

Title	分子線エピタキシー(MBE)法により成長した GaAs(111)B上MnAs/InAs/MnAsダブルヘテロ構造の 縦型スピndeバイス応用
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## Abstract

Spintronics, or spin transport electronics, represents a rapidly evolving field that utilizes the intrinsic spin of electrons, alongside their charge, to develop innovative technologies for data storage, sensing, and computation. Semiconductor spintronics combines the benefits of semiconductors, such as bandgap tunability and carrier modulation, with spin-dependent phenomena, enabling novel devices with enhanced functionality. A key concept in spintronics is the spin field-effect transistor (spin-FET), which uses a gate voltage to modulate spin-polarized currents, offering the potential for low-power, high-speed computing. Spin valves, on the other hand, rely on the relative alignment of magnetizations in ferromagnetic layers to control resistance, forming the foundation of many spintronic devices.

This work explores the growth, characterization, and application of MnAs/InAs/MnAs double heterostructures in vertical spin valve (VSV) devices, combining ferromagnetic MnAs layers with a thick low-temperature-grown InAs (LT-InAs) channel. These heterostructures, grown using molecular beam epitaxy (MBE) on GaAs (111)B substrates, represent a significant step forward in hybrid semiconductor/ferromagnetic spintronic systems. The use of LT-InAs offers advantages in growth combination with MnAs at same temperature but presents challenges in defect management and interface quality.

The growth of LT-InAs was optimized by varying parameters such as the V/III beam equivalent pressure ratio and growth temperature. Optimized growth conditions yielded samples with minimal surface roughness, high carrier concentration, and n-type conduction, as confirmed by Hall measurements. Structural characterization using X-ray diffraction (XRD) revealed lattice expansion in LT-InAs, attributed to strain relaxation mechanisms. Atomic force microscopy (AFM) and scanning electron microscopy (SEM)

showed defect-minimized, uniform surfaces, critical for achieving good-quality interfaces with MnAs layers.

The MnAs/InAs/MnAs heterostructures demonstrated well-defined interfaces, as verified by cross-sectional SEM and energy dispersive X-ray spectroscopy (EDS). Magnetization measurements revealed distinct coercive fields for the top and bottom MnAs layers, enabling spin-dependent transport in the double heterostructure. Vertical spin valve devices were fabricated using advanced lithography and etching techniques, achieving precise device geometries for current-perpendicular-to-plane (CPP) measurements. Spin valve measurements were performed using AC lock-in method and showed clear resistance changes corresponding to the parallel and antiparallel alignment of the MnAs layers. We achieved a highest of  $\sim 1.2\%$  spin injection efficiency at 240 K measurement temperature.

This work marks the first successful demonstration of a vertical spin valve device using MnAs/thick-InAs/MnAs heterostructures, paving the way for further advancements in semiconductor spintronics. The findings highlight the challenges of impedance mismatch and interface quality but also emphasize the potential of this hybrid material system for efficient spin transport and injection. Future directions include improving LT-InAs growth using advanced techniques like migration-enhanced epitaxy (MEE), reducing impedance mismatch through conductive alloys, and exploring novel device architectures such as gate-all-around spin field-effect transistors (spin-FETs). These advancements will contribute to the realization of high-performance spintronic devices for next-generation technologies.

**Keywords:** Semiconductor spintronics, vertical spin valve, MnAs/InAs/MnAs double heterostructure, molecular beam epitaxy, low-temperature InAs.