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Review Article

Materials driving from semiconductor to quantum computing for the evolution of information technology

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ABSTRACT

In the modern era, Information Technology (IT) has emerged as a cornerstone of global development, influencing nearly every aspect of human life. The continuous advancement of IT systems is deeply rooted in innovations in material science. The development of advanced materials plays a crucial role in enhancing device performance, enabling miniaturization, and improving energy efficiency for both low-power portable devices and high-power data centers. Materials used in IT span a wide range of functional categories, including electronic, magnetic, photonic, and quantum materials, each contributing uniquely to computing, storage, and communication technologies. This paper provides a comprehensive overview of key material classes that have revolutionized the IT sector. Semiconductor materials form the backbone of electronic logic and memory systems, while magnetic materials enable efficient data storage solutions. Photonic materials support high-speed communication through optical technologies, and spintronic materials offer promising pathways for energy-efficient and high-speed devices. Furthermore, quantum computing materials provide a platform for next-generation computation using qubits based on superconductors and silicon isotopes. The paper highlights the importance of interdisciplinary research in advancing material innovations and discusses future trends that will shape the evolution of Information Technology.

1. Introduction

In today's rapidly evolving digital landscape, information technology (IT) plays a crucial role in shaping the way we live, work, and communicate. IT involves the use of computers, networks, and systems to store, retrieve, and send information. It streamlines complex tasks in various industries, from healthcare to finance, by providing solutions that make processes faster and more efficient. Understanding IT basics is crucial not only for professionals but also for students who wish to excel in a technology-driven world. Gaining knowledge in IT opens up opportunities for invention and problem-solving, skills that are highly valued in today's job market. This system powers everything from smartphones to supercomputers, permitting us to connect globally and operate complex systems. IT applications are noticeable in everyday life, from sending an email to conducting business transactions online. The concept of information technology traces nearly every part of modern life, making it vital for students to grasp its importance early on [1].

An information system is a set of interrelated components that collect, manipulate, store data and distribute information and provide a feedback mechanism to monitor performance. An Information system (IS) is a formal, sociotechnical, organizational system designed to collect, process, store, and distribute information. In a sociotechnical perspective, information systems are composed by four components: task, people, structure (or roles), and technology [2]. In quantum science and engineering, researchers seek to understand and leverage quantum mechanics—the rules originally advanced to describe the behavior of subatomic particles—and apply them to real-world devices.

The first quantum revolution of the 20th century, scientists observed quantum properties that allowed development of technologies such as the magnetic resonance imaging, transistor, lasers, and semiconductors. The second quantum revolution is happening right now. Experts are composed to move from observation to actualization, realizing new quantum technologies that change the game in a wide range of fields [3]. Semiconductors, a noteworthy type of material in the information era, are becoming more and more commanding in the field of quantum computing. In the last eras, semiconductor quantum computation was explored systematically across the world and established with a dramatically, fast speed [4].

The progress and invention of electronic materials have been the driving force behind the continuous progress of the electronics industry. The development of new materials for Information and Communications Technologies (ICT) is fundamental to innovation, device performance, and energy efficiency for low-power (portable appliances) and high-power (data centre) applications. Now a day's researchers work on materials for ICT is cross disciplinary and encompasses the development of devices for information processing and storage, and communication. This paper provides a comprehensive overview of key material classes such as semiconductor materials, magnetic materials, Photonic materials, spintronic materials and quantum computing materials that have revolutionized the IT sector. This paper highlights the importance of interdisciplinary research in advancing material innovations and discusses future trends that will shape the development of Information Technology.

2. Semiconductor materials

Semiconductors are materials with electrical conductivity between that of conductors and insulators. Semiconductors, in general, have conductivity between $10^{-8}\Omega^{-1}$ cm^{-1} and $10^{3}\Omega^{-1}$ cm^{-1} (resistivity between 10^{8} Ώcm and 10^{-3} Ώcm). The conductivity of a semiconductor can be varied over a wide range, by the process of doping. Conductivity of doped semiconductors remains almost independent of temperature over a wide range of temperature. These properties make semiconductors suitable for fabricating electronic devices.

