

RBS and PIXE analysis of nanostructured magnetic FePt-based alloys

CRISAN Ovidiu¹, Vasiliu Florin¹, Crisan Alina¹, Mercioniu Ionel¹

Pantelica Dan², Pantelica Ana², Ionescu Paul², Statescu Mihai², Dracea Maria Diana²

¹National Institute for Materials Physics, RO077125, 105 Atomistilor Str., Magurele-Bucharest, ROMANIA

²Horia Hulubei National Institute for Physics and Nuclear Engineering (IFIN-HH), P.O.B. MG-6, RO-077125, 30 Reactorului St., Magurele, ROMANIA

The major objective is the R&D of novel rare-earth (RE) free nanocomposite magnets derived from the FePt binary alloy system[1,2]. Compared with either Nd-Fe-B or Sm-Co permanent magnets (PM), the FePt-based PM exhibit superior corrosion resistance and can operate at significant higher temperatures due to their higher Curie point. The promising FePt system can provide nanocomposite magnets with good magnetic properties, especially in the high temperature and corrosion-resistant applications. The hard magnetic $L1_0$ FePt phase has high coercivity, high magnetocrystalline anisotropy and its Curie temperature is around 500°C. Equiatomic FePt is usually first obtained in its soft magnetic A1 fcc structure and until recently, high temperature annealing (500°C) was thought that is needed in order to promote formation of the hard magnetic ordered $L1_0$ phase. To overcome this fundamental issue and make these magnets economically worthwhile, the so-called temperature of ordering (T_o - equivalent to the temperature of annealing needed to promote the hard magnetic phase) has to be decreased. Our group has proven that it is even possible to achieve the hard magnetic phase without post-synthesis annealing.

Multicomponent FePt-based alloys will be obtained in form of melt spun ribbons by rapid solidification (RS). An appropriate proportion of the hard/soft phases is needed for optimal magnetic properties and may be obtained by careful tuning of Fe:Pt relative proportions in the region where, according to the phase diagram, the $L1_0$ phase is formed.

This interplay of structure and magnetic properties is most finely characterized using synchrotron XRD and neutron diffraction studies. Recent preliminary results of synchrotron XRD studies on FePtNbB alloys [3] showed the co-existence of hard and soft magnetic phases during crystallization of the amorphous precursor, in the temperature range of 500-750C, concurrent with the crystallization process. These results prompts us to further structural investigations using the combined protocol synchrotron XRD and neutron diffraction in order to monitor the

magnetic exchange coupling mechanisms dynamically, during the disorder-order phase transformation process. By this, optimization of the alloy performances and of the hard/soft phase structure via compositional modulation and tuning of synthesis parameters can be achieved for obtaining an exchange coupled hard/soft nanostructured magnet.

FePt-based nanomaterials could be the best choice for high temperature operating nanocomposite magnets in view of their high coercivity and chemical stability. In certain conditions FePt may exhibit both disordered cubic A1 (soft magnetic) and ordered tetragonal $L1_0$ (hard magnetic) phase symmetries, emerged from the same metastable precursor upon synthesis (a sine-qua-non condition for exchange spring magnets [4]). Both soft and hard magnetic phases with sizes at the nanometric scale interact by magnetic exchange-coupling across interfaces, achieving maximum energy products $(BH)_{max}$ far beyond the limit of single-phase magnets. Promising permanent magnet properties of these alloys are associated to the ordered $L1_0$ FePt tetragonal phase. This highly ordered phase has high magnetic anisotropy (107 MJ/m³), high coercivity (0.8 T), and excellent chemical stability [2]. The accomplishment of a microstructure composed of alternatively disposed hard and soft magnetic regions (crystallites) at the nanometric scale requires a tight control of the main parameters implied in the preparation procedures. The hope for permanent magnet materials with improved performance such as higher energy products, but also elevated operation temperatures and better corrosion resistance is thus intimately related to the achievement of true nanoscale structures (< 10 nm) in bulk specimens together with a better control of the chemistry and magnetic properties of the hard/soft interfaces

It was also recently developed [5] a nanocomposite exchange-coupled two-phased magnet based on FePt, made of hard magnetic $L1_0$ FePt nanosized grains dispersed within a soft magnetic residual matrix with high Curie temperature, increased coercivity and energy product. Moreover, a quite outstanding result has recently been obtained by us [6], namely that certain FePtAg-based alloys exhibit direct formation of hard magnetic $L1_0$ FePt phase without the need of post-deposition annealing and shows good exchange spring permanent magnet properties. Very recently, results of in situ temperature dependent XRD studies performed on our FePtNbB samples at DESY-HASYLAB Hamburg have been published [3]. The study allowed the monitoring of the disorder-order A1 to $L1_0$ gradual phase transformation. Thus, the resulting phase structure and $L1_0$ abundance depends on the initial as-cast state and stoichiometry

The phase evolution with temperature is however hindered by the concurrent crystallization processes, and it is necessary to further continue these temperature dependent in situ synchrotron studies for temperatures higher than 750C and for samples such as newly synthesized crystallized FePtAgB [7], samples where optimal magnetic properties can be achieved and further crystallization processes do not interfere with the observation of the disorder-order phase transformation. The microstructure and the relative hard-soft magnetic phase composition have to be correlated with the magnetic exchange coupling mechanism.

Some preliminary PIXE analysis has revealed important compositional differences between various surface areas of FePt-based alloys. In the aim to obtain optimized alloys by improved preparation conditions and annealing treatments, it is necessary to make a systematic analysis of these compositional data, in correlation with the final desired magnetic properties.

Another important point is related to the need of precise determination of the cationic and oxygen composition of such films. RBS analysis will allow to obtain profiles of cationic distributions but also of other important elements, present in these specimens, such as nitrogen and oxygen. Preliminary studies of nitriding in controlled conditions of the FePt-based alloys have revealed improved magnetic behavior induced mainly by the interstitial occupancy of Fe and Pt tetragonal sites by nitrogen atoms, thus inducing controlled disorder-order phase transformation with increased content of the hard magnetic L10 FePt phase. Therefore it is of high interest to detect *depth-selective* the degree of penetration of nitrogen inside the microstructure in relation to the mechanisms of interstitial diffusion into the FePt lattice.

We propose RBS and PIXE analysis of two systems: FeMnPt and FeCoPt. For each of the two systems three specimens (one in as cast state and two with different annealing treatments) must be analyzed. Additionally, for each system, it is very interesting for us to study of one single specimen containing nitrogen and oxygen, for the reasons explained above. Therefore, a total of 8 specimens will be furnished for these investigations.

All specimens are prepared by melt spinning, in the shape of long and continuous metallic ribbons, having a maximum thickness of 20 μm , a length of 1 cm and a width of 3 mm.

This kind of measurements is needed in order to probe the exchange coupling mechanisms at the interfaces between hard and soft magnetic regions. It can also locally probe the influence of the atomic segregation in the intergrain patches and it can provide essential means for optimization the magnetic performances by optimizing the microstructure of the samples at every stage of annealing.

Beam request:

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