height difference of 1mm, the time difference is about one hundred billionth of a billion, that is, 300 billion years is one second, which is in line with the general relativity prediction. This time, the first high-performance optical atomic clock entered the space with the Mengtian experimental chamber and received extensive attention. The optical clock can measure time more accurately, and China is also expected to build the world s highest-precision orbital time-frequency system.

2.1.3 The industrialization of quantum gravimeter and quantum gradiometer has made remarkable progress, and the quantum gravity measurement market will usher in three major growth factors.

Important breakthroughs have been made in quantum gravity measurement instruments. Quantum gravity measurement instruments are completing the transformation from laboratory to commercialization. The competition pattern of traditional measurement industry is being changed by the commercialization of quantum precision instruments.

According to the technical maturity, R & D progress and commercialization progress of various countries, the quantum gravity measurement market will usher in three major growth factors :

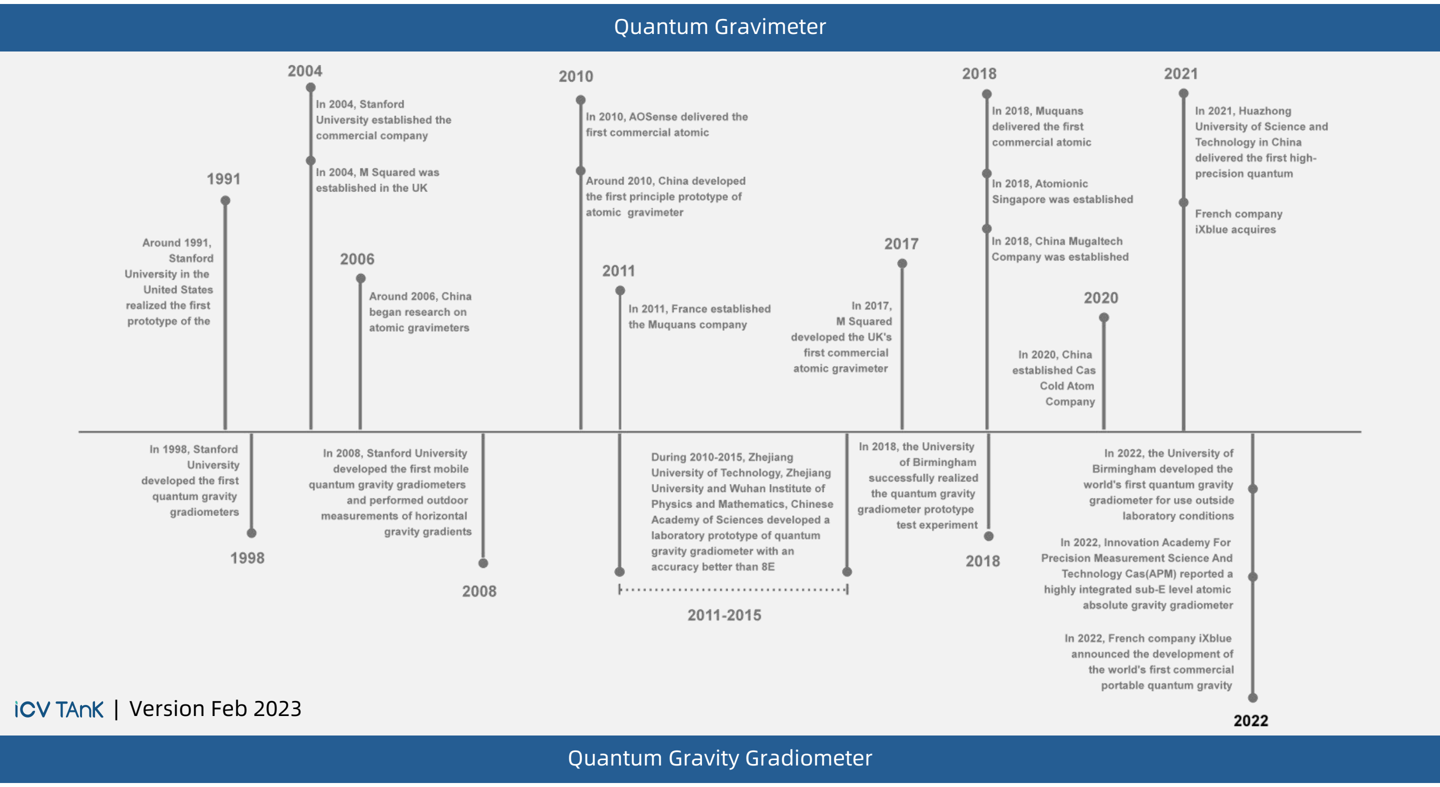
At present, the technical advantages of quantum gravimeter have been demonstrated, and the gradual maturity of commercialization will bring rapid growth of market share. For example, China s gravity measurement instrument technology has broken the monopoly, will continue to replace the current traditional instruments and equipment, and will expand the market with the construction of the gravity network .

the global quantum gravity gradiometer has begun to transform from laboratory to commercial and military, and it is expected to complete the transition in three years, with rich application scenarios. The progress of basic research on quantum application technology will promote the corresponding product data of quantum precision instruments, and the resulting increased application scenarios and market share will drive the exponential growth of market size.

The measuring instruments in the field of gravimetry are mainly classified as gravimeters and gravity gradiometers. According to different functions, they are divided into relative and absolute measuring instruments. In terms of quantum gravity measuring instruments, because the quantum gravity measuring instrument based on cold atom interferometer belongs to absolute measuring instrument, the instrument is mainly divided into quantum absolute gravimeter and quantum absolute gradient instrument.

With the rapid development of absolute gravity technology of cold atom measurement and the breakthrough of quantum gravity gradient sensor, quantum geophysical detection technology based on high-precision quantum earth gravity and magnetic field sensor has become one of the subversive technologies for fine detection of

Exhibit 2-2 : The development of quantum gravimeter and quantum gravity gradiometer



ICV predicts that the rapid growth point of the quantum gravimeter market may be 2023 . the rapid growth point of quantum gravity gradiometer may be 2026.

deep strategic mineral resources, volcanic activity monitoring and earth structure, and has become the key development direction of international geophysical detection equipment.

The research and development of quantum precision measurement technology in the United States, Germany, China, Japan, the United Kingdom and other countries started earlier, and their research level has always been at the commanding height of cutting-edge technology, especially in gravity field and geophysical exploration. After a long period of technical accumulation and equipment iteration, the technical level is relatively leading and the equipment is mature.

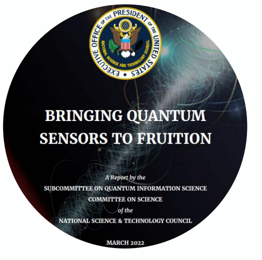
China s gravity measurement market is currently monopolized by other countries. The main imported commercial absolute gravimeter is FG5-X produced by Mi-crog Lacoste company in the United States. At present, Chinese local enterprises are completing the transformation of quantum gravimeter from laboratory to commercialization. It is expected to break the monopoly situation in the field of gravity precision measurement through quantum information technology, and thus enter the precision measurement instrument industry. In the long run, the competitive landscape of the global precision measurement industry may usher in a turning point.

At present, quantum gravity measurement instruments are completing the transformation from laboratory to commercialization. Among them, the main research institutions of quantum gravimeter have completed the transformation from laboratory to commercialization. Companies in the United States, France, China and Singapore have launched various types of commercial quantum gravimeters. In terms of quantum gravity gradiometer, it has been relatively mature under laboratory conditions before. In 2022, the team of University of Birmingham brought this kind of instrument to the first demonstration in a non-laboratory environment for the first time, which brought important breakthroughs to the commercialization progress and laid a foundation for sensing applications in fields such as archaeology, navigation and urban planning. In general, the commercialization of quantum gravity gradiometers started relatively late, but there are also commercial breakthroughs in 2022.

I. The United States released the latest quantum sensing policy

The National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS) released a report entitled " Bringing Quantum Sensors to Fruition can be found. "

In March 2022, the United States released the Bringing Quantum Sensors Fruition, a quantum sensor strategy policy. This is the first time that a country has released an independent strategic plan report in the field of quantum precision measurement. At present, China, Britain, Germany, France and other countries have increased their attention to the field of quantum precision measurement in different degrees and different technical fields. In the future, there will be a separate plan to point out the future strategic development direction in more detail.



Based on the " National Strategic Overview of Quantum Information Science " and the " National Quantum Initiative (NQI) " bill, the report describes that the five main types of quantum sensors currently used are atomic clocks, atomic interferometers, optical magnetometers, devices using quantum optical effects, and atomic electric field sensors. From research and development to industrialization, quantum measurement mainly faces four major challenges : talent diversification, technical feasibility, key auxiliary technologies and components, and intellectual property rights and technology transfer. The report proposes short-term and medium-term recommendations for the development and application of quantum measurement for 1-8 years. Its long-term goal is to promote economic development, security applications and scientific progress through the development of quantum technology. The report enhances the QIS national strategy and reflects the importance and determination of the United States in the field of quantum measurement.

II. the United States and China have made progress in space quantum research

Quantum study of ultracold bubbles in NASA space station

In the Cold Atom Laboratory (CAL) of the National Aeronautics and Space Administration (NASA), scientists form ultracold atomic gases into ultracold atomic bubbles, which helps to open up new avenues for quantum research.

This ultracold atomic bubble can be used to study a new type of experiment for a peculiar state of matter, that is, the fifth state of matter (different from gas, liquid, solid, and plasma). This state of matter is called Bose-Einstein Condensed State (BEC), which is a boson atom in the

A gaseous, superfluid state of matter produced by cooling to near absolute zero. In BEC, scientists can observe the quantum properties of atoms on a visual scale. For example, atoms and particles sometimes act like solids, and sometimes act like waves, that is, they exhibit the quantum properties of wave-particle duality .

China Space Station Decoding Dream Laboratory Science Experiment Cabinet

The ultra-cold atomic physics experimental system (CAPR) of the space station is one of the main scientific loads of the Mengtian experimental cabin of the Chinese space station. It is expected to provide a long-term stable operation experimental system for ultra-cold atomic physics research.

At the same time, the Mengtian experiment warehouse is also equipped with high-precision time-frequency experiment cabinet I and high-precision time-frequency experiment cabinet II. The high-precision time-frequency experimental system will be built into the world s most accurate space-time frequency system through the combination of atomic clocks with different characteristics in the cabin. The high-precision time-frequency signal generated by the system uses the microwave and laser time-frequency transmission load placed outside the cabin to transmit high-precision time-frequency signals to a certain range of ground and space.

The space quantum research includes the successful launch of CPT atomic magnetometer with the Chinese Academy of Sciences Lijian-1 rocket and space new technology test satellite SATech . China has sent three atomic clocks to its space station to create an unusually precise space-based timing system, including the first strontium atomic clock to enter space.

Quantum gravity gradiometer breakthrough

III. UK and France have made achievements in the research and development of quantum gravity measurement.

Birmingham University quantum gravity gradiometer out of the laboratory

Researchers from the University of Birmingham in the UK published a study in the Nature magazine on the 23rd, saying that the world s first quantum gravity gradiometer under non-laboratory conditions came out. This kind of sensor using quantum technology can find objects hidden underground, which is a long-awaited milestone for scientists and will have a profound impact on academia, industry and national security.

France s iXblue announced a technological breakthrough and developed the first compact and portable differential quantum gravimeter (DQG) in the industrial world. The iXblue compact gravity gradiometer has high sensitivity and unprecedented stability, providing a new perspective for near-surface geophysics, civil engineering and gravity-assisted navigation.

iXblue launches the first quantum compact gravity gradiometer

With its high sensitivity and unreported stability, the iXblue compact gravity gradiometer provides a new perspective for near-surface geophysics, civil engineering, and gravity-assisted navigation. The DQG industrial prototype developed (and validated) by the iXblue quantum sensor department can simultaneously measure the absolute values of the gravitational acceleration g and its vertical gradient zz.

On the one hand, the gravity gradient is more sensitive to mass anomalies near the sensor, and its immunity to vibration makes it more sensitive to smaller objects. On the other hand, gravity is more sensitive to larger objects farther away. DQG provides the best of both worlds. The fusion of the two data sets is expected to eliminate the ambiguity between the determination of gravity anomaly quality and its location.

2.2 Development Status

> The main progress part mainly includes the commercial progress of quantum precision measurement, national policy and investment and financing news. This part of the content continues the industry progress of the 2022 Global Quantum Precision Measurement Industry Development Report released by ICV Joint Photon Box, starting in May. In general, the quantum precision measurement industry in 2022 business progress in the national business news is active, the degree of attention increased.

In the future, with the maturity of technology and system optimization, the performance indicators of quantum measurement accuracy, stability, environmental adaptability, volume and power consumption will continue to improve. In addition to the relatively mature five directions of quantum frequency reference, quantum magnetometer, quantum gravimeter, quantum gyroscope and quantum target recognition, new technical directions and applications are constantly emerging, which broadens the technical route and lays a theoretical and experimental foundation for the precise measurement of more physical quantities (such as temperature, stress, etc.). In the future, the quantum precision measurement industry will develop and grow along the market direction of special level (scientific research, national defense), industrial level (energy, aviation) to civil level (medical, transportation).

- Replace the existing precision measurement industry market share. For example, chip-level molecular clock replaces high-stability crystal oscillator .
- to meet the emerging needs of technology iteration. For example, battery quality detection, brain-computer interface .
- develop new industry standards and evaluation systems. For example, measurement and standard setting.

In terms of the overall development trend, the field of quantum precision measurement has great development potential and broad market application prospects, and each technical path has corresponding research and development progress. There are prototype products reported in the fields of quantum clock source, quantum magnetometer, quantum radar, quantum gravimeter, quantum gyroscope, quantum accelerometer and other quantum sensors, which are mainly used in military, aerospace, scientific research and other fields.

The accuracy of quantum measurement technology products has exceeded the traditional capabilities of traditional testing institutions or third-party certification bodies. It is necessary to study and establish the standards and evaluation and certification system of quantum measurement, clarify the indicators and test methods of quantum measurement products, and get through the detection and certification links.

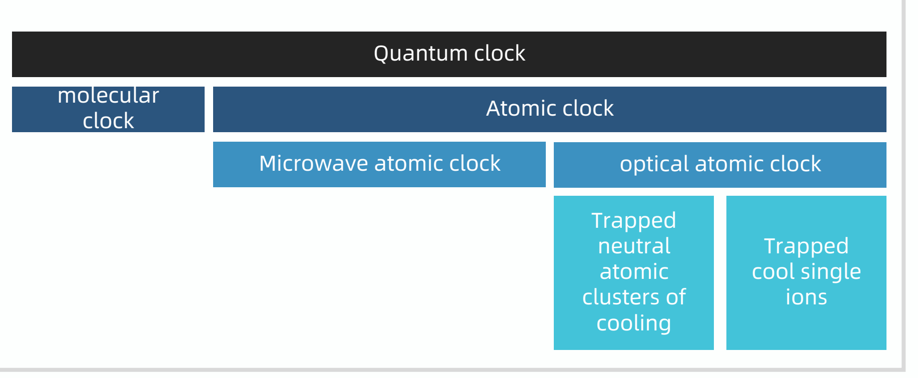
The downstream civilian market of the quantum measurement industry has yet to be explored. At present, atomic clocks are used in the communication market and the power market. Magnetic field measurement has been reported in medical and vehicle navigation. In the future, metrology applications may enter the civil market earlier, such as microwave quantum metrology and standard metrology equipment. The specific application combination points and solutions depend on the in-depth communication and cooperation between quantum measurement enterprises and vertical industry users. After achieving certain results in the pilot application of typical industries, more users can understand the advantages of quantum measurement technology and further promote cross-industry fields.

In the future, the development of quantum sensors to miniaturization, low power consumption and low cost will effectively promote the development of the upstream industry, promote the upgrading of the processing technology of components and component modules, improve the performance index and reduce the manufacturing cost, realize compact and chip-based components, thus reversely driving quantum sensors to further miniaturization and cost reduction.

2.2.1 Quantum clock :

The commercial development of microwave atomic clock is mature, and it is developing towards chip and low cost. Optical atomic clock is the current key research and development direction, breaking through to higher time accuracy.

Exhibit 2-4 : Main classification of quantum clocks



The research of atomic clock is changing from microwave frequency band to optical frequency band. Because the optical frequency is 4-5 orders of magnitude higher than the microwave frequency, the uncertainty accuracy of the optical atomic clock will be better than that of the microwave atomic clock under the same transition spectral linewidth. At the same time, chip-level molecular clock (CSMC) has also made new research and commercial progress. The chip-scale atomic clock (CSAC) has also matured and is commercially available.

Optical clock is the optical atomic clock. It is also an important research direction of quantum precision measurement. At present, atomic optical clocks are mainly atomic and ion technology path systems : one is to trap cooled neutral atomic clusters, and the other is to trap cooled single ions. At present, the trapping method is mainly the use of optical lattices and ion traps, and the laser cooling method is currently mainly used for cooling.

Optical atomic clocks can be understood by microwave atomic clocks. Their principles and architectures are similar, including wave oscillators, wave detectors, and atomic control units. Optical frequency can also be understood as the upgrading of microwave frequency.