Semiconductor technology forms the foundation of modern electronics, allowing everything from compact smartphones to advanced medical equipment. We know it wouldn't exist in the digital world without semiconductors. A fundamental requirement for creating circuits and electronic devices these materials are vital because they allow engineers to control the flow of electrical current [5].

2.1 Key characteristics of semiconductors

Middle ground properties: Semiconductors lies between conductors (allowing free flow of electricity) and insulators (blocking electricity).
Customizability: Their electrical properties through doping, enabling precise control of current flow can be modified by Engineers.
Versatility: They perform functions like amplifying, processing electrical signals and switching.

2.2 Common semiconductor materials

Silicon (Si):
Properties: Abundant, cost-effective, and reliable.
Applications: Used in general solar cells, computing, and consumer electronics due to its versatility and low cost.

Germanium (Ge):
Properties: High sensitivity and electrical conductivity to temperature changes.
Applications: Ideal for high-speed transistors and some photodetectors but less common due to cost and availability.

Gallium Arsenide (GaAs):
Properties: Superior electron mobility, low noise, and excellent performance at high frequencies.
Applications: Preferred for high-speed communication systems, satellites, and optoelectronic devices.
Applications: These modifications enable the creation of critical components such as:
Transistors: Act as electronic switches for data processing.
Diodes: Regulate current flow to protect circuits.
Integrated Circuits (ICs): Combine multiple functions into a single chip.

2.3 The role of semiconductors in modern electronics

Automotive technology: Power advanced driver-assistance systems (ADAS) and electric vehicle controls.
Healthcare: Enable diagnostic imaging equipment and life-saving devices.
Renewable energy: Convert solar energy into electricity efficiently.
Communication: Facilitate high-speed data transfer in devices like smartphones and routers.

2.4 Foundational semiconductor devices

A) Transistors
Function as electronic switches or amplifiers in circuits.
Crucial for processors, memory chips, and power control systems.

B) Diodes
Allow current to flow in one direction, protecting circuits and enabling rectification.
Commonly used in power supplies and signal demodulation.

C) Solar Cells
Convert sunlight into electrical energy using semiconductor materials like silicon.
Found in renewable energy applications, including solar panels.

D) Integrated Circuits (ICs)
Combine multiple electronic components into a single chip.
Enable compact, powerful devices such as microcontrollers, sensors, and processors.

2.5 Emerging semiconductor applications

A) AI Chips
Optimized for artificial intelligence and machine learning tasks.
Provide high-speed computations for applications like autonomous vehicles and data centers.

B) IoT Devices
Leverage semiconductors for wireless communication, sensing, and data processing.
Include smart home devices, industrial sensors, and wearable technology.

C) 5G Communication Modules
Use advanced RF semiconductors to handle high-frequency signals.
Enable ultra-fast data transfer for mobile networks and connected devices.

2.6 Applications of semiconductors in daily use

Semiconductors are integral to modern life, powering countless devices we rely on daily. Their versatility and adaptability have made them indispensable in various industries and applications.

Computing: Semiconductors are the backbone of computers and laptops, driving faster processing speeds and efficient storage. Microprocessors and memory chips allow seamless multitasking and advanced computing capabilities.

Communication: Smartphones, routers, and 5G networks depend on semiconductor technology for high-speed data transfer and reliable connectivity. RF semiconductors ensure smooth wireless communication in mobile devices and satellite systems.

Healthcare: Advanced medical equipment like MRI scanners, pacemakers, and diagnostic tools leverage semiconductors for precision and reliability. These technologies improve patient outcomes and drive innovation in healthcare.

Automotive technology: Semiconductors power electric vehicles, advanced driver-assistance systems (ADAS), and infotainment systems.

Household electronics: Everyday items like washing machines, refrigerators, and LED lights depend on semiconductors for energy efficiency and functionality. They make home appliances smarter and more durable.

