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Effect of Measurement Geometry on Permeability Measured by a Broadband Method

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Increasing the frequency of electro-magnetic devices has been continuously forced magnetic materials to operate over several GHz range. This trend also requires an easy and precise measurements method for the frequency dependent permeability of the magnetic materials. In general, the permeability measurement techniques have been classified into two groups. The first one is utilizing the impedance variations of a pick-up coil impulsed by an external electromagnetic field. This technique has been widely used and considered as a reliable and accurate measurement in MHz frequency range. The second method is utilizing transmission line (TL) including stripline, coplanar waveguide (CPW) and coaxial transmission line [1-2]. These TL methods have been shown to measure the permeability of films over GHz ranges. Among various TL, coplanar waveguide (CPW) can be adequate for the high frequency range and easy implementation of magnetic samples with little restriction. Therefore, this research was aimed to establish the measurement method using CPW and to investigate the feasibility and limitation of this method. In this experiment, permalloy (100~1000nm), 4 πM_s of ~10 kG and H_c of ~0.5 Oe, were fabricated by RF magnetron sputtering system in Ar plasma atmosphere. The permeability measurements for the films were performed by both a broadband CPW and a network analyzer and commercial permeameter based on a single turn strip loop. The CPW was designed near 50 Ω impedance matching the network analyzer and cables. Fig.1 showed schematic diagram of broadband CPW permeameter. To obtain the S-parameters, the magnetic films with an area of 4 x 4 mm^2 were placed on the CPW and 2 μm thick polyimide films were used for separation of two layer. And hard magnetic direction of the films was aligned both parallel and perpendicular to magnetic field direction of the signal line. In order to consider the effects of the measurement geometry on the permeameter, the thickness of the films and the width of the signal lines were varied. As a result, the permeability of the films was shown to be strongly dependent on the geometry. This dependency was proven to be related with the demagnetization field caused by the geometry through the analysis of the LLG equation.

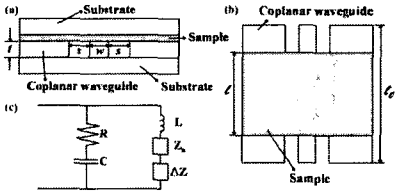

Fig. 1. Schematic diagram of broadband CPW permeameter. a) Cross sectional view, b) Top side view, c) Equivalent circuit.

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Annealing Effect on Magnetostatic Properties Nanocomposite Fe-Zr-N Films

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Soft magnetic thin films are widely used in devices of modern microelectronics as a high-frequency (f > 100 MHz) field-amplifying components, in particular, in read-write heads. High saturation induction ($4\pi M_S$), low coercivity (H_C), high permeability, thermal stability up to 600°C and high anticorrosion are the most desirable characteristics of these materials. For the last years, the iron-rich Fe-Zr, Fe-Ta, Fe-Hf, Fe-Ti films with nitrogen incorporation were found to exhibit the above properties. Moreover, the post-deposition heat treatment of the films at a relatively high temperature of 300-600 °C promotes an improvement of their soft magnetic characteristics. In the present work, we report results on the investigation of the magnetic properties and microstructure of the as-deposited and annealed at T = 200-700 °C Fe-Zr-N films.

The Fe-Zr-N films with the 0.7-μm thickness were deposited by RF sputtering onto glass square substrates. The samples were prepared at power value P = 150 W and deposition time τ = 100 min. Structural properties were studied by means of the X-ray diffraction technique. The bulk magnetic characteristics of the Fe-Zr-N films have been measured by a vibrating sample magnetometer (VSM). The study of the near-surface magnetic properties of the samples was carried out employing magneto-optical micromagnetometer (MOMM) with a surface sensitivity of about 20 nm of the thickness depth.

The experimental data, obtained by both VSM and MOMM, are evidence of the absence of in-plane magnetic anisotropy in the whole examined Fe-Zr-N films. The near-surface values of the coercivity, H_C^{SURF}, and the saturation field, H_S^{SURF}, were found to be 1.1-1.2 times as much than H_S^{BULK} and H_C^{BULK}. This fact can be ascribed to different domain structure of near-surface and volume film regions. It was discovered that with increasing annealing temperature, the change of the saturation magnetization MS does not exceed ± 10 %. Actually, the increase and the decrease of MS were observed for the films, annealed at T = 450-525 and 600-700 °C, respectively. The saturation induction, BS, of the annealed at T = 525 °C film was equal to 1.9 T. At the same time, the strong annealing effect on the values of H_C and H_S was revealed. In particular, with increasing annealing temperature to 450 °C, the magnitudes of H_C and H_S decrease, and at T > 525 °C, they increase. At T = 450 and 500 °C, H_C and H_S have minimal values (H_S^{BULK} ~ 2 Oe, H_C^{BULK} ~ 0.05 Oe). The temperature dependences of H_C and H_S were explained by microstructure changes of the Fe-Zr-N films after their post-deposition heat treatment.

The near-surface hysteresis loops, observed for the Fe-Zr-N films, have attracted attention. It was found that the loops of the as-deposited and annealed at T > 600 °C films have conventional forms, and those, observed for the films, annealed at T = 200-525 °C, have complicated shapes. According to [1], the discovered unusual hysteresis loops are possible only in magnetically inhomogeneous samples. This fact indicates that at T = 200-525 °C, the near-surface film layer of 20-nm thick, which is measured by the magneto-optical method, have heterogeneous structure, and at T > 600 °C, it becomes homogeneous.

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