Electric field control of magnetic anisotropy in bilayer contacts with Rashba-type spin-orbit interaction

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Uniaxial magnetic anisotropy (MA) plays an important role in spintronic applications in which ferromagnetic (FM) thin films and heterojunctions are utilized. The MA in such magnetic materials originates from spin-orbit interaction (SOI) expressed by *L-S* coupling and the low dimensionality of the lattice structure. As a result, out-of-plane MA often occurs at surfaces and interfaces of these magnetic heterojunctions. The magnetization direction in ferromagnets is usually controlled by an external magnetic field. Recently, control of magnetic ordering by using spin-transfer torque, the magnetostrictive effect, ferroelectricity, the piezoelectric effect, and electric field has attracted much attention in the field of spintronics.

Quite recently, another type of SOI, the Rashba-type SOI (R-SOI) was proposed to be a source of MA. Theoretical analysis of MA was performed for a two-dimensional layer by using exchange-split free electron and single-orbital TB models with R-SOI.[1-3] The study using TB model[3] predicted that the layer shows in-plane MA for both low and high electron densities, while it shows out-of-plane MA otherwise. The occurrence of MA by the R-SOI may be attributed to a characteristic change in the Rashba-split energy state under an exchange field produced by the FM layer itself or by magnetic ions/atoms in an FM material attached to a non-magnetic (NM) layer. It is interesting to note that the R-SOI may be controlled by an external electric field because of its intrinsic nature.

In this work,[4] we theoretically study the uniaxial MA of a bilayer made of NM and FM layers putting an emphasis of relative role of the R-SOI on NM layer and *L-S* coupling, that is, atomic-SOI (A-SOI) on the FM layer. We construct a simple model for the bilayer based on the first-principle calculation of the Rashba-split bands of the Au(111) surface. In this model, the electronic structure of NM layer is given by a single-orbital TB model, while that of FM layer is presented in the full 3*d*-orbital TB model, in addition to the orbital mixing between NM and FM layers. After numerical calculation, we have shown that the R-SOI of the NM layer produces MA via *p-d* mixing between the NM and FM layers. The MA energy caused by the R-SOI is less than 1 meV, while that caused by the A-SOI is a few meV per unit cell. Both interactions show an oscillatory dependence of the uniaxial MA energy on the electron number. Because the "phases" of these oscillations are different, the uniaxial MA originating from the R-SOI alone could be the same order of magnitude as that produced by A-SOI alone under certain conditions. The result indicates that an external electric field with reasonable magnitude may change the MA from being out-of-plane to in-plane, and vice versa.

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