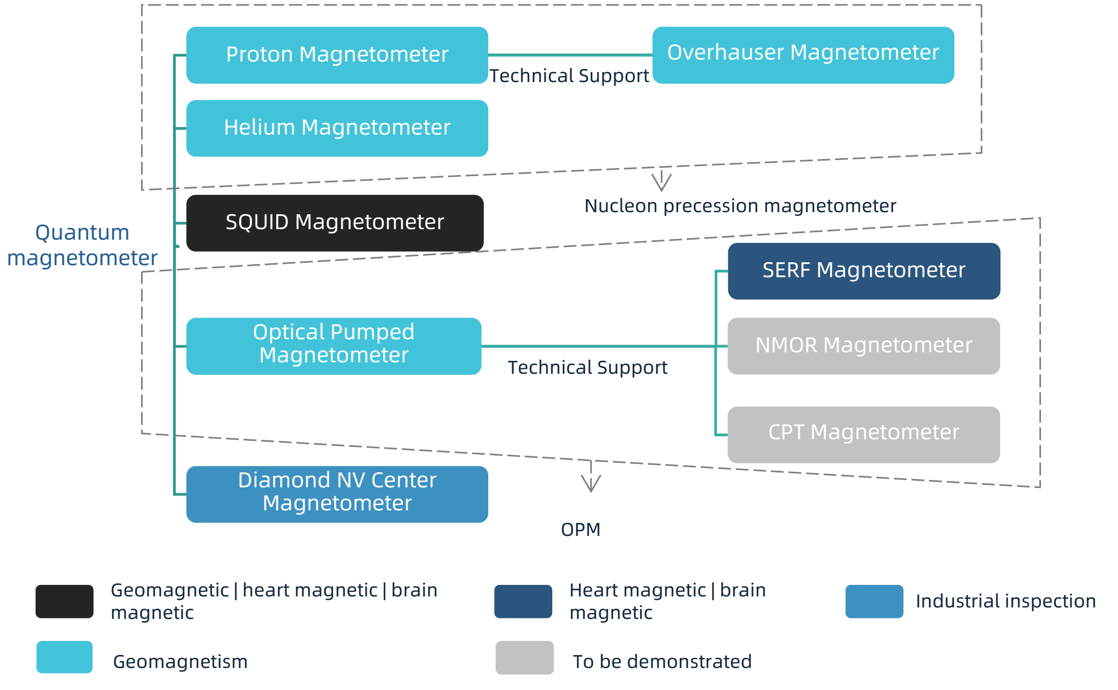
The difference is that the laser frequency will be much higher than the microwave, so the structure of the optical clock is more complex, and to replace the rubidium atoms with different types of atoms, in order to test the reliability of the laser (the main requirement of the atomic type is that the new atom must be able to respond to the higher frequency of the light wave), researchers are also continuing to study to determine which kind of atom is suitable for the optical clock. At present, the candidate atoms are mainly alkaline earth metals such as strontium, ytterbium, mercury, calcium and aluminum.

The main difference between atoms and ions is that ion clocks generally trap a single ion, while neutral atoms trap a large number of ions.

2.2.2 Quantum magnetometer :

Industrialization is further promoted and plays an important role in important fields such as biomedicine, scientific research, military defense and industrial testing. At present, the technical route of atomic magnetometer and diamond NV color center magnetometer has been focused on, which may promote the update and iteration of high-end medical devices and become an important tool for nanoscience research.

Exhibit 2-5 : Main classification of quantum magnetometers



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NOTE : Spin-exchange-relaxation-free (SERF) magnetometers, nonlinear magneto-optical rotation (NMOR) magnetometers, and coherent population trapping (CPT) magnetometers require optical pumping effects. It is a kind of generalized optical pumping magnetometer, also known as OPM (Optical Pumping Magnetometer). At present, the ultra-sensitive atomic magnetometer OPM for magnetocardiac-encephalomagnetic is an atomic magnetometer based on the SERF technical path. The optically pumped magnetometer in the figure refers to a class of magnetometers that use the optical pumping effect to polarize atoms and destroy the polarization state by applying an external RF field to achieve magnetic field measurement.

Quantum magnetometer is one of the main representatives in the industrialization of quantum precision measurement, and the commercialization is relatively mature. Using the principle of quantum mechanics, quantum precision measurement technology is expected to break through the limit of classical measurement, and has great advantages in sensitivity and other indicators.

Trend 1 : Quantum magnetometer has development direction in national defense and military applications

The military applications of quantum magnetometers include geomagnetic navigation, anti-submarine warfare, etc., which do not depend on current traditional geolocation technologies such as GPS. At present, quantum magnetometer has been applied in magnetic anomaly map mapping and water anti-submarine technology. Magnetic anomaly map is used for inertial navigation and quantum navigation positioning, which does not depend on GNSS (global navigation satellite system) and radar. Anti-submarine technology mainly identifies underwater targets through airborne suspended aero-magnetometer on the horizontal plane.

In the future, quantum magnetometers will have the following military applications : First, after completing the geographic mapping map, quantum magnetometers can be applied to quantum navigation systems, which can be used in conjunction with quantum sensors such as quantum gravimeters to provide more accurate information and reduce dependence on GNSS and radar . secondly, the enabling technology of shipborne magnetometers for anti-submarine warfare still needs to be improved to enhance the magnetic detection ability of target recognition for submarines or mines, and significantly improve the underwater combat capability. Third, wearable brain magnetic detection equipment will be likely to be installed in the soldier s helmet, remote real-time feedback combat personnel physiological state and guide the operation, timely feedback combat personnel intelligence report.

Trend 2 : classic magnetic measurement sensor gradually ' quantization '

Some sensors based on classical physics technology are gradually transitioning to quantum sensors. On the one hand, the reason for the development of this trend is that quantum sensors are based on quantum manipulation, and the measurement accuracy can break through the classical limit ; on the other hand, quantum systems give quantum sensors better stability because they are not affected by manufacturing differences, defects, impurities or aging, which makes them more suitable for precision measurement. Quantum magnetometer technology is the pioneer of classical sensors towards quantization. At present, the more mature commercial products include proton magnetometer, Overhauser magnetometer, optical pump magnetometer and SQUID magnetometer. SERF magnetometer and diamond NV color center magnetometer are entering commercialization.

The development of classical sensors to quantum sensors will also promote the development of many fields of society. For example, the magnetometer used on the satellite requires stable performance and long working time, and the quantum magnetometer just meets this characteristic ; reduced procurement costs and operating and maintenance costs for high-end medical equipment, enabling wider applications to benefit the general public ; the application of new rapid and accurate detection equipment can improve the diagnostic efficiency, and even bring great convenience to the society in the era of COVID-19 or other epidemics in the future ; the battery defect detection technology based on quantum magnetometer is expected to be implemented in the short term to maintain the safety of people 's lives and property. High sensitivity magnetic imaging microscope can promote the development of basic scientific research.

Trend 3 : SERF technology will enable the next generation of magnetoencephalography instruments

At present, most of the brain and heart diagnostic techniques used in hospitals, magnetoencephalography and magnetocardiography, use SQUID technology to obtain magnetic field data, but SQUID equipment covers a large area, complex equipment, expensive, harsh operating environment (liquid helium refrigeration, magnetic shielding) and other problems limit its wide application, and the general public cannot benefit from this high-end medical examination. Moreover, helium is a rare gas, and global resources are being consumed, especially magnetoencephalography. The technology behind it urgently needs new ways to get rid of previous development restrictions.

In terms of the current development status, the SERF atomic magnetometer developed on the basis of OPM is expected to change the status quo. SERF is not only less costly than SQUID, but also has the advantages of being sensitive to low-frequency signals, operating at room temperature, low power consumption, small size, and wearable. The resolution of SERF is also close to or beyond that of SQUID, which is suitable for large-scale application. This is also an important reason why OPM has received a lot of attention and research in basic physics and practical application research. Public information shows that at present, the price of MEG equipment based on SERF magnetometer is about one-half to one-third of that of SQUID magnetometer. After large-scale commercialization in the future, the price of MEG equipment is expected to be lower. More medical institutions will have the ability to purchase, and the related diagnostic costs will be greatly reduced.

Trend 4 : Quantum magnetometer has broad application prospects, diamond NV color center magnetometer and atomic magnetometer have great potential

Diamond NV color center magnetometer and atomic magnetometer based on quantum spin technology are the most promising commercial quantum sensors in recent years, and their applicable industries and application scenarios are also diversified.

At present, the relatively mature application fields of quantum magnetometer are biomedical, physical research and geomagnetic exploration. In the medical field, the new generation of magnetoencephalography and magnetocardiography based on SERF magnetometers has verified the feasibility in experimental demonstrations, and can be commercialized in the short term. It is expected to replace the SQUID market share or open a new market for miniaturized wearable weak magnetic measurement. In addition, SERF atomic magnetometer can also solve the quality detection and classification of lithium batteries. The development of CPT and NOMR technology also makes people expect atomic magnetometer to achieve more landing applications.

In the fields of physical research, geomagnetic navigation, military defense, industrial detection and other applications, the main products are early quantum magnetometers such as proton magnetometers. In the short term, diamond NV color center magnetometer may become the main quantum magnetometer in scientific research and nondestructive testing. Because of its good biocompatibility and strong spatial recognition ability, it is a technology with high frequency, high attention and rapid development mentioned by academic teams and countries. The diamond NV color center magnetometer has not yet reached the physical limit, and many teams are working on it. It is expected to become a new generation of quantum magnetometers and meet the emerging scientific research needs of studying single cells, proteins, DNA or single molecule recognition, single atom nuclear magnetic resonance and so on.

Trend 5 : Many countries have issued policies to support the development of quantum magnetometers, and relevant research institutions have carried out the layout.

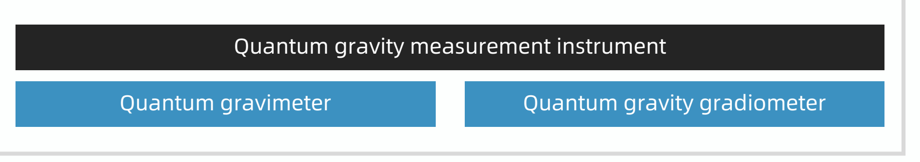
The United States, the United Kingdom, Germany, France, China, Australia and other countries have disclosed research plans and projects related to quantum magnetometers. Among them, solid-state quantum sensors (diamond NV color center magnetometer) and optically pumped alkali magnetometer (OPM) related to magnetic measurement in the field of quantum sensors have been proposed as key research and development directions. The latest Bringing Quantum Sensors to Fruition released by the United States focuses on the research progress and application prospects of optical magnetometers and NV color center magnetometers, and illustrates their great application value and potential.

In addition, universities in other countries have carried out relevant basic research layout. For example, Tokyo Institute of Technology in Japan launched the application of solid-state quantum sensors in the field of MEG ; the Institute of Scientific Devices, Beijing University of Aeronautics and Astronautics, China has carried out research on quantum precision measurement techniques based on atomic spin SERF effect and diamond color center. At present, there are many quantum sensors in different research and development stages. Many countries are coordinating to shorten the process of product introduction to the market, accelerate technology transfer, and continuously strengthen their own leadership in their respective fields. In the case of minimizing the impact on performance, miniaturization, compactness and cost reduction are the key goals of the major upstream suppliers.

2.2.3 Quantum gravity measurement instrument :

The commercialization of quantum gravimeter is further mature, the commercialization of quantum gradient meter is breakthrough, and the first commercial product appears. Quantum gradiometer has more application value than quantum gravimeter.

Exhibit 2-6 : Main classification of quantum gravimeter



The principle of quantum gravity sensor is to use laser and magnetic field to capture and control the quantum state of cold rubidium atoms in vacuum environment, and to realize the measurement of gravity field and gravity gradient field by measuring the atomic ratio of different energy levels.

Classical gravity measurement techniques have high accuracy, but they have long been limited by mechanical wear and low sampling rate, which makes them unable to perform long-term continuous observation and application on mobile platforms. Atomic interference gravimeter and gravity gradiometer have the advantages of high precision, low drift and no mechanical wear. They are the new generation of precision gravimeter with great application potential.

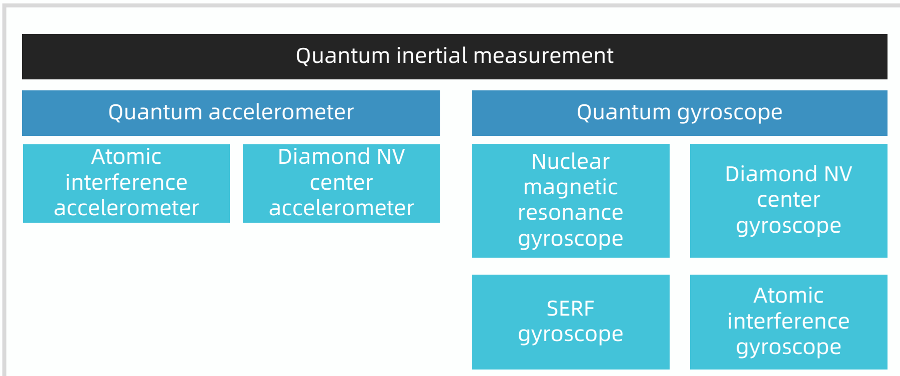
In terms of quantum gravimeter, it has a high maturity and has been fully demonstrated in static and dynamic scenarios with comparable or even superior performance to classical instruments. It is the key development direction of international geophysical exploration equipment and is recognized as the next generation of absolute gravimeter.

In terms of quantum gravity gradiometer, it has the characteristics of high measurement accuracy and good long-term stability, especially for vibration and noise suppression. The quantum gravity gradiometer can measure the absolute gravity gradient, and there is no drift in theory. It is the best choice for long-endurance high-precision inertial navigation and gravity matching assisted navigation.

2.2.4 Quantum inertial measurement instruments :

The cold atom technology can realize self-calibration navigation, which will greatly improve the passive navigation accuracy of submarines. NV color center technology may further miniaturize the gyroscope. Full quantum inertial navigation and quantum inertial aided navigation

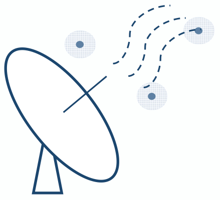
Exhibit 2-7 : Quantum Inertial Measurement Devices (Quantum Accelerometer & Quantum Gyroscope) Main Categories



The technology used in the quantum accelerometer is mainly cold atom interferometry. The principle of this technology is the same as that of the cold atom gravimeter, which is currently highly concerned. However, the gravimeter measures the acceleration of gravity, and the accelerometer is an acceleration in a certain direction. The laser or well is needed to offset the gravity effect in the vertical direction. If the cold atom accelerometer is relatively easy to implement in the case of relatively small space environment and gravity influence.

Compared with classical accelerometers, the advantages of cold atom accelerometers are high precision, no drift, and gravitational map positioning. However, the cold atom accelerometer can also be used in combination with MEMS, which can avoid drift and error accumulation caused by classical instruments through self-generation characteristics and self-correction functions. At present, instruments such as cold atom accelerometers are bulky, so the main body of the load is still on large vehicles, such as submarines and ships. If the volume improvement can be reduced in the future, there may be more application scenarios. Relevant literature shows that the advantages of NV color center accelerometer are convenient integration and miniaturization, and it will have more advantages than traditional MEMS. A single NV color center can simultaneously complete the three-axis acceleration detection.

In terms of quantum gyroscopes, the technical path will be relatively more. The development direction is : improving sensitivity ; miniaturization ; develop methods to integrate quantum gyroscopes with other sensors (such as accelerometers and magnetometers) to provide more complete environmental images ; enhancing robustness (improving the reliability and stability of the quantum gyroscope, making it more resistant to external interference and environmental conditions) ; explore new applications of quantum gyroscopes, such as navigation and control systems in autonomous vehicles and satellites, and precision measurements in physics and engineering.



2.2.5 Quantum radar :

Target detection. Atmospheric, wind speed and other measurements. Single photon imaging quantum, increase the detection distance, detection speed, generate images. In the future, quantum characteristics are used to identify stealth targets.

Quantum radar is divided into three categories according to the different working modes of transmitter and receiver :

- Quantum emission and classical reception mainly include interferometric quantum radar.
- Classical emission, quantum reception, such as quantum enhanced lidar.
- Quantum emission, quantum reception, such as quantum irradiation.

According to the different forms of detection signals, quantum radar can also be divided into single-photon detection quantum radar and multi-photon detection quantum radar.

- Single photon detection quantum radar : The transmitter emits single photons or entangled photon pulses to explore the possible region of the target. If the target exists, the signal photons will return to the receiver with a certain probability. The target information can be extracted by measuring the state of the returned single photon.
- Multiphoton detection quantum radar : The transmitter transmits coherent electromagnetic wave or entangled electromagnetic wave, and uses the correlation of multiple photons in the transmitted signal to detect the target. The receiver completes the target detection by measuring and identifying the state of a single photon.

Quantum radar is an emerging technology that uses quantum properties for measurement. The characteristics of quantum radar different from classical radar mainly include : different information carriers and signal systems, different signal processing methods and information acquisition methods, different transmitter and receiver structures and devices. The following is the future development direction of quantum radar :

Improve spatial resolution : Improve spatial resolution by improving the purity and efficiency of quantum sources and making better use of quantum information.

Improve the depth detection range : By developing new quantum sources and new information processing methods, the depth detection range of quantum radar is improved.

Enhancing robustness : By developing new quantum sensing technology, the adaptability of quantum radar to interference and environment is enhanced.

Extended application field：By developing a new quantum radar system, the application of quantum radar in medicine, security, environmental monitoring and other fields is extended.

In general, the future development direction of quantum radar is to improve the measurement accuracy, depth and robustness, and expand its application fields.

