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Magneto-optical Kerr effect in NiZn ferrite films of variable thickness

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Abstract

NiZn ferrites films deposited by RF sputtering technique on (1 0 0)-Si substrates have been studied by the magneto-optical Kerr effect. The coercivity behavior as a function of the thickness indicates a spin reversal mainly governed by the single domain regime. The Jiles–Atherton Model was used to fit the experimental hysteresis loop. The k pinning parameter of the model increases by increasing film thicknesses

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Keywords: Domain effects; Magnetization curves, and hysteresis; Ferrimagnetics; Magnetic properties of thin films; Magnetic recording materials

1. Introduction

The study of NiZn ferrites with spinel structure is of current theoretical and technological interest. NiZn ferrites belong to a class of soft magnetic materials whose magnetic properties can be understood by adequate theoretical models [1,2]. Epitaxial NiZn ferrite films have attracted considerable interest as candidates for new electronic devices, sensors, and electro-magnetic-compatibility applications [3]. NiZn epitaxial ferrite films are integrated onto electronic devices through the deposition of additional layers on the ferrite [4]. Thus, it is desirable to study how structural and magnetic properties of epitaxial NiZn ferrite films can be controlled by the growth parameters. Related to this topic, a number of experimental investigations have been performed on NiZn ferrite films. Structural and magnetic properties of thin films obtained by laser ablation are discussed in Ref. [5]. Magnetic properties of sputtered NiZn ferrite thin films were studied as a function of annealing temperature [6]. Magnetic properties of sputtered MnZn ferrite thin films deposited on thermally oxidized Si substrates were reported in Ref. [7]. In this paper, we report on the coercivity dependence as a function of the thicknesses of sputtered NiZn ferrite films. Coercivity was measured at room temperature by using the magneto-optical Kerr effect (MOKE). The Jiles–Atherton model was used to fit the experimental hysteresis loops.

2. Experimental

Films were produced by a high-oxygen pressure RF sputtering process and deposited onto 10×10 mm (1 0 0)-Si substrates. A NiZn ferrite target with a composition of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ was prepared by solid-state reaction of NiO, ZnO and Fe_2O_3 powders by using a sintering temperature of 1100 °C. Oxygen pressure during deposition was 7.05×10^{-1} mbar. Deposition temperature was 600 °C. Films thicknesses were calculated using the rate and time of deposition, obtaining films with 80 ± 8, 160 ± 16, and 240 ± 24 nm. During the whole deposition process temperature remained stable within less than 1 °C. More details on the deposition method can be found in Ref. [8]. X-ray diffraction (XRD) was carried out on a Philips PW1710 diffractometer with copper target. Regarding the lattice parameter, we obtain the value 8.38 ± 0.01 Å, resulting in a composition of $x\approx0.75$ in $Ni_xZn_{1-x}Fe_2O_4$ [9].

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A diode laser with a wavelength of 532 nm was used as the light source for the MOKE measurements. The longitudinal Kerr signal was obtained by monitoring the changes of the reflective intensity, which is proportional to the magnetization of the sample. The magnetic field is produced by an electromagnet with maximal magnetic field of 1500 Oe. The signals produced at the detector were sent to the computer by means of optical fiber. All MOKE measurements were performed at room temperature.

3. Results and discussion

Fig. 1 displays the XRD diffraction pattern of a NiZn ferrite film with 160 nm of thickness grown on (1 0 0)-Si. The figure shows the (2 2 2), (4 0 0), (5 1 1) and (4 4 0) reflection peaks of the spinel single-phase NiZn ferrite. The R peaks stand for the XRD sample holder. A similar structure was found for the other samples.

The Kerr signal as a function of the magnetic field for films with different thicknesses is shown in Fig. 2. H_c indicates the coercivity field value in each case and M_s the saturation magnetization. The coercivity field obtained from Fig. 2 is shown in Fig. 3 as a function of NiZn film thickness. As Fig. 3 indicates, the coercivity shows an increment with increasing thickness.

