Fabrication of a spin injection device having a top-gate structure

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1. Introduction

Electrical injection of spin-polarized electrons into a semiconductor channel and their control by a gate voltage are major prerequisites for creating viable semiconductor spintronic devices such as spin transistors, which feature nonvolatility, reconfigurable logic functions, and ultralow power consumption. While there have been many reports on spin injection into GaAs, Si, or Ge, only a handful of experiments on the gate control of spin signals have been reported [1-3]. Moreover, the gate operation was done only in back-gate structures. However, the back-gate structure suffers from a low operation speed and a large power consumption due to a large parasitic capacitance. Thus, a top-gate structure is indispensable for practical applications. In this study we fabricated a spin injection device having a top-gate structure, and demonstrated a gate control of spin-valve signals in InGaAs channel.

2. Experimental Method

Layer structure consisting of (from the substrate side) a 250-nm-thick undoped GaAs buffer layer, a 700-nm-thick n^--$In_{0.04}Ga_{0.96}As$ channel layer, a 15-nm-thick n^--$In_{0.04}Ga_{0.96}As$→n^+-GaAs transition layer, and a 15-nm-thick n^+-GaAs layer was grown by molecular beam epitaxy (MBE) on semi-insulating GaAs(001) substrates. The doping concentration of the n^--$In_{0.04}Ga_{0.96}As$ channel layer was 3×10^{16} cm^{-3} and that of the n^+-GaAs layer was 5×10^{18} cm^{-3} to form a narrow Schottky barrier.

The sample was then processed into a lateral spin transport device by using electron beam lithography and Ar ion milling techniques. The top-gate electrode of Al was deposited on the n^--$In_{0.04}Ga_{0.96}As$ channel between the injector and detector contacts (Fig. 1). Spin-dependent transport properties for lateral spin transport devices were evaluated in a four-terminal cross-nonlocal geometry where the nonlocal voltage (V_{NL}) between contacts 3 and 1 was measured under a constant current (I_{bias}) supplied between contacts 2 and 4 at 4.2 K (Fig. 1). The negative V_G was applied to the top-gate with respect to terminal 2, which was grounded.

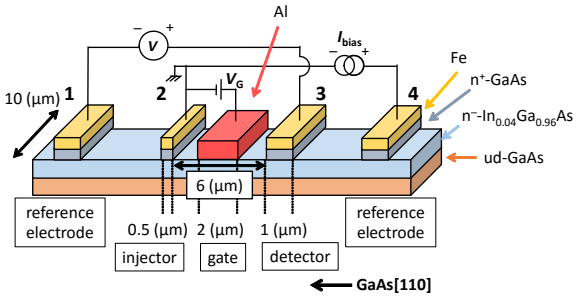

Fig. 1. Lateral spin injection device with a top-gate structure and circuit configuration.

3. Results and Discussion

Figure 2 shows spin-valve signals at 4.2 K for a cross-nonlocal geometry at V_G ranging from 0 to −1.4 V. The injection current was set to 40 μA. We observed clear spin-valve signals for the entire V_G range investigated, indicating the injection of spin-polarized electrons into an n^--$In_{0.04}Ga_{0.96}As$ channel. The amplitudes of the spin-valve signals decreased as $|V_G|$ increased. This contrasted with our previous results obtained in a device with a back-gate structure, in which the amplitudes of the spin-valve signals increased as $|V_G|$ increased for $V_G < 0$ [3]. In summary, we experimentally demonstrated the gate control of spin signals through a top-gate structure, although the origin of the V_G dependence of the spin signals in the present study has not been fully understand.

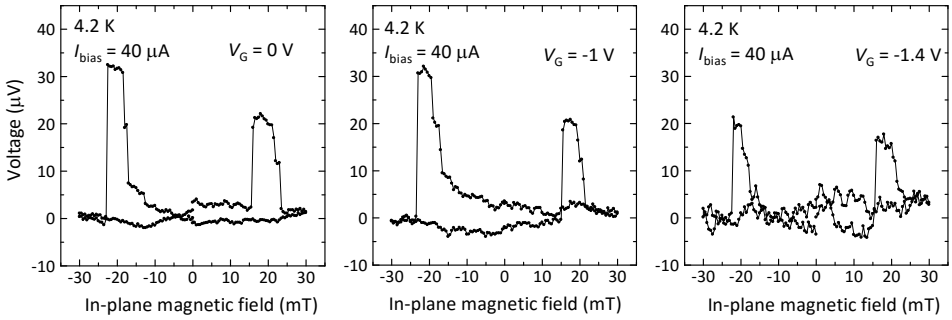

Fig. 2. Spin-valve signals at 4.2 K for a cross nonlocal geometry at V_G = 0, −1.0 and −1.4 V.

Reference

[1] H. Goto et al., APL **92**, 212110 (2008).
[2] T. Sasaki et al., PRA **2**, 034005 (2014).
[3] T. Miyakawa et al., APEX **9**, 023103 (2016).

Acknowledgments

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