FeNi thin films deposited onto polymer-FeNi nanoparticles composite substrates

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Abstract

Magnetic nanoparticles (MNPs) are the subject of intensive research due to the special properties required for technological and biomedical applications [1]. It was shown earlier that fundamental magnetic characteristics including the saturation magnetization depend on the variations of size and shape of MNPs [2-3]. MNPs embedded in polymer matrices are an excellent example of functional nanostructuers with potential for application such as biomedical sensing devices, flexible electronic, electromagnetic shielding, magnetic inks and adhesives etc. [3-4]. The composite would have a lighter weight then a purely metallic compound but may have comparable and even better electromagnetic properties, with the possibility of other multi-functionality. The compounds could be also used as covers to protect sensors or other electronics form corrosion while increasing the sensitivity of the sensor. One of the expanded areas are flexible substrates for magnetic field sensors and biosensors based on giant magnetoimpedance [5]. In this work we designed, fabricated and tested polymer/FeNi MNPs/thin FeNi film composites for electronic applications.

The electrophysical method of electric explosion of wire (EEW) was used for the fabrication of FeNi MNPs. Detailed description of EEW installation can be found elsewhere [6]. The roll of FeNi wire (Fe – 48 wt%, Ni – 52 wt% diameter 0.5 mm) was positioned at the top of the feeding mechanism which pushed the wire into the reaction chamber through a calibrated hole in the metal contact plate, playing the role of the upper electrode of a parallel plate capacitor. The electrodes were connected to a direct current high voltage source. The voltage applied to the electrodes was 30 kV and the distance between the contact plates was 70 mm. The specific surface of the permalloy MNPs was determined by low temperature nitrogen adsorption technique (BET) using Micromeritics TriStar 3000. FeNi-filled composites were prepared based on the commercially available acrylic copolymer of 95% of butyl methacrylate and 5% of methacrylic acid hereafter marked as BMK-5. Liquid casting method for the composites preparation was elaborated. Acrylic polymers are versatile and well compatible with most of the inorganic materials including metals and metal oxides due to the presence of polar ester groups in the monomeric units. The composites containing 0 and 5 wt. % of MNPs were prepared. Fe20Ni80 thin films of 100 or 200 nm were deposited onto polymer, composite and glass substrates by rf-sputtering (Figure1).

The X-ray powder diffraction patterns were collected on a Bruker D8 Advance diffractometer equipped with a Cu tube, Ge(111) incident beam monochromator (k = 1.5406 A). The sample was mounted on a zero background silicon wafer embedded in a generic sample holder. Preliminary identification of the initial phases was evaluated using the Powder Diffraction File (PDF) database. PANalytical X'Pert High Score program was used for identification and Miller indexing of all observed maxima. Scanning electron microscopy (SEM) was done by JEOL JSM-7000F operating at 30 kV. The X-ray powder diffraction data were in good agreement with single phase FeNi cubic bcc structure The calculated average crystallite size d = 45 ± 5 nm is in a good agreement with SEM results. Comparative analysis of structural features and magnetic properties of FeNi films deposited onto polymer and polymer/FeNi MNPs substrates revealed certain advantages of composite substrates (perhaps due to the thermal and electric conductivity providing better conditions for the sputtering deposition). The next steps will be to improve adhesion between composite and metallic film, to improve magnetic anisotropy of FeNi films and to study microwave properties of obtained composites.

References

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Figures:

