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Giant Spin Hall Effect in Perpendicularly Spin-polarized FePt/Au Systems

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The generation and detection of spin current are important issues for the further development of spintronics. Spin Hall effect (SHE) makes the conversion between charge current and pure spin current in nonmagnetic semiconductors or metals, which enables us to generate or detect spin current without ferromagnetic materials. Thus, it is expected that SHE provides a new functionality of materials for spintronic devices. The theoretical predictions of SHE have stimulated scientific interests, and the optical detection of SHE was demonstrated in nomagnetic semiconductors. Recently the electrical detection of SHE was also reported in nonmagnetic metals such as Al[1] and Pt[2,3]. However, complicated device structures or sophisticated measurement techniques were required to detect SHE, and the small magnitudes of SHE signals limit the possibility of device applications.

In this paper, we present the electrical detection of giant SHE at room temperature in perpendicularly spin-polarized FePt/Au systems[4]. We fabricated a multi-terminal device with a nano-sized Au Hall cross and a FePt perpendicular spin injector through the use of electron beam lithography and Ar ion etching. Perpendicularly magnetized FePt generates or detects the perpendicularly polarized spin current without external magnetic field, which allows us to simplify the device structure.

A non-local spin injection technique has been employed to detect the direct and inverse SHE signals. In the case of inverse SHE, the spin polarized electric current is injected from FePt to Au; the spin current flows in Au due to the spin accumulation, and the non-local Hall voltage induced by SHE is detected by the Au Hall cross. For the direct SHE, on the other hand, the electric current flows in the Au cross; the spin current is generated by SHE, and the generated spin current is detected by the FePt spin injector. An important point is that the SHE is detected even at zero applied field owing to the perpendicular magnetization of FePt.

Non-local Hall voltages were successfully observed in both direct and inverse SHE geometries, and show clear hysteresis loops resulting from the magnetization reversal of FePt. The magnitudes of SHE signals at room temperature are significantly larger than those in previous reports[1-3]. The spin Hall angle aH, which is the ratio of the spin Hall conductivity to the electric conductivity, has been evaluated to be 0.113. This large aH in Au is explained from the mechanism of skew scattering. aH shows the weak temperature dependence, which is consistent with the dominant contribution of skew scattering in the present Au. We believe that the giant SHE opens a way of new techniques for spintronic devices.

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Prospects of Si-based Diluted Magnetic Semiconductors

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Diluted magnetic semiconductors (DMSs) have attracted much attention in recent years due to the possibility of integrating spin and charge degree of freedom in one material [1]. Among various DMS materials, Si-based DMSs was highly expected as the optimal in spintronics devices, because it can be directly integrated into the modern electronics. Here we review recent progresses in the studies of Si-based DMSs. From over 40 related papers in literature we summarized a few typical examples here. Ferromagnetism (FM) with a Curie temperature (T_c) 210 K was observed in $Si_{0.93}Mn_{0.07}$ films obtained by vaccum evaporation [2]. FM with T_c over 400 K was found in crystalline $Si_{0.95}Mn_{0.05}$ films deposited through sputtering followed post-crystallization [3]. FM with T_c over 400 K was reported in both n-type and p-type single-crystal Si through Mn ion implantation and the FM is proved to be hole-mediated [4]. Recently, FM with a T_c of about 250 K has also been observed in $Si_{0.9782}Mn_{0.0228}$:B films prepared by rf sputtering and the mechanism was again believed to be hole-mediated [5]. These results show that the FM is very sensitive to the deposition processes. In our reasearches, we deposited transition metal Cr or Mn doped hydrogenated amorphous silicon (a-Si:H) thin films by magnetron co-sputtering to overcome the solubility limit of impurity in crystalline silicon [6]. The samples without any second phases or clusters show FM with T_c over 300 K. Moreover, we investigated the structure, FM and electrical properties of samples prepared with or without hydrogen. Hydrogenated samples have higher saturation magnetization, conductivity and carrier concentration than those of un-hydrogenated ones having the same content of Cr or Mn. As a result, hydrogen plays an important role in TM-doped a-Si:H films. Only after enough hydrogenation to diminish the dangling bonds will some of the carriers mediate FM. FM arises from carrier mediated or bound magnetic polaron mechanism in our samples and those in literature will be elucidated and compared. Preliminary results of a Hall bar device made of a-SiMn:H will be presented.

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