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Influence of substrate type on the property of nickle–zinc ferrite thin films

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Abstract

$Ni_{0.45}Zn_{0.5}Mn_{0.05}Fe_2O_4$ ferrite thin films (NZFs) were deposited on different substrates [Si(100), Si(111) and $MgAl_2O_4$(100)] by radio frequency (RF) magnetron sputtering method. The phase structure, surface morphology and magnetic property of NZFs were investigated using the X-ray diffractometer (XRD), atomic force microscopy (AFM) and vibrating sample magnetometer (VSM), respectively. All the NZFs deposited on three kinds of substrates possess spinel structure, while only the film deposited on $MgAl_2O_4$(100) substrate [NZF/$MgAl_2O_4$(100)] has a preferred orientation along the direction of (100) because of the strong inducing effect of substrate. NZF/$MgAl_2O_4$(100) owns smoother surface than that of the film deposited on Si(111) substrate [NZF/Si(111)]. However, NZF/$MgAl_2O_4$(100) possesses larger grain size and much inhomogeneous distribution of grain size than that of NZF/Si(111). NZF/$MgAl_2O_4$(100) has the greatest saturation magnetization (M_s) of 345 kA/m and coercivity (H_c) of 5.80 kA/m. According to the stress model, the coercivity of NZFs deposited on various substrates has been calculated and discussed, which matches with the experiment results.

Keywords: NiZn ferrite thin film; Magnetron sputtering; Substrate type; Surface morphology; Magnetic property

1. Introduction

NiZn ferrites have favorable properties such as high saturation magnetization, low eddy current losses, and high resistivity, which can be applied in thin film devices of high frequency like transformers, inductors and so on [1,2]. During the past decades, the trend on miniaturization and integration of electromagnetic devices requires the soft magnetic materials with downsizing and lightweight design. Therefore, the investigation about NiZn ferrite thin films (NZFs) is vital for their potential applications in integrated electromagnetic devices. The preparation methods of NZFs mainly include pulsed laser deposition [3], spin spray plating [4,5], sol–gel [6,7], and magnetron sputtering [8,9]. In comparison with other preparation methods, radio frequency (RF) magnetron sputtering has been extensively studied for its large area deposition, high adhesion and efficiency.

It is well-acknowledged that the phase structure, surface morphology and magnetic property of ferrite films are dependent on the film composition, sputtering process and annealing parameters. Yan et al. [6] have deposited $Ni_{1-x}Zn_xFe_2O_4$ ($x=0.0-0.7$) ferrite films on Si substrate. When the substitution amount of zinc was 0.5, NiZn ferrite film showed high saturation magnetization (M_s) of 683 kA/m at room temperature. By altering the argon (Ar) pressure from 0.8 to 1.6 Pa, the preferred orientation of NiZn ferrite film with a nominal composition of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ changed from (311) to (400) in reference [8]. Simultaneously, the influence of annealing parameters on the structure and magnetic property of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ ferrite film has been investigated in reference [10]. The NiZn ferrite films showed a high saturation magnetization (M_s) of 320 kA/m and low coercivity (H_c) of 6.85 kA/m when the films were annealed at 700 °C, heating rate 2 °C/min, and duration time 1 h. Moreover, grain growth of NiZn ferrite thin films deposited on Si(100) can also be affected by annealing temperature and duration time. As the results showed, with the annealing temperature increasing from 700 to 900 °C, correspondingly grain growth exponent went up from 3 to 4, indicating that volume diffusion happened [11]. Wang et al. [12] have investigated the effects of annealing temperature on the structural and magnetic properties of the

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$Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite thin films on Si(100) substrate. The results showed that H_c decreased from 14 to 11 kA/m when the average grain size increased from 47 to 172 nm by varying the annealing temperature from 600 to 900 °C, while M_s increased from 433 to 544 kA/m. In addition, the substrate type is very important for growing magnetic films with high quality in view of the lattice mismatch and the difference of thermal expansion coefficients between the film and substrate. Aiming at the substrate effects, Wang et al. [13] have discussed the property of $Mn_{0.5}Zn_{0.5}Fe_2O_4$ ferrite thin films deposited on different substrates to testify the hypotheses above. According to the stress model, the H_c of $Mn_{0.5}Zn_{0.5}Fe_2O_4$ ferrite thin films is mainly affected by the thermal stress which is determined by the difference of thermal expansion coefficients between the film and substrate. However, there are few reports on the dependence among the substrate type, phase structure and magnetic property of NiZn ferrite films (NZFs). This presentation will demonstrate the various substrates on the phase structure and magnetic property of NZFs. In this current work, one deposited the NZFs on different substrates [Si (100), Si(111) and $MgAl_2O_4$(100)] by RF magnetron sputtering, and the preferred orientation and magnetic property were studied and the theoretical coercivity (H_{cm}) was calculated based on the stress model.

