Interfacial enhancement of *g*-factor at CoFeB/MgO characterized by a high sensitivity ferromagnetic resonance spectroscopy

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Introduction The large perpendicular magnetic anisotropy (PMA) at the CoFeB/MgO interface [1,2] has attracted much attention since it enables to realize a superior thermal stability as well as energy-efficient switching of magnetization while reducing the size of magnetic tunnel junction (MTJ). In fact, the switching energy lower than 1 pJ/bit has been reported for a sub-30-nm-sized MTJ [3]. Recent advances in the voltage-controlled magnetic anisotropy studies are also supported by the highly developed thin-film deposition techniques that enable to precisely control the CoFeB/MgO interface [4].

"Static" magnetic properties such as the saturation magnetization and interfacial PMA constant (K_i) can be relatively easily characterized by the conventional vibrating sample magnetometer (VSM). On the other hand, characterization of "dynamic" magnetic properties such as the magnetic damping (α) and *g*-factor are extremely difficult because one need to detect a tiny electromagnetic signal originating from the magnetic oscillation in an ultrathin (~ 1 nm) CoFeB film. Although the cavity ferromagnetic resonance (FMR) is often used to investigate the change in α at the CoFeB/MgO interface [2], the possible change in *g*-factor has yet to be observed. This is because the characterization of *g*-factor requires a broadband FMR measurement while continuously sweeping the excitation frequency as well as the external magnetic field, whereas the excitation frequency of the cavity FMR setup is solely determined by the cavity size.

Therefore, in this work, we utilize custom-build vector network analyzer (VNA-)FMR setup which is capable of field modulation detection for investigating the *g*-factors of CoFeB ultrathin films attached to an MgO layer. The highly sensitive VNA-FMR spectroscopy allows to determine the change in the *g*-factor as a function of CoFeB thickness. By comparing with the results of VSM measurements, we also show that the enhancement of *g*-factor is associated with the PMA at the CoFeB/MgO interface.

Experiments Thin films consisting of CoFeB (*t* nm)/MgO junctions were prepared on thermally oxidized Si substrates with a Ta buffer layer. All films were deposited at room temperature and ex-situ annealed in vacuum at T_{ann} = 150- 350˚C for 1 h. The blanket films were directly placed on a custom-build jig with a coplanar waveguide, and the broadband FMR measurements were performed under various static out-of-plane magnetic fields with a small (~ 20 Oe) modulation. The thicknesses of magnetically dead layer (t_d) were evaluated from the VSM measurements and were subtracted from *t*.

Figure 1(a) shows the dependence of *g*-factor as a function of effective thickness (t_{eff}, $t_{eff} = t - t_d$). It is evident from Fig. 1(a) that the *g*-factor is enhanced for $t_{eff} < 1$ nm. From the inverse relationship of *g*-factor in the ultrathin region, we estimated the change in the *g*-factor at the CoFeB/MgO interface (Δg) and is plotted as a function of T_{ann} in Fig. 1(b) together with K_i estimated from the VSM measurements. Δg increases until T_{ann} = 200˚C, and then decreases gradually with T_{ann}, which coincide with the change in K_i. These results suggest that both the enhancements of *g*-factor and K_i originate from the revival of the orbital angular moment at the CoFeB/MgO interface.

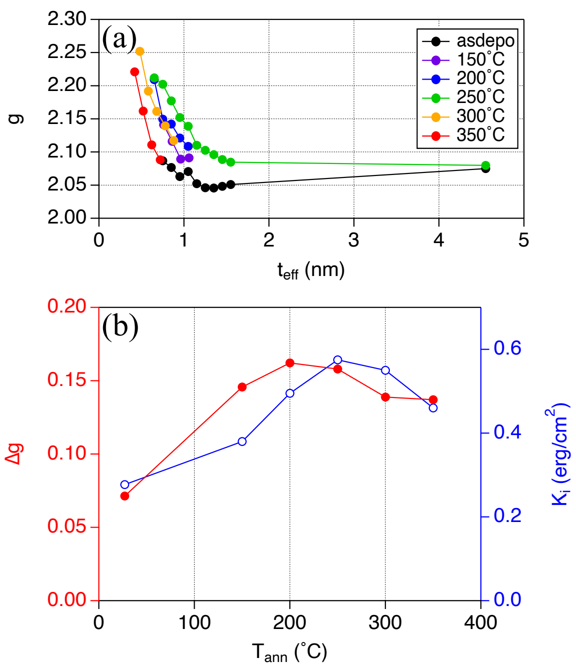

Figure 1 (a) *g*-factor as a function of t_{eff}. (b) Δg and K_i as a function of T_{ann}.

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References [1] S. Yakata et al., J. Appl. Phys. **105**, 07D131 (2009). [2] S. Ikeda et al., Nat. Mater. **9**, 721 (2010). [3] K. Ando et al., J. Appl. Phys., **115**, 172603 (2014). [4] T. Nozaki et al., Micromachines, **10**, 00327 (2019).