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Core technology development trends of quantum industry and global market growth trends

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Abstract: This study analyzes the advantages of three key technologies in the quantum industry (quantum computers, quantum cryptography, and quantum sensors) in Chapter 2. It analyzes the development trends of quantum technologies and the global market growth trends for each technology, such as quantum computers, which have been accelerating since around 2012; quantum cryptography, which is replacing the existing digital cryptographic communication network using QKD services; and quantum sensors, which provide the foundation for the realization of quantum computer/quantum cryptography communication technology based on the results of precise measurement of quantum states in Chapter 3. The study concludes by presenting the process of a full-fledged quantum industry in Korea and ways to improve the performance of quantum computers in Chapter 4. In order to dramatically improve the performance of quantum computers, it is necessary to understand the materials of the superposition of the two quantum states and to develop a technology development strategy that can address these shortcomings at an early stage.

Keywords: *Full-scale process of quantum industry in Korea, Global market trend of quantum industry, Material understanding, Precision measurement, QKD service, Quantum computer, Quantum computing performance, Quantum cryptography, Quantum sensor, Technology development strategy, Two-quantum superposition.*

1. Introduction

Korea's Quantum Technology development project has been planned since November 2022 and is being carried out as a mega-project with a huge budget of KRW 996 billion 2023~2031. Through this project, the company is developing three core technologies for the quantum industry(quantum computer, quantum cryptography, and quantum sensors). As an action plan, i) it plans to build a 50 QB (Quantum Bits) quantum computing system with a budget of KRW 49 billion by 2026 and increase its performance to 500 QB by 2030, and ii) accelerate the development of 1,000 QB-class quantum technology in the early 2030s through 'verification/utilization of Korean quantum computing system[1, 2]. As such, quantum technology has been applied to a wide variety of industries, including pharmaceuticals/chemicals, automobiles, energy, aviation/space, artificial intelligence, finance, transportation/logistics, manufacturing/semiconductors, bio/medical, and defense/security, driving breakthrough technological innovations across future industries and economies[3, 4].

This study analyzes the advantages of three key technologies in the quantum industry (Quantum computers, quantum cryptography, and quantum sensors) in Chapter 2. Analyzes the development trends of quantum technologies and the global market growth trends for each technology, such as quantum computers, which have been accelerating since around 2012, quantum cryptography, which is replacing the existing digital cryptographic communication network using QKD(Quantum Key Distribution) services, and quantum sensors, which provide the foundation for the realization of quantum computer/quantum cryptography communication technology based on the results of precise measurement of quantum states in Chapter 3. Concludes by presenting the process of full-fledged

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quantum industry in Korea and ways to improve the performance of quantum computers in Chapter 4.

2. Core technologies of the quantum industry

The quantum industry is dominated by three core technologies: quantum computers for groundbreaking ultra-fast computation, quantum cryptography for high-reliability and security, and quantum sensors for high-precision measurement. As a result, it has established itself as an epoch-making innovative technology that surpasses the limits of existing technology in the field of computing, security, and measurement. Through this, it is leading technological innovation in future high-tech industries, including all manufacturing industries such as semiconductors[4]. The characteristics of the three core technologies of the quantum industry are shown in Table 1.

Table 1.
Advantages, Requirements, and Applications of quantum technology.

	Features	**Requirements**	**Applications**
Quantum Sensors	- Ultra-sensitive/ultra-Precise sensors (Magnetism, gravity, Electric field, light measurement)	- Quantum materials by measurement object design - Ambient temperature/ cryogenic operating environment - Stable measurement environment	- Superconducting interference devices - Interatomic interferometer, etc.
Quantum Cryptography	- Physical/original security (Quantum state collapse utilization)	- Minimize fiber loss - Quantum relay technology - Photon Generators/ Detectors Performance Improvements	- QKD with photons - Extended communication distance and Improved stability (Satellite and terrestrial relay)
Qquantum Computers	- Parallel computational power (Utilize QB Nesting/ Entanglement) - Exponential Computational speed	- Cryogenic environments - Noise suppression and error correction - QB Physics (Superconductivity/Ion Trap/Photon)	- QB-class semiconductor process (Based on superconductor) - Vacuum/laser system, etc. (Ion trap based)

Note: Source: 1) Establishment of Quantum Technology R&D Investment Strategy to secure future strategic technologies (Ministry of Science and ICT press release, April 4. 2021)
2) CES 2025 Forecast report_key challenges and future strategies of quantum Technology (jack0604_ Blog, December 27. 2024) / reconstruction.

3. Quantum technology development trend and market size

3.1. Quantum technology development trends

3.1.1. Quantum computers

Since around 2012, technological development has been accelerating due to the continuous development of quantum computing software and platforms. Compilers that perform specific functions(QB batching, scheduling, optimization, etc.) (Forest, ScaffCC, Qiskit, ProjectQ, XACC, t|ket>, OpenQL, etc.) are leading the global technology market. Currently, NISQ (Noisy Intermediate-Scale Quantum) technology with errors of 50~100QB, which is medium-scale, is implemented. It is evaluated as having excellent scalability and short development period using existing semiconductor processes, so it is being adopted by leading companies such as Google and IBM[5].

