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Gate control of spin-valve signal and Hanle signal in GaAs observed by a four-terminal nonlocal geometry

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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 a spin transistor. There have been many reports on the injection into GaAs, Si, or Ge. On the other hand, the control of spin signals by the gate voltage has been limited only for spin accumulation signals measured by a three-terminal geometry[1]. In this study we demonstrated the gate control of both spin-valve signal and Hanle signal in GaAs through a four-terminal nonlocal geometry.

2. Experimental

A layer structure consisting of (from the bottom) p-GaAs (Be = 5×10^{18} cm^{-3}, 200 nm)/ud-$Al_{0.3}Ga_{0.7}As$ (50 nm)/n^{-}-GaAs (Si = 3×10^{16} cm^{-3}, 700 nm)/n^{+}-GaAs (Si = 5×10^{18} cm^{-3})/Fe (10 nm)/Al (10 nm) was grown by MBE on a p-GaAs(001) substrate. A four-terminal lateral spin transport device with a p-i-n junction-type back-gate structure was fabricated (Fig.1). Spin-valve signals and Hanle signals were measured at 77 K through a four-terminal cross nonlocal geometry, in which a constant bias current (I_{Bias}) was supplied between terminals 3 and 1, while the nonlocal voltage (V_{NL}) between terminals 2 and 4 was measured. The negative gate voltage (V_G) was applied to the p-type substrate with respect to the terminal 3 which was grounded.

3. Results and Discussion

Figure 2 shows spin-valve signals and Hanle signals at I_{Bias} = 20 μA for V_G = 0, –1.5 and –2.5 V. For positive values of I_{Bias}, the spin-polarized electrons were injected from contact 3 into an n-GaAs channel. Importantly, the amplitudes of both the spin-valve signals and the Hanle signals were modulated by V_G. This is the first demonstration of the gate control of spin signals observed by a four-terminal nonlocal geometry. Based on the standard spin injection theory, the amplitude of spin-valve signal(ΔV_{NL}) should be proportional to the sheet resistivity (ρ_{sh}) of the n-GaAs channel. However, we found that the ΔV_{NL} increased by approximately two times, while ρ_{sh} increased by approximately five times when V_G was changed from 0 to –2.5 V. This indicates that the change in ΔV_{NL} with V_G cannot be simply explained by the change in ρ_{sh}, but also by other factors, such as a change in spin injection efficiency with V_G.

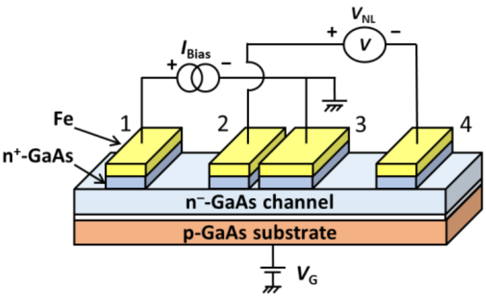

Fig. 1. Device structure

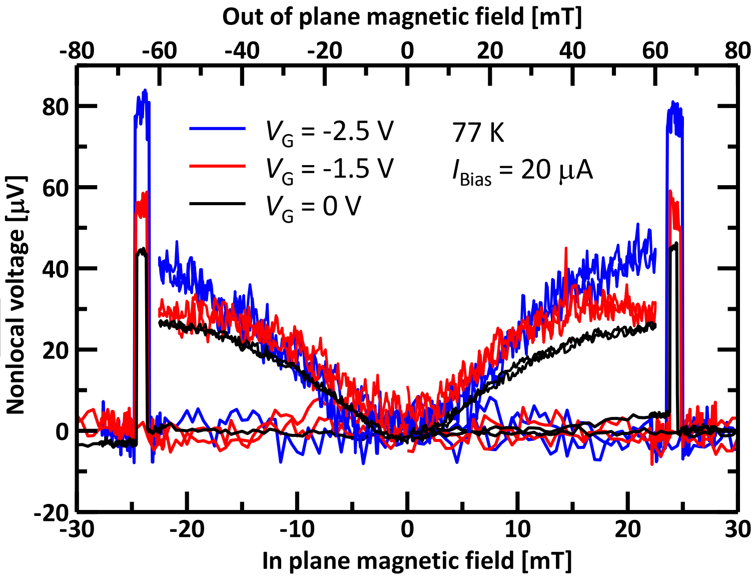

Fig. 2. Spin-valve signals and Hanle signals at I_{Bias} = 20 μA for V_G = 0, –1.5 and –2.5 V.

[1] Y. Ando *et al.*, APL 99, 132511 (2011).

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