3. Magnetic Materials

The materials that can be magnetized easily and can be used to make magnets are known as magnetic materials. These materials are attracted to magnets. Examples: Cobalt, nickel, iron, steel, etc. Magnetic materials are materials that exhibit a response to an applied magnetic field. They are crucial in various applications ranging from everyday electronic devices to advanced industrial machinery. The behavior of these materials under a magnetic field is primarily determined by the arrangement of their atomic magnetic moments and their interaction with the external field.

3.1 Characteristics of magnetic materials

1. Magnetic materials will produce strong or weak magnetic fields under the action of external magnetic fields. Its magnetic field strength is marked out in a table, showing a regular curve. And although this kind of magnetic field is not substantial, if you place a piece of magnetic material on the ground and sprinkle some magnetic powder around it, its magnetic field will be represented by the magnetic powder.
2. The magnetic properties of magnetic materials will vary with the temperature. When the temperature of a magnetic material increases, its magnetism will decrease, and when the temperature increases to a certain level, its own magnetic function will disappear.
3. The resistivity is relatively high. The resistivity of magnetic materials is higher than that of ordinary metals and can be used in fire protection systems in circuits [7].

3.2 Magnetic materials in electronic devices

Magnetic materials play a crucial role in various electronic devices, including power supplies, transformers, data storage systems, motors, sensors, and wireless communication devices, due to their ability to interact with magnetic fields and facilitate energy conversion, data storage, and signal transmission.

3.2.1 Power supplies and transformers

In power supplies and transformers, magnetic materials are essential for voltage conversion and regulation. Transformers, for example, rely on magnetic cores made of soft magnetic materials like silicon steel or ferrite. These materials enhance the efficiency of electromagnetic induction, enabling the transformer to step up or step-down voltage effectively. The magnetic properties allow the transfer of electrical energy from one coil to another without direct electrical contact, making transformers indispensable in power distribution systems, where they convert high-voltage electricity for safe use in homes and industries.

3.2.2 Data storage

Magnetic materials are also vital in data storage applications, particularly in hard disk drives (HDDs) and magnetic tapes. In HDDs, thin layers of magnetic material are used to store digital information. The read/write heads of the drive alter the magnetic alignment on the disk surface, allowing data to be written or retrieved. Magnetic tapes, commonly used for backup storage, also utilize similar principles to store data in a magnetic field, enabling long-term data preservation.

3.2.3 Motors and sensors

In motors and sensors, magnetic materials facilitate the conversion of electrical energy into mechanical motion and vice versa. For example, permanent magnets and electromagnets are used in the design of electric motors, including brushless motors, which are widely used in applications ranging from automotive to robotics. Sensors, such as current sensors, use magnetic materials to detect and measure the magnetic fields produced by electrical currents, providing critical feedback in control systems [8].

3.3 Types of magnetic materials used in electronics

3.3.1 Hard magnetic materials (Permanent magnets)

Hard magnetic materials, also known as permanent magnetic materials, are materials that can maintain their magnetic properties for a long time after magnetization and do not easily lose their magnetic properties. The main characteristics of hard magnetic materials are that they can maintain their original magnetism for a long time after magnetization, have large coercivity (H_c = 10^4~10^6 A/m), thicker hysteresis lines, and high maximum magnetic energy product (BH)max and remanent magnetism.

3.3.2 Soft magnetic materials

Soft magnetic materials refer to when the magnetization occurs at Hc is not greater than 1000A/m, such materials are called soft magnets. Typical soft magnetic materials can achieve maximum magnetization strength with the minimum external magnetic field. Soft magnetic material is a magnetic material with low coercivity and high permeability.

3.3.3 Magnetic alloys

Magnet alloys are alloys composed of iron and other metal elements (e.g. cobalt, nickel, rare earth elements, etc.), which have excellent magnetic properties and are widely used in many fields, such as electronics, communications, and energy. According to the different magnetic properties, magnet alloys are usually divided into two categories: soft magnetic alloys and hard magnetic alloys.

(a) Soft Magnetic Alloys: These alloys are characterized by low hysteresis loss and good permeability, making them excellent for applications such as transformers, motors, and inductors. Common soft magnetic alloys such as silicon steel and iron-nickel alloys are mainly used in power electronics, home appliances, automotive electronics and other fields.

