【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : Materials Science and Device Physics in SiC toward Robust Electronics

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Research Project Number : 21H05003 Researcher Number : 80225078
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Keyword : silicon carbide, oxide/semiconductor interface, transistor, junction breakdown, high-temperature IC

【Purpose and Background of the Research】

Silicon carbide (SiC) is a promising wide bandgap semiconductor for high-power and high-temperature applications. The features of SiC include its very high critical electric field strength, extremely low intrinsic carrier density, availability of high-quality and large-diameter wafers, and controllability of n- and p-type conduction in a wide range.

Based on the principal investigator's achievements, 1~3 kV SiC power transistors and diodes have been commercialized, demonstrating remarkable energy saving. However, the performance of SiC power transistors has been far from the ideal one, due to very poor quality of the oxide/SiC interface. Furthermore, basic material properties of SiC under high electric field (MV/cm) have been still unknown, which hampers designing SiC device structures.

In this project, formation of high-quality oxide/SiC interface, fabrication of high-performance SiC MOS transistors and complimentary MOS (CMOS) devices are targeted. Another goal is clarification of high-field phenomena in SiC. These scientific insights and innovative technologies will serve as the core for future robust electronics based on SiC semiconductor (Fig. 1).

【Research Methods】

The major subjects and research methods of this project are described below.

1) Formation of high-quality oxide/SiC interface by an original technique, which excludes oxidation of SiC. In this technique, the density of interface defects can be drastically reduced compared with the conventional process.
2) Fabrication of high-mobility SiC MOS-transistors and establishment of a physics-based model, which can predict the characteristics of SiC transistors.
3) Investigation of p-channel SiC transistors and demonstration of high-temperature operational SiC CMOS devices. It is important to reveal both the potential and limitation of SiC-based CMOS for high-temperature operation.
4) Accurate determination of impact ionization coefficients as well as drift velocities of electrons and holes under high electric field.
5) Clarification of breakdown mechanism in SiC pn junctions and metal/SiC interfaces including their high-temperature characteristics.

In all the subjects, both experimental and theoretical approaches are tried, and these studies contribute to advancement of semiconductor physics, materials science, and device engineering.

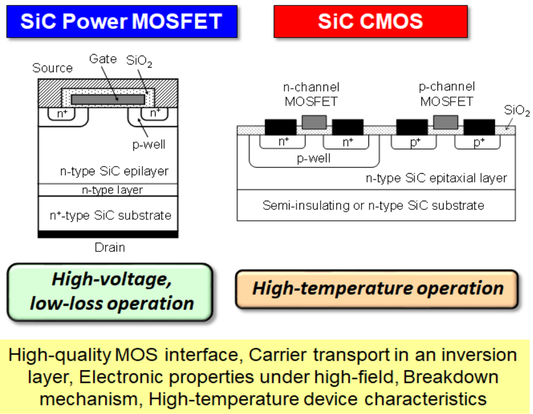

Fig. 1 SiC power MOSFET and SiC CMOS with major research subjects.

【Expected Research Achievements and Scientific Significance】

Scientific impacts of the expected research achievements include establishment of carrier transport and scattering mechanism in a complex interface, very hot carrier physics in a semiconductor, where a full band analysis is required. These insights will be useful for basic study on other wide bandgap semiconductors such as GaN, Ga_2O_3, and diamond.

Industrial impacts include the enhanced performance and cost reduction of SiC power transistors, development of high-temperature SiC CMOS ICs and ultrahigh-voltage (> 10 kV) SiC transistors in a future. The high-temperature ICs and ultrahigh-voltage transistors will be key devices in the field of high-temperature electronics and power grids, respectively.

【Publications Relevant to the Project】

- T. Kimoto and H. Watanabe, "Defect engineering in SiC technology for high-voltage power devices (Review)" Appl. Phys. Express, **13**, 120101/1-44 (2020).
- T. Kobayashi, T. Okuda, K. Tachiki, K. Ito, Y. Matsushita, and T. Kimoto, "Design and formation of SiC (0001)/ SiO_2 interfaces via Si deposition followed by low-temperature oxidation and high-temperature nitridation," Appl. Phys. Express, **13**, 091003/1-4 (2020).

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