



Magnetic nanostructures in FeNbB studied by small-angle neutron scattering

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Abstract

The evolution of nuclear and magnetic microstructure during crystallization of amorphous FeNbB alloys at temperatures between 450°C and 510°C is investigated by a small-angle neutron scattering (SANS). From the nuclear and magnetic scattering the corresponding size distributions of BCC-Fe nanocrystals are determined. The average radius of the magnetized core of BCC-Fe grains has been found to be smaller in comparison with the size of nanograins itself. © 2000 Elsevier Science B.V. All rights reserved.

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Nanocrystalline Fe–M–B alloys (M = Zr, Nb and Hf) exhibit excellent soft magnetic properties in combination with high saturation magnetization values [1]. These heterogeneous materials are prepared by controlled crystallization of amorphous precursors and consist of nanoscale BCC-Fe grains embedded in residual amorphous matrix. The amount as well as the size of nanocrystals depends strongly on the annealing conditions. Small-angle neutron scattering technique, (SANS), allows to determine the size distributions of nanocrystals in partially crystallized alloys as well as the magnetic microstructure [2,3].

Ribbons of the Fe_{80.5}Nb₇B_{12.5} were prepared by the method of planar flow casting and annealed under protective argon atmosphere for 1 h at temperatures between 450°C and 510°C. SANS measurement were carried out at the V4 instrument of the BER II reactor at the Hahn-Meitner Institut Berlin, Germany, at a wavelength of 0.607 nm in a range of momentum transfer $0.05 \text{ nm}^{-1} < Q < 3 \text{ nm}^{-1}$. The samples were placed between the poles of an electromagnet. A horizontal

magnetic field of 1 T has been applied perpendicular to the incident neutron beam. After usual corrections for background, transmission and efficiency, highly anisotropic two-dimensional SANS patterns were found and analyzed according to

$$I(Q, \varphi) = A(Q) + B(Q)\sin^2 \varphi \quad (1)$$

where φ is the angle between the scattering vector Q and the external magnetic field B_0 . For complete alignment of the moments along B_0 , $A(Q)$ corresponds to nuclear scattering and $B(Q)$ to magnetic scattering, which is proportional to the Fourier transform of the magnetisation density $M(r)$.

$A(Q)$ and $B(Q)$ are plotted in Fig. 1(a) and (b) as function of Q . We first note that even the as-quenched state shows evidence of significant scattering intensities below 2 nm^{-1} corresponding to non-crystalline inhomogeneities induced during melt spinning process. The marked increase in the intensity $A(Q)$ and $B(Q)$, observed in the low- Q region with an increase of the annealing temperature up to 510°C reflects the progressive crystallization of the amorphous precursor [4].

From magnetic and nuclear scattering we have determined the particle size distributions by means of inverse Fourier transformation assuming a spherical shape of the particles, as confirmed by TEM [4]. The size

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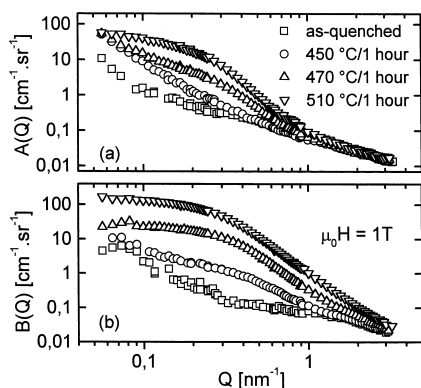


Fig. 1. Nuclear and magnetic scattering curves (a) $A(Q)$ and (b) $B(Q)$ at room temperature in magnetic saturation ($B = 1$ T) for $\text{Fe}_{80.5}\text{Nb}_7\text{B}_{12.5}$ annealed for 1 h at different temperatures.

distributions of spheres weighted by the square scattering contrast and by the volume $V(R)$ are plotted in Fig. 2 as a function of the radius R . For the nuclear contribution (Fig. 2(a)) a first maximum is observed around 1 nm for all samples including the as-quenched alloy. The position of this maximum corresponds well to the size of the clusters with atomic medium-range order (MRO), which were observed in amorphous phase of as-quenched as well as partially crystallized $\text{Fe}_{79}\text{Nb}_8\text{B}_{13}$ alloys by using high-resolution electron microscopy [5]. However, we cannot exclude that this peak is connected also with some artefacts from fitting procedure, which could arise from not considering the existence of shell around the particle (see below). Pronounced second major maxima occur at $R = 4.4, 5.4$ and 6.4 nm for samples annealed for 1 h at $T_a = 450^\circ\text{C}, 470^\circ\text{C}$ and 510°C , respectively. Size and volume fraction of nanocrystalline grains grow with an increasing T_a . From magnetic contribution a similar behaviour is derived as for the particles (see Fig. 2(b)). However, the maxima in $D(R)$ are shifted to lower values of R and the corresponding volume fraction is lower than that of the nanocrystals. This implies that the distribution of a magnetization density within the volume of BCC-Fe nanograins is not fully homogeneous.

In fact the whole series of data can be explained using a shell model by which compositional and magnetization density profiles around the spherical core of the particles were approximated. The existence of Nb-enriched shell in

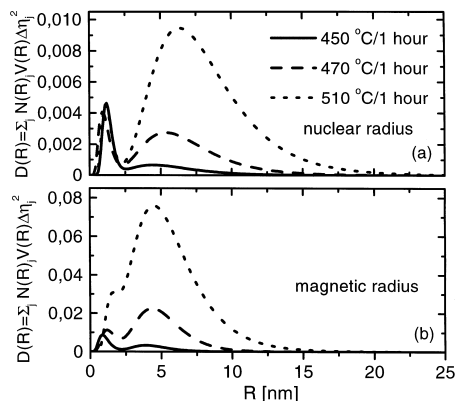


Fig. 2. Size distributions of BCC-Fe nanocrystals in $\text{Fe}_{80.5}\text{Nb}_7\text{B}_{12.5}$ determined from (a) $A(Q)$ and (b) $B(Q)$ assuming spherical particles.

nearest vicinity of nanocrystalline grains has been confirmed for alloys of similar composition by using AP-FIM-technique [6]. The increasing Nb content is known to suppress significantly the Curie temperature as well as the saturation magnetization value in FeNbB alloys, which could result in the presence of magnetically weaker regions at the interphases between the Fe grains and the residual matrix. A detailed analysis by using the shell model is currently in progress and the more extended paper on this subject will be published elsewhere.

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