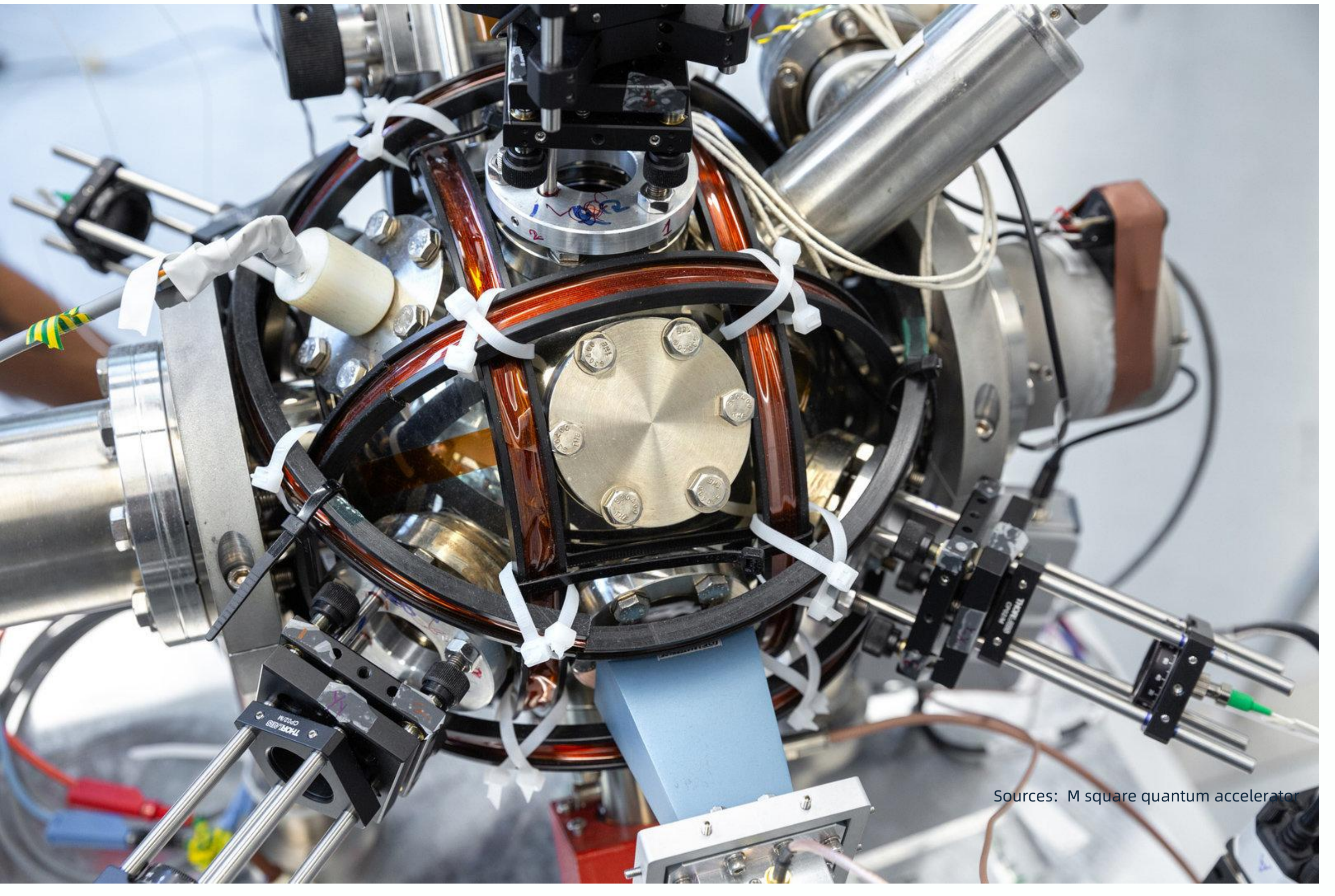
2.2.6 Quantum antenna (field strength meter) : Special communication system performance enhancement, combat communication and confidentiality, support against electronic warfare, military antenna performance enhancement.

The Rydberg atomic antenna is used for RF electric field detection. The principle is that Rydberg atoms can detect weak electric fields with high sensitivity and spatial resolution. At present, Rydberg atoms have been used to detect electric fields in various frequency ranges, including microwave, terahertz and radio frequency (RF) fields. The sensitivity of Rydberg atom electric field detection can reach the order of several millivolts per meter, which is much higher than many other types of electric field sensors. This technology is being studied in the fields of precision measurement, security and surveillance, and quantum computing.

Compared with traditional antennas, atomic antennas may completely change wireless communication technology by providing improved signal reception and transmission capabilities. In the future, the development of atomic antennas is likely to focus on :

- Miniaturization : Reduce the size of the atomic antenna to make it suitable for portable devices such as smartphones and laptops.
- Integration with existing technologies : Develop methods to integrate atomic antennas with existing communication systems (such as 5G networks) to enhance their performance and functionality.
- Improve efficiency : Improve the efficiency of the atomic antenna to reduce energy consumption and improve its overall performance.
- Improvements : Explore new applications and functions of atomic antennas, such as quantum communication, to expand their potential uses.

In general, the future of atomic antennas has great potential, and many exciting developments are about to emerge, which are expected to enhance wireless communication technology in an innovative way.



Sources: M square quantum accelerator

Chapter 3

Industry Chain Analysis

3.1 Upstream Analysis of Industrial Chain

3.1.1 Upstream overall analysis:
Most of the upstream of the industrial chain are enterprises in the United States, Britain, Germany and Japan, providing lasers, cryogenic systems, magnet environments, vacuum systems, electronic components, cables, materials (special metals, diamonds, rare earths, etc.) that can be used for quantum systems.

Exhibit 3-1 : Upstream enterprise map of industrial chain

Electronic Components	赋同量子 PHOTEC, 国光量子, RHK Technology, SCONTEL, TMD, Elliot Scientific, HAMAMATSU, Sivananthan Laboratories, RadiWave Labs, BardeenQ, zeropoint motion, Atlantic Microwave, APERIO GLOBAL, G&H, PERATECH
Laser	Novanta Photonics, TOPTICA Photonics, OEwaves, Raycus, THORLABS, NKT, Oeabt, QANT, nLIGHT, 鲲腾量子, LBTEK, BOCIC, IPG Photonics, Menhir Photonics, MenloSystems, NuCrypt
Cryogenic System	Lake Shore Cryotronics, STAR Cryoelectronics, Delft Circuits, Leiden Cryogenics, AmpliTech, BLUEFORS, attocube
Magnet Environment	Cryomagnetics, Inc., Magnetic Shields, Quantum Design
Vacuum System	Johnsen Ultravac, BARTORR 巴托真空科技, WAYES-VAC 维意真空, Linkit, Htc
Material	3D-OXIDES, Applied Quantum Materials Inc., SUPERCON, Diatope, elementsix, ADDED SCIENTIFIC

Note : As an industrial ecological map, the above LOGO only reflects commercial companies in the upstream and midstream. The above LOGO only appears once, but it does not mean that the company has no layout or product in other links.

At present, there are many technical routes of quantum measurement, great differences in principles, and many types of upstream materials and device providers in the industry. The current global quantum precision measurement industry is in the early stage of development. Industrial resources are concentrated in the core system design and the engineering development of the whole machine, which leads to the lack of R & D investment in the upstream powerful components and process manufacturers for the quantum industry, which restricts the overall development of the industry.

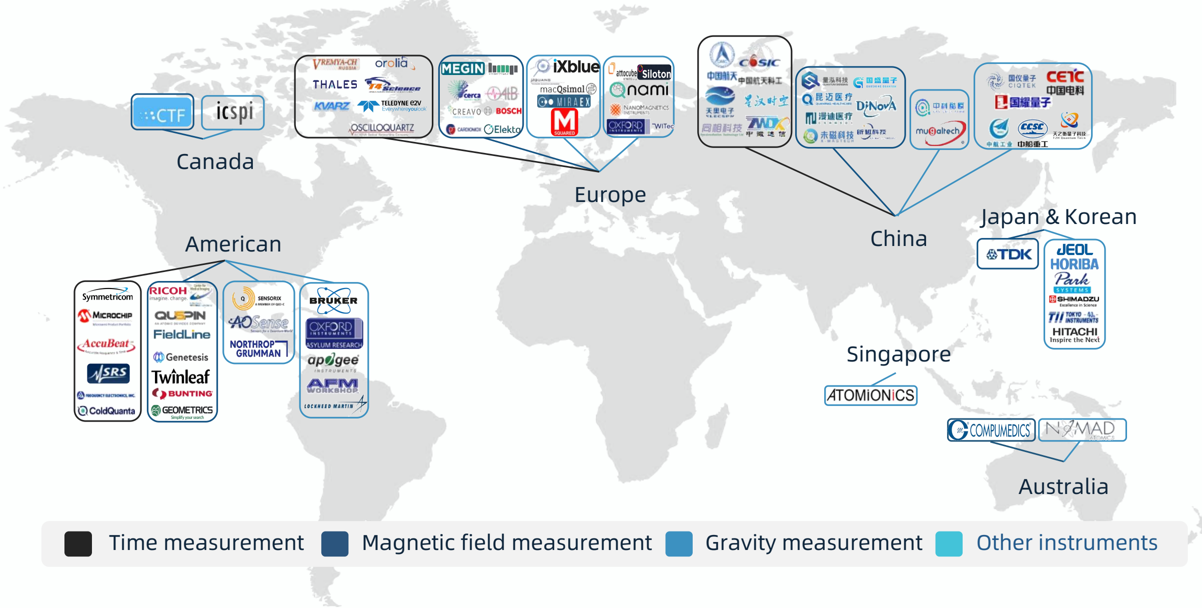
The upstream development status of the quantum precision measurement industry includes the following aspects :

- R & D and production : This part includes the development and production of quantum precision measurement technology and equipment, such as quantum sensors, quantum metrology instruments, etc.
- Device supply : Quantum precision measurement requires a series of devices, such as stable lasers, cryogenic technology, etc.
- Technical support : This part includes technical training, technical services, etc., to provide technical support and advice to customers.

At present, with the continuous improvement of technology and the growth of market demand, the upstream of quantum precision measurement industry is developing rapidly. At the same time, the country s support policies have also had a positive impact on its development.

3.2 Midstream Analysis of Industrial Chain

Exhibit 3-2 : Global distribution of major players in quantum precision measurement



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Global quantum precision measurement start-ups are mainly located in Europe, the United States and China.

According to the ecological map of quantum precision measurement industry, the midstream market-oriented suppliers are marked in countries / regions and technical fields. It can be seen that the main quantum precision measurement market participants in the world are mainly distributed in North America (22 in the United States, 2 in Canada) and Europe (25). Followed by the Asia-Pacific region, China (20), Japan (6), Australia (3), South Korea (2), Singapore (1).

Country	Number of enterprises
Europe	25
American	22
China	20
Japan	6
Australia	3
Canada	2
Korean	1
Singapore	1

The United States, Europe and China are involved in time-frequency, magnetic field measurement, gravity measurement, scientific research and industrial instruments. China also has related start-up companies in the field of quantum radar. At present, Japan and South Korea are relatively mature in magnetic field measurement, scientific research and industrial instruments, but they are still in the laboratory research stage in the field of time-frequency and gravity measurement, and no enterprises can provide specific products. Canada and Australia are involved in magnetic field measurement, scientific research and industrial instruments. Singapore has a start-up company in the field of gravity measurement to provide quantum gravimeter-related products and services.

At present, European and American countries have a deep research foundation in the field of quantum measurement, and have a rich variety of technical products. The product types include atomic clocks, atomic gravimeters, quantum magnetometers, diamond color center microscopes, Rydberg atoms, quantum gyroscopes, quantum accelerometers and other technologies and applications, and actively explore applications in communication networks, geological exploration, aerospace defense, power energy and other fields. Some of these companies have received military R & D orders from national defense departments. Quantum measurement enterprises are mainly founded by scientific research teams of universities and research institutes.

The threshold of quantum measurement technology is relatively high. At present, most quantum measurement enterprises are hatched from universities or research institutes.

Quantum precision measurement is a civil-military dual-use technology. At present, there are many research directions and wide application fields. The main development direction of quantum precision measurement is military application and scientific research. Globally, start-ups that focus on the development and application of quantum measurement technology products are gradually transforming from universities and scientific research institutions. In the field of quantum precision measurement, there are more mature military products and use cases, and some mature technical directions have begun to enter the transition stage from engineering prototype to commercial products. However, in general, the scale of commercial application and industrialization of quantum measurement is still limited, the development is still in its infancy, and the industrial chain and ecology are not yet mature. The threshold of quantum measurement technology is relatively high, which requires knowledge and technology accumulation in the fields of quantum physics and test metrology, and strict requirements for high-end professional talents. At present, most of the quantum measurement companies are hatched from universities or research institutes.

3.2.1 Quantum clock industry chain analysis

There are many kinds of products and technologies in the field of quantum precision measurement, and the industrial ecology is still developing. However, relatively mature products such as microwave atomic clock, superconducting interferometer magnetometer, cold atom gravity interferometer, atomic force microscope, and electron paramagnetic resonance spectrometer have related industrial chains. Other industrial chains that have completed prototypes or gradually commercialized products in the laboratory have gradually taken shape.

Exhibit 3-3：Quantum Clock Enterprise Graph

Quantum clock

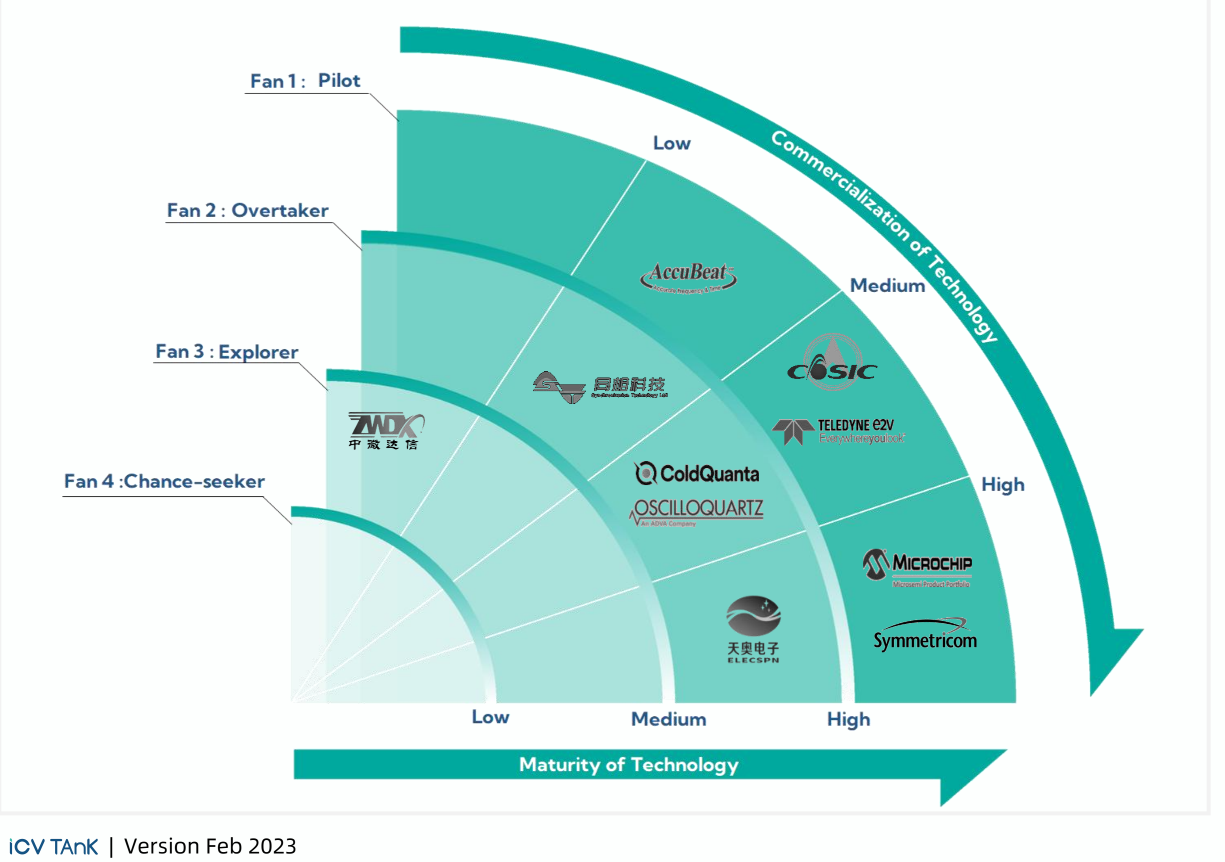
Note：As an industrial ecological map, the above LOGO only reflects commercial companies in the upstream and midstream. The above LOGO only appears once, but it does not mean that the company has no layout or product in other links.

At present, commercial products are mainly microwave atomic clocks (rubidium clocks, hydrogen clocks, cesium clocks), microwave chip-level atomic clocks, optical clocks, chip-level molecular clocks, and time-frequency synchronization products (protocols).

In terms of quantum clocks, optical clocks are leading institutions such as Microsemi (Microchip) and Symmetricom. At present, only Zhongwei Daxin has the relevant public layout of molecular clock. In terms of microwave clocks, the current global microwave clock products are mature, and the products and markets are relatively mature. The main players in China are Tian ao Electronics and 203. Among the countries with atomic clock technology in the world, the United States and Europe have more commercial companies. There are few commercial companies in other regions, and the technology is mainly mastered in the formulation of national measurement standards and related research institutes. Among them, the United

States Symmetricom company is the technology leader of the atomic clock. In addition, according to public reports, the EU and Japan have also realized the development of chip-level atomic clock prototypes.

Exhibit 3-4 : CTF model in quantum clock field

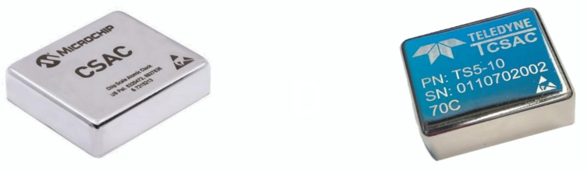


3.2.2 Introduction of quantum clock major companies

Microchip Technology Incorporated

The American company, founded in 1989, is a leading supplier of intelligent, interconnected and secure embedded control solutions. The product system is rich. Among them, the clock and timing (Clock & Timing) product-chip atomic clock (CASC) was launched in 2011 and is the world s first commercial chip-level atomic clock. Funded by DARPA in 2001, participants include NIST, Sandia Lab, Symmetricom (now Microchip, Microsemi s parent company), Teledyne Scientific, etc.

Exhibit 3-5 : Microchip atomic clock schematics



Microchip Teledyne

OscilloquartzSA

Oscilloquartz is a Swiss company specializing in the development, production and sales of frequency control and synchronization solutions for various applications. Its product portfolio includes oscillators, quartz crystals, GPS and GNSS standard oscillators, frequency synthesizers, holding units and timing devices. The company serves a wide range of industries such as telecommunications, data centers, energy and utilities, military and aerospace.

Chengdu Spaceon Electronics Co.,Ltd.

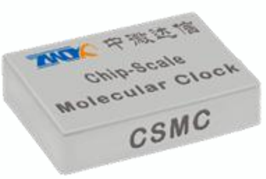
Chinese company, founded in 2004, was listed in 2015 (Code 002935), with 43.3 % controlled by China Power Ten. Mainly engaged in time and frequency products, BeiDou satellite application products research and development, design, production and sales. According to the company s annual report, the products are mainly divided into BeiDou satellite products, frequency series products, time synchronization series products.

ZWDX

China company, founded in 2017, provides measurement and control system in the field of quantum computing. It has a normal temperature quantum measurement and control system superconducting & silicon-based quantum dots. It will develop low-temperature quantum measurement and control chips. In the field of quantum precision measurement, it has developed the world s first chip-level molecular clock, and will develop innovative products such as quantum time-frequency synchronization and quantum aperture array of quantum temperature sensor chips.

