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High-frequency properties of $[Co_{90}Nb_{10}/Ni_{0.45}Zn_{0.55}Fe_2O_4(t)]_6$ multilayer films for application in GHz range

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ABSTRACT

A series of $[Co_{90}Nb_{10}/Ni_{0.45}Zn_{0.55}Fe_2O_4(t)]_6$ multilayer films were fabricated on Si(111) substrates by means of radio frequency magnetron sputtering. The influences of Ni-Zn ferrite interlayer thicknesses (t) on the static and high-frequency soft magnetic properties of multilayer films have been investigated. As increasing the ferrite thickness (t) from 0 to 6 nm, the saturation magnetization M_s decreased from 876 emu/cm^3 to 488 emu/cm^3, but the in-plane uniaxial magnetic anisotropy effective field H_k and electrical resistivity ρ varied from 17 Oe to 52 Oe and from 170 μΩ cm to 3670 μΩ cm respectively. As a consequence, the resonance frequency f_r of the multilayer films were continuously increased from 1.45 GHz to 2.7 GHz. The results showed that the interlayer ferrite thickness had an important effect on magnetic properties of the multilayer films and that it can be convenient to adjust the natural resonance frequency.

1. Introduction

With the development of advanced electromagnetic devices used in gigahertz (GHz) range, such as data transmission, spintronics devices, and micro-inductors, a great deal of research effort has been devoted to explore the soft magnetic thin films with high frequency performance [1–3]. The fundamental requirements for these films are high saturation magnetization (M_s), high natural resonance frequency (f_r), large permeability (μ), and high electrical resistivity (ρ) simultaneously [4–6]. In general, magnetic metallic alloys possess high M_s, however, their extremely low resistivity limits their applications in the high-frequency range due to large eddy current loss. An approach to increase the resistivity of magnetic films is the addition of amorphous qualitative elements (e.g. O, B, N) [4, 7–9], or nonmagnetic insulating materials (SiO_2, Al_2O_3,) [10–11]. It is well known that CoNb metallic and Ni-Zn ferrite films have been excellent soft magnetic performance, and meanwhile the Ni-Zn ferrite films possess electrical insulating properties [12–14]. Therefore it is feasible method that Ni-Zn ferrite films are used as the adulterant with CoNb thin films to obtain the soft magnetic composite films with high M_s and ρ. However there is relatively little work on the magnetic properties of composited multilayer films with use of magnetic insulator. In addition, preferable high-frequency properties of magnetic films are usually obtained at a limited and certain thickness since microstructures and/or stress of films could be changed as thicknesses increasing, which influence the high-frequency properties obviously [15–16]. Therefore it is necessary that investigation on preparation and magnetic properties of multilayer thin films with the thicknesses varied.

In this paper, the $[Co_{90}Nb_{10}(10\,nm)/Ni_{0.45}Zn_{0.55}Fe_2O_4(t\ nm)]_6$ multilayer films have been deposited by sputtering and the high-frequency magnetic properties were investigated as the thickness (t = 0, 2, 4, 6 nm) of the ferrite films increased.

2. Experiment

The $[Co_{90}Nb_{10}(10\,nm)/Ni_{0.45}Zn_{0.55}Fe_2O_4(t\ nm)]_6$ multilayer films were prepared on Si(111) substrates attached to a water-cooling system by radio frequency (RF) magnetron sputtering at room temperature with a base pressure lower than 5×10^{-5} Pa. One was Co target, on which Nb chips were placed in a regular manner. The other was $Ni_{0.5}Zn_{0.5}Fe_2O_4$ ceramic target. Both targets were 76 mm in diameter and 3 mm in thickness. For the sputtering process of the $Co_{90}Nb_{10}$ layer the argon pressure and RF power were kept at 0.2 Pa and 50 W. During the deposition of the ferrite films, a mixed gas of argon and oxygen was used as the ambient gas. The relatives oxygen partial pressure, the total ambient gas pressure and the RF power were kept at 20%, 2.0 Pa, and 200 W respectively.

