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Investigation of magnetic anisotropy of Ni–Mn–Ga seven-layered orthorhombic martensite

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Abstract

Single martensitic variant of $Ni_{50.5}Mn_{29.4}Ga_{20.1}$ single crystal was prepared by successive compressions. Magnetization curves were measured along the [0 0 1], [0 1 0], and [1 0 0] variant directions in the temperature range 296–340 K. Magnetic anisotropy constants and their temperature dependencies were determined from the curves. The [0 0 1] direction (short axis) is easy direction of magnetization, the [0 1 0] is mid-hard direction and the [1 0 0] is hard magnetization direction. At room temperature $K_1 = 1.7 \times 10^5 \, Jm^{-3}$, $K_2 = 0.9 \times 10^5 \, Jm^{-3}$, $K_3 \approx 0$.
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The mechanism of a giant magnetic-field-induced (MFI) straining in Ni–Mn–Ga martensites is a structure reorientation due to the martensitic twin boundaries motion [1]. Driving force for the motion is a difference of magnetic energies between martensitic variants, i.e. large magnetic anisotropy is a precondition for obtaining any MFI strain in Ni–Mn–Ga martensite [2]. MFI strain of value 9.5% has been observed by Sozinov et al. [3] on a single crystal of Ni–Mn–Ga seven-layered orthorhombic martensite (7M). In our article we show how to obtain a single variant state which is necessary for the proper determination of magnetic anisotropy of the martensite. In the orthorhombic 7M, there are six possible martensitic variants separated by twin boundaries, and three magnetization directions [4]. The magnetic anisotropy energy E can be expressed for orthorhombic crystal as:

$$E = K_1\alpha_1^2 + K_2\alpha_2^2 + K_3\alpha_3^2 + K_4\alpha_1^2\alpha_2^2 + K_5\alpha_2^4, \qquad (1)$$

where α_i are directional cosines and K_i are anisotropy constants.

A $Ni_{50.5}Mn_{29.4}Ga_{20.1}$ single crystalline prism-shaped sample cut along {1 0 0} cube faces of the parental $L2_1$ austenitic phase was used for the measurement. The crystal structure determined by X-ray diffraction is 7M at room temperature. Lattice parameters are $a = 0.618 \, nm$, $b = 0.580 \, nm$ and $c = 0.552 \, nm$. From AC susceptibility measurement was determined that the martensitic transformation from $L2_1$ to the 7M is finished at $T_M = 352 \, K$ during cooling and that the reverse transformation from the 7M to $L2_1$ is finished at $T_A = 356 \, K$ during heating. At about $T_{IM} = 263 \, K$ the 7M structure transforms to the tetragonal one.

Polarized light microscopy showed that after cutting and polishing the sample contained random configuration of the martensitic variants (multivariant sample). Simple compressions (14 MPa) did not change the variant configuration.

By heating the multivariant sample to austenite and cooling it back to room temperature through martensitic transformation under compressive stress 14 MPa the variants with the [0 0 1] axis in the direction of stress developed. At this point the sample contained two variants. Additional compression in the perpendicular direction to the [0 0 1] direction the sample developed the second preferential direction [0 1 0]. To finalize the procedure, the sample was again compressed in the

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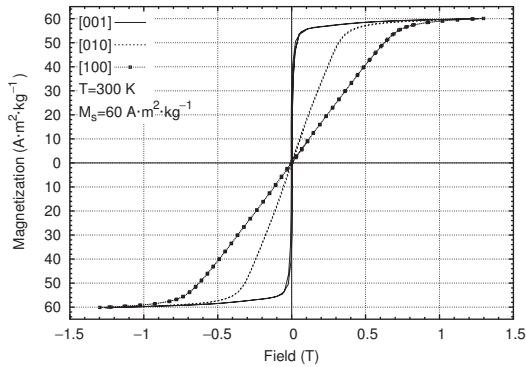*E-mail address:* ladislav.straka@hut.fi (L. Straka).

Fig. 1. Magnetization curves of the single crystal of seven-layered modulated orthorhombic martensite in single variant state. Curves were measured along the [0 0 1], [0 1 0], and [1 0 0] directions and corrected for demagnetization.
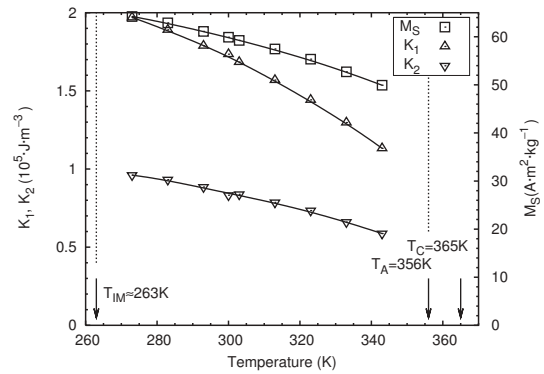

Fig. 2. Temperature dependence of the anisotropy constants $K_1(T), K_2(T)$, and saturation magnetization $M_S(T)$ of the 7M martensite. Temperature range of measurement is limited by a stability of the 7M martensite.

direction of the first compression. This way we succeeded to prepare the sample containing mostly one martensitic variant. The evolution of the martensitic structure from the multivariant to the single variant state was reflected in changes of the shape of the magnetization curves and confirmed by X-ray diffraction and polarized light microscopy.

Magnetization curves measured along the [1 0 0], [0 1 0], and [0 0 1] directions of the single variant sample are shown in Fig. 1. Very low hysteresis of magnetization curves and their rectilinear character suggest that magnetization process mostly by rotation and that only the second order anisotropy terms are significant in Eq. (1). In that case we can determine the anisotropy constants K_1, K_2, K_3 directly from the anisotropy field (knee on the magnetization curve). Fig. 1. shows that short c-axis ([0 0 1] direction) is easy axis of magnetization, i.e. $K_3 \approx 0$, b-axis is mid-hard axis ($K_2 = 0.9 \times 10^5$ Jm^{-3}), and long a-axis is hard axis ($K_1 = 1.7 \times 10^5$ Jm^{-3}) of magnetization. Slow approach to saturation of the curve measured along the [0 0 1] direction suggests that the sample contained a small

amount of other variants with hard axes in the magnetization direction.

The anisotropy constants were determined from the magnetization curves in the whole range of the stability of the 7M structure (296–340 K). At higher temperatures the measurement is limited by transformation to austenite and at lower temperatures it is limited by the intermartensitic transformation. Temperature dependence of the anisotropy constants $K_1(T), K_2(T)$, and saturation magnetization $M_S(T)$ is shown in Fig. 2. The $K_1(T), K_2(T)$ dependencies follow the magnetization power law with exponent between two and three [5].

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