2. Experimental procedures

The 600 nm thick NiZn ferrite thin films (NZFs) were deposited on different substrates by RF magnetron sputtering method. The NZFs deposited on Si(100), Si(111) and $MgAl_2O_4$(100) substrates were labeled as NZF/Si(100), NZF/Si(111) and NZF/$MgAl_2O_4$(100), respectively. The target used for deposition was a sintered ferrite with the composition of $Ni_{0.45}Zn_{0.5}Mn_{0.05}Fe_2O_4$. The background pressure was less than 4×10^{-4}Pa. The deposition parameters were sputtering power 140 W, pressure 1.4 Pa (argon) and heating temperature of substrate 300 °C. The samples were annealed at 800 °C in air for 2 h. X-ray diffraction patterns of the samples were recorded using an X-ray diffractometer (XRD, DX-2700) with Cu Kα radiation. Surface morphology of the films was observed by an atomic force microscope (AFM, SPA-300HV). The grain size (D) and surface roughness (RMS) were analyzed by the software of SPI4000. The in-plane static magnetic property at room temperature was carried out with applied static magnetic field up to 400 kA/m by a vibrating sample magnetometer (VSM, BHV-525).

3. Results and discussion

3.1. Structural and morphological characterization

Fig. 1 shows the XRD patterns of NZFs deposited on different substrates. All the NZFs possess spinel structure. NZF/$MgAl_2O_4$(100) presents the preferred orientation along the direction of (100), while NZF/Si(100) and NZF/Si(111) possess other diffraction peaks besides (400) diffraction peak. It means that NZF/Si(100) and NZF/Si(111) are typical polycrystalline ferrite films. Apart from the spinel phase, there are few impurity phases like FeO(200) as shown in Fig. 1(a) and (b) exclusively.

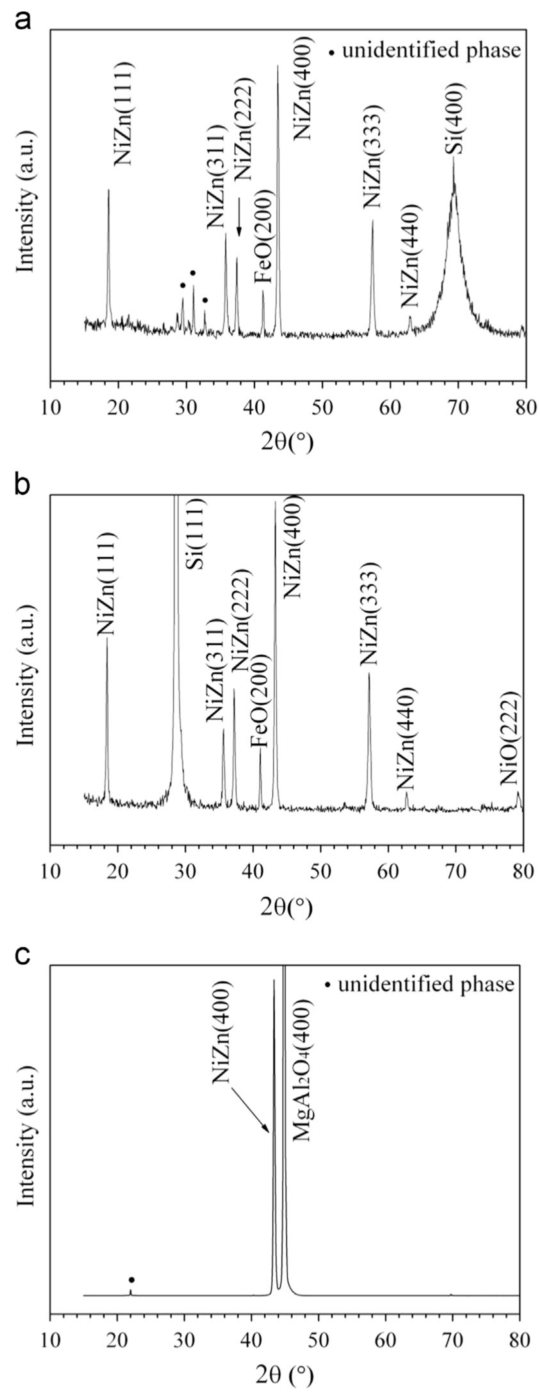

Fig. 1. XRD patterns of $Ni_{0.45}Zn_{0.5}Mn_{0.05}Fe_2O_4$ ferrite films (NZFs) deposited on different substrates: (a) NZF/Si(100), (b) NZF/Si(111) and (c) NZF/$MgAl_2O_4$(100).

It is well-acknowledged that the lattice parameters of Si, $MgAl_2O_4$ substrates and NiZn ferrite film are 0.5446 nm, 0.8080 nm and 0.8339 nm [14–16], respectively. The lattice mismatch of NZF/$MgAl_2O_4$(100) is only 3.21%, hence $MgAl_2O_4$(100) substrate shows the strong inducing growth along the direction of (100) (see Fig. 1c). However, the lattice mismatch of NZF/Si despite Si(100) or Si(111) substrate is