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Thin ferrite films deposited by PLD on silicon substrate

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$NiFe_2O_4$, $NiZnFe_2O_4$, $ZnFe_2O_4$ and $BaFe_{12}O_{19}$ ferrite crystalline and amorphous films were grown on silicon. The energy of the laser beam, the O2 pressure, the substrate temperature, and the distance between the target and the substrate were varied in order to establish the optimal deposition conditions. The microstructures of the thin films were characterized by XRD, SEM, EDAX, SIMS and AFM analysis. The XRD patterns of the thin films as deposited feature small peaks corresponding to the spinel phase. By annealing, the peaks become evident and show the high crystallinity of the samples. The results of SIMS and EDAX analysis prove the high stoichiometry of thin films obtained by PLD technique. Great deposition rate was registered for small distance target – substrate, but in this case the films hasn't homogeneity and many aggregates were observed in the thin film surface. Increasing the target – substrate distance the deposition rate becomes lower but the homogeneity is good and rarely aggregates were observed on the thin film surface. The results suggest that the crystallized ferrite films fabricated in our study are a mixture of amorphous phase and crystallites with the spinel structure. Annealing for fully crystallization may achieve a further improvement in microstructure and XRD patterns.

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Keywords: Pulsed laser deposition, Soft ferrite film, Silicon substrate

1. Introduction

Soft ferrites are widely used in electronics. Soft magnetic thin films with high electric resistivity are needed for developing microinductors and microtransformers. An important step in realization of planar ferrite devices is the study of the influence of the microstructure on the magnetic properties.

The magnetic properties depend on the induced anisotropy caused by the comprehensive strain to the thin film plan [1]. Some times the films consist of small crystalline grains surrounded by thin region of amorphous material. Postdeposition annealing improves the crystallinity of the films, at the same time reducing the field required for saturation. For Ni ferrite film was observed that the interlayer exchange coupling increases when the bilayer is annealed at temperatures below 600°C [2,3]. For integrated planar circuits operating at high frequencies however, designs based on thin NiZn ferrite films are expected to have important application [4]. The oxygen pressure during growth affects the unit cell volume and stress of the film [5]. The Zn ferrite films, tough antiferromagnetic, are studied for application to magnetic devices, particularly the optical magnetic memory devices [6].

This paper is focused on the PLD of few ferrite films on silicon as most used substrate in electronics. The temperature of the substrates is a very important factor and the microstructure of the films depends on this. The main purpose of this work was to clarify the influence of the substrate and of the temperature of the substrate on the microstructure of the ferrite films. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) have been used to observe the microstructures and morphological characteristics, to which the quality of the film is highly sensitive. The film structure was determined by X-rays diffraction analysis (XRD) and compared with that of the bulk material. The energy dispersive X ray analysis (EDS) and secondary ion mass spectroscopy (SIMS) were used to verify the stoichiometry of the samples. The magnetic properties were studied by vibrating sample magnetometer (VSM) measurement. The results are interpreted in terms of the role of the PLD parameters and of the post annealing process on the microstructure and magnetic properties of the thin ferrite films.

2. Experimental Results

All The ferrite targets with nominal composition $NiFe_2O_4$, $Ni_{0.5}Zn_{0.5}Fe_2O_4$, Zn Fe_2O_4 and $BaFe_{12}O_{19}$ were prepared by the usual soft ceramic technique [7]. The structure of the targets was determined by X-ray to be compared with the thin films structure.

The deposition of the Ni, NiZn and Zn thin films was done in a stainless-steel high-vacuum chamber, as described elsewhere [8,9] using an excimer laser, Lambda Physik model COMPex 102. The films were grown with a pulse energy in the range of 65 –75 mJ, at a repetition rate of 10 Hz. In all the cases discussed in this paper the substrate was the silicon (100). Flowing O_2 gas pressure ranging between 1 and 200 mTorr was used [10]. The substrate temperature during deposition was between 400 - 600°C. The deposition time was increased from 30 min to 2 hours. The thickness of the films was determined with a profilemeter with 5 Å resolutions or by ellipsometric measurements and by SIMS measurement presented in Fig. 1.