Exhibit 3-6 : ZWDX Chip Level Molecular Clock Prototype Product Map

Atypical packaging



Typical package

ColdQuanta

American company, founded in 2007. The company focuses on cold atom quantum technology. Current products include UHV glass batteries, cold atom sources, magneto-optical traps, Albert : quantum matter machines, trapped ion devices, atomic clocks, and radio frequency connectors. The company has developed portable atomic clocks for the Ministry of Defense and the Office of Naval Research. This new atomic clock can achieve precise timing and provide GPS support for infrastructure.

Exhibit 3-7 : ColdQuanta atomic clock product diagram

Microwave clock

Optical clock

3.2.3 Quantum magnetic field measurement industry chain analysis

Exhibit 3-8 : Quantum magnetic field measurement enterprise map

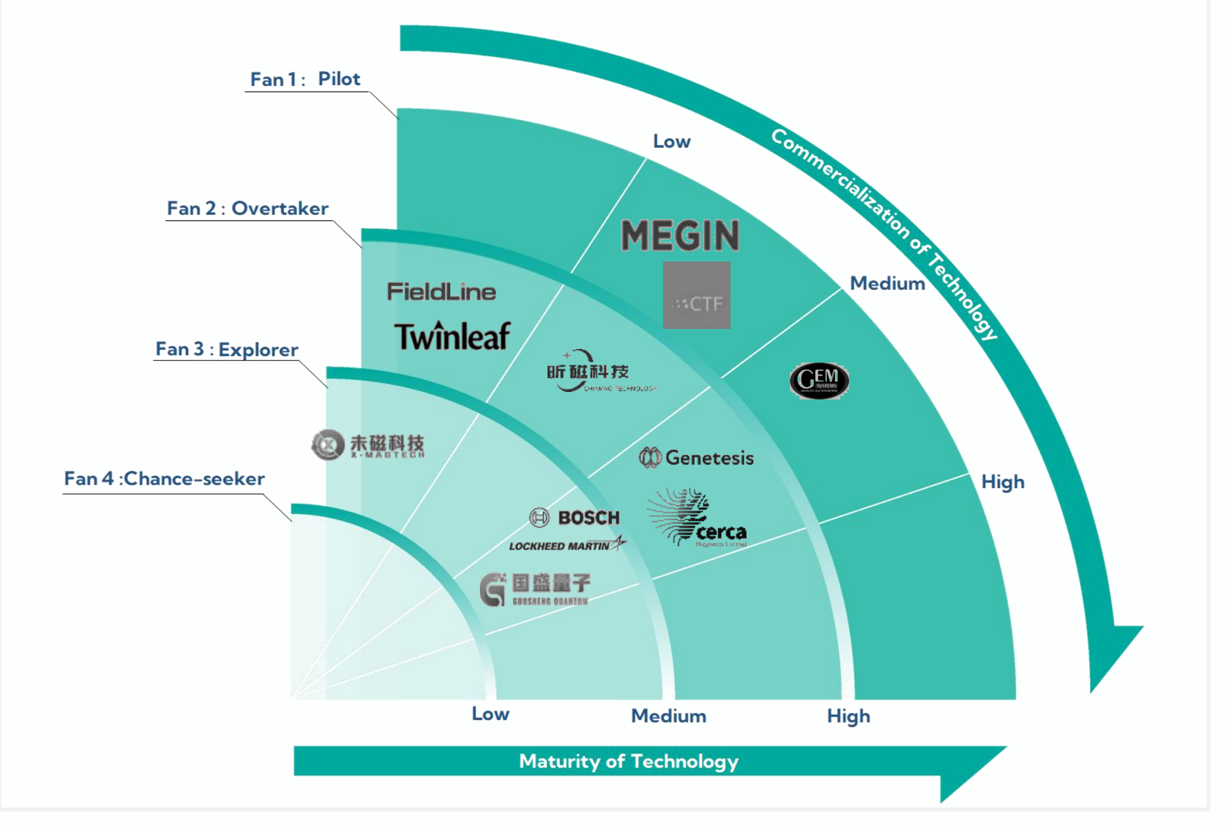
Quantum magnetic field measurement

In terms of quantum magnetic field measurement, it can be applied to magnetic measurement equipment in the field of life and health in the fields of geography, geology and biomedicine. Quantum magnetometer (SQUID / OPM / SERF / NV color center), which is mainly used for weak magnetic detection, can be used in military defense, geological and biomedical fields.

At present, there are many technical paths for quantum magnetic field measurement. At present, the market is mainly dominated by early optical pump magnetometers and SQUID. In the future, SERF and NV color center magnetometers may seize the market and further promote quantum commercialization through cost advantages.

The commercialization of magnetometers in the world is more mature in biomedicine, geomagnetic exploration and physical research. Although there are many start-ups in China, the bidding information related to magnetoencephalography measurement is manufactured by manufacturers in other countries.

Exhibit 3-9 : CTF Model in Quantum Magnetic Field Measurement



3.2.4 Introduction of major companies in quantum magnetic field measurement

Genetesis

In 2017, the development of magnetocardiograph based on atomic magnetometer began by purchasing atomic magnetometer, and the world s first non-superconducting magnetocardiograph CardioFluxTM based on atomic magnetometer was launched. The data collection and processing were realized remotely by machine learning algorithm through cloud computing platform. The product was certified by the U.S.FDA 510K in 2019, and was officially certified by the FDA s breakthrough imaging device in December 2020, which was used in many hospitals in the United States. It is announced that the number of clinical trials has been close to 2000 people.

QuSpin

Focusing on OPM manufacturing, we manufacture optical atomic magnetometers for biomedical and geophysical applications. At present, there are zero field magnetometer and full field magnetometer. The zero-field magnetometer is an ultra-sensitive vector magnetometer that can work in low-field environments. It is mainly used in magnetoencephalography, fetal magnetocardiography, and magnetic relaxation measurements. The full-field magnetometer is a compact high-sensitivity scalar magnetometer that can operate in the magnetic field of the earth and can solve very small field changes. It is mainly used in geophysics, space, mineral and energy exploration, and unexploded ordnance detection.

Exhibit 3-10 : Quspin magnetometer product diagram

Zero-field magnetometer

Full-field magnetometer

Cerca Magnetics Limited

Kent Magnetic Shields Limited (MSL) was developed in collaboration with the University of Nottingham. The world s most advanced functional wearable brain scanner will be launched to the market. It aims to allow people to move freely while being scanned. Major competitors in the market are acquiring small and medium-sized enterprises to expand their product portfolio and improve their manufacturing capabilities.

Chinmag technology

Hangzhou XinMagnetic Technology Co., Ltd.was incubated in the Institute of Innovation and Technology of Zhejiang University in 2015. It is a medical high-end weak magnetic imaging equipment research and development company. At present, it is developing a new generation of cardiac biomagnetic detection system (QBM-C2049 type) based on quantum precision measurement technology (based on atomic magnetometer). The core technology and products of the system have completely independent intellectual property rights, and the complexity of equipment research and development, production cost and use cost exceed similar foreign instruments.

Guosheng Quantum

Established in Hefei National University Science Park, it has developed a variety of sensing devices and quantum series products based on quantum technology. The main customers include global R & D, manufacturing, production testing and other units. The main fields include quantum measurement, quantum sensing, quantum optics, quantum chips, quantum materials, quantum education and so on.

3.2.5 Quantum gravity measurement industry chain analysis

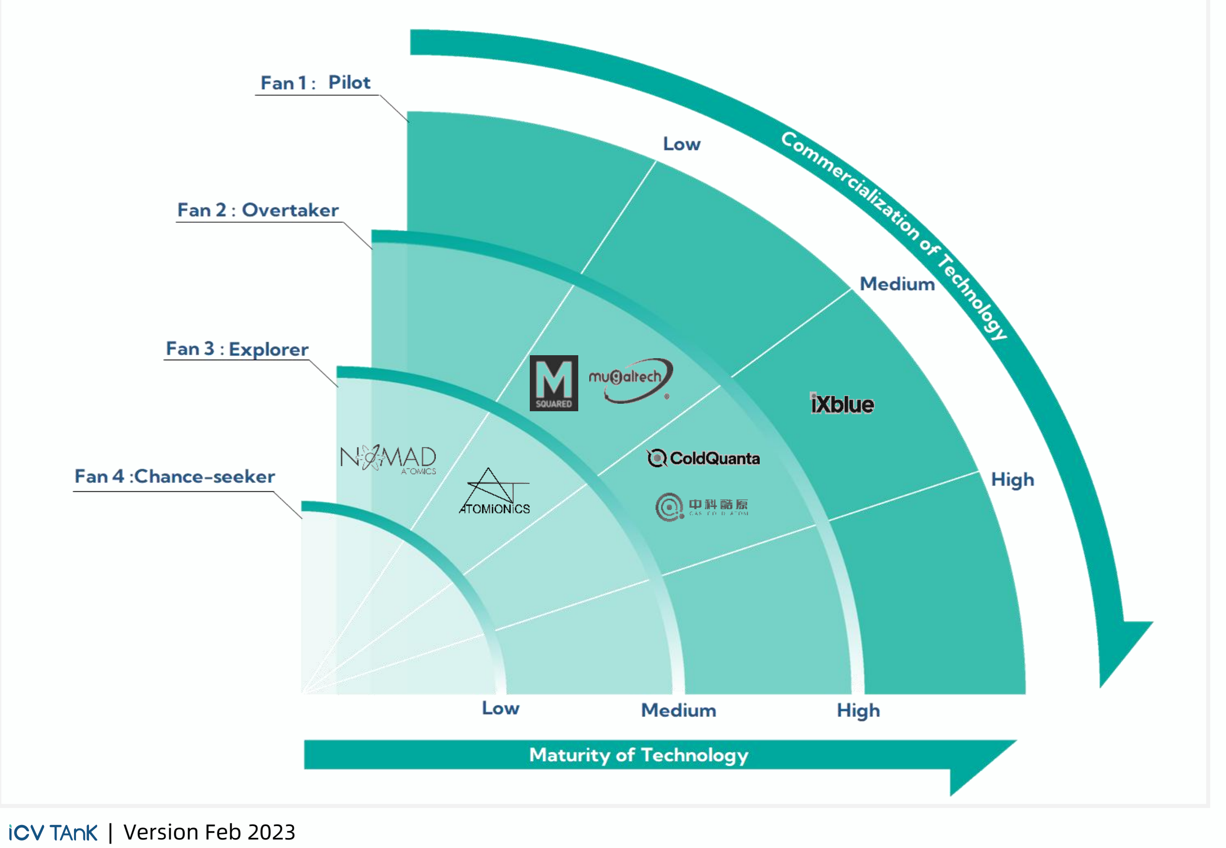
Exhibit 3-11 : Quantum gravity measurement company map

Quantum gravity measurement

In terms of quantum gravity measurement, there is only a technical path based on cold atom interferometer, and all of them are absolute measuring instruments. These instruments are monopolized by foreign countries and the market is mature, often used with relative gravimeters. At present, there are 2 in the United States, 1 in the United Kingdom, 1 in Australia and 2 in China. The main participants of the quantum gravity measurement instruments include : AOSense (USA), M squared (UK), Atomionics (Singapore), iXblue (France), Muquans (France, acquired by IXblue), National Shield Quantum (China), China Science Cool Source (China), Micro-Ga Quantum (China), Nomad Atomics (Australia), global distribution as shown in the figure.

At present, quantum gravity measurement instruments are completing the transformation from laboratory to commercialization. Among them, the main research institutions of quantum gravimeter have completed the transformation from laboratory to commercialization. Companies in the United States, France, China and Singapore have launched various types of commercial quantum gravimeters. It mainly provides products and technologies for research institutes, universities and relevant government units and enterprises related to geo-geological research, marine research, offshore operations, inertial navigation, aircraft research, etc.

Exhibit 3-12 : CTF model in the field of quantum gravity measurement (quantum gravimeter & quantum gravity gradiometer)



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3.2.6 Introduction of main quantum gravity measurement companies

AOSense

American company, founded in 2004. The company is a leading developer and manufacturer of innovative atomic optical sensors in the fields of precision navigation, time and frequency standards, and gravity measurement. The products mainly include gyroscope, accelerometer, inertial measurement unit (IMU), gravimeter, gravity gradiometer and atomic frequency standard. The company has designed and built the most advanced cold atom technology for many government-funded projects funded by DARPA, Air Force, Army, Navy, NASA, NSF, DTRA and the intelligence community. It has received funding from the US Department of Defense SBIR / STTR project.

CAS Cold Atom

The Chinese company, founded in 2020, is committed to the development and technical services of atomic gravity sensors and related optical and electronic products, providing reliable products and solutions for the research and application of gravity precision measurement. The company s technical team is composed of the core team of the Institute of Precision Measurement Science and Technology Innovation of the Chinese Academy of Sciences engaged in cold atomic physics research. It is one of the earliest teams in China to start research on neutral atom quantum information technology. The company s technical team has developed China s first set of atomic gravimeter, atomic gravity gradiometer and other quantum sensors.

Exhibit 3-14 : zhongkekuyuan gravity measurement equipment and other product maps

Atomic Quantum Gravimeter

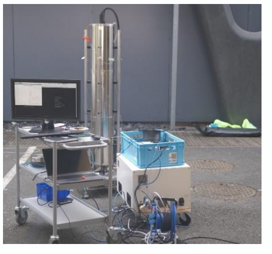
Desktop magneto-optical trap (Compact-MOT)

iXblue

iXBlue is a leading marine technology company based in France, founded in 2000. The company focuses on providing innovative solutions for marine science, exploration and fisheries. iXBlue maintains close cooperation with marine research institutions and government departments around the world to promote the development of marine science and technology.

Exhibit 3-13：iXblue gravity measurement product diagram

Quantum Gravimeter



Quantum Gravity Gradiometer

M Squared Laser Ltd.

M Squared is a UK-based photonics and quantum technology company founded in 2003. M Squared s products include lasers, microscopes, quantum devices and instruments (ICE BLOC series for laboratory laser platforms). As a global leader in quantum sensing, timing and computing, M Squared has achieved milestones such as the UK s first commercial quantum gravimeter and accelerometer. The company s product portfolio also includes complementary optical and electronic products. With its profound strength in high-end quantum product engineering and commercialization.

Mugaltech

Technology-based SMEs in Zhejiang Province, and has passed the ISO9001 quality management system certification. The company independently grasps the core technology of gravimeter products, and forms a close cooperative relationship with Zhejiang University of Technology and Zhejiang University. The company s gravimeter products won the bid for the whole machine procurement project, and the modular products serve many scientific research institutes and enterprise users, and the business scale has grown steadily.

3.2.7 Introduction of other major companies of quantum precision measurement equipment

Exhibit 3-11 : CTF model in the field of quantum gravity measurement (quantum gravimeter & quantum gravity gradiometer)

Other quantum precision measurement equipment

ADDED SCIENTIFIC	ALTER	ALTRAN	apogee INSTRUMENTS
MIRAEX	mulberry sensors	NVISION	OEwaves
CAMPBELL SCIENTIFIC	PHOTON FORCE	Fraunhofer	QinetiQ
QDTI	QUBITRIUM	Raytheon Intelligence & Space	RSK
RYDBERG TECHNOLOGIES	DEVICE	THALES	UNIKLASERS
国耀量子	zeropoint motion	Qubic	
CETC 中国电子科技集团公司第十四研究所	CASIC	中国航天科技集团公司 China Aerospace Science and Technology Corporation	Siloton
QLM	SMG SILICON MICROGRAVITY	SENSORIX	Terra Quantum
GRAD	Geomatrix EARTH SCIENCE LTD	LI-COR	Quant AD LLC

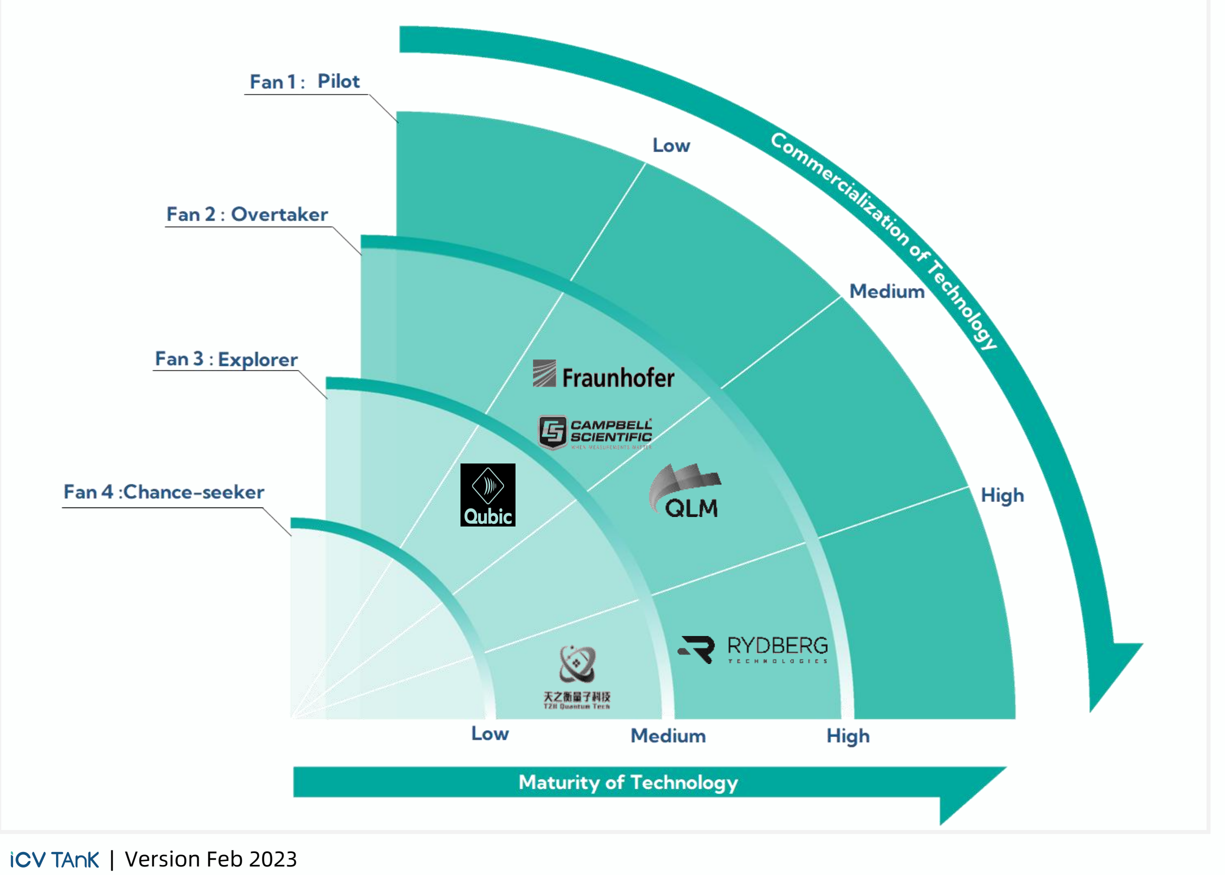
product category

quantum radar	Atomic antenna	Quantum accelerometer	
quantum gyroscope	Quantum optical instruments	EPR	AFM
etc.			

