Spin-orbit torques in ferromagnetic bilayer

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Spin-orbit effects in nonmagnetic heavy metals have attracted much attention because of their potential application to nanostructured magnetic devices such as a magnetic memory and a microwave generator. In a ferromagnetic/nonmagnetic bilayer system, an in-plane electric field applied to the nonmagnet produces spin current flowing in the direction perpendicular to the electric field by the spin-Hall effect. The spin current injected into the attached ferromagnet excites magnetization dynamics by the spin-transfer effect. Recent experiments have demonstrated several kinds of magntization dynamics, such as switching of a perpendicular ferromagnet and magnetization oscillation of an in-plane ferromagnet, by this spin-transfer torque [1,2].

Spin-orbit effects are also observed in ferromagnets in the anomalous Hall effect and the anisotropic magnetoresistance. These effects also produce the spin-transfer torques in ferromagnetic bilayers. Based on spin transport theory and spin-dependent Landauer formula, we developed a theory of interlayer spin-transfer torque excited by the anomalous Hall effect and the anisotropic magnetoresistance in a ferromagnetic bilayer [3]. We derive an analytical formula of the spin-transfer torque, and show that the spin-transfer torque can point to an arbitrary direction by changing the magnetization direction, in contrast to spin-Hall systems in which the direction of the spin-transfer torque is geometrically determined. It enables us to control the magnetization direction more efficiently than with spin-Hall systems. For example, by choosing an appropriate magnetization direction of one ferromagnet, the spin-transfer torque enables us to switch another perpendicular ferromagnet with low current and high accuracy, as shown in Fig. 1.

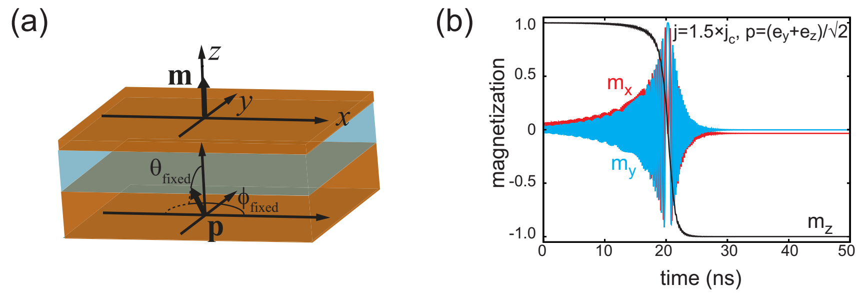

Figure 1: (a) Schematic view of a ferromagnetic/nonmagntic/ferromagnetic multilayer. The bottom ferromagnet shows the anomolous Hall effect, and acts as a spin injector to the top ferromagnet, which is perpendicularly magnetized. The spin-transfer torque excited on the magnetization in th top ferromagnet excites the magnetization switching. (b) The time evolution of the magnetization in the top ferromagnet.

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