Spin-Hall and anisotropic magnetoresistance in Pt / ferrimagnetic Co-Gd / Cr layers

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Antiferromagnetic spintronics is an emerging research field and has attracted much attention because of the unique properties of antiferromagnets: zero net magnetization and small magnetic susceptibility. Also antiferromagnets exhibit the high speed magnetization dynamics compared with those for ferromagnets used in the conventional spintronic devices. Recent studies demonstrated that the flow of spin angular momentum, *i.e.* spin current (J_s) was generated from the antiferromagnet and J_s also interacts with the magnetic moments of antiferromagnet [Ref. 1]. However, the detailed mechanism of the interaction between J_s and the antiferromagnetic structure has not fully been understood yet.

We consider that the ferrimagnetic Co-Gd amorphous alloys, in which the Co and Gd moments are coupled antiferromagnetically, are a promising system for the systematic investigation of the interaction between J_s and the antiferromagnetic structure. In this study, the Co-Gd composition dependence of spin-Hall magnetoresistance (SMR) was investigated for the in-plane magnetized $Co_{100-x}Gd_x$ amorphous alloys sandwiched by the Cr and Pt layers. In addition to the SMR, we also measured the composition dependence of anisotropic magnetoresistance (AMR) of the Pt / $Co_{100-x}Gd_x$ / Cr layers.

Thin films were deposited on a thermally oxidized Si substrate using a magnetron sputtering system. First, a 4 nm-thick Cr buffer was deposited on the Si-O substrate. Then, Co and Gd were co-deposited to form $Co_{100-x}Gd_x$ layers with a thickness of 30 nm. Finally, a 4nm-thick Pt layer was deposited, which served as not only the capping layer to prevent the Co-Gd from oxidation, but also the layer generating transverse J_s from the charge current via the spin-Hall effect owing to its large spin-orbit coupling.

The *M*-*H* curves showed the magnetization (M) was changed with x. As x was increased from 12 to 37, the local minimum of M appeared at x = 25, indicating that the compensation point (composition) of the present Co-Gd exists around x = 25. The composition dependence of AMR showed the sign change from positive to negative as x was increased, and zero AMR was observed near the compensation composition. On the other hand, the non-zero SMR was obtained even when the AMR became almost zero. Our experimental results clearly indicate the different scattering mechanisms for AMR and SMR. In contrast to the AMR effect based on the *s-d* scattering in the bulk, SMR depends on other parameters such as spin mixing conductance at the interface that do not play an important role for the AMR effect. That is a possible reason for the different composition dependences between SMR and AMR.

[Ref. 1] T. Jungwirth, X. Marti, P. Wadley and J. Wunderlich, *Nature Nano*. **11**, 231 (2016).