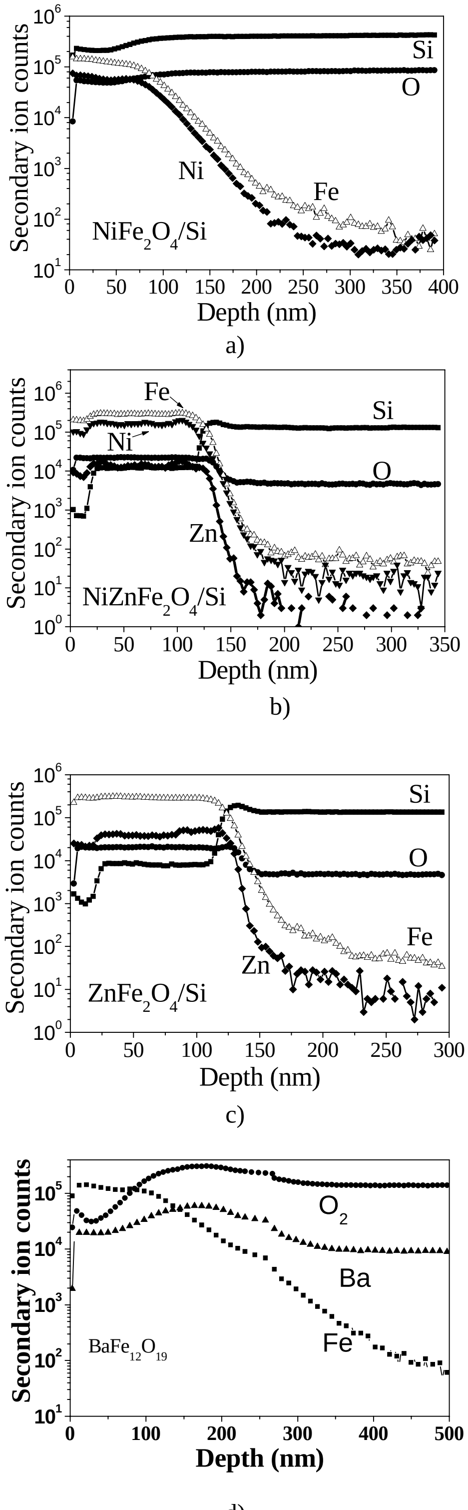

Fig. 1. The SIMS anlysis of the thin films: a) NiFe$_2$O$_4$ b) NiZnFe$_2$O$_4$ c) ZnFe$_2$O$_4$ d) BaFe$_{12}$O$_{19}$

The films have kept the stoichiometry of the sample as SIMS measurements have proved. The target – substrate distances, influences the thickness of the films. The rate deposition ranges between 2 – 20nm/min. The microstructure of the thin films is influenced by the distance substrate – target and by the energy of the laser beam.

Short distances promote target splashing and the film surface becomes rough. If the distance increases to 4 – 5 cm the droplets are rare as feature the picture in Fig. 2. This sample was deposited in oxygen at 50 mbar and the substrate temperature was kept at 550°C. The beam energy was 65mJ and the pulse frequency was 5Hz. The XRD pattern has demonstrated the coexistence of the crystalline and amorphous phases (see Figure 3). The post annealing of the thin films at 1000°C for 2 hours induces amorphous phase transformation in crystalline one.

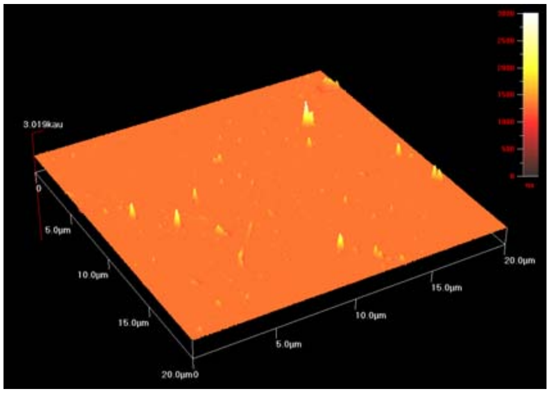

Fig. 2. The AFM picture of the thin ZnFe$_2$O$_4$ films grown on silicon substrate heatted at 550°C.

