Vortex Spin-Torque Oscillator using Co_2(Fe,Mn)Si Heusler Alloys with various Fe-Mn Compositions

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Introduction A spin torque oscillator (STO) is a nanoscale oscillator consisting of a FM/NM/FM (FM: ferromagnetic metal, NM: nonmagnetic metal or insulator) junction. Since the output power (P_{out}) of a STO is determined by the magnetoresistance ratio of the junction, FMs exhibiting high spin polarization are strongly desired to develop high P_{out} STOs. Previously, our group achieved high P_{out} exceeding 1 nW by using Co_2(Fe,Mn)Si (CFMS) Heusler alloys [1-3]. Also, in the recent work, we developed CFMS-based vortex STO exhibiting high P_{out} of 10.3 nW with an extremely high quality factor (Q) of 4000 [4]. Although these studies demonstrated the advantage of the use of CFMS alloys for achieving high P_{out}, systematic investigations on the relationships among the magnetic properties of CFMS films, the oscillation properties, *e.g.*, P_{out}, and the threshold current (I_{th}) are still missing. In this study, we fabricated CFMS-based vortex STOs with various Fe-Mn compositions, and investigated the influences of the magnetic properties on the spin torque oscillations.

Experiment CFMS (20)/Ag (5)/CFMS (30) (in nanometer) films were prepared on Cr/Ag-buffered MgO (001) substrates by using an ultrahigh-vacuum-compatible magnetron sputtering system with a base pressure $P_{base} < 1 \times 10^{-7}$ Pa. The Fe-Mn composition of the CFMS films were controlled by co-sputtering a Co_2FeSi and a Co_2MnSi alloy targets. The CFMS films were deposited at room temperature, and were annealed at 500 ˚C to promote the $L2_1$ ordering. The structural analysis and the magnetization measurement were carried out by using X-ray diffraction and a vibrating sample magnetometer, respectively. The 30-nm-thick CFMS layer was formed into a 240-nm-diameter circular shape by employing electron-beam lithography and Ar-ion etching to stabilize a magnetic vortex. In order to excite the magnetization dynamics, dc current was fed into the device using a source meter, and the rf signal from the device was detected by using a spectrum analyzer.

All the CFMS films showed high $L2_1$ ordering (> 60%) regardless of the Fe-Mn compositions whereas both the saturation magnetization (M_s) and the coercivity (H_c) of the CFMS films monotonically increased with increasing the Fe concentration. P_{out} of the device was increased by the Fe substitution and the maximum P_{out} of 15. 9 nW was obtained for $Co_2Fe_{0.4}Mn_{0.6}Si$. Also, similar to the dependences of M_s and H_c on the Fe-Mn composition, almost linear increase of I_{th} was observed except around $Co_2Fe_{0.4}Mn_{0.6}Si$ where a remarkable reduction of I_{th} was observed. This result suggests that I_{th} of a vortex STO is determined not only by M_s, H_c and the spin polarization of FM electrodes but also by the Gilbert damping constant regardless of the strongly non-uniform magnetization configuration of a magnetic vortex. These knowledges would be profitable for the development of high P_{out} and highly efficient vortex STOs.

References

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