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Evolution of physical properties of amorphous Fe–Ni–Nb–B alloys with different Ni/Fe ratio upon thermal treatment

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ABSTRACT

Amorphous ribbons $(Fe–Ni)_{81}Nb_7B_{12}$ with Ni/Fe = 0, 1/6, 1/3 and 1 were prepared by planar flow casting. Thermal treatment of samples was performed in vacuum at temperatures chosen to map the evolution of selected properties in the course of transformation from amorphous state. The coefficient of thermal dilatation exhibits changes at temperatures close to the glass transition, Curie and crystallization temperatures; these effects are enhanced or suppressed by cyclic thermal treatments up to the vicinity of these temperatures. The values of saturation magnetostriction λ_S allow to infer about processes taking place in the investigated materials, especially with respect to formation of new magnetic phases or magnetic anisotropy.

Complex processes of structural transformations induced by thermal treatment are strongly affected by Ni percentage. A transitional, magnetically harder phase, which is formed at lower temperatures preferentially near surfaces of the Ni-richest alloy, produces characteristic hysteresis loop shape. This shape disappears after annealing at higher temperatures and enables the material to show the lowest coercivity of the whole alloy series. The saturation magnetic polarization reflects mainly the resulting Curie temperature, which falls with increasing Ni percentage. Magnetic hysteresis loops were also used in the study of dynamics of magnetic domains by MOKE. Domain shape evolution is shown in dependence on composition and thermal treatment as well as a function of applied magnetic field, ranging from remanent sample state to magnetic saturation.

1. Introduction

Alloys based on iron and nickel constitute primary metallic materials and are in the constant focus of interest in physical and materials research as well as in industrial applications, representing the class of construction materials as well as of advanced materials with unique properties. Alloying of Fe and Ni together with further additions of specific elements leads to systems which are attractive from mechanical, magnetic and structural point of view. Several combinations of alloys based on Fe and Ni are soft magnetic materials.

Rapidly quenched system based on Fe–Ni–P–B with respect to the transition from ferromagnetic to paramagnetic state has been studied previously [1]. Our present work is oriented on the Fe–Ni–Nb–B system with constant amounts of B and Nb and varying ratio of Ni to Fe. Changes of the Curie temperature, magnetic hysteresis loops, magnetostriction and magnetic domains dynamics are investigated on samples after specific thermal treatment.

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2. Experimental

Samples with the composition (Fe–Ni)81Nb7B12 having the ratio Ni/Fe = 0, 1/6, 1/3 and 1/1 were prepared by planar flow casting in form of ribbons ∼20 μm thick with 6 mm width. The as-quenched samples were in amorphous state as confirmed by X-ray diffraction and transmission electron microscopy. Ribbon samples were used for dilatation measurements under special heating regimes. The thermal regime has been as follows: as-quenched samples were linearly heated with the heating rate of 5 K/min to 500 °C where they were isothermally annealed for 30 min (curves labelled as 1 in Fig. 1a–d). After controlled cooling with the same rate the samples were again linearly heated to 550 °C followed by another 30 min annealing (curves labelled as 2 in Fig. 1a–d) and controlled cooling. The third linear heating cycles with the same heating rate up to 550 °C are labelled as 3. The values of T_C were determined as local extremes of the temperature coefficients of dilatation; the values of T_g were determined in a similar manner.

Magnetostriction, alongside with magnetization, is another important property of magnetic materials. It is generally accepted that amorphous metallic alloys represent isotropic medium where the following relations for parallel λ_{par}, perpendicular λ_{perp} and saturation magnetostriction λ_S, hold as $\lambda_S = 2/3\ (\lambda_{par} - \lambda_{perp})$. The values of λ_{par} and λ_{perp} are determined from the field dependencies of magnetostrictions $\lambda(H)$ in parallel and perpendicular directions to the applied magnetic field H [2–4]. Upon thermal treatment of amorphous metallic alloys either relaxation processes or transformations from amorphous into crystalline state take place (at higher temperatures) and the assumption about the isotropic medium is no longer fully valid; the values of λ_{par} and λ_{perp} are affected by the changes of the structure.