- Google: Plans to develop a 1 million QB-class general-purpose quantum computer with quantum error tolerance by 2029 by implementing and advancing error correction technology
- IBM: Developed 433QB-class quantum processor(Osprey) to develop 4,000QB-class quantum processor by the end of 2025

3.1.2. Quantum cryptography

Quantum cryptography technology using QKD service is replacing the existing digital encryption

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system and cryptographic communication network. Compared to the current digital communication network, where the information is leaked and damages occur when the encryption key is leaked, quantum cryptography communication has the advantage that the encryption key can be directly determined through the QKD service in the quantum state, so even if the encryption key is leaked, the user's information is not leaked[6]. A next-generation quantum cryptography method is being developed that wirelessly transmits signals in the form of light using lenses. China has succeeded in experimenting with quantum communication at a distance of 1,200km for the first time in the world, and is considered to be the closest leading technology to commercialization[7]. In order to effectively connect quantum cryptography between quantum computers and quantum devices, fault-tolerant quantum computing networking(Quantum Internet) technology must be implemented[8]. To solve this problem, it is necessary to develop QCKD(Quantum Cryptography Key Distribution), quantum repeaters, quantum memory, and quantum error correction, which are more advanced than existing computer networking technologies. In South Korea, mobile telecommunications companies SK Telecom and KT are focusing on QCKD research[5].

3.1.3. Quantum sensors

Based on the results of precise measurement of the quantum state, it provides a basic foundation for the implementation of quantum computers and quantum cryptography communication technologies. It is evaluated to go beyond the limits of existing measurement technology, so it is being introduced into various measurement fields(High-resolution imaging, spectral analysis, interferometer, magnetic field sensing, etc.). In particular, it is expected to be very useful in the military electronics industry as it is capable of long-range/ultra-precise measurements[9]. Typical developments include atomic clocks and SQID(Superconducting Quantum Interference Device). The electron is a ytterbium atomic clock that operates at optical frequencies that has been developed since the early 2000s and is more than 100 times more accurate than a cesium atomic clock. The latter is a magnetometer that measures an extremely small magnetic field of 10 aT/Hz1/2, with a measurable magnetic field strength of 10^{-15}T, and can measure up to 5×10^{-18}T[10].

3.2. Quantum industry market size

Global quantum computing market is expected to grow at a CAGR of 34.8% from USD 8,854 million in 2023 and USD 11,60.1 million in 2024, forming a super-large market of USD 126,20.7 million by 2032. Quantum computers are the application of quantum physics concepts to computing, and are expected to enable highly accurate machine learning calculations in terms of speed, data volume, and bit rate[5, 11].

Global quantum cryptography market is expected to grow at a CAGR of 25.63% from USD 5,707 million in 2023 and USD 698 million in 2024, forming a large market of USD 3,447.9 million by 2031. With cyber threats on the rise, the growing demand for quantum cryptography solutions is driving market growth in sectors such as finance, healthcare, and government[12].

Global quantum sensor market is expected to grow at a CAGR of 15.7% from USD 327.7 million in 2023 and USD 377.3 million in 2024, forming a large market of USD 1,211.5 million by 2032. Quantum sensors are expected to leverage the quantum properties of particles to achieve extreme accuracy in detecting gravity, magnetic fields, temperature, and other environmental changes[13].

4. Conclusion

Quantum computer technology is estimated to be capable of high-speed computation, which is more than 30 trillion times faster than current digital computers. In order to improve the performance of quantum computers, it is necessary to focus on solving the problem of QB for quantum programming languages and quantum compilers that can more effectively express various quantum algorithms. Quantum cryptography communication technology is evaluated as enabling high-reliability information security by fundamentally blocking hacking because the information itself is changed if there is an attempt to eavesdrop or eavesdrop. It is necessary to gradually expand wired quantum cryptography communication technology and focus on applying wireless quantum cryptography technology to long-distance vehicles such as UAM(Urban Air Mobility) aircraft, satellites, etc.. Quantum sensor technology is expected to bring about a breakthrough in manufacturing processes(semiconductor and battery design, defect analysis, etc.) by enabling ultra-precise measurements that can detect even the smallest changes in magnetic field, temperature, and gravity. While it has the advantage of being able to measure with high precision, it is necessary to focus on the development of advanced control technology that can effectively express sensing functions by improving fragile quantum properties[1, 14].

South Korea's quantum industry began in earnest in April 2021 with the confirmation of the *Quantum Technology R&D Investment Strategy*. Through this, the company is promoting i) the development of original technologies for each of the three core technologies of quantum technology, ii) the establishment of a 50 QB-class Korean quantum computing system by 2025, iii) the expansion of 1,000 QB-class researchers by 2030, and iv) the promotion of problem-solving projects based on public-private partnerships. Since around June 2022, industry, academia, associations, and the private sector have been working together to revitalize the quantum industry and accelerate technology development[1, 14]. With the rapid development of quantum technology around the world, it is expected that it will be possible to develop quantum computers of more than 1,000 QB within the next 1~2 years. The error rate, coherence time, scalability, and gate response speed of the superposition of the two quantum states of QB will determine the overall characteristics of the quantum computer. Therefore, in order to improve the performance of quantum computers, it is necessary to develop a technology development strategy that can solve the shortcomings caused by the superposition of the two-quantum state.

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Transparency:
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