The multilayered structure was obtained by switching on/off the baffle plates that above the targets and then moving the substrates to/off the position over the targets alternately. The thicknesses of CoNb layer and Ni-Zn ferrite layer were controlled at about 10 nm and t (= 0, 2, 4, 6) nm by regulating the sputtering time respectively. When

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depositing Ni-Zn ferrite film with t = 0, it only moved the substrates to the Ni-Zn ferrite target and stayed for 15 s but switch off the baffle plate. The total cycles were 6. The structural properties of the multilayer films were measured by X–ray diffraction (XRD, X′ Pert PRO PHILIPS with Cu K_α radiation). The static magnetic measurements of the films were performed by using a vibrating sample magnetometer (VSM, Lakeshore 7304 model). The saturation magnetization (M_s) and coercivity (H_c) was evaluated from the loops of which the applied field H was parallel to film plane. The H_k was determined by calculating the measured easy-axis and hard-axis loops of the films. The resistivity (ρ) was determined by the conventional four-probe method. The complex permeability $\mu = \mu' - i\mu''$ of the ferrite films were measured by a PNA E8363B vector network analyzer using shorted microstrip transmission-line perturbation method from 170 MHz to 5.2 GHz [17]. In this measurement, the samples (5 mm × 5 mm × 0.42 mm) were positioned in the middle of the strip line with an inner height of 0.8 mm between the upper line and ground plate, while the width of the upper line was 3.94 mm and the length was 9 mm. All the above observations and measurements were performed on as-deposited samples at room temperature.

3. Results and discussion

Fig. 1 showed the XRD patterns of multilayer films with t = 0 and 6 nm. The Fig 1(a) exhibited the main peak (111) around 44° belonging to the Co of fcc phase (◆), however the Fig 1(b) showed the peaks of both fcc Co (◆) and spinel Ni-Zn ferrite(♣). It indicated that $Ni_{0.45}Zn_{0.55}Fe_2O_4$ layer as-deposited is crystalline [18–19]. Fig. 2 showed the magnetic hysteresis (*M-H*) loops along the easy (EA) and hard axes (HA) of the multilayer films with t = 0 and 6 nm. The applied field H was parallel to the films plane. As seen in Fig 2, the films showed

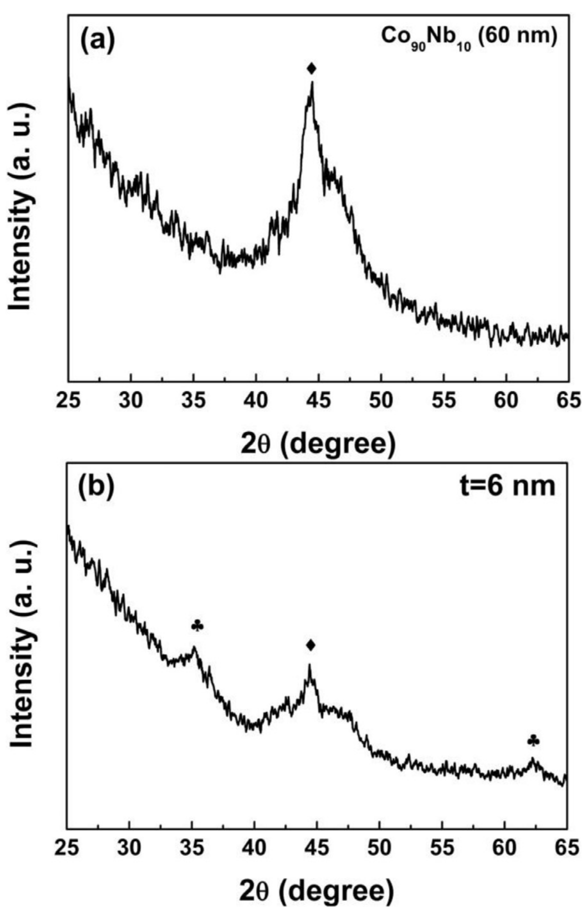

Fig. 1. XRD patterns of multilayer films (a) t = 0 and (b) 6 nm.