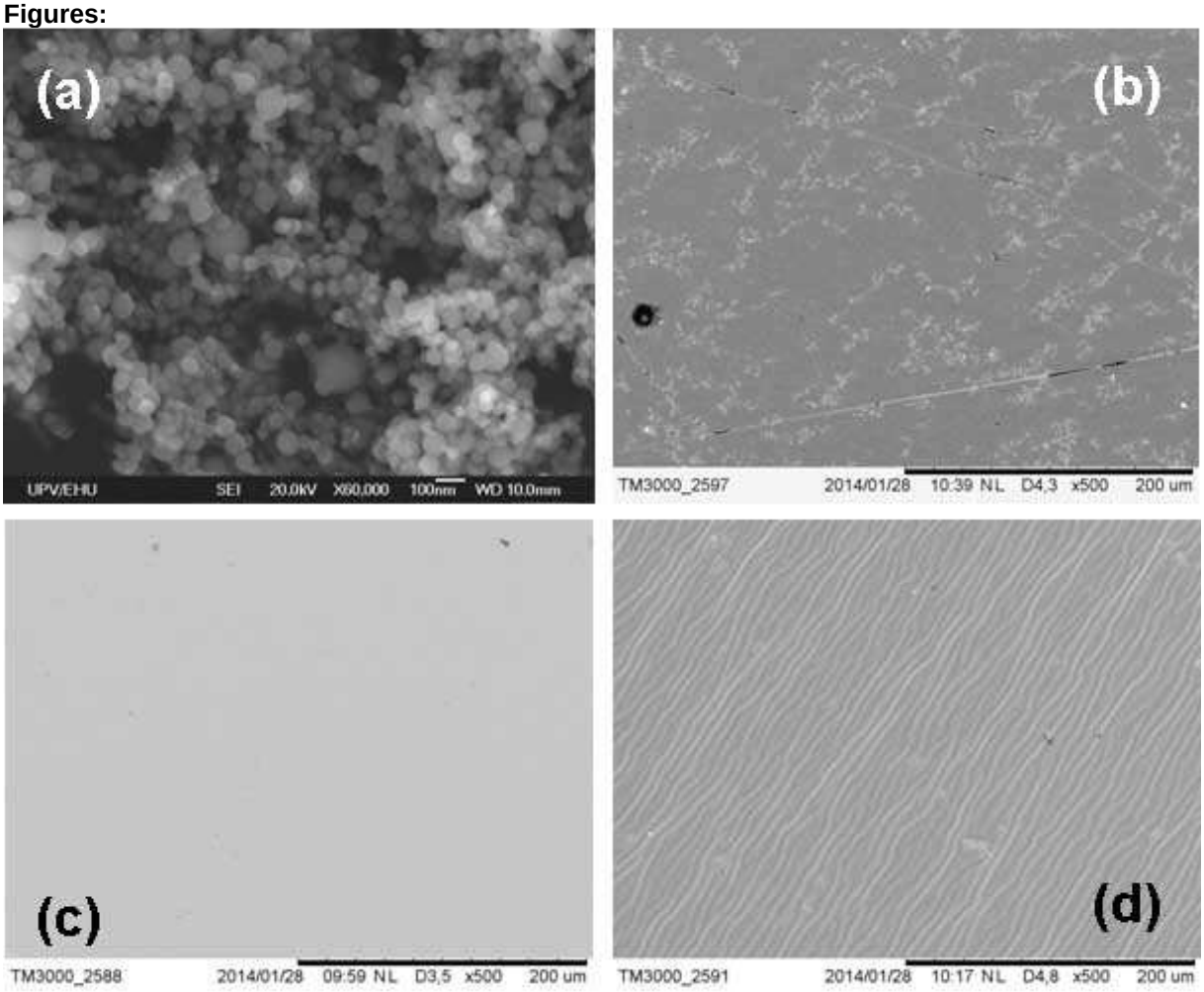

Figure 1. Structural features of the samples studied by SEM: (a) FeNi MNPs. Polymer/5% FeNi MNPs FeNi film of 100 nm (top view): MNPs are seen through the metal film and their distribution can be studied (b). Thin FeNi film of 100nm deposited onto glass substrate has very low roughness (c). FeNi thin film of 100 nm deposited onto polymer substrate without MNPs - higher roughness and specific "wave" structure (comparing with FeNi film deposited onto substrate with FeNi MNPs) shows a disadvantage of pure polymer substrate.

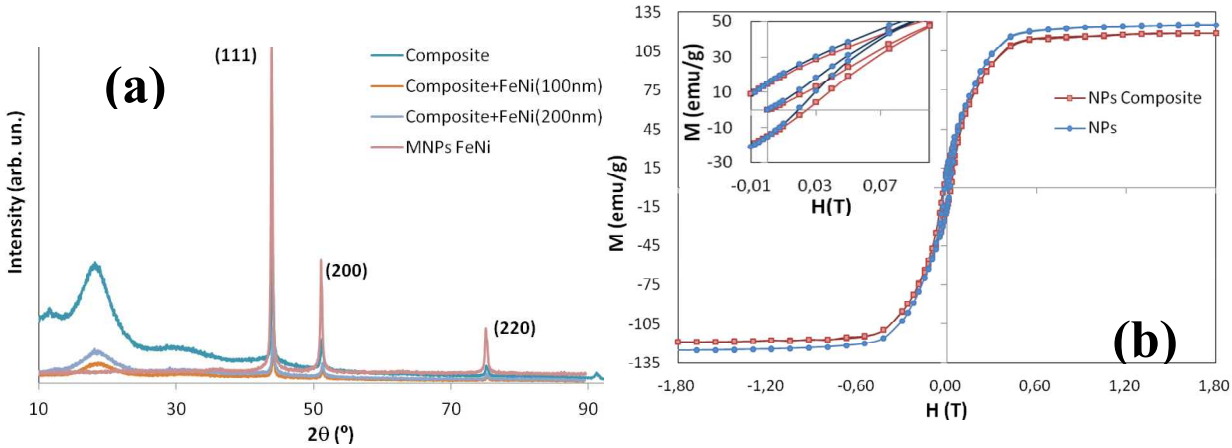

Figure 2. X-ray powder diffraction pattern including (hkl) Miller Index for the EEW FeNi MNPs, composite polymer/FeNi MNPs and FeNi films deposited onto composite substrates (a). Hysteresis loops of FeNi nanoparticles and MNPs in polymer matrix (5% concentration), inset shows primary magnetization curves difference (b). Although the saturation magnetization (recalculated on the mass of the nanoparticles) is only slightly lower in the case of the composite there is a clear difference in the primary magnetization curve slope.