

Study of the unusual increase in the Curie temperature of the residual amorphous phase in nanocrystalline $\text{Fe}_{90}\text{Zr}_7\text{B}_2\text{Cu}_1$

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Abstract

Nanocrystalline $\text{Fe}_{90}\text{Zr}_7\text{B}_2\text{Cu}_1$ with ferromagnetic BCC nanocrystals of about 10–20 nm size embedded in a residual amorphous matrix was produced from amorphous precursor by partial crystallization. A significant increase in the Curie temperature of the residual amorphous phase (T_C) as compared to that of the amorphous precursor was found by combined bulk magnetic and Mössbauer measurements. The unusual increase of T_C for alloys with different nanocrystalline fractions correlates with the quantity of the BCC phase.

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Nanocrystalline alloys consisting of ferromagnetic BCC nanocrystals of about 10–20 nm size embedded in a residual ferromagnetic matrix show good soft magnetic properties at room temperature [1]. This behaviour is usually attributed to a coupling between these phases, leading to the averaging out of the magnetocrystalline anisotropy of the nanosized grains [2]. Besides the good soft magnetic properties, the anomalous increase of the Curie temperature (T_C) in the connecting amorphous tissue as compared to that of the amorphous precursor is also a characteristic property of some magnetic nanocomposites. An explanation for the anomalous T_C increase for FeZrBCu nanocrystalline alloys was suggested [3] in terms of an exchange-field penetration from the BCC nanocrystals into the amorphous matrix. However, this model failed to explain the fact that the anomalous Curie-point increase can be observed only at low B content [4]. The improvement of the exchange-field-penetration model [5] is based on a linear extrapolation of the T_C values for the bulk amorphous $\text{Fe}_{100-2x}\text{Zr}_x\text{B}_x$ alloys to account for

the unusual increase of the Curie point of the residual amorphous phase for $\text{Fe}_{87}\text{Zr}_6\text{B}_6\text{Cu}_1$ alloys with different nanocrystalline fractions. Since the controversies remained, the aim of this paper is to study the $\text{Fe}_{90}\text{Zr}_7\text{B}_2\text{Cu}_1$ alloy—exhibiting the highest increase of T_C of the connecting amorphous tissue—with different nanocrystalline fractions. Mössbauer spectroscopy, besides providing the relative amount of Fe atoms in the nanocrystalline phase, makes also possible—in contrast to bulk magnetic measurements—the determination of T_C at high nanocrystalline fractions.

The amorphous ribbons were produced by melt-spinning in a protective Ar atmosphere. The ribbons with a cross section of 1 mm × 15 μm were annealed in a Perkin–Elmer DSC calorimeter: the fully nanocrystalline sample (100% nc) was heat treated to the end of the first crystallization stage, samples with smaller nanocrystalline fractions (10%, 30%, 50%, 70% nc) were defined by the corresponding fraction of the evolved energy. The nanocrystalline state was verified and the grain size of the BCC crystals was determined by X-ray diffraction with a Philips X'pert diffractometer. The magnetic measurements were performed in a Quantum Design MPMS-5S SQUID magnetometer with a magnetic field lying in the plane of the ribbons. ⁵⁷Fe Mössbauer

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measurements were performed below room temperature in a closed-cycle cryostat and at higher temperatures in a vacuum furnace by using a conventional constant-acceleration spectrometer.

Room-temperature spectra of the nanocrystallized samples are shown in Fig. 1. They consist of a sextet corresponding to the BCC phase (denoted by the broken line) and a broad asymmetric central line (dotted line) related to the paramagnetic state of the residual amorphous phase.