(b) Hard Magnetic Alloys: Hard magnetic alloys have high magnetic energy product and magnetic field strength, can maintain stable magnetic properties, and are usually used in the manufacture of permanent magnets. Common hard magnetic alloys include neodymium-iron-boron (NdFeB), aluminum-nickel-cobalt (AlNiCo) and cobalt-based alloys. They are widely used in high-tech fields such as electric motors, sensors, loudspeakers, and magnetic resonance imaging (MRI) (9).

3.4 Emerging applications

The group faces the challenges deriving from emerging applications by conducting research on the following topics:

Efficient energy production and conversion. Study and characterization of Fe–Si alloys and soft ferrites for electrotechnical applications (motors and transformers) and for power electronics devices;

Fabrication and characterization of magnetic devices, integrated with other functional materials in composite structures, that convert mechanical vibrations into electrical current;

Study and modelling of new magnetic phenomena. Through computational magnetism techniques, the group studies how to optimise materials and devices in order to maximise their performance in emerging applications such as spintronics, thermomagnetism, and nanoscale magnetism;

Research on thermomagnetic phenomena: measurement setups for transverse thermoelectric effects such as Nernst and spin Seebeck effects and their reciprocals (Ettingshausen and spin Peltier) are available. A Peltier-cells-based differential calorimetry setup is also available for the experimental investigation of magnetocaloric materials. Within this laboratory, experimental investigations are supported by fundamental research and the production of materials with thermomagnetic properties;

Computational magnetism activities support the development of emerging applications by filling the gap between more fundamental physical research and technological innovation. The main activities include: (i) Investigation of emerging thermomagnetic effects to optimize materials properties; (ii) Advanced micromagnetic simulations to help designing novel magnetic devices such as racetrack memories based on DMI interactions, spin waves in 3D and Physical Unclonable Functions (PUF) based on exotic magnetic textures. [10]

3.5 Applications in practical life

1. Magnet Applications in Traditional Industry

In describing the magnetic sources, electromagnetic induction, and magnetic devices of magnetic materials, we have mentioned the practical application of some magnetic materials. Magnetic materials have been widely used in various aspects of traditional industry.

2. Magnet Applications in Medicine

In medicine, the use of nuclear magnetic resonance (NMR) can diagnose abnormal tissues of the human body and judge diseases. This is the familiar technology of nuclear magnetic resonance imaging.

3. Magnet Applications in the Field of Astronomy

Sunspots are areas of intense magnetic activity on the sun. The outbreak of sunspots will have an impact on our lives, such as the temporary disruption of radio communications. Therefore, the study of sunspots is of great significance to us. Geomagnetic changes can be used to explore deposits. Because all substances have strong or weak magnetism, if they gather together to form deposits, they will inevitably interfere with the geomagnetic field in the vicinity and cause anomalies in the geomagnetic field. According to this point, we can measure the magnetism of the earth on the land, ocean, or in the air, obtain the geomagnetic map.

4. Magnet Applications in the Military Field

Magnetic materials such as neodymium magnets have also been widely used in the military field. Ordinary mines, for example, can only explode when they come into contact with a target, so their role is limited. If magnetic sensors are installed on mines, because tanks or warships are made of steel, when they approach (without touching targets), the sensors can detect changes in the magnetic field, which makes mines explode and increases their lethality.

4. Photonic materials

Photonic materials and the devices that can be made from them are essential to many areas of technology. For instance, they are the basis of the telecommunications systems that brings phone, TV and internet signals to your home. They can now produce light so efficiently; it is revolutionising the cost of lighting and its impact on the environment. In the form of solar cells, they can be a source of clean and renewable energy, available to everyone all around the world [11].

4.1 Characteristics of photonic materials

Photonic Band Gaps (PBG): Similar to electronic bandgaps in semiconductors, these materials (specifically photonic crystals) have periodic structures that prevent light of certain frequencies (colors) from propagating, effectively acting as insulators for light.

Periodic Structure: Photonic crystals consist of alternating materials with different refractive indices arranged in 1D, 2D, or 3D lattices to interact with light in specific, designed ways.

