

Development and Investigation of SiC and SiC-Based Devices

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The modern development of the nuclear industry, nuclear energy, and aerospace technology is in dire need of the development of a new generation of electronics capable of operating at elevated levels of radiation and high temperatures and in chemically active environments. The problem of creating such devices is very important for ensuring the safety of operation of strategically important systems: nuclear power plants and spacecraft, for the disposal of nuclear waste, noise-immune location, remote sensing of the Earth, and control of the extraction and use of natural resources.

Devices with the specified set of properties have not yet been produced in the world and cannot be implemented using traditional semiconductor materials (Ge, Si, CdTe, GaAs).

One of the most promising wide-gap semiconductors is SiC, which has high electrical and mechanical strength, as well as high-temperature, chemical, and radiation resistance. In recent years, significant progress has been achieved in growing pure epitaxial SiC layers with low deep-level concentrations and relatively high diffusion lengths of charge carriers.

Success in obtaining such epitaxial SiC layers with a large area (more than 150 mm in diameter) and various thicknesses makes it possible to develop industrial production of a new generation of highly efficient devices based on them.

Despite the achieved successes and the beginning of industrial production of devices based on SiC in the physics and technology of this material, there are still many unsolved problems. For example, until now it has not been possible to obtain a cubic silicon carbide polytype (3C-SiC) suitable in terms of its quality for the creation of semiconductor devices. Although 3C-SiC has the highest charge carrier mobility among the silicon carbide polytypes and its value does not depend on the crystallographic direction, in this regard it should be noted that the physics of the formation of one or another SiC polytype, as well as their mutual transformations, also still lack a generally accepted theoretical explanation. An interesting task is also to study the radiation resistance of silicon carbide and search for possible ways to increase it. An equally important task is to optimize the technology of various devices based on SiC to obtain a product with the best combination of electrophysical parameters.

The articles placed in this special collection are devoted to research in the most relevant sections of the physics and technology of silicon carbide. Scientists from different countries consider both fundamental issues of SiC polytypism and applied issues of optimization of parameters of devices based on it. On the whole, this collection gives a good picture of current trends in the development of research on semiconductor silicon carbide.

Three articles of this collection are devoted to the growth and research of 3C-SiC [1–3]. In [1], the process of heteroepitaxial growth of 3C films on silicon was studied. This article discusses a quantum confinement effect observation in the 3C-SiC nanostructures and a perspective for the use of nanotextured island 3C-SiC layers as a two-dimensional surface quantum superlattice for high-frequency applications. The nature and mechanisms of the light-emitting properties of these structures are studied in detail.

In [2], the process of obtaining thick β -SiC epitaxial layers on the surface of metals by the CVD (chemical vapor deposition) method was analyzed. Such coatings are required for a number of medical applications of metal products.

The article [3] considers an alternative technology for obtaining epitaxial 3C-SiC films—sublimation growth of hexagonal silicon carbide on the substrate surface. This article also touches on the radiation resistance of SiC. It is shown that the photoluminescence spectra of the irradiated films differ from the spectra of irradiated 3C single crystals. The authors attribute this to a different spectrum of structural defects in the initial samples.

As noted above, an important issue in the physics and technology of SiC is the controlled production of epitaxial layers of various polytypes. In [4], a new technology is proposed for this. This technology is based on the rapid thermal processing technology and the understanding of polytype structure formation during the recrystallization of amorphization by ion-implantation silicon carbide. Local ion implantation and recrystallization were used to form polytype patterns in the substrate. These patterns act as structural templates during epitaxial growth at growth conditions, leading to a stable replication of the polytype pattern formed in the substrate.

The next article [5], devoted to important issues of self-diffusion of carbon and silicon in SiC, also actually adjoins the topic of polytypism and radiation resistance. It is known that each SiC polytype has its own equilibrium concentration of carbon vacancies. A change in this concentration, according to some researchers, can lead to a change in the polytype. On the other hand, it is believed that the composition of the best known radiation defects (Z1/2 and EH6/EH7) includes a carbon vacancy. Therefore, the change in the concentration of vacancies due to the external injection of carbon atoms is of considerable scientific and practical interest.

The last three articles in this collection are devoted to various aspects of SiC-based devices. It is known that silicon carbide is promising primarily for the creation of high-power semiconductor devices. The article [6] is devoted to the optimization of the technology of one such device, IGBT (insulated-gate bipolar transistor). In this paper, the authors explored the possibility of using a SiC planar IGBT structure to approach a high performance comparable to the SiC trench IGBT and, at the same time, to maintain a low gate oxide field. A new SiC planar IGBT (BP-IGBT) with buried p-layers under the p-body is proposed.

20 years ago, the lifetime of minority charge carriers in silicon carbide was several nanoseconds. It took the efforts of a large number of scientists before this value reached modern values at the level of milliseconds. In [7], studies of the lifetime were continued using as-grown n-type 4H-SiC Schottky barrier diodes. In this study, minority carrier traps were investigated by means of minority carrier transient spectroscopy (MCTS) and high-resolution Laplace-MCTS measurements. A single minority carrier trap with its energy level position at $E_v + 0.28$ eV was detected and assigned to boron-related defects.

The last article in the collection also focuses on optimizing Schottky diode technology [8]. It was shown that the diffusion welding (DW) is a comprehensive mechanism that can be extensively used to develop silicon carbide (SiC) Schottky rectifiers as a cheaper alternative to existing mainstream contact forming technologies. In this work, the Schottky barrier diode (SBD) was fabricated by depositing Al-Foil on the p-type 4H-SiC substrate with a novel technology: DW.

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