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SPIN INJECTION AND DETECTION IN Bi THIN FILMS

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Spin injection has been a basic research topic of continuing interest. Electrical spin injection from a ferromagnetic metal into a nonmagnetic metal was first demonstrated in bulk Al, and spin diffusion lengths of order 1 μm were measured at low temperature [1]. Recent spin injection experiments on Al films patterned into mesoscopic structures have shown a dramatic increase in the magnitude of the injected nonequilibrium spin population, and measured spin diffusion lengths of order 1 μm [2]. Generalization of the spin injection technique to novel materials systems has been a continuing focus of fundermental research. In the present work, the spin injection technique is extended to a new materials system, a semimetal. A study of the electrical injection and detection in Bi thin films is presented.

The device consists of Bi thin film and two ferromagnetic contacts: a spin injector ($Ni_{81}Fe_{19}$:FM_1) and a detector ($Co_{84}Fe_{16}$: FM_2). A 20 nm thick $Ni_{81}Fe_{19}$ film was deposited on a thermally oxidized Si(100) substrate in a dc magnetron sputtering system with a base pressure of 4×10^{-8} Torr, and patterned in size of 100×2000 μm^2 by a combination of standard optical lithography and a lift-off process. Then, FM_2 electrode was also fabricated via the same procedure. The FM_1 and FM_2 electrodes were connected with the extended Ti(10 nm)/Au(50 nm) contact pads. A 7 μm thick Bi layer was deposited on the electrodes using a shadow mask.

Fig. 1 exhibits representative output voltage signal (V) in devices with (a) L = 1 μm and (b) L = 2 μm by sweeping magnetic fields along the long axis of the contacts, measured at 2 K by non-local geometry measurements. When the electrical potential is applied across the FM/Bi interface, spin polarized electrons are injected from an FM_1 and are extracted at the contact '*1*' on the Bi layer, whereas the voltage can be measured between a detector (FM_2) and contact '*2*'. This is because the spin-polarized electrons from the up- (down-) subband of the FM1 electrode (injector) are injected across FM_1/Bi interface, spin accumulation in the spin-up (-down) subband occurs in the Bi layer, giving rise to non-equilibrium state. The spin accumulation due to the spin injection can be detected by FM_2 electrode (detector). Our results indicate that the spin-polarized electrons are injected from FM_1 into the Bi layer without losing their spin information and are detected by FM_2 electrode due to the spin accumulation in the Bi layer.

In order to determine the spin diffusion length (δ_S) of the Bi thin film, we used Johnson and Silsbee theory, describing the relationship between the spin diffusion length and spin injection. The measured resistance change (ΔR_S) due to the spin accumulation in the Bi thin film follows

$$\Delta R_S = \frac{2V_S}{I_e} = \frac{\eta_1 \eta_2 \rho \delta_S^{\;2}}{Ad} , \tag{1}$$

or

$$\Delta R_S = \frac{2V_S}{I_e} = \frac{\eta_1 \eta_2 \rho \delta_S}{A} e^{-d/\delta_S} , \tag{2}$$

where $\eta_{1,2}$ is a phenomenological factor which describes the efficiency of transport of spin polarized electrons, ρ the electrical resistivity, A area, and d distance between two electrodes. From Johnson and Silsbee theory, the spin diffusion length in the Bi film is estimated to be $\delta_S \approx 100$ μm (see Fig. 2). Discussed is Hanle effect signal in our device, suggesting that the injected spin-polarized electrons can be controlled by inducing a coherent spin precession caused by an external magnetic field with angle Φ applied out of the plane of two ferromagnetic electrodes.

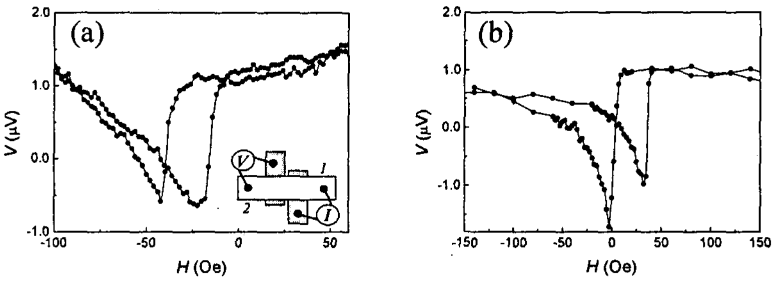

Fig. 1 Typical output voltage signal against magnetic fields, swept upward along the long axes of two electrodes in devices with (a) L = 1 μm and (b) L = 2 μm. The inset shows a schematic of non-local geometry measurements, in which there is no current flow between an injector and a detector.

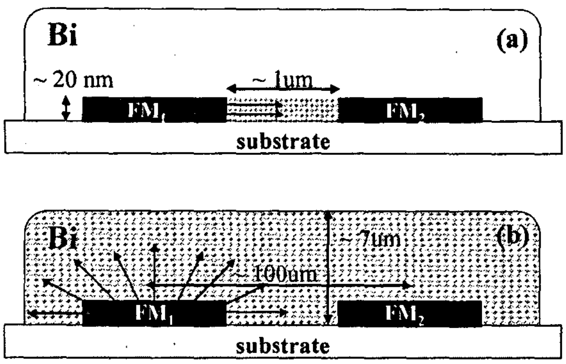

Fig. 2 Spin injection models based on the spin channel length of (a) edge-to-edge and (b) center-to-center

References
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