PA10

Exchange Bias and Magnetic Hardening in $NiFe_2O_4$/NiO Composites

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Much attention of exchange biased investigation has been paid on bilayer or multilayer films, core-shell nanoparticles, and ball-milled nanocomposites [1]. In this article, we present an easy way to synthesize $NiFe_2O_4$/NiO nanocomposites which are homogeneous mixtures of $NiFe_2O_4$ and NiO in the required stoichiometric proportions. Moreover, the structural and magnetic properties of $NiFe_2O_4$/NiO nanocomposites were systematically studied as functions of NiFe2O4 concentration and particle sizes. The composition of nanocomposites, with formula $(NiO)_{100-x}(NiFe_2O_4)x$ ($7.7 \le x \le 45.8$ vol.%), was prepared by combustion of mixtures of nickel nitrate, iron nitrate, citric acid, and glycine. The combustion ashes were furtherheat treatment to obtain nanosized $NiFe_2O_4$ embedded in a NiO nanoparticle matrix. The mean crystallite sizes of the samples, annealed in air at 200-1000℃ for 1hr, are in the range from 5.8 to 53.1 nm. Magnetic hysteretic measurements after field cooling revealed an exchange bias at low temperatures in such nanocomposites meanwhile, a coercivity enhancement for samples annealed at the temperature T≥700℃ was observed. The effect of the crystallite size, the composition and the temperature on the shift of the hysteresis loops and the increment of the coercivity of the samples has also been analysed. As the annealed temperature increases, the coercivity (H_C) increases to show a maximum and dropped. The HC maximum is centered on annealing temperature 700C, independent of the composition of samples, and the corresponding crystallite size is between 23.4 and 32.7 nm. The highest coercivity ($H_C \approx 1.4$ kOe at T=78 K) and exchange-bias field ($H_E \approx 0.63$ kOe at T=78 K) were measured in a sample with $NiFe_2O_4$ volume % of x =10.32. The observed variations are explained in terms of interfacial exchange coupling between a ferromagnetic phase (the $NiFe_2O_4$ particles) and an antiferromagnetic phase (the NiO matrix), whose magnetic moment configuration is strongly affected by the field-cooling process. Hence, the combustion process is demonstrated to be a suitable technique to develop new types of FM-AM exchange-biased nanoparticles, from which novel applications of this phenomenon may be developed.

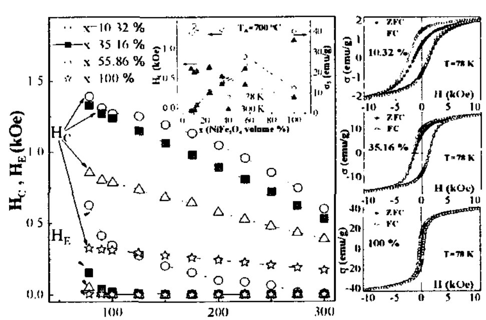

Fig. 1 (Left) Variation of the H_C and exchange field (H_E) with temperature for $NiFe_2O_4$/NiO nanocomposites with x = 10.32, 35.16, 55.86, and 100 volume % annealed at T_A = 700 °C. Inset: Coercivity (H_C) and saturation magnetization (σ_S) vs x($NiFe_2O_4$ volume %) for $NiFe_2O_4$/NiO nanocomposites annealed at T_A 700 °C. (Right) Hysteresis loops of ZFC and FC measured at 78 K for $NiFe_2O_4$/NiO nanocomposites with x 10.32, 35.16, and 100 volume % annealed at T_A 700 °C.

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PA11

Magnetic Properties and Microstructure of Nano-grain $L1_0$ FePt(200) Films

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Recently, faced-centered tetragonal (fct) $L1_0$ FePt phase thin films have much attention [1-4] because of its high uniaxial magnetocrystalline anisotropy energy ($K_u \sim 10^8$ erg/cm^3), large coercivity (H_c), high saturation magnetization (Ms), and good corrosion resistance. Most investigations focued on its outstanding perpendicular magnetic anisotropy. The microstructure, magnetic properties, and formation mechanisms of $L1_0$ FePt(001) structure are also clearly pointed out. However, the in-plane magnetic anisotropy $L1_0$ FePt thin films were seldom investigated. Therefore, the magnetic properties, microstructures, and formation mechanisms of in-plane magnetic $L1_0$ FePt thin films were still unanswered. In this investigation, $L1_0$ FePt films and CrRu underlayer were deposited on a preheated natural-oxidized silicon (100) wafer substrates by conventional dc magnetron sputtering. The substrate temperature (T_s) was ranged from 275 to 450℃. Form the magnetic measurements, the out-of-plane coercivitys ($H_{c\perp}$) were lower than 700 Oe, but the in-plane coercivity ($H_{c//}$) rapidly increased from 200 Oe to about 2100 Oe when T_s was increased from 275 to 325℃, and then almost kept constant with the further increment of T_s to 400℃. Besides, the in-plane squarenesses (S//) of FePt/CrRu bilayer films increased from 0.78 to about 1 as the T_s was increased from 275 to 350℃, and declined to 0.53 when the T_s was further increased to 450℃. It indicates that the alignments of c-axis on the plane became increased as T_s was rose from 275 to 350℃. Further increased T_s to exceed 350℃, interlayer diffusions at FePt/CrRu interface destroyed alignments of c-axis on the plane and declined the $S_{//}$. The FePt films staked on CrRu underlayer favored to exhibit the in-plane magnetic anisotropy when T_s = 275 - 350℃. This result was also in agreement with x-ray diffraction(XRD). From XRD, only FePt(200) and CrRu(002) peaks were found when T_s = 350℃. This indicates that the CrRu(002) texture underlayer can induce the FePt(200) orientation which lets the easy-axis of [001] lie on the film plane. The hysteresis loops also confirmed that the easy-axis is parallel to the film plane. The in-plane saturation filed is about 5 kOe and the $H_{c//}$ is about 2150 Oe. However, when the applied field was aligned to out-of-film plane, the loop cannot be saturated even under 12 kOe. The S// closed to one and greatly exceeded the $S_\perp$. In order to understand the effects on the epitaxial growth at the FePt/CrRu interface, the cross sectional TEM bright field image of FePt(200)/CrRu(002) bilayer film are also investigated. A good epitaxial crystal growth starts from CrRu(002) underlayer and extends into FePt(200) magnetic layer. The lattice constant of CrRu is 2.91 Å, and the a-axis and c-axis lattice constant of FePt are 3.86 and 3.72 Å. Accordingly, the diagonal distance in the [011] direction is 2.68 Å. The lattice mismatch between $Cr_{90}Ru_{10}$(002)[100] and $L1_0$ FePt(200)[011] is about 8.6 %. When the FePt magnetic layer was deposited on textured CrRu(002) underlayer, the $L1_0$ FePt(200) preferred orientation generated from the epitaxial growth of CrRu(002)[100] ‖ $L1_0$ FePt(200)[110]. Some mismatch dislocations were observed, in order to modulate the mismatch strain energy at FePt(200)/CrRu(002) interface. From the plane view TEM bright field images, a uniform dispersed and nano-$L1_0$ FePt grain with an average grain size of about 8.6 nm was clearly observed as FePt(200)/CrRu(002) bilayer film deposited at 350℃.

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