Other types mainly include the immature fields of industrialization and business system. For example, quantum radar, atomic antenna, quantum accelerometer, quantum gyroscope, quantum optical instrument and other quantum instruments.

The relatively mature quantum precision measurement scientific instruments and equipment mainly provide laboratory or industrial high-end instruments and equipment for biomedicine, materials, nanotechnology and other fields. AFM and EPR / ESR are mature commercial products. There are many suppliers of AFM, including the United States and Canada in North America. Europe has Britain, Germany, France, Switzerland, Russia, Austria, Italy, Hungary. Asia has Japan, Israel, China.

Exhibit 3-12 : CTF model for quantum precision measurement of other equipment fields



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3.3 Downstream analysis of industrial chain

At present, the main downstream applications are still concentrated in the fields of military defense and scientific research. The outstanding medical field is mainly due to the superior detection ability of magnetometers to biological weak magnetism. The field of satellite navigation and communication is mainly the high-precision time-frequency and time-accurate application of atomic clocks.

Military Defense

- Gravity and magnetic exploration
- Time-frequency
- Electronic warfare (EW)
- Quantum full inertial navigation system
- Magnetic anomaly map
- Special communication
- Nondestructive quality inspection of weapon equipment
- Spaceborne magnetic survey
- Geomagnetic navigation
- Gravitational map navigation
- Target detection
- Space exploration
- Anti-stealth operations
- Anti-submarine warfare (ASW)

Scientific Research

Time Measurement

- Time accuracy
- Atomic time formulation
- Atomic time formulation
- Time synchronization

Gravity Measurement

- Geophysics
- Two-dimensional materials
- Geodynamics
- Mineral resources exploration
- Geological disaster early warning
- Topological magnetic structure
- Geotectonics
- Environmental research
- Geological exploration
- Superconducting magnetism
- Magnetic stratigraphy
- Drilling orientation
- Magnetic domain imaging

Gravity Measurement

- Geophysics
- Basic research of physics
- Quality benchmark establishment
- Hyperfine structure constant
- Determination of physical constant G
- Geological exploration
- Space exploration
- Gravity and magnetic exploration
- Basic scientific problems of gravity
- Geophysical application research
- Underground mass distribution
- Universal gravitational constant
- Geodynamics
- Weak equivalence principle test
- Rotation angular velocity
- Gravity acceleration
- Establishment and improvement of gravity field model
- Tidal model
- Gravity field gradient
- Geoid mapping

Imaging

- Atmospheric measurement
- Wind speed measurement
- Distance measurement
- Ghost imaging

Medical Treatment

Cleveland Clinic fraserhealth Cincinnati Children's Ascension SAN CAMILLO IRCCS SRL

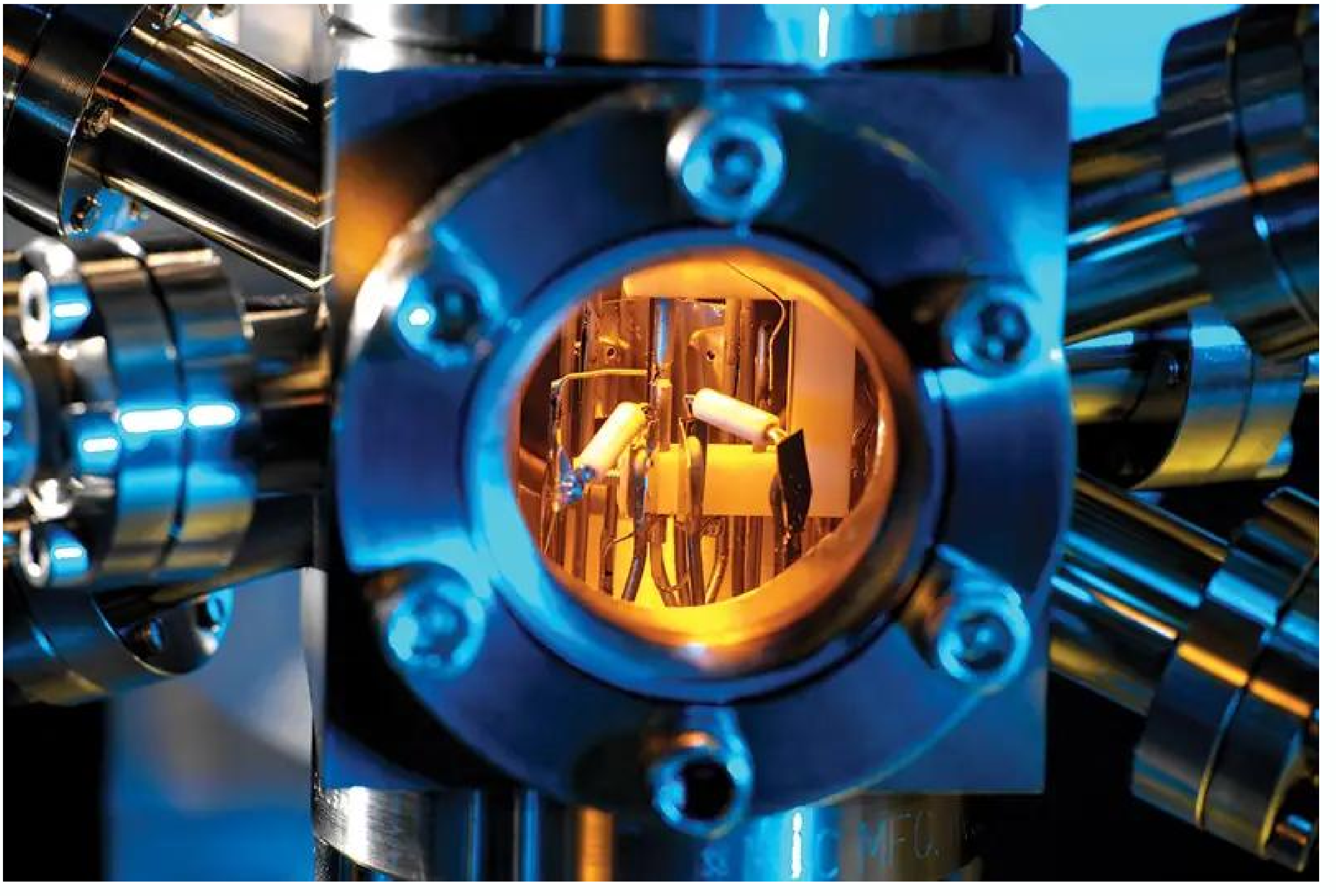
- Magnetoencephalography detection
- Fetal cardiac magnetic detection
- Heart examination
- Nuclear magnetic resonance

Satellite Navigation

ROYAL NAVY U.S.ARMY NASA CASIC 航天科工 CSIC 中船重工

Communication

東陽テクニカ TOYO Corporation ADVA Optical Networking

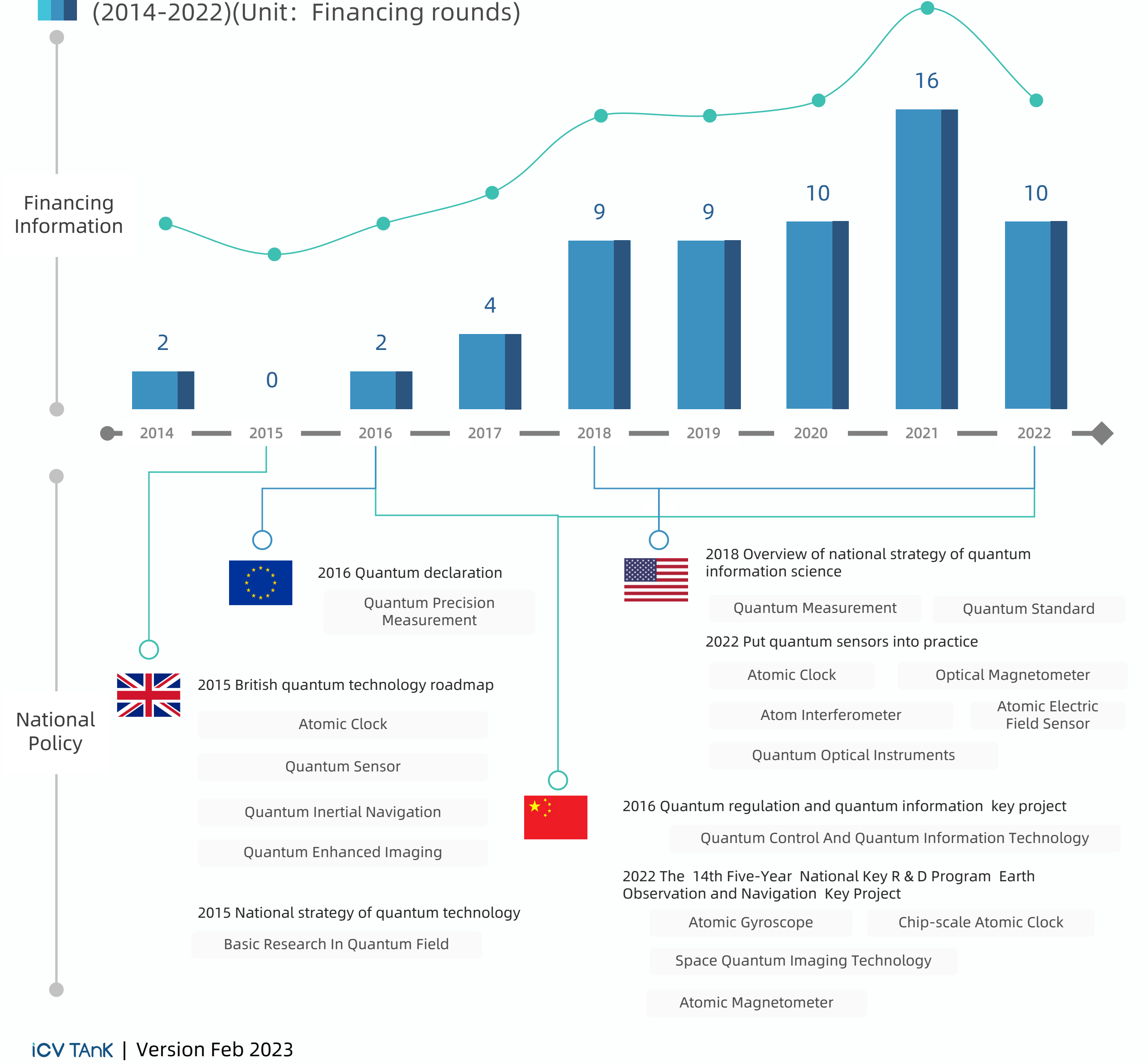


Chapter 4
Investment and Financing Analysis

4.1 Historical Financing and National Policy Analysis

As a representative of credibility, the country s special research on technology path is an important reference index for investors. The policy of each country on quantum research deployment can be used as the light of the capital. This chapter will analyze the investment and financing market from the perspective of national policy, so as to find out the characteristics of the company favored by the investors and make a judgment on the future trend.

Exhibit 4-1 : Financing round trend and national policy map (2014-2022)(Unit: Financing rounds)



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Note : Some policies cover the panoramic strategy of quantum information technology. The graphic part only extracts the main technical paths and devices of quantum precision measurement and quantum sensing.

The quantum precision measurement industry is recognized as the earliest track to achieve quantum commercialization , and its commercial application progress is leading in the field of quantum information technology. However, in fact, the division of the field of quantum precision measurement is later than quantum computing and quantum secure communication. The main principle is to take advantage of the latter s shortcomings of quantum systems susceptible to external interference . Quantum precision measurement involves the preparation of quantum states. Its research path is not only complex and numerous, but also the microscopic theory is not convenient for people to understand. The combination of these reasons leads to extremely high cognitive barriers in the industry, which discourages investors.

4.1.1 National Policy

So far, the scientific and technological powers have not only clarified the technical route shown in Exhibit, but also emphasized the basic research, technology transformation, technology application, industrial promotion, talent training and international cooperation in the field of quantum. Some of the policy reports analyze and study the possible commercialization time and development roadmap in the technology field.

China has clearly proposed to break through bottlenecks in core technologies, materials, devices, etc., to achieve long-term maintenance and high-precision manipulation of quantum coherence and quantum entanglement, and to apply them to fields such as quantum precision measurement. The metrology development plan (2021-2035) strengthens quantum metrology and implements the quantum metrology plan.

The National Strategy Overview of Quantum Information Science released by the National Science and Technology Council of the White House Office of Science and Technology Policy states that quantum measurement is expected to provide advanced sensors for military missions, develop new measurement science and quantum benchmarks, and improve navigation and timing technology. In 2022, putting quantum sensors into practice was released to further promote the application of quantum precision measurement related industries.

4.1.2 Investment and financing forecast

The main breakthrough point of investment and financing for quantum precision measurement is 2018, and the technical path of concern is closely related to the policy direction of various countries. For example, Chinese start-ups were mainly established in 2016 and later, which coincided with the promulgation of key projects, and

Exhibit 4-2: Quantum Precision Measurement Financing Information (2020-2022)

Nation	Firm name	financial rounds	Origin Currency	Publication Date
USA	ColdQuanta	B	US $110 million	2022.11
		A+	US $20 million	2021.05
		A	US $32 million	2020.11
	Genetesis	C	US $17.5 million	2022.10
		B	-	2021.03
		B	US $9.2 million	2020.04
China	CAS Cold	A	Tens of millions of RMB	2022.03
		Angel	Millions of RMB	2020.11
	QDGDZ	Equity	Undisclosed	2021.06
	ZWDX	Angel	Tens of millions of RMB	2022.05
	Cshmedi	Pre A+	Undisclosed	2021.05
		A	Hundreds of millions of RMB	2021.09
		Pre-A	Tens of millions of RMB	2020.07
	Quanmag	Pre-A	Tens of millions of RMB	2022.07
		Angel	Undisclosed	2020.04
	Mugaltech	Angel	Undisclosed	2020.06
	Ciqtek	C	Hundreds of millions of RMB	2021.12
		B	Hundreds of millions of RMB	2021.01
	Xmagtech	A	Hundreds of millions of RMB	2022.06
		Equity	Undisclosed	2021.07
		Equity	Undisclosed	2021.05
		Angel	Tens of millions of RMB	2020.10
	Chinmag	Strategy Financing	4 million RMB	2021.11
		A	Undisclosed	2021.09
		Angel	Undisclosed	2021.08
	Guosheng	Angel	Undisclosed	2022.07
England	Siloton	Seed	£ 470000	2022.02
	M Squared Lasers	Equity&Bonds	£ 32.5 million	2020.10
	Zero Point Motion	Seed	£ 2.58 million	2022.03
	Cerva Magnetics	VC	Undisclosed	2020.11
	Creavo	B	Undisclosed	2021.03
switzerland	Qnami	A	CHF 4 million	2021.05
Singapore	Atomionics	Seed	-	2021.03
Australia	Nomad Atomics	Seed	S $1.51 million	2021.01
		Pre-seed	-	2020.06

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began to receive financing in 2017.

In recent years, a number of start-up companies in the field of quantum measurement have been incubated around the world. The products have gradually matured in the continuous engineering iteration, and various application scenarios have been explored to promote the progress of quantum commercialization. It is expected that after 2022, more start-ups and investment and financing activities will emerge under the new policies of China and the United States, especially the relevant technical paths involved in the policies.

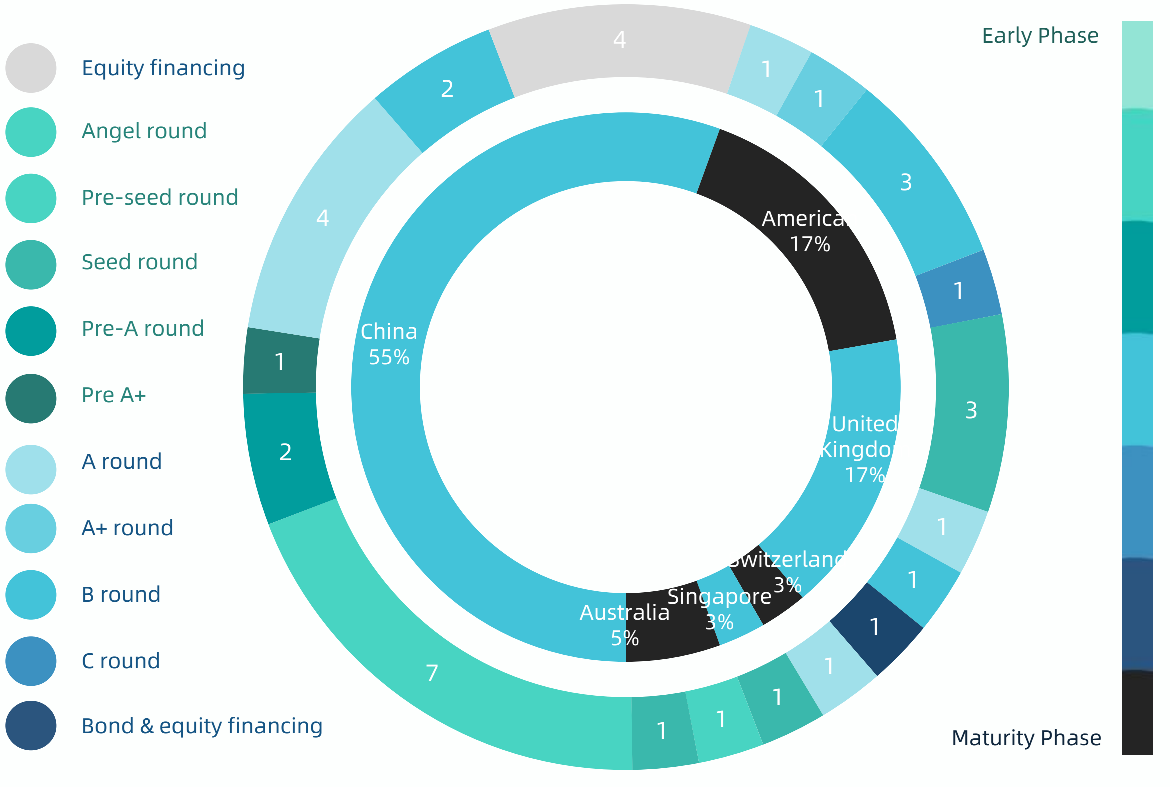
4.1.3 Number of financing rounds

In the past three years (2020-2022), financing events mainly occurred in China, the United States, the United Kingdom, Switzerland, Singapore and Australia, with a total of 35 rounds. Among them, China has the most financing events, a total of 20 rounds, accounting for 57 % of the global public financing information . followed by the United States, a total of 6 rounds, accounting for 17 % of the world . the United Kingdom ranked third, with a total of 5 rounds, accounting for 14 % of the world . there were two related financing incidents in Australia, accounting for 6 %. Switzerland and Singapore each reported one related financing incident, accounting for 3 % of the world. In general, the main leaders of quantum precision measurement are China, the United States and the United Kingdom.

