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Description	

Clear Spin Valve Signals in Conventional NiFe/In_{0.75}Ga_{0.25}As-2DEG Hybrid Two-Terminal Structures

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Abstract. We investigated the transport properties of ferromagnetic/semiconductor hybrid two-terminal structures utilizing an In_{0.75}Ga_{0.25}As/In_{0.75}Al_{0.25}As 2DEG formed on a GaAs (001) substrate with In_xAl_{1-x}As step-graded buffer layers. We used NiFe as ferromagnetic electrodes for injection/detection of spin-polarized electrons, which were formed on side walls of the semiconductor mesa to contact electron channel directly. We measured spin valve properties at low temperatures, and successfully found clear spin valve signals as well as clear channel width dependence. The results with such clear dependence suggest successful spin transport in the present samples.

INTRODUCTION

Spin field effect transistors (spin-FETs) proposed by Datta and Das [1] has been paid much attentions, because their operation is based on the combination of spin filter by ferromagnetic (FM) electrodes and spin precession by spin-orbit (SO) interaction in the channel. In order to realize spin-FETs, we have studied spin transport in original In_{0.75}Ga_{0.25}As two-dimensional electron gas (2DEG) [2], and demonstrated spin injection signals from a FM in the non-local configuration [3]. However, the previous samples were affected by the local Hall effect (LHE) via fringe field of FM contacts, therefore we could not obtain spin valve signals in the conventional configuration. In this paper, we report on the fabrication of simple two-terminal samples, and demonstrate clear spin valve signals without LHE.

EXPERIMENTAL PROCEDURE

Our 2DEG structures having large SO interaction were a metamorphic In_{0.75}Ga_{0.25}As/In_{0.75}Al_{0.25}As modulation doped heterostructure grown by molecular beam epitaxy. Its electron concentration and mobility at 1.6 K are $N_s = 5.1 \times 10^{11} \text{ cm}^{-2}$ and $\mu = 5.4 \times 10^4 \text{ cm}^2/\text{Vs}$, respectively. Figure 1 shows top view and

schematic cross-section of a fabricated hybrid structure. We fabricated three kind of samples with different channel width, $W = 1.6 \text{ } \mu\text{m}$, $2.5 \text{ } \mu\text{m}$, and $6.2 \text{ } \mu\text{m}$. The channel length, L , was fixed to $2.2 \text{ } \mu\text{m}$ which is about 3.7 times as long as the estimated mean free path $l_e = 0.6 \text{ } \mu\text{m}$. We used electron-beam lithography and wet etching with H₂SO₄-base solution for mesa fabrication with 400-nm-depth. The FM electrodes consisted of 50-nm-thick Ni₄₀Fe₆₀ were fabricated on side walls of the mesa structures by radio-frequency sputtering process. We note that Ar-ion etching during 2 minutes in the same chamber was carried out before the formation of FM electrodes to remove native

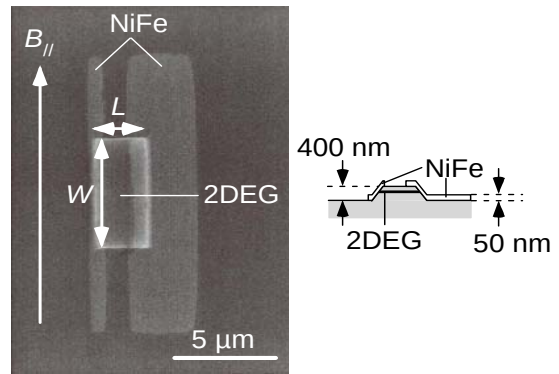


FIGURE 1. Top view and schematic cross-section of a NiFe/2DEG hybrid two-terminal structure.

oxides on FM/2DEG contact area.

We measured transport properties by AC lock-in technique in a conventional liquid He cryostat with a super conducting magnet. Typical measurement temperature was 1.5 K.

RESULTS AND DISCUSSIONS

Figure 2 shows spin valve properties of the samples at 1.5K. In the present samples, symmetrical spin valve signals were clearly observed without hysteresis loops. The results suggest the present design indeed reduces the LHE. Additionally, we note that the results were obtained in longer channels with $L = 2.2 \mu\text{m}$ compared to the mean free path, $l_e = 0.6 \mu\text{m}$. The fact indicates the spin relaxation should not be induced by the elastic scattering.

Furthermore, we found some unique features of spin valve peaks. Figure 3 shows the plots of peak positions and full-width half-maximum (FWHM). From the plots, as the channel width became narrower, the peak shape became sharpened and the positions were shifted close to zero field. We think such peak behaviors originate from the coercive force of FM contacts. Thus, it unfortunately depended on the aspect ratio of effective contact regions corresponding to mesa side-walls and/or excess FM parts on mesa-top. However, the results also suggest successful spin transport in the present samples due to these channel width dependence.

To confirm magnetic structures in FM contacts, we

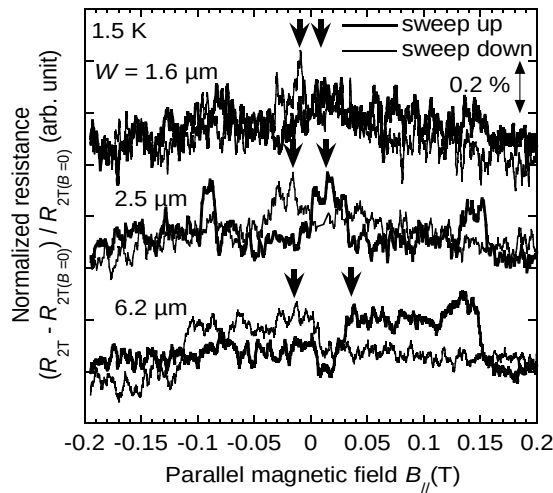


FIGURE 2. Spin valve properties of NiFe/2DEG hybrid two-terminal structures.

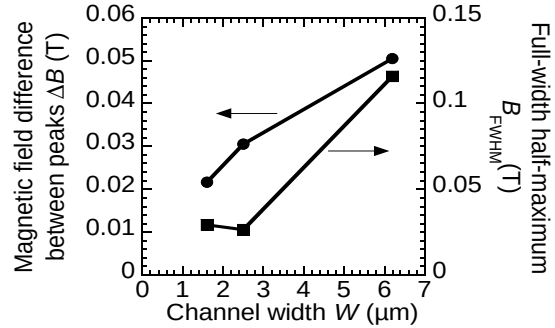


FIGURE 3. Channel width dependences of spin valve peaks.

measured magnetic force microscopy (MFM) of the hybrid structures, although the images are not shown here. We found clear domain walls at the edges of mesa-top as well as many domains in both the FM contacts on isolation area. However, we could not observe magnetic dipoles at mesa side-walls due to the limit of MFM resolution. At the present, we conclude that the deep mesa structures resulted in complex domain structures in FM contacts as well as channel width dependence of spin valve properties.

SUMMARY

We investigated spin valve properties of NiFe/ $\text{In}_{0.75}\text{Ga}_{0.25}\text{As}$ -2DEG hybrid two-terminal structures utilizing a metamorphic modulation doped heterostructure. We successfully found clear spin valve signals as well as clear channel width dependence at 1.5 K. With such clear dependence and MFM measurements, we think that the results suggest successful spin transport in the present structures.

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