Light Manipulation and Control: They can bend, guide, and trap light in tiny volumes, making them essential for creating waveguides and microcavities.

Structural Coloration: Many photonic materials produce color not through pigments, but through the nanostructure of the material itself, which scatters light and creates specific wavelengths.

Tunability: The optical properties (e.g., bandgap position) can be tuned by changing the material's structural parameters or using external stimuli like electric fields, as noted in the ScienceDirect review on Tunable Photonics.

Nonlinear Optical Response: These materials can change their refractive index in response to the intensity of light passing through them, enabling applications like optical switching.

4.2 Common examples and applications

Photonic Crystals: Used in reflective flat displays, sensors, and inks, according to ScienceDirect.

Photonic Crystal Fibers (PCF): Used for advanced light transmission and sensing.

Optoelectronics: Used in OLEDs, solar cells, and data storage, as listed by UK Research and Innovation (UKRI).

Biomaterials: Utilized for bioimaging and drug delivery due to their unique structural, chemical, and optical properties, as described in studies on PMC.

4.3 Key roles and applications

Optoelectronics and Telecommunications: Used in semiconductor lasers, LED lighting, and amplifiers, driving high-bandwidth communication networks.

Information Technology & Computing: Enabling the development of photonic integrated circuits and advanced optical memory storage.

Sensors and Imaging: Photonic structures, such as photonic crystals, act as ultra-sensitive, real-time sensors for temperature, pH, and environmental monitoring.

Biomedical and Healthcare: Applied in bioimaging, specifically using near-infrared emitting materials for deep tissue imaging, as well as in drug delivery systems.

Energy Efficiency: Enhancing the performance of solar cells through tailored materials like quantum dots.

Photonic materials often work by creating specific refractive index contrasts (photonic crystals) that create band gaps, allowing them to restrict, guide, or trap light.

4.4 Material types and examples

Photonic Crystals: Materials with periodic structures that manipulate photons.

Graphene and 2D Materials: Used for fast photodetectors.

Perovskites and Quantum Dots: High-efficiency materials for photovoltaics.

5. Spintronic materials

SPINTRONICS is a methodology that exploits the spin property of electrons rather than their charge characteristic and prioritizes data storage. Fundamental to the discipline of spintronics, the concept of electron spin provides an additional degree of flexibility for manipulating and storing information beyond that of traditional charge-based electronics [12].

5.1 Characteristics of spintronics

There are some characteristics of Spintronics given below:

Non-Volatility: The Spintronic devices can retain information without continuous power supply.

Fast Switching: The Spintronics allows for the fast switching between different states due to manipulation of spin.

Low Power Consumption: The Spin-based operations can be achieved with the lower energy consumption compared to charge-based operations [13].

5.2 Key spintronic materials and technologies

Magnetic Tunnel Junctions (MTJs): The fundamental core element utilizing materials like Cobalt-Iron-Boron (CoFeB) and Magnesium Oxide (MgO) to create high tunneling magnetoresistance ratios.

Topological Insulators & Heavy Metals: These materials provide efficient spin-charge conversion, enabling faster magnetization switching in spintronic devices via spin-orbit torque.

2D Ferromagnets: Emerging materials allowing for atomic-scale, high-density memory devices.

Multiferroic Materials: Materials such as rare-earth ferrites and manganese perovskites, which allow for the control of magnetism with electric fields, enabling more energy-efficient switching.

5.3 Role of spintronic materials in IT

Next-Generation Memory (MRAM/SOT-RAM): Utilizing materials like MgO-based magnetic tunnel junctions (MTJs), Spintronics provides **non-volatile memory**, meaning data is retained without power, eliminating leakage. Spin-Orbit Torque RAM (SOT-RAM) offers high-speed, high-endurance memory suitable for caching.

Energy-Efficient Logic & Computing: Spintronic devices can perform logic operations, reducing power consumption compared to traditional CMOS transistors by orders of magnitude, making them crucial for "green" electronics.

5.4 Key emerging applications

Next-Generation Non-Volatile Memory (STT-MRAM): STT-MRAM offers high speed, high endurance, and non-volatility (retaining data without power), making it suitable for IoT devices and data centers.

