Title	GaAs(111)B上に分子線エピタキシャル成長したMnAs/III-As複合構造の横型スピントロニクス素子応用
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Abstract

In spintronics electron spin is used as information carrier in addition to its charge. It is already well established metal-based spin-devices practical applications. To use spin degree of freedom into semiconductor spintronic device technology such as in spin field effect transistor (spin-FET), there are three main technological challenges are, firstly, injection of spin polarized carrier from a ferromagnetic (FM) into semiconductor (SC) channel and detection by FM, secondly, SC channel should have strong spin-orbit coupling (SOC) to precess spin during transport through SC channel, and finally, control of the spin precession by gate electric field to modulate spin signal. Therefore, exploring promising FM/SC hybrid structures are important. Here, we synthesized MnAs/III-As hybrid structures on GaAs(111)B as a possible candidate for future spin-FET and investigated the first challenging issue into the hybrid structures. We carried out successful molecular beam epitaxial (MBE) growth of MnAs(~5-200 nm)/GaAs(~0-10 nm)/thick-InAs(~200-1200 nm) /GaAs(111)B hybrid structures at low temperature MnAs epitaxial growth. In reflection high energy electron diffraction (RHEED) study, we see double step lattice transition ~4 nm of InAs from GaAs surface and abrupt lattice transition of GaAs ~3.6 nm from InAs lattice respectively. The origin of these transition is still unclear for such lattice mismatch growth. In 2θ x-ray diffraction (XRD) measurement of MnAs(~200 nm)/thick-InAs(~1200 nm) /GaAs(111)B, we see single phase epitaxial growth of hexagonal MnAs with cubic InAs and GaAs (only low temperature MnAs growth case). Also, the extracted lattice parameters are consistent with their bulk values which imply that the grown epitaxial layers are strain relaxed. To check deviation of c-axis, we carried out ω scanning. From ω and 2θ measurement, we also observed less deviation (InAs ~0.12° and MnAs~0.22°) of c-axis normal to the planes of thicker MnAs(200 nm) and InAs(1200 nm) layers. Hence, the 2θ and ω scanning indicates good epitaxial growth of MnAs and InAs. We also estimated thickness dependence threading dislocation density from the ω-θ broadening, we found reduction of the dislocation density with increasing grown layer thickness. It means better crystal quality in thicker case. Also comparatively, InAs shows less dislocation density in similar thickness than that of on GaAs(001). Besides, we also confirmed smooth surface and maze-like magnetic structures by atomic force microscopy (AFM) and magnetic force microscopy (MFM). The MnAs ~5-200 nm samples show strong magnetic anisotropy along [-2110] and [01-10] lateral and [0001] out of plane directions by superconducting quantum interference device (SQUID) magnetometry. It also reveals easy and isotropic magnetization in lateral directions which is similar to MnAs directly on GaAs(111)B. We also see higher MnAs thickness higher saturation magnetization and lower coercive field which seems directly related to the crystal quality. The better the crystal quality the better the magnetic response. It also shows over room temperature (~300 K) magnetism (estimated Curie temperature ~320-324 K). However, to evaluate contact between MnAs/InAs on GaAs(111)B, we studied transmission line model (TLM) device and found isotropic Ohmic behaviors in lateral [-110] and [11-2] directions of cubic InAs. Specific contact resistance, of MnAs/InAs interface at ~300 K is ~$(10^{-5}$-$10^{-4})$ Ω-cm^2 which is little higher than typical Ohmic contact. However, over room temperature isotropic magnetic and isotropic electric behaviors in lateral directions gives good flexibility to design lateral spintronic device. We studied trials of lateral spin valve device of MnAs (~50 nm)/GaAs (~1, 3)/InAs (~200 nm)/GaAs(111)B grown samples in lateral spin valve device application. Through the study, we improved device processing and carried out lateral spin valve measurement using AC lock in technique. We successfully confirmed spin injection and detection through simultaneous local spin valve (LSV) and non-local spin valve (NLSV) measurements in lateral spin valve device of 1 nm GaAs barrier insertion sample at 1.5 K. We obtained large spin diffusion length ~10 μm and spin injection efficiency

~1.6% which is similar to other FM/narrow gap hybrid structures. However, ~2.0 time enhancement of NLSV signal can also be seen in FM-FM input case than that of FM-NM input case. On the other hand, at 300 K, the extracted spin diffusion length ~2.6 µm and spin injection efficiency ~6.3% which is significantly large value in comparison to other FM/narrow gap hybrid structures at 300 K. The enhancement of spin injection efficiency at 300 K is due to better impedance matching between MnAs/InAs rather than at 1.5 K.

In conclusion, we can say that large spin injection efficiency ~6.3 % of the hybrid structure is record value at ~300 K which is very promising for future spin-FET application. Further, higher GaAs thickness dependence investigations are necessary to clarify spin injection efficiency more in details as well as other two challenging issues also have to be investigated before approaching spin-FET applications.

Keywords: 1. Molecular beam epitaxy (MBE), 2. MnAs, InAs, GaAs(111)B, 3. Magnetic properties, 4. Electrical properties, 5. Lateral spin valve