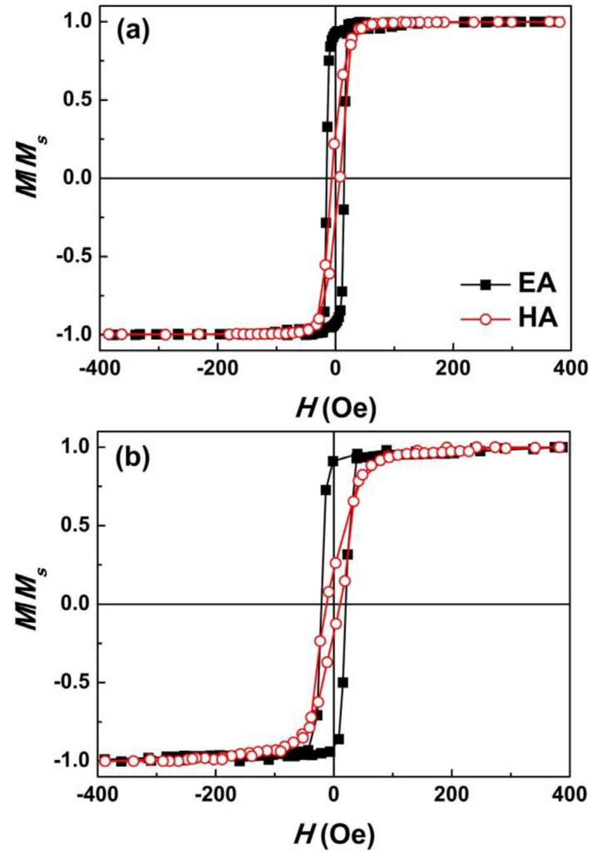

Fig. 2. The *M-H* loops along the easy and hard axes of multilayer films (a) t = 0 and (b) 6 nm.

good soft magnetic properties. Moreover the difference between the hysteresis loops measured along EA and HA direction displayed an in-plane uniaxial magnetic anisotropy (IPUMA), and it was obtained without using oblique sputtering and magnetic field, which was also reported in previous work [12]. Fig. 3 showed the coercivity of EA and HA H_{ce}, H_{ch} and in-plane anisotropy effective field H_k as a function of the thickness t. As seen in Fig 3, the H_{ce} and H_{ch} increased from 13 Oe to 23 Oe and 6.5 Oe to 19 Oe as the ferrite thickness t increased respectively. Meanwhile, as t increased H_k varied from 17 Oe to 52 Oe, which is consistent with the changed trend of the H_c. It may be due to introduce larger magnetic anisotropy of the ferrite layer and interface magnetic anisotropy between CoNb and ferrite layer added [20–21]. Furthermore, as t increased from 0 to 2 nm, the H_k increased

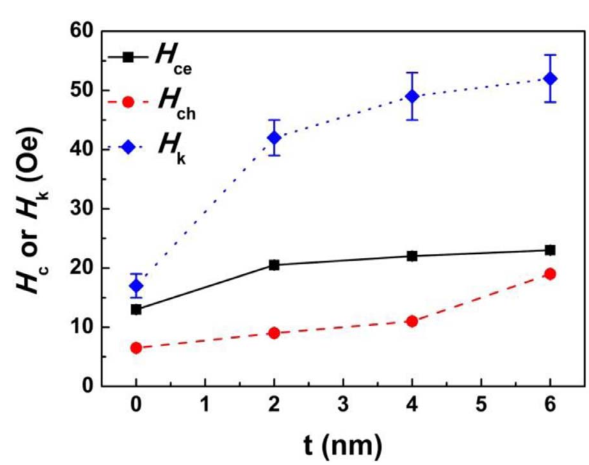

Fig. 3. H_{ce}, H_{ch} and H_k of multilayer films as a function of the Ni-Zn ferrite layer thickness t nm.