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

Broad Section C

Title of Project : High-mobility Semiconductor Devices due to Control of Phonon Field caused by Defect-free Nano-periodic Structures

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Keyword : neutral beam, damage-free nano-periodic structure, phonon field control, phonon scattering suppression

【Purpose and Background of the Research】

Higher levels of performance in information-communication devices like mobile terminals and sensors are leading to dramatic jumps in data and traffic. To deal appropriately with this information explosion, technical innovations that can provide significantly higher performance and power savings in information processing and data storage are essential. Here, the problems of heat generation and heat dissipation brought on by the ongoing miniaturization of semiconductor integrated circuits are particularly prominent, so semiconductor devices with new structures that can lower heat generation and energy consumption are desirable. These needs can be met if electronic devices can be made even faster while suppressing heat generation, and if carrier-phonon scattering in the channel region of a MOS transistor can be suppressed, there would be no deterioration in mobility intrinsically caused by heat generation. This would simultaneously satisfy the two needs of the faster operation and lower heat generation.

We here propose the introduction of a composite structure as a transistor channel structure that embeds damage-free semiconductor nanopillars in a periodic manner using matrix material. This structure suppresses carrier-phonon scattering in the transistor channel area according to the material used, nanopillar size, and nanopillar interval and achieves a transistor channel layer with dramatically improved mobility and minimal heat generation.

【Research Methods】

Using damage-free nanostructure fabrication technology, we fabricate ultra-fine sub-10 nm periodic phononic-crystal nanopillars free of interface roughness and defects and establish technology for fabricating composite material embedding good-quality matrix material. At the same time, we establish technology for detecting phonon generation and transport characteristics in this composite material on a nanometer order and technology for analyzing electron and phonon bands. Based on these technologies, we develop a transistor that uses composite material in the channel layer to enable phonon fields and carrier transport to be controlled as needed.

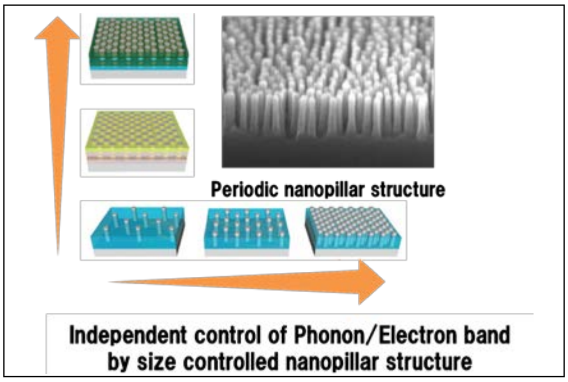

Figure 1 Defect-free Nanostructures fabricated by neutral beam etching.

【Expected Research Achievements and Scientific Significance】

To date, there have been no empirical studies on electron transport in a phonon-field control system, so exploring the possibility of electron-transport control by simultaneous control of phonon and electron bands from an experimental and theoretical basis is very significant from an academic viewpoint. This problem also presents a challenge to explore the possibility of applying such electron-transport control to electronic devices based on a totally new concept.

In applications, achieving high-mobility and low-heat-generation semiconductor devices will make possible not only high-speed calculations but also diverse types of energy-saving electronic equipment. This, in turn, will lead to a quantum leap in the state of electronics while also contributing to solutions to energy and environmental problems. In short, we anticipate research results having a great ripple effect on electronics and society.

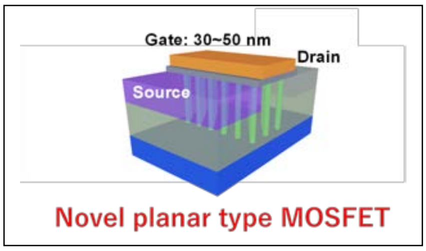

Figure 2 MOSFET device containing nanopillar structure for channel region.

【Publications Relevant to the Project】

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【Term of Project】 FY2020-2024

【Budget Allocation】 150,000 Thousand Yen

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