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PROSPECTS OF MODERN SEMICONDUCTOR MATERIALS SCIENCE AND ITS IMPORTANCE IN AGRICULTURE

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ABSTRACT: This article presents scientifically grounded considerations about materials science — its past, present, and future. It discusses semiconductor materials as a part of materials science, their current state, and the widespread use of devices based on these materials in all areas of life, as well as perspectives for further development of the field.
Keywords: materials science, fundamental, experimental, metals, dielectrics, semiconductors, silicon, germanium, engineering, solid solution, technology, vacuum electronics, synthesis.

Introduction

Materials science is the study of the nature of material properties, methods of controlling them, and the creation of various types of materials possessing optimal and desirable combinations of characteristics. The creation of new materials has defined the stages of technological progress for centuries and will continue to do so. As a result of the development of fundamental sciences and experimental technology, materials science has become a rapidly advancing field of great importance.

Since the 1940s, alongside the creation of metallic devices to enhance the productivity of human physical labor, the task of creating devices that increase the productivity of intellectual labor has become increasingly important. The solution to this problem was found through the creation and wide application of a new class of materials — dielectrics and semiconductors.

Development of Semiconductor Materials

Among semiconductor materials and compounds used in industry, as well as their solid solutions, the most widely studied are those based on silicon (Si) and germanium (Ge), along with A^3B^5 and A^2B^6 compounds such as $GaAs$, GaP, $CdTe$, and CdS. These materials are being actively studied to develop new types of promising devices.

Due to these materials, significant progress has been made in computing technology, telecommunications, data storage and transmission, information technology, energy conversion, automation, renewable energy sources, and consumer electronics. The ability to control fast processes such as charge carrier motion, electric and magnetic field interactions, and optical and acoustic wave propagation forms the foundation of electronics, microelectronics, and nanoelectronics.

From Vacuum to Solid-State Electronics

Until the late 1940s, vacuum devices were used to perform these tasks, relying on the emission of free charge carriers from refractory metal cathodes and their movement toward the anode under an applied electric field. However, as computing, radio, and television technology developed, the demand for higher operating speed and reliability increased.

Vacuum electronics showed limitations: low speed (on the order of milliseconds), low efficiency $(2–5\%)$, high power consumption and cost, excessive heat generation, and short service life $(4000–5000\ hours)$. These drawbacks stimulated the search for new ways to control charge carriers and physical fields, leading to the invention of the transistor in the late 1940s and early 1950s — a device enabling direct control of charge transport within solids.

As a result, vacuum electronics evolved into solid-state electronics, which not only eliminated previous shortcomings but also provided many advantages. The synthesis of semiconductor materials marked a major breakthrough, with silicon and germanium elements and compound semiconductors forming solid solutions that enabled the creation of modern semiconductor devices.

p–n Junction and Charge Control

It became possible to vary charge carrier concentration over several orders of magnitude and thus control electrical conductivity purposefully. By creating regions of contact between differently conducting materials (p–n *junctions*), rectification, signal registration, and amplification became possible. The p–n junction forms the foundation of nearly all solid-state electronic devices.

Compared with vacuum electronics, solid-state devices operate at much higher speeds — in the nanosecond ($10^{-9}\,s$) and picosecond ($10^{-12}\,s$) ranges — with higher efficiency and the possibility of extreme miniaturization, giving them undeniable superiority.

Modern Semiconductor Production

At present, the most significant and widely used material in the electronics industry is silicon, which constitutes about 30% of the Earth's crust. The global production of polycrystalline silicon semiconductors continues to increase, reaching around 15,000 tons per year, while monocrystalline silicon — mainly used in microelectronics — is produced at approximately 10,000 tons per year.

Microelectronics development is closely linked to advancements in computing, informatics, television, telecommunications, and consumer technologies. As noted, the synthesis of semiconductor compounds such as $GaAs$, GaP, $CdTe$, CdS, ZnS, and others plays a crucial role. Growing these compounds on silicon or germanium substrates — the typical representatives of group-IV semiconductors — further enhances their technological attractiveness.

Epitaxial Technologies and Integration

The remarkable properties of most semiconductors become evident only when impurity concentrations affecting conductivity are extremely low — on the order of 10^{10}–10^{13} $atoms/cm^3$ (10^{-7}–10^{-3} $at.\%$) — and when crystal structure perfection is extremely high. Without epitaxial technologies, achieving the synthesis of such high-quality materials and modern microelectronic devices would be impossible.

With the improvement of epitaxial techniques, the integration level of circuits (i.e., the number of devices per crystal) and their packing density (per cm^2 and in the future per cm^3) have steadily increased. The evolution progressed from Integrated Circuits (IC) to Large-Scale Integration (LSI), Very-Large-Scale Integration (VLSI), and Ultra-Large-Scale Integration (ULSI). Today, the linear dimension of a single device in such circuits is about 200 times smaller than the thickness of a human hair, and the integration level reaches 10^9 elements per chip.

Conclusion

Thus, the rapid development of materials science and the electronics industry demands the creation of new solid solutions with unique electrophysical, photoelectric, and optical properties based on well-studied elemental semiconductor systems. Today, there is virtually no field in which semiconductor-based devices have not found application.

In education, semiconductors play a vital role, as most laboratory instruments used to reinforce theoretical knowledge are based on semiconductor devices. In agriculture, semiconductors are widely used in modern thermometers, humidity and light sensors, and other devices.

Agrometeorological stations rely on semiconductor-based equipment. The use of innovative technologies and semiconductor devices in agriculture contributes significantly to ensuring food security. Smart agriculture and agricultural digitalization are implemented using instruments built on semiconductor technologies.

Devices for soil composition analysis, water quality and flow measurement, pest monitoring, ultrasound diagnostics for animals, high-quality drying of agricultural products, and laser leveling systems — all are based on semiconductor materials. Therefore, the prospects for materials science and semiconductor research remain exceptionally high.

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