In general, the main leaders of quantum precision measurement are China, the United States and the United Kingdom. Among them, China s quantum precision measurement market has the most active investment and financing, accounting for more than half of the world s total. However, there is no public amount report on investment and financing in the Chinese market, and it is impossible to carry out specific amount statistics. However, according to public information, Guoyi disclosed that its financing amount is close to 1 billion, which may be the highest financing amount in China s quantum sensing field.

4.2 Global Financing Analysis of Quantum Precision Measurement

Exhibit 4-3：Number of countries and financing rounds (2020-2022)(Unit：financing rounds)



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In terms of financing rounds, from the picture data, the global investment in quantum precision measurement is distributed as follows : China leads the investment in quantum precision measurement with 51.61 % of investment rounds . the United States ranked second with a 19.35 % investment round share . the UK ranked third with a 16.13 % share of investment rounds . singapore ranked fourth with 6.45 % investment . australia and Switzerland have the same investment level of 3.23 %.

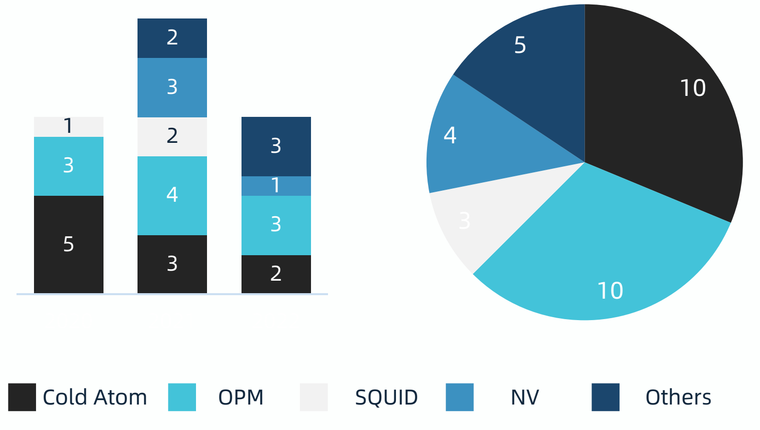
This data shows that investment in the field of quantum precision measurement is highly concentrated in a few countries, of which China accounts for the largest share. The high level of investment in these countries indicates that these regions have a strong interest in the development and commercialization of quantum technology. The data also show that there may be competition in global quantum technology investment, and different countries are seeking to become leaders in this field. It should be noted that this data may not represent the current global situation.

In terms of financing stage, China mainly focuses on early investment such as angel wheel and seed wheel . in the United States, the recent progress of financing information investment stage is relatively mature, which is composed of ColdQuanta and Genetesis, focusing on cold atomic technology and OPM atomic magnetometer technology respectively. In the UK, there have been seed rounds of financing for start-ups recently, and there are relatively mature financing rounds. For example, M Squared Lasers based on cold atom technology. Quantum precision measurement enterprises in Australia, Switzerland and Singapore are in the early stage.

4.3 Global technology path financing analysis of quantum precision measurement

According to the technical path investment round analysis : the number of quantum precision measurement financing is rising steadily. Cold atom technology and optically pumped magnetometer (OPM) technology are currently the two technologies that investors are most interested in in the field of quantum technology.

Exhibit 4-4: Classify the number of historical financing by technology path market
(2020-2022)(Unit: financing rounds)



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Note : Cold atom technology includes cold atom clock and cold atom interferometer . OPM is optically pumped magnetometer technology . SQUID is a superconducting quantum interference device . NV is diamond NV color center technology . others are quantum optical sensors, quantum radar and other devices.

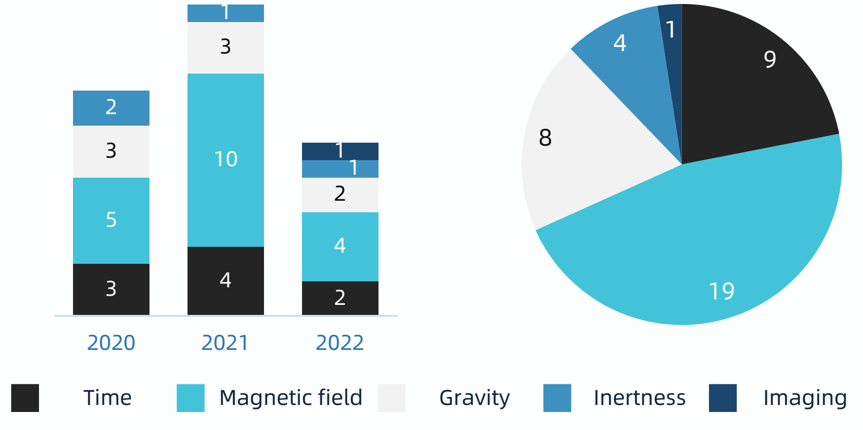
The number of quantum precision measurement financing is steadily increasing. Cold atoms and OPM are the current popular technology paths for financing, and commercial development and financing rounds are relatively mature. At present, the NV color center is gradually attracting attention, which is the initial stage of financing . other types of quantum optical sensors have also received attention under the promotion of national policies.

The most technological paths for financing are cold atoms and OPM, both of which are 10 cases. Among them, the most investment activities are cold atoms, with a total of 5 rounds in 2020. The attention of the OPM atomic magnetometer is more balanced in each period. The technical financing information of SQUID has a total of 3 rounds, and there is no financing information in 2022. The NV color center has gradually gained attention and received four rounds of financing, and three financings in 2021 are comparable to cold atoms and slightly less than OPM atomic magnetometers. From the perspective of the total amount of three years, the number of financing of all technology paths is 32 times, and cold atom enterprises and OPM enterprises are financing 10 times (both accounting for about one-third of the total) . sQUID financing 3 times (9.38 %), NV financing 4 times (12.5 %), and other new technology paths 5 times (15.6 %). In general, cold atoms and OPM still occupy most of the industry share.

4.4 Financing Analysis of Global Application Direction of Quantum Precision Measurement

According to the number of historical financing rounds of application market classification： quantum magnetic field measurement， quantum time-frequency time-accurate， quantum gravity measurement Application category is more concerned by investors in the field of quantum technology.

Exhibit 4-5：Classify the number of historical financing rounds by application market(2020-2022)(Unit：financing rounds)



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Note : A single technical path may contain multiple application scenarios. For example, cold atom technology can be divided into three directions : time-frequency, magnetic field measurement and inertial measurement.

In the past three years, the field of quantum precision measurement mainly consists of five parts : time-frequency, magnetic field measurement, gravity measurement, inertial measurement and quantum imaging. The largest proportion is quantum magnetic field measurement. The left diagram shows the number of financing rounds in each quantum application field. It can be seen from the time range that the table covers three years (2020-2022) of data.

In general, it can be seen from this table that financing in the field of quantum magnetic field measurement is the most active, while financing in other fields is relatively stable. However, since the table data covers only three years, it is impossible to draw more about the financing trends in the field of quantum science.

The above figure shows the number of financing applications of different types of quantum technology. It can be seen from the table that the number of financing applications of quantum magnetic field measurement is the highest, reaching 19. The number of financing for quantum time-frequency timing and quantum gravity measurement is also relatively high, 9 and 8, respectively. However, the number of financings for quantum inertial measurement and quantum imaging applications is significantly smaller, only 4 and 1, respectively.

From this table, we can see that the current quantum magnetic field measurement , quantum time-frequency timing , quantum gravity measurement application categories are more concerned by investors in the field of quantum technology, while the quantum inertial measurement and quantum imaging application categories currently have less financing, and further efforts may be needed to improve their attractiveness.

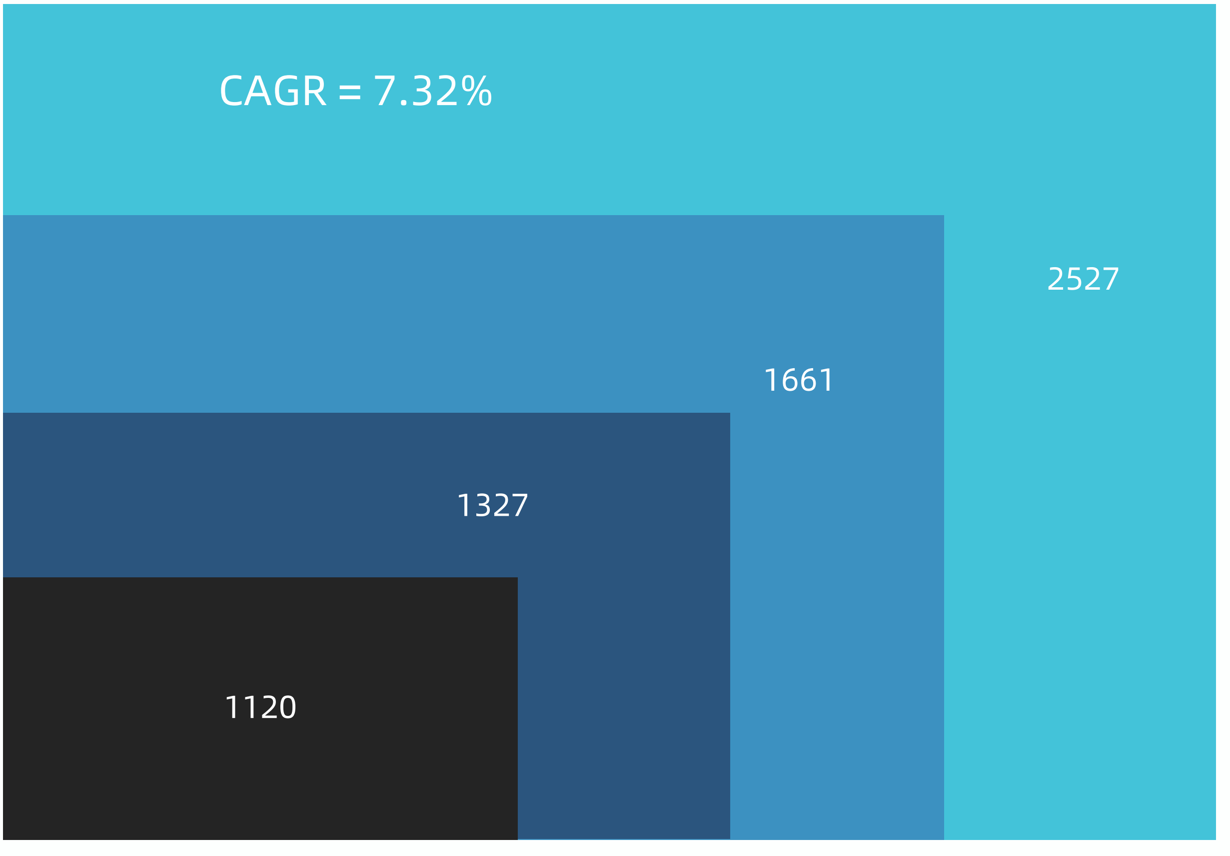
Sources: University of Birmingham

Chapter 5
Market Size Analysis

5.1 Quantum Precision Measurement Global Market Size Prediction

These data show the market size of the quantum precision measurement market from 2019 to 2030, and the annual compound growth rate from 2019 to 2030. The market is developing rapidly and has high growth potential.

Exhibit 5-1:Quantum precision measurement global market size prediction (2019 & 2022 % 2025 & 2030) (Unit: $ millions)



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2022: Industrial commercialization has further matured and the overall scale has begun to take shape.

The market size above mainly includes quantum time measurement, quantum magnetic field measurement, quantum gravity measurement, and other quantum precision measurement instruments. The global quantum precision market is expected to grow from USD 1.12 billion in 2019 to USD 2.527 billion in 2030. The market size is on the rise, with a compound annual growth rate of 7.97 %.

2030E : The industrialization is mature, and the current data is based on existing application speculation. In the future, with the development of quantum information technology, there will be more quantum precision measurement equipment that may further expand the market.

In 2030, the quantum precision measurement market data is expected to grow to $ 2.527 billion. From the data, the market share of all quantum precision measuring instruments is increasing over time, indicating that the demand for these technologies is growing.

Compared with other instruments, the market share of quantum clock is growing slowly, but it still occupies the largest share in all instruments. The market share of quantum magnetometers and gravimeters has grown faster, indicating that these technologies are becoming increasingly important in various applications. In addition, the market share of other instruments is also growing, indicating that the demand for these technologies is also growing. In the future, the commercialization of devices such as quantum gyroscopes, quantum accelerometers and quantum antennas will further expand the quantum precision market.The products and markets in the field of quantum precision measurement have gradually matured.

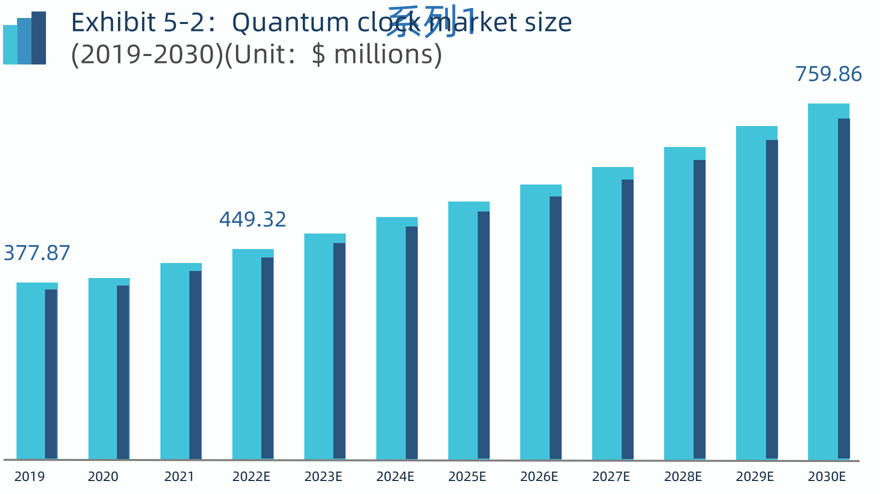
This article will expand the more mature subdivision application fields, namely : quantum time measurement, quantum magnetic field measurement, quantum gravity measurement, and regions of each market.

5.2 Global Market Analysis of Quantum Clock

5.2.1 Quantum clock global market size prediction

The market size of quantum clocks is expected to reach USD 449.32 million in 2022 and USD 759.86 million in 2030, with CAGR of 6.56 % from 2019 to 2030.

Exhibit 5-2: Quantum clock market size (2019-2030)(Unit: $ millions)



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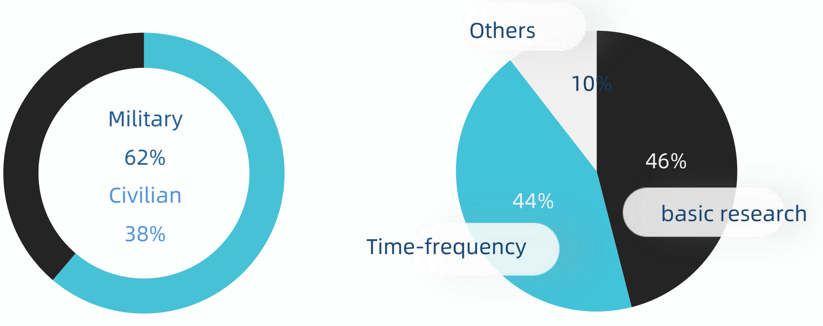
With the construction of 5G network and the progress of artificial intelligence and information society, the transmitted big data puts forward higher requirements for time synchronization of various intelligent mobile terminals. Quantum clocks can provide high-precision time benchmarks for remote control of mobile network terminals and various artificial intelligence devices. In military applications, quantum clocks can be mounted on a variety of weapons such as extended-range projectiles to improve strike accuracy. It can also be installed on a variety of portable individual devices to maintain high-precision time synchronization between mobile combat units and command systems. It is expected that the atomic clock will play an important role in the information battlefield. Therefore, the quantum clock market has broad development prospects.

The market size of quantum clocks is expected to reach $ 450 million in 2022, and is expected to grow to $ 760 million by 2030, with CAGR of 6.56 % from 2019 to 2030.

From this table, it can be seen that the quantum clock market size was $ 378 million in 2019 and reached about $ 760 million in 2030. The average annual growth rate (CAGR) in 2020-2030 is 6.96 %, which indicates that the size of the quantum clock market has grown steadily during this decade. During the forecast period, the size of the quantum clock market shows an upward trend year by year, and will continue to grow in the next few years. In general, it can be seen from the table that the quantum clock market has certain growth potential and there is still much room for development in the next few years.

