Formation and Dynamics of Magnetic Vortex in Co-Based Heusler Alloys

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[Introduction] A part of $L2_1$-ordered full Heusler alloys are theoretically predicted to be half-metals, in which the density of states at the Fermi level exists only in one spin channel. These half-metallic materials enable us to obtain high tunnel magnetoresistance (TMR) and giant magnetoresistance (GMR). Thanks to the high GMR effect, we successfully demonstrated large rf output power of spin-torque oscillation even for the current-perpendicular-to-plane (CPP) GMR device by using the $L2_1$ ordered $Co_2(Fe_{0.4}Mn_{0.6})Si$ (CFMS) Heusler alloy as the ferromagnetic layers [1,2]. However, the micromagnetic simulation suggested that the incoherent magnetization precession was induced by spin torque because of the non-uniform effective magnetic field in the case of nanopillar device [1]. One of the effective ways to improve the incoherency of magnetization precession is to exploit a magnetic vortex structure in Heusler alloys because spin torque oscillators utilizing the vortex dynamics generally exhibit narrow oscillation linewidth. In this study, we systematically investigated the control of magnetic structures in nanodisks consisting of CFMS. Also, we studied the magnetization dynamics excited in the disk-shaped CFMS from the viewpoint of application to spin torque oscillators.

[Experimental Procedure] Epitaxially grown CFMS thin films were prepared on an MgO (100) single crystal substrate employing an ultrahigh vacuum magnetron sputtering system. The stacking structure is MgO subs. || Cr (20 nm) | CFMS (t nm), where t was varied in the range from 15 nm to 50 nm. The CFMS films were deposited at room temperature, and were subsequently annealed at 500ºC to promote $L2_1$ ordering. The thin films were patterned into circular disks with various diameters (D). The magnetization reversal for epitaxial CFMS disks was evaluated using a longitudinal magneto-optical Kerr effect (L-MOKE) for the disk arrays. For comparison, the magnetic properties for polycrystalline CFMS disks and $Ni_{81}Fe_{19}$ (Permalloy; Py) disks with the same diameters as the epitaxial CFMS disks were also investigated. In order to characterize the magnetization dynamics of microfabricated disks, the coplanar waveguides were located on the disk arrays, and the rf power was applied to the coplanar waveguide for the excitation of magnetization dynamics, which was detected using a vector network analyzer.

[Results and Discussion] The characteristic magnetization reversal behavior with the nucleation and annihilation of magnetic vortex core was observed for the 50 nm-thick epitaxial CFMS disks with 200 nm $\leq D \leq 5$ μm. The switching field (H_{sw}) monotonically decreased with the aspect ratio of D to t, and the slope of H_{sw} versus D / t remarkably depended on t. This is different tendency for the case of Py disk showing the same slope regardless of t, which is attributable to the non-negligible magnetic anisotropy in the epitaxial CFMS disks. In addition to the characteristic L-MOKE loops, the high frequency modes of spin waves excited in the CFMS disks suggest the formation of magnetic vortex in the CFMS disks.

[1] T. Seki *et al.*, *Appl. Phys. Lett.* **105**, 092406 (2014). [2] T. Yamamoto *et al.*, *Appl. Phys. Lett.* **106**, 092406 (2015).