Temperature dependence of spin signals in an AlGaAs/GaAs-based high-mobility two-dimensional electron system

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1. Introduction

The injection of spin-polarized electrons from ferromagnets into semiconductors has attracted much interest for creating spin transistors. Spin injection into bulk semiconductors such as GaAs [1], Si [2], and Ge [3] has been realized at room temperature. On the other hand, a two-dimensional electron gas (2DEG) structure of AlGaAs/GaAs has attracted much interest for its high electron mobility, and it is used for high electron mobility transistors (HEMTs).

Up to date, however, electrical spin injection into an AlGaAs/GaAs 2DEG channel has been achieved only by using GaMnAs as a spin source [4], and the demonstration of spin injection was limited below 50 K because of the low Curie temperature (T_C < ~200 K) of GaMnAs. In this study, we demonstrated spin injection into an AlGaAs/GaAs 2DEG channel up to 138 K by using CoFe (T_C > 1000 K) as a spin source.

2. Experimental method

Figure 1(a) shows a layer structure of a spin injection device. Layers consisting of (from the substrate side) ud-GaAs (400 nm)/ud-$Al_{0.3}Ga_{0.7}As$ (100 nm)/n^--$Al_{0.3}Ga_{0.7}As$ (Si = 3 × 10^{18} cm^{-3} and 100 nm)/ud-$Al_{0.3}Ga_{0.7}As$ (15 nm)/ud-GaAs (50 nm)/n^--GaAs (Si = 7 × 10^{16} cm^{-3} and 100 nm)/n^+-GaAs (Si = 7.5 × 10^{18} cm^{-3} and 30 nm) were grown by molecular beam epitaxy (MBE) on a GaAs (001) substrate. Then a CoFe layer (5 nm) was grown by magnetron sputtering at room temperature. Using electron-beam lithography and Ar ion milling techniques, a four-terminal nonlocal device was fabricated (Figure 1(b)). The size of the injector and detector were 0.5 × 5 μm and 1.0 × 5 μm, respectively, and the spacing (d) between them was 0.5 μm.

3. Results and Discussion

From the Hall effect measurement, electron mobilities ranging from 24200 to 42700 cm^2/V s and sheet carrier concentrations ranging from 6.9 × 10^{11} to 8.5 × 10^{11} cm^{-2} were obtained at 77 K for the AlGaAs/GaAs 2DEG structure. Such relatively high electron mobilities indicate that the 2DEG channel was well formed at the interface of the AlGaAs/GaAs heterostructure.

Figure 2(a) shows a clear nonlocal spin-valve signal observed at 77 K, a higher temperature than that reported in Ref. 4, which used GaMnAs as a spin source. Furthermore, the temperature dependence of the spin-valve signal was investigated. Figure 2(b) shows $|\Delta V_{NL}/I_{bias}|$ as a function of temperature, where ΔV_{NL} is the amplitude of a spin-valve signal and I_{bias} is the bias current. The spin-valve signals were observed from 4.2 K to 138 K. Interestingly, the spin-valve signal doesn't show monotonic decrease as increasing temperature and it reaches to a peak at ~80 K. This contrasts with the result observed in bulk GaAs [1], in which monotonic decrease of spin-valve signals with increasing temperature was observed. These results contribute to better understanding of spin transport in a 2DEG channel, which is indispensable for the realization of the future spin transistors which can operate at a relatively high temperature.

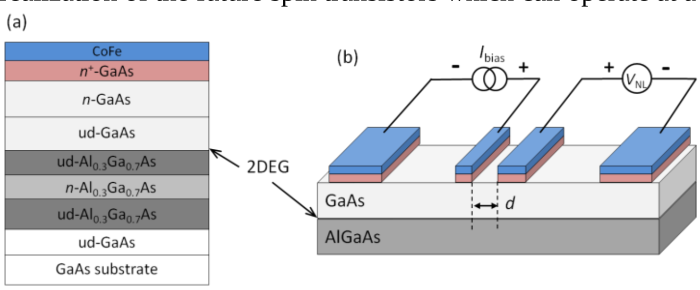

Fig. 1(a). 2DEG layer structure of a spin injection device. (b) Device structure and circuit configuration for nonlocal spin-valve measurements.

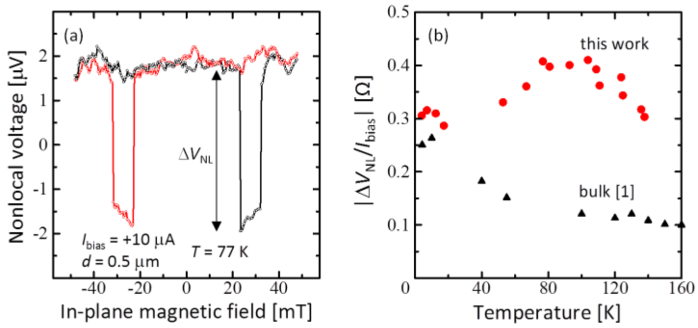

Fig. 2(a). A nonlocal spin-valve signal at 77 K. (b) Temperature dependence of $|\Delta V_{NL}/I_{bias}|$, where ΔV_{NL} is the amplitude of a spin-valve signal and I_{bias} is the bias current.

References

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