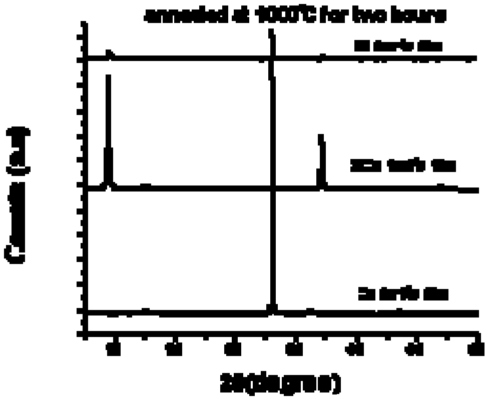

Fig. 3. The XRD patterns for Ni, NiZn and Zn films deposited in the same condition and annealed at 1000 °C for 2 hours.

In Fig. 3 is presented a SEM picture of the Zn ferrite thin films as deposited. Two phases are present in this picture. One is the crystalline one as small islands in an amorphous aggregation. By annealing the amorphous phase transforms in crystalline phase. Magnetic measurement done using vibrating sample and Squid measurements have demonstrated the influence of the PLD parameters on the microstructure and magnetic properties of the thin films.

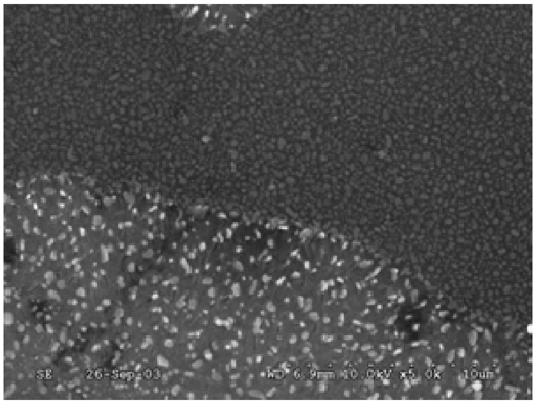

Fig. 4. The SEM picture of Zn films as deposited at 50 mtorr O_2 pressure and at 550°C substrate temperature.

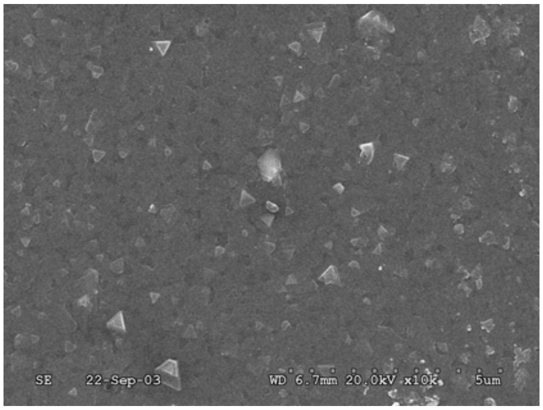

Fig. 5. The SEM micrograph of the as deposited barium ferrite film at 50mtorr O_2 pressure and at 550 °C substrate temperature.

A special attention was paid to the deposition of the barium ferrites on silicon substrate [11,12]. The microstructure of the thin film growth on silicon heated at 550 °C under 50 mTorr O_2 pressure is presented in Fig. 5. The SEM micrographs and the XRD patterns, presented in Fig. 6, confirm the crystalline structure of the thin films the highest deposition rate, 15 nm/min, was obtained for distance target – substrate 2 cm, but in this case the films are not homogeneous and many aggregates were observed in the thin film surface. Increasing the target – substrate distance to 5 cm the deposition rate diminishes down to 5 nm/min, but the homogeneity is good and rarely aggregates were observed on the thin film surface. The microstructure of the film grown in optimal conditions consists in a smooth surface and the average grain size is below the micrometer range.

3. Conclusions

This study shows that it is difficult to establish a common route in obtaining on silicon substrate, in similar condition, various ferrite films. The stoichiometry of the ferrites could be kept by controlling the oxygen pressure. The temperature of the substrate is a significant factor that controls the formation of the phases.

Acknowledgments

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