High frequency soft-magnetic properties and thermal stability of CoPd-SrTiO$_3$ nano-composite films

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Soft magnetic films with high permeability and ferromagnetic resonance frequency have been studied intensively for the application in micro-electronic device components. Recent work has been done on soft-magnetic Co-based nano-composite films to keep their permeability as high as possible to GHz frequency. However, the resonance frequency ($f_r$) of the films is still low which may limit the application in higher-frequency magnetic devices. According to the modified Landau-Lifshitz equation, it is required of large values of magnetic anisotropy field ($H_k$) and saturation magnetization ($M_s$) to obtain high $f_r$. Soft-magnetic films studied to date have large $M_s$, but show rarely high $H_k$. Recently, a few films demonstrate high $H_k$, whereas, they show low thermal stability, which is a big disadvantage for the high temperature processing in practical applications (such as Surface mounted technology at 250$^\circ$C for Printed circuit board). In this report, SrTiO$_3$ (STO) is employed as nonmagnetic ceramic phase due to its thermal stability and high resistivity ($\rho$). Pd is induced to form CoPd alloy nanoparticles to enlarge anisotropy ($H_k$). To prevent oxidation of Co metal, a kind of tandem sputtering method is used. The composition, structure, magnetic properties and thermal stability of the CoPd-STO films have been investigated.

The CoPd-STO nano-composite films were deposited onto Si and quartz substrates by sputtering methods, using a STO target and a composite target composed of a Co disk, Pd chips. The chemical composition of the films was analyzed by X-ray photoelectron spectroscopy (XPS). Film structures were investigated by XRD. The microstructure of films was characterized by TEM. The magnetization was measured with VSM. The permeability ($\mu$) was determined by a shielded loop coil method.

The CoPd-STO films consist of amorphous STO matrix and CoPd nano-particles. The CoPd phase shows fcc structure. The CoPd-STO films have a typical in-plane uniaxial soft magnetic properties, with the easy axis (parallel) and hard axis (perpendicular to easy magnetic direction) (Fig. 1). The magnetization hysteresis loops of the films show magnetization ($B_s$) of about 10 kG, $H_k$ of around 950 Oe, and $\rho$ of 300 $\mu\Omega$·cm. It is noteworthy that the magnetic properties of the sample after annealing treatment at 250 $^\circ$C shows no obvious change compared with that of the as-deposited film. Form XRD analysis (Fig. 2), it is clearly proved that the CoPd particles have no change after annealing treatment for both size and crystalline structure. The measured $\mu'$ is approximately 10, which keeps constant up to 3 GHz. The calculated $\mu'$ by L.L.G formula is consistent with the measured results and shows the resonance frequency at about 9 GHz.

Reference


Fig.1 Hysteresis loops of CoPd-(STO) nano-composite film: a) as deposited, b) annealed at 250 $^\circ$C for 30 min.

Fig.2 XRD spectra of the as-deposited and annealed CoPd-STO samples.