5.2.2 Global market share analysis of quantum clock

Exhibit 5-3:The share of main application fields of quantum clock and the share of subdivision fields of private fields(2020)



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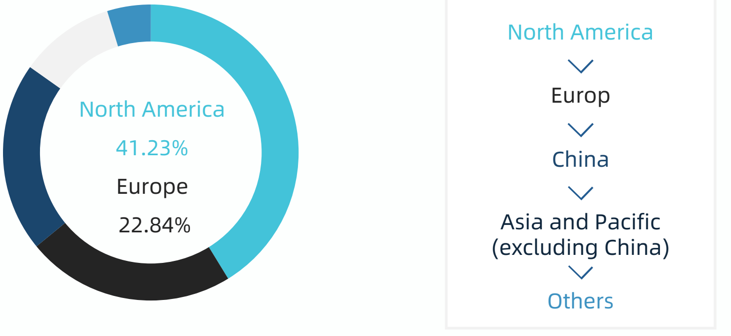
Quantum clocks are currently mainly military, and in the future, the infrastructure of 5G and information society will be more developed to civilian use.

The global demand for quantum clocks is mainly driven by the military sector, with aerospace being the main downstream application. In recent years, with the development of mobile communication, the scale of maritime field has increased, the market share of civil field has increased rapidly, and the market scale has increased rapidly.

According to ICV, the share of quantum clock applications in 2022 is mainly military applications, accounting for about 62 %. According to the ICV forecast, the quantum clock market will grow rapidly in the private sector in the future. It is speculated that the civil field will account for about 38 % in 2022. The civil scene is mainly divided into the right picture, which is divided into 46 % of the basic research . time-frequency 44 % . and 10 % in other fields. On future trends, further research on optical and molecular clocks will increase the market for basic research. However, the infrastructure of civil 5G and information society will make the time-frequency market in the civil field grow faster. In the future, quantum clocks are likely to give birth to more applications, such as judging altitude by small time differences at different heights.

In general, the civil scenarios of quantum clocks in the future will be relatively increased compared with relatively stable military applications. The military market may also have new applications, and the quantum clock market has great potential.

Exhibit 5-4:Quantum clocks are divided by market share in different regions.(2020-2022)



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The current market of quantum clocks is mainly distributed in North America, followed by Europe and China.At present, all countries are vigorously developing quantum clocks, and the future share may not change much.

The market share of quantum clocks is mainly distributed in North America, Europe, China, and other regions in the Asia-Pacific region except China. The market share from large to small is : North America (about 41 %), Europe (about 23 %), China (about 21 %), Asia-Pacific region except China (about 10 %), and other regions (about 5 %).

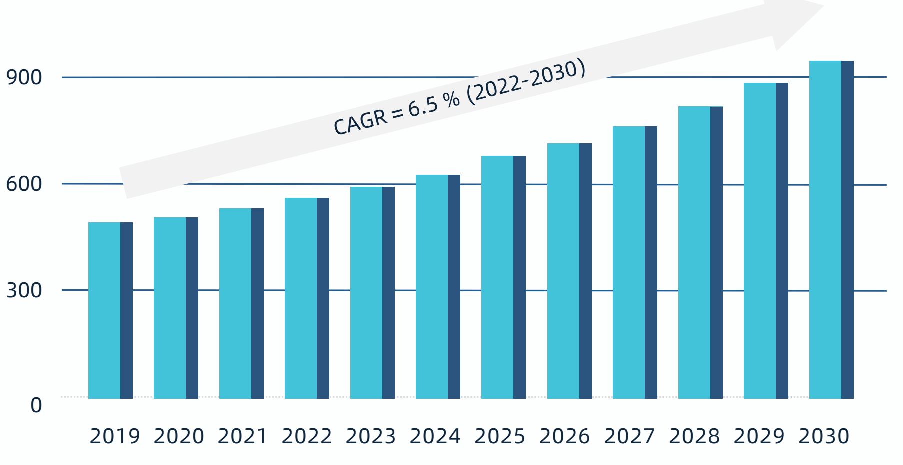
In general, the quantum clock in North America may be the largest application area of quantum clock because of its relatively early development and mature market. The market share of Europe and China is similar, accounting for 44 % in total, and it is also the main use area at present. The Asia-Pacific region (excluding China) accounts for about 10 % and 5 % in other regions, which is relatively small and has great development potential.

5.3 Analysis of Global Market Scale of Quantum Magnetometer

5.3.1 Quantum magnetometer global market size prediction

Quantum magnetometer market is mainly divided into four areas : biomedical, military defense, physics and scientific research, and others. Among them, biomedicine, military defense, physics and scientific research are three mature application fields of quantum magnetometers . Others include existing prototypes but not publicly available practical market applications, such as Lockheed Martin s Dark Ice, BOSCH s quantum magnetometer and quantum gyroscope demonstration systems. The field of physical research refers to many fields such as geomagnetic exploration, material detection and space exploration.

Exhibit 5-4: Global quantum magnetometer market size (2019-2030E)(unit: $ millions)



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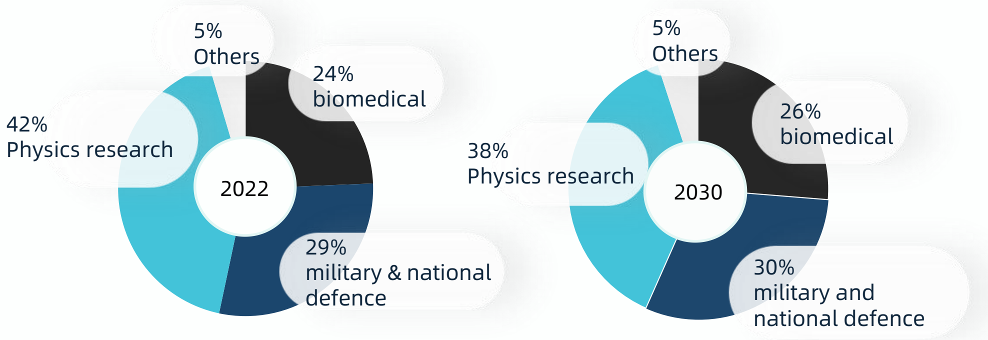
At present, quantum magnetometer technology is mainly based on magnetic measurement of microscopic particle spin system, and SQUID is based on superconducting Josephson effect and magnetic flux quantization phenomenon. The main goal of the new generation of quantum magnetometer is to further improve the accuracy of micromagnetic measurement, reduce costs and improve its use and promotion. At present, the atomic magnetometer can work at room temperature, and its measurement accuracy has exceeded the SQUID magnetometer.

This part mainly introduces the principle of each quantum magnetometer, and summarizes the main technical paths of quantum magnetometer : nuclear precession magnetometer, SQUID magnetometer, optical pump magnetometer, SERF magnetometer, NMOR magnetometer, CPT magnetometer, Diamond NV color center magnetometer.

According to ICV, the global market size of quantum magnetometers will be about $ 550 million in 2022, with a compound growth rate of about 6.5 % from 2022 to 2030. It is expected to grow to $ 910 million by 2030. Among them, the magnetoencephalography market is expected to accelerate commercialization progress under the advantages of OPM products. In 2022, the biomedical market share will be about $ 134 million, with a compound growth rate of about 7.5 % (2022-2030) . in the field of military defense in 2022, the market share is about $ 159 million, and the compound growth rate is about 7.1 % (2022-2030) . in 2022, the field of physical research accounted for the highest proportion (42 %), with a market share of about USD 231 million and a compound growth rate of about 5.3 % (2022-2030). In 2022, the other market share is about $ 25 million, and the compound growth rate is about 7.8 % (2022-2030).

5.3.2 Global market share analysis of quantum magnetometer

Exhibit 5-5: Global market share of quantum magnetic measurement applications(By industry) (2022 & 2030E)



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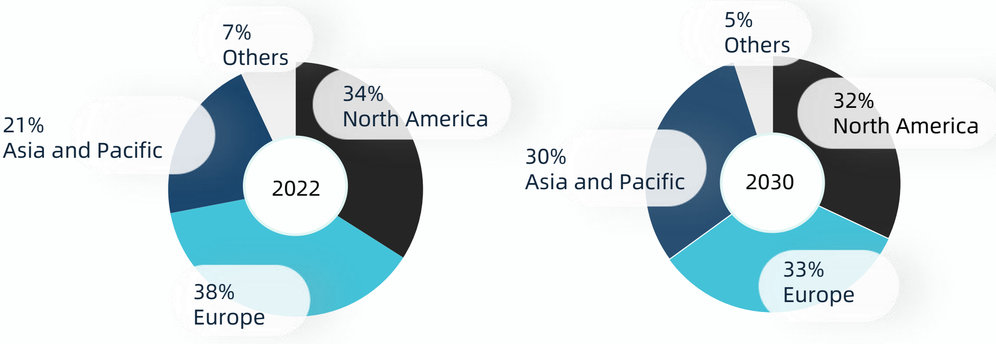
The ICV report shows that from the geographical distribution of the global market, the current quantum magnetometer market is mainly concentrated in Europe and North America, accounting for more than 2 / 3 of the total market. Among them, the European market accounts for the largest proportion, about 38 %, followed by North America, accounting for about 34 %, and the Asia-Pacific market accounts for about 21 %. The technology development of quantum magnetometers in Europe and the United States is more mature and the industrialization process is faster. In the future, if the Asia-Pacific region continues and increases the research and development of new quantum magnetometers such as OPM and NV color center magnetometers, it will be expected to seize part of the magnetoencephalography, industrial testing, and physical research markets. It is expected that the Asia-Pacific market will expand to about 30 % in 2030, and the market share of North America and Europe will be about 32 % and 33 % respectively in 2030, and about 5 % in other regions.

Exhibit 5-6：Global quantum magnetic measurement market share(classified by region)(2022 & 2030E)



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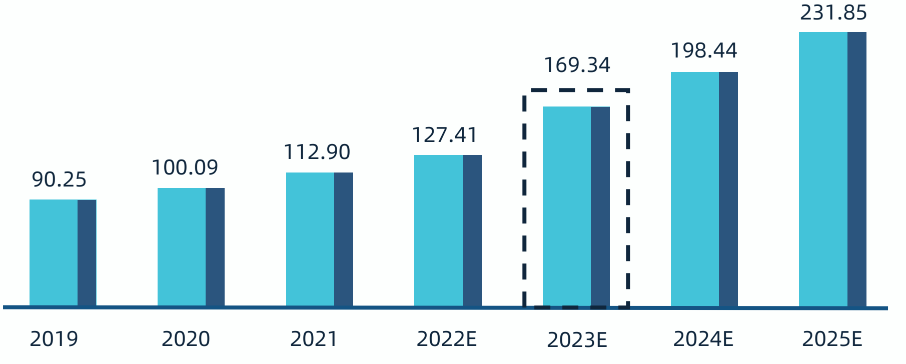
From the perspective of the application fields of various industries in the world, ICV believes that the market share of quantum magnetometers in the field of physical research will be the highest in 2022, accounting for about 42 %. The second is the military defense field, accounting for about 29 % . biomedicine accounted for about 24 % . other areas account for about 5 %.

5.4 Analysis of Global Market Scale of Quantum Gravimeter

5.4.1 Global market size prediction of quantum gravimeter

Exhibit 5-7: Quantum gravity measurement market size (2019-2025E)(unit: $ millions)



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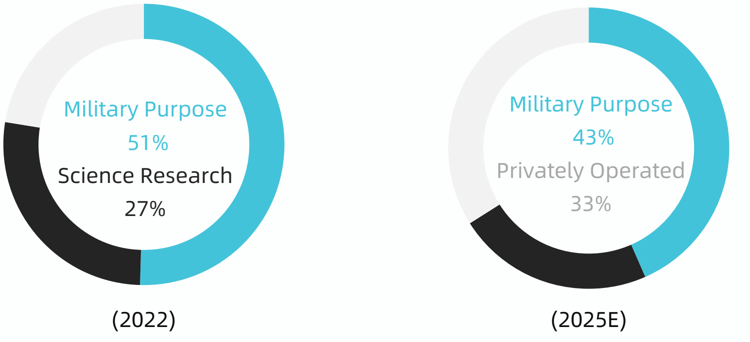
According to the characteristics of the industry, this paper will be divided into two kinds of quantum gravimeter and quantum gravity gradiometer. According to the type of platform, it can be divided into vehicle platform, ship platform, airborne platform and satellite platform. The region is divided into North America, Europe, Asia Pacific, and others.

This paper analyzes the main application fields of the product, as well as the consumption scale, development status and future trends in different fields. Application areas are divided into military, laboratory research and commercial applications. At present, the technical advantages of quantum gravimeters have been demonstrated, and the gradual maturity of commercialization will bring a trend of increasing market share. ICV predicts that the market size of quantum gravity measurement will reach USD 127.41 billion in 2022 and USD 231.85 billion in 2025, with a compound annual growth rate of 17.03 %. ICV proposed that the main breakthrough point of the quantum gravity measurement instrument market may be in 2023. Because the technical maturity and commercialization of quantum gravimeter in the world will be further improved, and quantum gravity gradiometer has the first commercial product in 2022.

5.4.2 Global market share analysis of quantum gravimeters

Exhibit 5-8：Quantum gravity measurement application market share
(2022 & 2025E)



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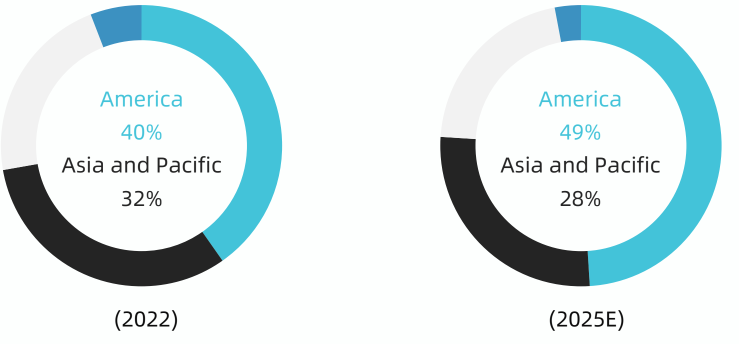
The application field of quantum gravimeter will be transformed into more civil scenarios in the future, mainly in the field of oil and gas exploration.

The open part of ICV data provides research and analysis. In the market share & industry analysis (part), the data show that ICV s share of the application market in 2022 predicts that quantum gravity measuring instruments will be mainly used in the military field, up to 51 % (statistics include gravity mapping applications and spaceborne gravimeters). Second, the share of research is 27 %. The rest is 23 % of the civilian market related to gasoline exploration.

Exhibit 5-9: Quantum gravity measurement area market share
(2019-2025E)



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At present, the regional share of quantum gravity measurement equipment is mainly the United States and the Asia Pacific, which are 40 % and 32 %, respectively, for geological exploration and scientific research. ICV estimates the market share of different regions in 2025, of which North America accounts for as high as 49 %, the Asia-Pacific region accounts for about 27 %, Europe accounts for 21 %, and Others accounts for 3 %. The complete content also includes estimation analysis and trend analysis in different fields. The article also shows the division of quantum gravimeters and quantum gravity gradiometers on different platforms.

Appendix 1 - Cutting-edge Tech Fan—Future Industry Participants' Evaluation Model

The CTF model of ICV TAnK helps the public understand the development of cutting-edge technology fields and corresponding companies. Cutting-edge technology has many characteristics such as un-converged technology routes, high uncertainty in technology development, and early stage of commercialization promotion. With the continuous development of technology, a reasonable model is needed to evaluate the company, and form a consensus on the comprehensive evaluation of cutting-edge technology suppliers in specific periods.

The CTF model consists of four differently-sized fan-shaped regions and three-dimensional coordinates. The horizontal coordinate is the Maturity of Technology (i.e. the technology, R&D, team), the lateral coordinate is the Commercialization of Technology (i.e. the revenue, customer, application case), and the vertical coordinate is the Enterprise Heritage (i.e. the elements that the supplier has accumulated over the long-term operation that can help the development of the enterprise). The CTF model divides suppliers into the following four fans according to their comprehensive performance in three dimensions: Pilot, Overtaker, Explorer, and Chance-seeker.

As emerging technologies are in a period of rapid growth and have high uncertainty, the CTF diagrams for each sub-field need to be updated on a regular basis.

Fan 1 - Pilot: Companies in this sector are characterized by their large scale, and they have accumulated a lot of experience in the development of previous technology tracks, which has laid a solid foundation for them to enter new frontier technology fields. They have the ability and resources to lead a new wave of cutting-edge technologies and have the potential to have a profound impact on the future direction of the industry.

Fan 2 - Overtaker: Companies in this sector have begun to take shape after a period of development, they get advantages out of their powerful research and development strengths. Because of their bunch of buildup about particular technologies, it's resonable to expect that these companies could 'be promoted' to the Pilot sector in the future

Fan 3 - Explorer: Companies in this sector have relatively small scale, however, it embarked on the emerging technology development track earlier. The development of the particular technology is still at early stage. Compared to Pilot and Overtaker, they usually fall short in terms of overall technical strength.

Fan 4 - Chance-seeker: Companies in this sector has a keen business sense. It is a newly established company in the industry, so its size is small, but its founding team members have certain resources for the company to develop in the new track. There is currently no engineering prototype of the product, and no or little marketing.

The CTF model can help clients in the field of cutting-edge technology evaluate the procurement and investment of a technology supplier. In particular, it should be noted that the supplier in the navigator fan is not always the best choice. Under the actual needs of the enterprise, the company in the transcender or explorer fan may be a better choice.

Appendix 2 Industry Progress

The main progress part mainly includes the commercial progress of quantum precision measurement, national policy and investment and financing news. This part of the content continues the industry progress of the ' 2022 Global Quantum Precision Measurement Industry Development Report ' released by ICV Joint Photon Box, starting in May. In general, the quantum precision measurement industry in 2022 business progress in the national business news is active, the degree of attention increased.

May

1. France 's iXblue launches quantum sensor for precise underground mapping
2. China National Instruments Quantum Opens ' Quantum Science Valley '
3. The Institute of Satellite Geodesy and Inertial Sensor Technology at the German Aerospace Center (DLR) has developed new instrument technologies based on quantum mechanical processes and methods. The institute was officially opened on May 30,2022.
4. Hebei Province Market Supervision Bureau, the Provincial Department of Science and Technology, the Provincial Department of Industry and Information Technology, the Provincial State-owned Assets Supervision and Administration Commission jointly developed ' Hebei Province to strengthen the construction of modern advanced measurement system implementation plan '.