As the sputtering process mainly involves a nucleation process, then the island size in the deposited films increases as a function of film thickness. It is known that coercivity is related to both the nucleation process and the pinning of domain walls. In the single-domain regime, coercivity increases as the single-domain grain size increases [10]. We expect a large number of defects like grain boundaries, dislocations, point defects, etc. to increase with sample thickness, in this regime. An increase in coercivity can be explained by the fact that defects act as the domain wall

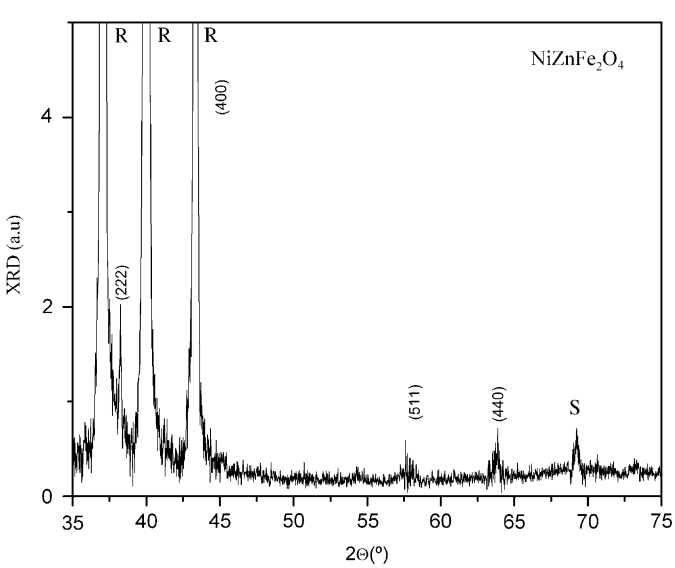

Fig. 1. X-ray diffraction pattern of the NiZn ferrite sample of $L = 160$ nm thick, deposited on Si(1 0 0) substrate. The planes correspond to the spinel single phase NiZn ferrite. R peaks stand for the XDR sample holder.

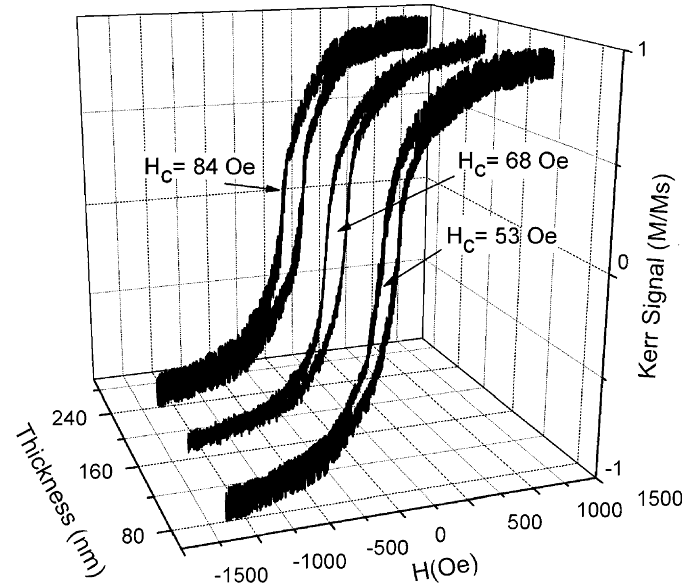

Fig. 2. The Longitudinal Kerr hysteresis loops at different thicknesses ($L = 80 \pm 8$ nm, $L = 160 \pm 16$ nm and $L = 240 \pm 24$ nm) for NiZn ferrite films. H_c indicates the coercivity field in each case and M_s the saturation magnetization.

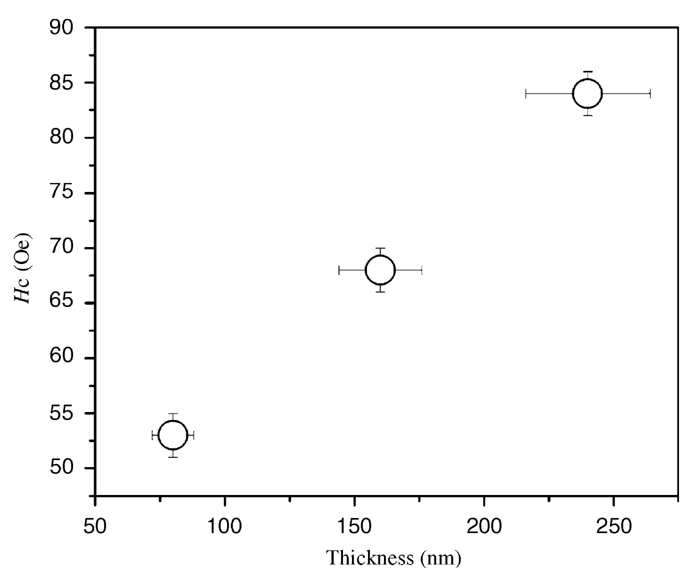

Fig. 3. Variation of the coercivity of NiZn ferrites as a function of thickness.