The alloys selected for the present study contain magnetic atoms of Fe and Ni as major constituent elements, thus the investigation of these materials included

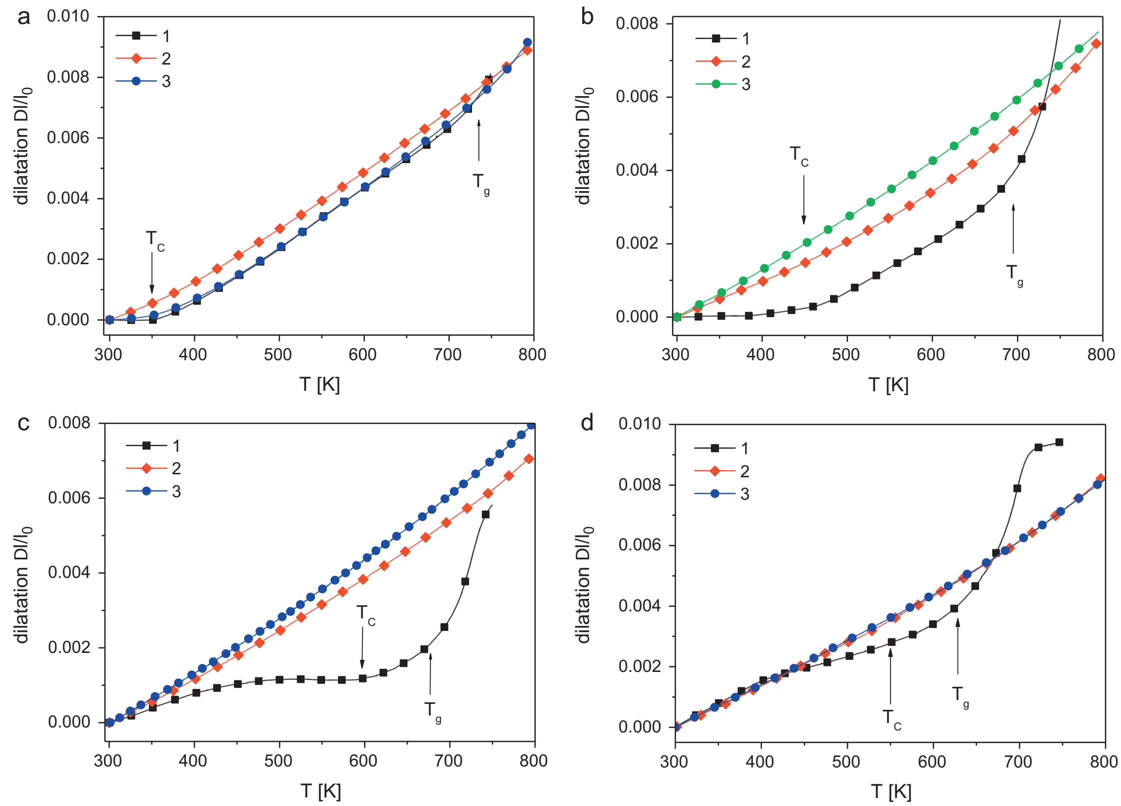

Fig. 1. Dilatation of Fe–Ni–Nb–B alloys in as-quenched state (curve 1) and after subsequent thermal treatment at 500 °C/0.5 h and cooling (curve 2) and after subsequent thermal treatment at 550 °C/0.5 h and cooling (curve 3). (a) $Fe_{81}Nb_7B_{12}$, (b) $(Fe_6Ni_1)_{81}Nb_7B_{12}$, (c) $(Fe_3Ni_1)_{81}Nb_7B_{12}$, (d) $(Fe_1Ni_1)_{81}Nb_7B_{12}$. Heating and cooling rates 5 K/min. The positions of Curie temperatures T_C and glass transition temperatures T_g are indicated by arrows.