June

1. The Optica for Quantum 2.0 conference was held in June, covering the prospects and challenges of quantum sensors, quantum networks, quantum internet and quantum computing.
2. Quantum sensor company WeiMag completed more than 100 million yuan A-round financing.
3. The United States set up a new Open Quantum Initiative undergraduate quantum scholarship.
4. Announced by the German Federal Ministry of Education and Research (BMBF), the research project forschungsprogramm quantensysteme (forschungsprogramm quantensysteme) aims to bring Germany to the leading position in the field of quantum computing and quantum sensors in Europe in the next decade and to improve its competitiveness in quantum systems.
5. Alto University will develop brain imaging equipment based on quantum optical sensors.

July

1. Implementation Opinions of the Fujian Provincial People 's Government on Implementing the State Council 's ' Quantitative Development Plan (2021-2035) ' The Canadian government has announced funding of up to $ 1.15 million for quantum entrepreneurs.
2. ColdQuanta wins 2022 Best Sensor Innovative Product Award
3. The US National Science Foundation (NSF) has invested $ 3 million to establish an integrated quantum science and engineering postgraduate training program, ' Linked Quantum Sensing Technology (LinQ-STL) '
4. The CPT atomic magnetometer was successfully launched with the ' Lijian-1 ' rocket of the Chinese Academy of Sciences and the ' space new technology test satellite SATech '. The first flight of domestic quantum magnetometer in China was realized. It became the first domestic quantum magnetometer (atomic magnetometer) applied to space exploration in China, and realized the autonomous control of China 's aerospace-grade scalar magnetometer.

August

1. The British quantum sensing company QLM Technology received 12 million pounds of financing, and the British photonics hardware and technology development company QLM Technology raised 12 million pounds ($ 14 million) for its quantum sensing technology. The company has developed a laser sensor based on quantum technology that can measure a small amount of methane emissions.
2. Q-CTRL has established a quantum sensing division. Q-CTRL, an Australian quantum technology company, is establishing a dedicated sensing department to meet the recent $ 60 million contract. The sensing department has become one of the world 's largest departments using a new generation of ultra-sensitive software-defined quantum sensors for measuring gravity, motion and magnetic fields.
3. Oxford Instruments announced to provide a dilution refrigerator for the UK 's quantum sensing project. Recently, Oxford Instruments announced that it has been awarded the Proteox for the UK 's Quantum Sensing for the Hidden Sector (QSHS) project - its next generation Cryofree ® dilution refrigerator and leading magnet technology.
4. Quantum technology start-up Q.ANT has established partnerships with Bosch, TRUMPF and DLR to jointly develop attitude sensors that meet space standards. The aim is to use quantum sensors to control satellites

September

1. Notice of the Tianjin Municipal People 's Government on Printing and Issuing Tianjin Metrology Development Plan (2022-2035) Germany has invested 28 million euros in the development of quantum sensors for satellite control
2. Recently, a German consortium consisting of Q.ANT, Bosch, TRUMPF and DLR plans to use quantum technology to permanently improve the stability of satellite measurements.
3. Quantum company ColdQuanta won the best sensor award in 2022
4. Maxwell, the quantum radio frequency sensor platform of ColdQuanta, a cold atomic quantum technology company, recently won the best sensor award in the instrument and test category at the Sensors Converge 2022 conference and expo.
5. China sent three atomic clocks to its space station to establish an extremely accurate space-based timing system. The new clock on the Chinese space station will include a cold atomic rubidium microwave clock, a cold atomic strontium optical clock and an active hydrogen atomic clock.

October

Genetesis, a new era biomagnetic imaging company, recently announced that it has completed a C-round financing of up to $ 17.5 million. This financing will enable Genetesis to obtain FDA De Novo approval to initiate a series of new clinical trials to commercialize its biomagnetic system and roll it out in various care settings worldwide.

November

Sumitomo, a Japanese trading company, plans to push ' quantum sensors ' to the Japanese market. Developed by US start-up ColdQuanta, the technology is expected to provide extremely accurate location data without relying on GPS.
Shaanxi Provincial People 's Government 's Opinions on Implementing the Measurement Development Plan (2021-2035)

December

None.

Appendix 3 Technical Progress

May

1. The French PSL University found that the Rydberg superatom in the optical cavity can efficiently manipulate single photons.
2. Ultracold bubbles on NASA 's space station open up new avenues for quantum research

Jun.

1. Associate Professor Xia Fengnian of Yale University, Yuan Shaofan and Zhang Fan of the University of Texas at Dallas team demonstrated an atomic-scale thin intelligent quantum sensor that can simultaneously detect all the basic characteristics of incident light waves.
2. Guo Guangcan 's team has made important progress in the measurement of low-frequency RF electric field based on Rydberg atoms. The team 's Shi Baosen and Ding Dongsheng 's research group realized the precise detection of low-frequency RF electric field based on Rydberg atoms by using non-resonant heterodyne method.
3. A team of quantum physicists at the University of Birmingham, in cooperation and funding with the UK 's Defence Science and Technology Laboratory, has designed a new method that can not only reduce the size of the next-generation atomic clock, but also make it strong enough to walk out of the laboratory and be used in the ' real world '.

Jul.

1. Researchers from the Austrian Academy of Sciences, the University of Innsbruck in Austria and the Swiss Federal Institute of Technology in Zurich have calculated that the motion fluctuations of nanoparticles trapped between optical cavity mirrors may constitute the basis of new high-precision quantum sensors.
2. Scientists at the Indian Raman Institute (RRI) have accurately measured the transition frequency of the highly excited Rydberg state.
3. A research team of physicists from the University of Bristol, the University of Bath and the University of Warwick in the UK has shown that important physical properties can be measured with high precision without complex optical quantum states and detection schemes.
4. The German research team discovered a new method that combines several basic quantum optics concepts to achieve a simple, robust quantum optical displacement sensor that works below the classical noise limit at a sampling rate of up to 100 kHz.
5. A high precision Xenon isotope co-magnetometer has been developed by Prof. Sheng Dong from School of Engineering Science, University of Science and Technology of China and Prof. Lu Zhengtian from School of Physics.
6. Sun Luyan 's research group of the Institute of Cross-Information, Tsinghua University and Zou Changling 's research group of the University of Science and Technology of China cooperated to use Bose quantum error correction coding to improve the sensitivity of quantum precision measurement for the first time in superconducting quantum systems.

7. Researchers at Tsukuba University in Japan demonstrated how to use ultrafast spectroscopy to improve the temporal resolution of quantum sensors. By measuring the direction of the coherent spin in the diamond lattice, they show that the magnetic field can be measured even in a short time.
8. Researchers at Massachusetts Institute of Technology (MIT) have developed a method that enables such sensors to detect arbitrary frequencies without losing the ability to measure nanoscale features.
9. Peng Xinhua Research Group, Key Laboratory of Micro Magnetic Resonance, Chinese Academy of Sciences, University of Science and Technology of China, has made important progress in the field of spin quantum precision measurement, and first proposed and verified Floquet spin quantum amplification technology.
10. University of Exeter, UK

Jul.

Appendix 3 Technical Progress

Aug.

1. For the first time, quantum gravimeter is used to detect gravity changes caused by volcanic processes. This device can provide high-quality data under conditions that other technologies cannot use.
2. Professor Li Min, Professor Zhou Yueming, Professor Lu Peixiang and other innovative research groups of ' strong field ultrafast optics ' proposed a new method to accurately measure the tunneling time, and successfully realized the attosecond precision measurement of atomic tunneling ionization time.
3. Professor Peng Xinhua and Associate Researcher Jiang Min from the Key Laboratory of Micromagnetic Resonance, Chinese Academy of Sciences, University of Science and Technology of China have made important progress in the field of quantum precision measurement and beyond the standard model. They have realized the direct search of new bosons beyond the standard model by using ultra-sensitive quantum precision measurement technology, and the observation limit of axons with mass greater than 65 μeV has increased by at least 10 orders of magnitude compared with the international record.
4. Based on the optical microcavity-cantilever microfiber coupling system, Professor Xiao Yunfeng and Academician Gong Qihuang 's research group from the Institute of Modern Optics, School of Physics, Peking University, the Frontier Science Center of Nano-optoelectronics, State Key Laboratory of Artificial Microstructure and Mesoscopic Physics constructed the dissipative photoacoustic interaction with broadband response for the first time, and proved its important potential in acoustic wave detection.
5. The development of China 's first aluminum ion optical clock prototype based on quantum logic technology has made important progress recently, with an uncertainty of 7.9 × 10 ^ -18. This is a major achievement of the Wuhan Institute of Quantum Technology and the Institute of Precision Measurement Science and Technology Innovation of the Chinese Academy of Sciences to increase the key core technology research.
6. The intrinsic electric dipole moment of ytterbium-171 (Yb-171) was measured for the first time using the laser cold atom method by Professor Lu Zhengtian 's team of University of Science and Technology of China. The upper limit of the electric dipole moment less than 1.5 × 10 ^ -26e cm was obtained, and the upper limit of the schiff moment of ytterbium-171 nucleus was set.
7. NASA engineers have developed a quantum dot spectrometer for space sensing.
8. The research team at Tokyo Institute of Technology in Japan has developed a new device that can perform magnetocardiogram (MCG) at higher resolutions. Their method is based on a diamond quantum sensor containing nitrogen vacancies that act as special magnetic ' centers ' and are sensitive to weak magnetic fields generated by cardiac currents.
9. Berhanu Bulcha, an engineer at the Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA) Research Center, said that a heterodyne spectrometer can amplify a specific frequency, clearly identify and locate water sources on the moon, and will be able to distinguish water, hydrogen ions and hydroxyl-containing compounds. Its technology uses quantum tunneling effect to generate high-power terahertz laser, which fills the gap of existing laser technology in finding water on the moon.

1. The Air Force Research Laboratory (Nanoelectronic Materials Division) at Wright-Patterson Air Force Base (AFRL) in Ohio, the United States, is using heat flow experiments to manipulate quantum materials to function in new and different ways at higher temperatures, studying the limitations of low-temperature phonon engineering in isolating precision quantum systems from noisy thermal environments.
2. Researchers at the University of Chicago 's Pritzker School of Molecular Engineering (PME) have developed a method to optimize sensitive quantum sensors that can detect tiny perturbations in magnetic or electric fields, among other things.
3. Researchers Emily D. Caldwell, Laura C. Sinclair and Nathan R. Newbury of the National Institute of Standards and Technology (NIST) demonstrated a highly sensitive programmable frequency optical comb, in which the pulse time and phase are digitally controlled at ± 2 attosecond accuracy.

Sep.

1. Pan Jianwei of University of Science and Technology of China and his colleagues Zhang Qiang, Jiang Haifeng, Peng Chengzhi and so on cooperated with Shanghai Institute of Technology, Xinjiang Observatory, National Time Service Center of Chinese Academy of Sciences, Jinan Institute of Quantum Technology and Ningbo University. Through the development of high-power low-noise optical comb, high-sensitivity and high-precision linear sampling, high-stability and high-efficiency optical transmission technology, the high-precision time and frequency transfer experiment of 100 km free space is realized for the first time in the world. The time transfer stability reaches the order of femtosecond, and the frequency transfer stability is better than 4E-19. The experimental results effectively verify the feasibility of satellite-ground link high-precision optical frequency standard comparison, and take an important step towards establishing a wide-area optical frequency standard network.
2. An international team of scientists, including experts from the University of Adelaide, has designed a quantum thermometer to measure the ultra-cold space-time temperature and the law of quantum mechanics predicted by Einstein. The theoretical design is based on the same technology used to construct a quantum computer, which can be used to measure the ultra-cold temperature and has the accuracy that traditional thermometers cannot measure. This will help to verify the theory that the temperature of the space-time structure predicted by Canadian physicist William Unruh is quite low in the future.
3. Academician Du Jiangfeng 's team at the University of Science and Technology of China demonstrated a quantum sensor that uses renewable energy directly to obtain the energy required for operation. The device uses sunlight and environmental magnetic fields to power itself, which can effectively expand the use of quantum sensors and help significantly reduce the energy cost of quantum sensors in existing applications.
4. For the first time, the research team of JILA and NIST researcher James K.Thompson successfully combined the two ' weirdest ' features of quantum mechanics, entanglement and delocalization, to create better quantum sensors.
5. Thales announced that its superconducting quantum radio frequency antenna won the International European Navy Innovation Award (EURONAVAL). The antenna provides a wide frequency range

Oct.

1. A team led by Marta Berholts, an experimental physicist at the University of Tartu, has created a very different type of ' quantum watch ' that does not require an initial time zero as a reference point for time measurement. The team created this quantum watch by emitting lasers to helium atoms until they reach an excited Rydberg state with special properties.
2. The French National Center for Scientific Research published a paper describing a quantum accelerometer that uses lasers and ultracold rubidium atoms to measure three dimensions of motion with extremely high accuracy. This study extends the quantum accelerometer to three dimensions, enabling accurate navigation without GPS and reliable detection of valuable minerals underground.
3. The optical and photonics research group of the University of Colorado Boulder and its partners predicted and demonstrated fiber-based quantum enhanced remote sensing and photosensitive materials of great significance in detection in the experimentally constructed fiber-in-fiber entanglement-enhanced sensing reality model.
4. Led by the Massachusetts Institute of Technology, a research team including the University of Minnesota and Samsung has developed a new camera that can quickly detect terahertz pulses at room temperature and pressure with high sensitivity. It can simultaneously capture information about the direction or ' polarization ' of the wave in real time, which cannot be achieved by existing equipment. This information can be used to characterize materials with asymmetric molecules or to determine the surface morphology of materials. The team produced two different devices that can operate at room temperature : one uses quantum dots to convert terahertz pulses into visible light, enabling the device to produce material images ; the other uses the ability of quantum dots to convert terahertz pulses into visible light to produce an image showing the polarization state of terahertz waves.
5. An Australian research group led by Professor Igor Aharonovich of the University of Technology Sydney and Dr Jean-Philippe Tetienne of RMIT University has developed a microscope prototype with high resolution sensitivity. The team 's findings have now been published in Nature Physics. Its prototype of quantum microscopy is based on the atomic level. After laser irradiation, the light emitted can be directly correlated with other physical quantities, such as the chemical environment near the magnetic field or electric field.
6. Researchers at the QUEST Institute at the PTB in Germany have recently collaborated with the Max Planck Institute for Nuclear Physics (MPIK) and the Technical University of Brunswick to realize for the first time the timing of optical atomic clocks based on highly charged ions within the Quantum Frontiers cluster of excellence. This type of ion is suitable for measurement because of its extraordinary atomic properties and low sensitivity to external electromagnetic fields.
7. Interdisciplinary research teams including the Technical University of Munich (TUM) are working to advance the development of quantum-based hyperpolarizers in order to deploy them into clinical applications. The machine aims to significantly improve MRI imaging of metabolic processes, such as allowing earlier and more accurate assessment of tumors, and improving the selection and monitoring of tumor therapy.
8. In cooperation with the National Institute of Standards and Technology (NIST) and the University of Colorado Boulder College, a paper entitled " RF Joseph Arbitrary Waveform Synthesizer with Integrated Superconducting Duplexer " was published. The experimental results show that the overall research has taken an important step towards broadband, integrated, quantum-based microwave voltage source, and the useful power is higher than-30 dBm.
9. Zixin Huang and his collaborators at Macquarie University have established the final quantum limit through experiments to determine whether the spectral absorption line exists or does not exist, and whether there is a dark source of a brighter star source.

Nov.

10. The research team of Benjamin K. Malia and Yunfan Wu from Stanford University in the United States proved that the spatial distribution entanglement between network nodes provides better network scale expansion. A shared quantum non-destructive measurement entangles a clock network with up to four nodes. Compared with the network without spatial distribution entanglement, the accuracy of the network is improved by 4.5 dB, and the accuracy is improved by 11.6 dB compared with the sensor network operating under the quantum projection noise limit. The team also demonstrated the universality of atomic clock and atomic interferometer protocol methods, and optimized the essential difference comparison of sensor output in science and technology related configurations.
11. Researchers affiliated to the Q-NEXT Quantum Research Center demonstrated how to create a quantum entanglement network of atomic clocks and accelerometers, and demonstrated the device 's excellent high-precision performance. The study was conducted by an experimental team of scientists from Stanford University, Cornell University and the US Department of Energy Brookhaven National Laboratory. For the first time, the team used atomic entanglement as a networked quantum sensor, especially an atomic clock and an accelerometer. The experimental device produces ultra-precision measurement of time and acceleration. Compared with similar settings without quantum entanglement, the time measurement accuracy is improved by 3.5 times and the acceleration measurement accuracy is improved by 1.2 times.
12. In a study published in the journal National Science Review, the laboratory used an ensemble-NV-diamond magnetometer to study strange spin-dependent interactions. New experimental constraints on two types of external interactions are established on the micron scale.

Nov.

1. NTT, AIST, and Quantum Information and Quantum Life Research Center of Osaka University have designed algorithms that make high-precision sensing possible using quantum states. In quantum sensing, Undisclosed noise has a great influence on accuracy, so it is important to reduce its influence. Therefore, the new algorithm uses the quantum error suppression method designed for the realization of quantum computers to confirm for the first time in the world that the influence of Undisclosed noise can be greatly reduced. In this way, higher precision quantum sensing can be achieved without any modification of the hardware.
2. Professor Ning Cunzheng 's team in the Department of Electronics, Tsinghua University combines the controllable large-scale production ability of laser processing with the excellent properties of two-dimensional wide-bandgap semiconductor material boron nitride (hBN), solves several key problems existing in the current single-photon light source, and realizes the controllable large-scale production of high purity and high brightness single-photon light source in space.
3. In physics, weak microwave signals can be amplified with minimal additional noise. For example, artificial quantum systems based on superconducting circuits can amplify and detect a single microwave mode, albeit at milli-Kelvin temperatures. Researchers can use natural quantum systems to perform low-noise microwave amplification through stimulated emission effects ; however, they produce higher noise when the function is greater than 1 Kelvin.
4. Scientists have developed a diamond-based quantum amplifier. In this new paper published in the journal Progress in Science, Alexander Sherman and the team of chemical scientists at the Israel Institute of Technology in Haifa used the electron spin in diamond as a quantum microwave amplifier to work in quantum confined internal noise above liquid nitrogen temperature. The team reported details of the amplifier 's design, gain, bandwidth, saturation power, and noise, which will promote applications hitherto unattainable in quantum science, engineering, and physics.

Dec.

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