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Room temperature observation of large spin accumulation and transport signals in post annealed $Co_2FeSi/MgO/n^+$-Si on insulator devices

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Abstract

The post annealing temperature (T_A) dependence of room temperature spin signals in $Co_2FeSi/MgO/n^+$-Si on insulator were investigated. Because large spin signals and better signal to noise ratio were observed for the devices fabricated on the Si (2x1) surface, we can get the reliable data of T_A dependence of spin signals even at room temperature. The magnitude of 3-terminal narrow Hanle signals has a slight maximum as a function of T_A. The estimated spin polarization, 4 terminal non-local and 2-terminal local MR signals are nearly constant up to T_A = 400°C within experimental error. The large spin injection efficiency into Si (P_{Si}～40%) even at room temperature and spin signals at room temperature along with its robustness up to 400°C are observed. These results will pass a way to the future Si spintronics devices such a spin MOSFET.

1. Introduction

Recently, many studies of silicon (Si) spintronics have been reported. In order to realize the Spin-FET [1-3], highly efficient spin injection and detection in ferromagnetic metal (FM)/insulator (I)/semiconductor (S) junction are required. The spin injection/detection efficiency depends on the spin polarization of the FM, the spin selectivity of the tunnel barrier, and the conductivity matching condition. One of the most suitable types of spin source materials for spintronic devices is Heusler alloys. The Co-based Heusler alloys have attracted much interest as highly spin-polarized materials because of their high Curie temperatures, which are well above room temperature (RT) [2]. Recently, our group reported that Heusler alloy (Co_2FeSi) shows better spin polarization as compared with CoFe ferromagnet [4]. Our group has also reported the influence of Si surface conditions on the magnitude spin signal in CoFe/MgO/Si on insulator (SOI) devices [5]. The amplitude of spin signal is enhanced significantly when it is deposited on Si (2x1) surface compared to the case on Si (1x1) surface.

In the present study, we have used Si (2x1) surface in order to get better spin signal. The Heusler alloy Co_2FeSi/MgO electrode was deposited at 200°C and the study of the post annealing temperature (T_A) dependence of these devices has been performed at room temperature. Because large spin signals and better signal to noise ratio were observed for the devices fabricated on the Si (2x1) surface, we can get the reliable data of T_A dependence of spin signals even at room temperature. There are few reports discussed on post-annealing temperature dependence on spin accumulation and transport signals in Heusler alloys/*n*-GaAs devices. However, in the case of Si channels, there is no result for T_A dependence of spin accumulation and transport signals using Heusler alloys/MgO/SOI devices.

In this paper, T_A dependences on spin accumulation and transport signals at room temperature for Co_2FeSi/MgO (1.3 nm)/Mg (0.6 nm)/n^+-Si on insulator (SOI) have been discussed. The large spin injection efficiency into Si (P_{Si}～40%) even at room temperature and spin signals at room temperature along with its robustness up to 400°C are observed. These results would be useful for future Si spintronics devices.

2. Experiment

We have prepared 4-terminal devices with Co_2FeSi/MgO electrodes on phosphorous-doped (~1.5×10^{19} cm^{-3}) (100)-textured SOI substrates. The fabrication details are discussed elsewhere [4, 5]. The in-situ observation during deposition by reflection high energy electron diffraction (RHEED) confirms the epitaxial growth of Co_2FeSi and MgO on Si (100)-(2x1) surface as illustrated in Fig. 1(a). The Co_2FeSi/MgO contacts were patterned into dimensions of 2×100 μm^2 (contact 2) and 0.5×100 μm^2 (contact 3) by photolithography and Ar ion milling techniques as shown in Fig. 1 (b). Finally, ohmic pads consisting of Au/Ti were formed for all contacts. The post annealing temperatures used were 250°C to 425°C with 25°C intervals. These devices were measured at temperatures of 20 K and 300 K. We observed all spin signals for both temperature. We electrically detected 3-terminal Hanle, 2-terminal local and 4-terminal non-local MR signals using the 4-terminal devices shown in Fig. 1(b). The 3-T narrow Hanle signals were observed by applying a perpendicular magnetic field (B_Z) after the magnetization of the Co_2FeSi contact was aligned parallel to the plane along the long axis of the contact as shown in the inset of Fig. 2(b).

Figure 2(a) show the 3 terminal Hanle signals as a function of post annealing temperature measured at 300 K.