The marked increase in the full width at half maximum, 2Γ of the central line with decreasing temperature is the fingerprint of the magnetic transition in the residual amorphous phase (Fig. 2a). The Curie temperatures extrapolated from the 2Γ vs. T curves are upper limits for the value of T_C of the residual amorphous phase because concentration inhomogeneities and the stray magnetic field of the nanocrystalline BCC phase will result in broadened lines as well. The relative number of Fe atoms in the BCC phase, n_{bcc} is given by the area of the corresponding six-line compo-

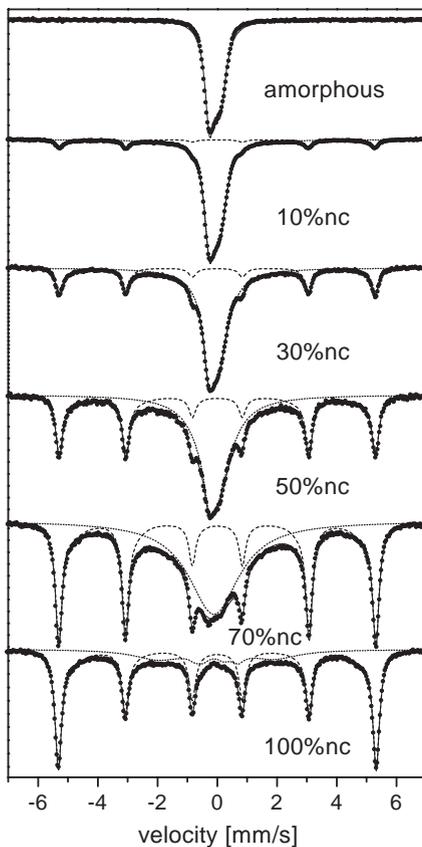
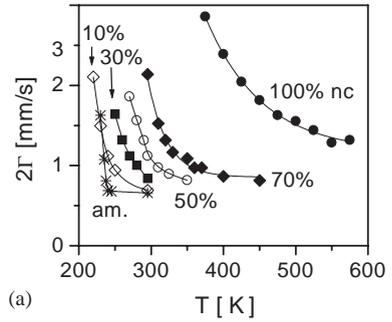
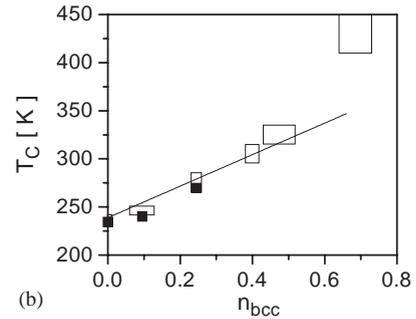


Fig. 1. Room temperature Mössbauer spectra of $\text{Fe}_{90}\text{Zr}_7\text{B}_2\text{Cu}_1$ with different nanocrystalline fractions. The full, broken and dotted lines belong to the fitted curve, the BCC component and the residual amorphous component, respectively.



(a)



(b)

Fig. 2. Temperature dependence of the full linewidth at half maximum (2Γ) of the residual amorphous phase (a) for samples with different nanocrystalline fractions in $\text{Fe}_{90}\text{Zr}_7\text{B}_2\text{Cu}_1$. The deduced Curie temperature is shown as a function of the relative amount of Fe in the BCC phase, n_{bcc} as determined from the Mössbauer measurements (empty symbols), together with the T_C values obtained from the magnetization measurements (full symbols) (b). Lines are guide to the eye.

nents, it correlates well with the degree of nanocrystallization defined by the evolved energy measured by DSC. The error of n_{bcc} largely depends on fitting uncertainties when the relative weight of one component is small. It seems that the Curie temperature of the residual amorphous phase follows well the increase in the amount of the BCC phase (Fig. 2b), the correlation is almost linear, except the 100% nc sample where the increase is more pronounced. The Curie point of the residual amorphous phase as determined from the bulk magnetic measurements for lower crystalline fractions is also found to increase and smear out considerably as a function of the nanocrystalline fraction. The T_C values below $n_{\text{bcc}} = 0.6$ correlate well with those deduced from the Mössbauer data (Fig. 2b).

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