Temperature Dependence of Magnetic Switching and Spin Valve Behaviors in MnAs/InAs/MnAs Double Heterostructure on GaAs (111) B

°Md Tauhidul Islam[1,*], Van Thuan Pham[1], Soh Komatsu[1], Masashi Akabori[1]
[1] Japan Advanced Institute of Science and Technology
[*] Email: s2220008@jaist.ac.jp

Ferromagnetic (FM)/semiconductor (SC) hybrid structures have gained significant interest in semiconductor spintronics due to their potential use in spin field-effect transistors (spin-FETs). In our work, we have developed MnAs/InAs-based hybrid systems, which have demonstrated promising performance in lateral device applications [1]. However, the channel length in such configurations is constrained by the limitations of lithographic techniques. To address this challenge, we prepared vertical MnAs/InAs/MnAs double heterostructures (DH) on GaAs (111) B using molecular beam epitaxy (MBE) [2], where the InAs channel, positioned between MnAs source and drain layers, allows its length to be precisely controlled by adjusting the thickness of the InAs layer during growth. For MBE, the standard growth temperature for InAs is approximately 480°C. To fabricate DHs using MBE, the whole growth process was performed at low temperature (LT) (~250°C) to align with the optimal conditions for MnAs growth. There have been some previous works related to similar tri-layer system [3], and non-local spin valve measurement using MnAs/InAs systems [4,5], but no report on vertical spin valve fabrication (VSV) and measurement using this DH structure. Thus, we fabricated VSV device from the DH to examine the spin transportation potential of this novel structure.

The MBE grown DH consisted of approximately 400 nm InAs channel with about 75 nm top and 150 nm bottom MnAs layers. From the magnetization measurement of the DH, we confirmed distinct magnetic switching behavior of top and bottom MnAs layers (Figure 1a), required for VSV operation. Different magnetization switching can be recognized by the double steps in the hysteresis curves and easier switching was observed at higher measurement temperatures. We fabricated VSV device using the DH with the help of electron beam lithography (EBL) and Ar^+ ion dry etching, which we presented in the past meeting [6]. We measured the device with AC lock-in technique at various excitation current and temperatures. Clearer spin valve signal was observed, and a significant influence of temperature was found (Figure 1b). Lower magnetization switching field (ΔB) at higher temperature aligned well with the DH's behavior. Increasing signal amplitude ($2\Delta R$) with temperature emphasized on the impedance mismatch effect between the FM and SC. A strong correspondence between the DH and VSV therefore highlighted the integrity of both device fabrication and measurement processes. A maximum spin injection efficiency of ~1.6% was extracted from the SV measurements, showing promising potential of this unique structure and device for vertical spin-FET realization.

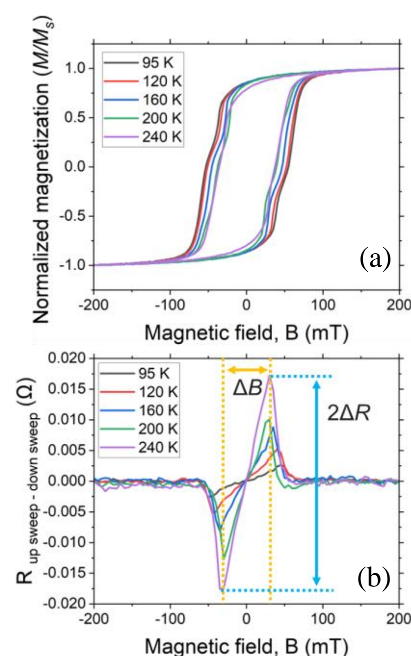

Figure 1: (a) Magnetic switching behavior and (b) SV behavior.

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