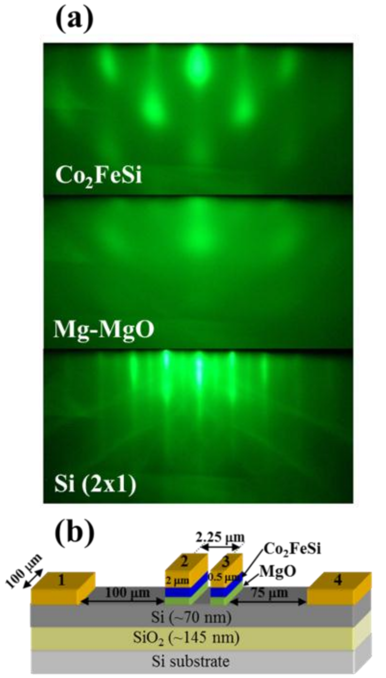

Fig. 1. (a) RHEED patterns of Co_2FeSi (top), the MgO (middle) and Si surfaces (bottom), respectively, for the incident direction of high-energy electrons are perpendicular to Si-<110> plane and (b) schematic diagram of lateral four-terminal devices we measured.

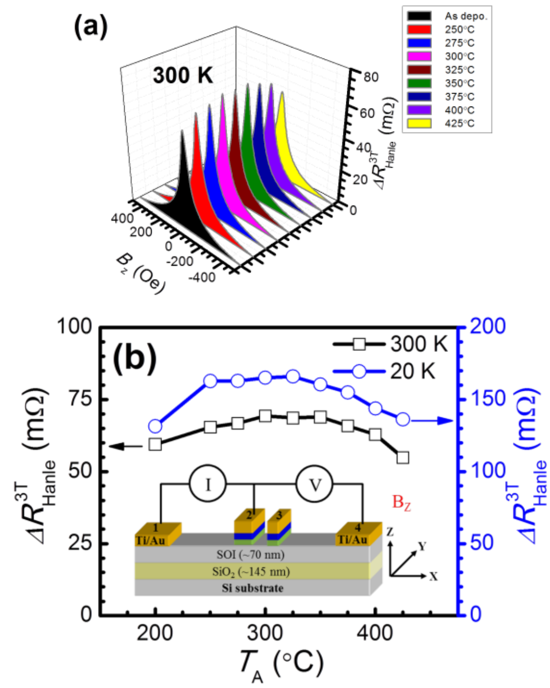

Fig. 2. The post annealing dependence of (a) the three terminal (3T) narrow Hanle signals and (b) the magnitude of 3T narrow Hanle signals ($|\Delta R^{3T}_{Hanle}|$) measured at 300 K. In the inset of (b) shows the electrical configuration and magnetic field for measuring 3T Hanle signals.

Figure 2(b) show the magnitude of 3-T narrow Hanle signals ($|\Delta R^{3T}_{Hanle}|$) as a function of post annealing temperature measured at 20 K and 300 K. It is obvious from Figs. 2 (a) and (b), $|\Delta R^{3T}_{Hanle}|$ has a slight maximum as a function of T_A. The data behavior measured at 20 K is consistent with those measured at 300 K. This indicates that we can obtain reliable T_A dependence of spin signals even at room temperature due to the observation of relatively large spin accumulation and transport signals at room temperature. The 2-T local and 4-T nonlocal signals follow the same trend (not shown here). The magnitude of room temperature 2-T local signal is as large as 40 mΩ at room temperature, while for 4-T non-local signal it is 4 mΩ for the long channel length of 2.25 μm.

The spin polarization and spin life times from 3T-Hanle measurements were estimated using modified spin diffusion equation. [4, 5] The estimated spin polarization (P) and spin life time (τ) are from P ~ 40% and τ ~ 2 nsec, respectively. The large spin injection efficiency into Si (P_{Si}～40%) and relatively long spin relaxation time (τ ~ 2 nsec) even at room temperature and spin signals at room temperature along with its robustness up to 400°C are first electrically observed in this study. These results would be useful for future Si spintronics devices.

3. Conclusions

We have observed reliable room temperature spin signals in $Co_2FeSi/MgO/n^+$-Si on insulator as a function of the annealing temperature by depositing on Si (2x1) surface. The T_A dependence of magnitude in 3-terminal narrow Hanle signals has a slight maximum as a function of T_A. This behavior is consistent with the T_A dependence of the magnitude of 2-terminal local and 4-terminal nonlocal MR signals. The estimated spin polarization (P) and spin life time (τ) are from P ~ 40% and τ ~ 2 nsec, respectively. The large spin injection efficiency into Si (P_{Si}～40%) and relatively long spin relaxation time (τ ~ 2 nsec) even at room temperature and spin signals at room temperature along with its robustness up to 400°C are first electrically observed in this study. These results will pass a way to the future Si spintronics devices such a spin MOSFET.

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