Neuromorphic Computing (AI Hardware): Spintronic devices, including magnetic tunnel junctions (MTJs), emulate synaptic behaviors (neurons) to achieve low-power consumption in AI inference and in-memory computing.

5.5 Application of spintronics in daily life

1. Data Storage: Hard Disk Drives (HDDs)

Application: Read heads in modern hard disk drives are the most widespread application of spintronics.

Material Principle: They use **Giant Magnetoresistance (GMR)** and **Tunneling Magnetoresistance (TMR)** effects, utilizing alternating layers of ferromagnetic (e.g., CoFeB) and non-magnetic materials to read tiny magnetic bits on a disk platter.

Impact: This technology allows for much higher storage density, enabling terabyte-level storage in laptops and data centers.

2. Non-Volatile Memory: MRAM

Application: Magnetic Random Access Memory (MRAM) is a transformative memory type for IoT, smartphones, and automotive microcontrollers, offering non-volatility—retaining data even when power is turned off.

Material Principle: Spin-Transfer Torque (STT-MRAM) uses spin-polarized current to switch the magnetic states of a Magnetic Tunnel Junction (MTJ), usually consisting of MgO barriers and CoFeB magnetic layers.

Impact: Provides faster write speeds, high endurance (10^{15}+ cycles), and lower energy consumption compared to traditional DRAM and Flash memory, enabling "instant-on" electronics.

3. Spintronic Sensors (IoT and Automotive)

Application: Magnetic field sensors are used for wheel speed detection (ABS), position sensing, and industrial automation.

Material Principle: TMR-based sensors detect small magnetic field changes with high precision, often used in hybrid or electric vehicle transmissions, speed-only information, and current sensing (e.g., motor control).

Impact: Offers high sensitivity and compactness, essential for IoT edge devices and automotive safety-critical systems.

4. AI Hardware and Computing

Application: Spintronic devices are used in Artificial Intelligence (AI) accelerators for in-memory computing and neuromorphic computing.

Material Principle: Using SOT-MRAM (Spin-Orbit Torque MRAM) and antiferromagnets, these chips can mimic brain-like functions with extreme energy efficiency (operating at sub-picojoule levels).

Impact: Mitigates the "von Neumann bottleneck" (data movement energy) in large-scale AI training.

High-Density Storage (Skyrmions): Magnetic skyrmions (topological magnetic structures) are being researched for high-density magnetic memory (racetrack memory), allowing data storage at a tiny fraction of current sizes.

High-Sensitivity Sensors: GMR (Giant Magnetoresistive) and MTJ sensors with improved spin sensitivity are utilized for biomedical magnetic imaging, navigation systems, and security applications.

6. Quantum computing

Quantum computing is an emergent field of computer science and engineering that harnesses the unique qualities of quantum mechanics to solve problems beyond the ability of even the most powerful classical computers. The field of quantum computing includes a range of disciplines, including quantum hardware and quantum algorithms. While still in development, quantum technology will soon be able to solve complex problems that classical supercomputers can't solve (or can't solve fast enough).

By taking advantage of quantum physics, large-scale quantum computers would be able to tackle certain complex problems many times faster than modern classical machines. Quantum computers have the potential to solve certain problems in minutes or hours that would otherwise take conventional machines millennia to complete. Quantum mechanics, the study of physics at small scales, reveals surprising fundamental natural principles. Quantum computers specifically harness these phenomena to access mathematical methods of solving problems not available with classical computing alone [14].

6.1 Characteristics of quantum computing

Superposition: Unlike classical bits (00 or 11), qubits can exist in a superposition of states, representing 00 and 11 simultaneously, allowing for parallel computations.

Entanglement: A phenomenon where qubits become interconnected, meaning the state of one qubit instantaneously influences another, regardless of distance, enabling faster, more complex processing.

Interference: Quantum algorithms use interference to amplify correct solutions and cancel out incorrect ones, increasing efficiency.

Qubits (Quantum Bits): The fundamental unit of quantum information that can exist in multiple states, unlike classical bits.