pinning. We used the Jiles–Atherton model [1,2] to discuss the experimental hysteresis loops. The Jiles–Atherton model is based on domain wall motion, of an irreversible component due to wall displacement and a reversible component due to domain wall bending. It is best suited to modeling soft magnetic materials. The magnetic susceptibility in the Jiles–Atherton model is described by the differential equation:

$$\frac{\mathrm{d}M}{\mathrm{d}H} = \frac{(1-c)(M_{\mathrm{an}} - M)}{\delta k(1-c) - \alpha(M_{\mathrm{an}} - M)} + c\frac{\mathrm{d}M_{\mathrm{an}}}{\mathrm{d}H}, \tag{1}$$

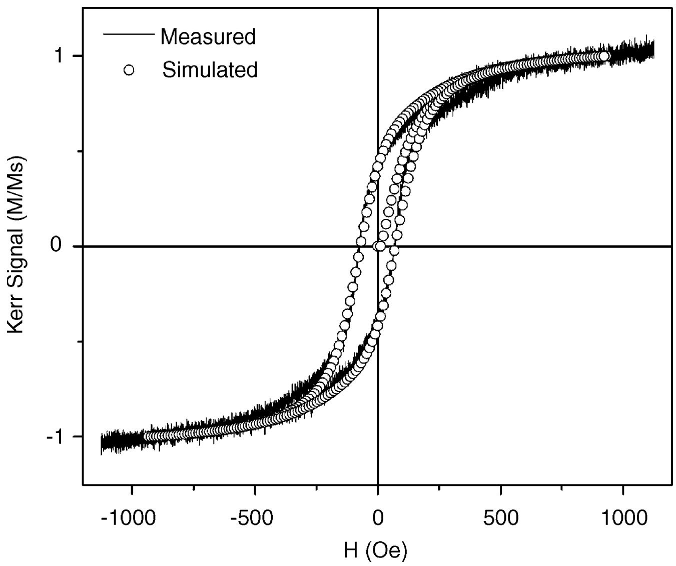

Fig. 4. Theoretical fitting of the experimental hysteresis loop (160 nm thick film) by means of the Jiles–Atherton model. The model parameters: $M_s = 1.6 \times 10^6$, A/m, $\alpha = 3.3 \times 10^{-3}$, $c = 0.13$, $k = 68$.

Table 1
k pinning parameters used for the simulation

L(nm)	80	**160**	**240**
k	30	68	70

where k is the pinning parameter, α is the mean field parameter, c describes the shape of the anhysteretic curve, M_{an} is the anhysteretic magnetization and δ is a constant that equals 1 for the ascendant hysteresis curve and -1 for descendant hysteresis curve. By solving differential Eq. (1), the magnetization M is obtained. The pinning parameter k may vary as a function of M and H. Nevertheless, the form of the solution remains the same whether k is constant or not, only the shape is modified by variable k.

Fig. 4 shows the experimental curve for the hysteresis loop of the 160 nm sample, modeled by the Jiles–Atherton model. Similar results have been obtained for the other two samples. Table 1 shows the k values used to fit the experimental curves.

The coercivity behavior described in this paper is analogous to the one described in Ref. [6], where magnetic properties of the NiZn ferrite film grown by an RF sputtering process were correlated with the morphological structure (grain size). The present work shows a direct relation between thickness and coercivity. The most interesting result of the present work is to show through coercivity measurements that the single-domain grain size increases as the film thickness increases.

4. Conclusions

We have produced NiZn ferrite thin films with different thicknesses via high oxygen RF sputtering technique. The (2 2 2), (4 0 0), (5 1 1) and (4 4 0) reflection peaks of the spinel –single-phase NiZn ferrite were observed. Coercivity as a function of the NiZn ferrite film thickness shows that the single-domain grain size increases with increasing thickness. This behavior can be inferred from the increment of the coercivity. The sputtered NiZn ferrite films obey to the case where the spin reversal is mainly governed by the single-domain regime. We found that the k pinning parameter of the Jiles–Atherton model increases with increasing film thickness in the single-domain regime.

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