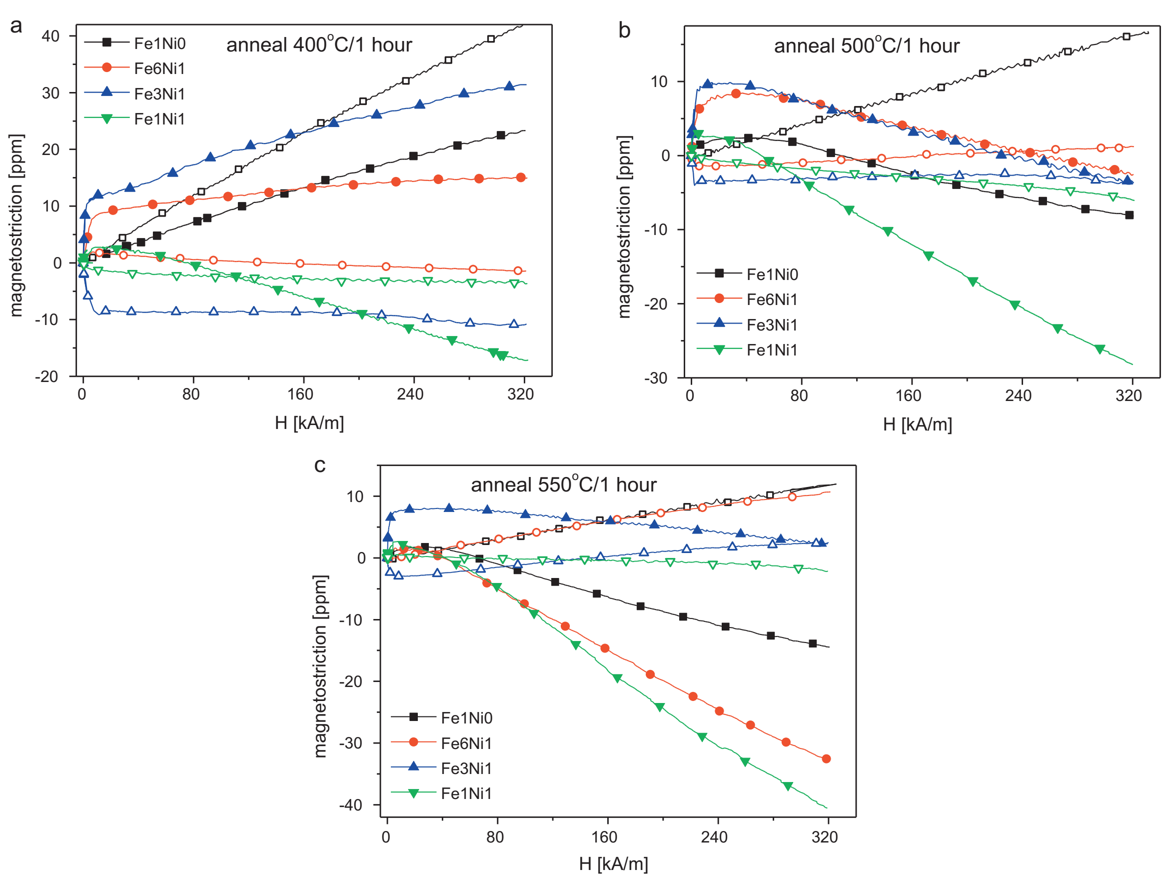

Fig. 2. Field dependencies of magnetostrictions in parallel and perpendicular directions for $(Fe)_{81}Nb_7B_{12}$, $(Fe_1Ni_1)_{81}Nb_7B_{12}$, $(Fe_3Ni_1)_{81}Nb_7B_{12}$ and $(Fe_6Ni_1)_{81}Nb_7B_{12}$ upon thermal treatment at (a) 400 °C, (b) 500 °C and (c) 550 °C for 1 h in vacuum. Full symbols – λ_{par}, open symbols – λ_{perp}.