Massive Parallelism: By leveraging superposition, quantum computers can process millions of possibilities at once, rather than sequentially.

Decoherence: A major challenge where quantum states are fragile and break down due to environmental interference, requiring specialized, cold, or vacuum environments.

6.2 Key material categories for quantum computing

Superconductors (Superconducting Qubits):

Aluminum (Al): Commonly used for forming Josephson junctions.

Niobium Nitride (NbN) & Niobium Titanium Nitride (NbTiN): Used as high- superconducting materials in quantum circuits.

Copper Oxides (e.g., YBCO): Investigated for high-temperature superconducting quantum devices.

Semiconductors & Spin Qubits:

Silicon (Si): Used for silicon spin qubits due to high purity, low nuclear spin noise, and compatibility with established semiconductor manufacturing.

Germanium (Ge): Utilized for fast gate-defined quantum dots, enabling high-quality, hole-spin qubits with strong spin-orbit coupling.

6.3 Role of quantum Computing

Simulation & Molecular Modeling: Quantum computers can simulate molecular interactions to accelerate pharmaceutical R&D, discover new catalysts, and design materials.

Optimization: They identify optimal solutions within vast, complex systems, such as optimizing global supply chains, traffic flows, energy networks, or investment portfolios.

Artificial Intelligence/ML: Quantum algorithms can process data and discover patterns faster than classical techniques, enhancing AI models.

Cryptography: They are designed to break current, widely used encryption, driving the development of new, secure post-quantum cryptographic methods.

Financial Modeling: Running simulations for risk management and complex forecasting faster than conventional computers.

Weather Forecasting: Processing vast, real-time data to create accurate climate models.

6.4 Emerging applications

Pharmaceuticals & Healthcare: Accelerating drug discovery by simulating molecular interactions, and developing personalized treatment plans using genetic data.

Materials Science: Discovering new materials for batteries and solar cells, such as simulating electrolysis for hydrogen fuel production.

Financial Services: Optimizing portfolios, risk management, and fraud detection, potentially creating billions in operating income.

Logistics & Manufacturing: Solving complex scheduling, route planning, and manufacturing design problems, reducing time-to-market for products.

Quantum Machine Learning: Enhancing artificial intelligence by speeding up classification tasks, improving neural network training, and finding hidden patterns in high-dimensional data.

6.5 Major real-life quantum computing applications

Drug Discovery and Healthcare: Quantum simulations allow pharmaceutical companies to model molecular interactions, significantly reducing the time and cost required to bring new medicines and vaccines to market. It also aids in personalized medicine through faster genetic sequencing.

Logistics and Supply Chain Management: Companies use quantum algorithms to solve massive optimization problems, such as vehicle route planning, warehouse logistics, and inventory management, to minimize costs and time.

Finance and Risk Management: Quantum computing can analyze vast datasets to improve portfolio optimization, manage market volatility, and detect fraud, creating a projected $ 2 billion to $ 5 billion in operating income for the financial sector.

Climate Change and Sustainability: Quantum models can design better catalysts for carbon capture and storage (CCS) and improve the efficiency of materials for renewable energy storage.

Material Science and Manufacturing: Companies are researching new, more efficient battery technologies and materials, such as improved catalysts for petrochemical alternatives.

Cybersecurity: Quantum Key Distribution (QKD) protocols offer highly secure communication channels that can detect eavesdropping, protecting sensitive data.

7. Conclusion

The rapid development of information Technology is connected to advances in material science, which continue to redefine the limits of performance, efficiency and scalability. Advanced materials from semiconductors and magnetic materials to photonic, spintronics and quantum materials have collectively allowed the development of faster, smaller and more energy efficient device that for power communication systems. As technological demands grow, particularly with the rise of artificial intelligence, big data and quantum computing, the need for innovative materials will become even more critical. Future progress in IT will depend on constant interdisciplinary collaboration, by integrating Physics, Chemistry, Engineering and computer Science to discover and improve novel materials. Eventually, continued advancement of material science will remain a key driven in shaping the next generation of transformative IT technologies.

Authors' contributions

The author reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

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