# Magnetic structure of $Ni_{49}Fe_{18}Ga_{27}Co_6$ alloy at reversible austenite-martensite transformation: magnetic force microscopy

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Geisler ferromagnetic alloys are interesting because they have a magnetic shape memory effect [1, 2]. Reversible martensitic transitions in these alloys are characterized by burst-like changes in the crystalline and magnetic structure. Some compositions of quadruple alloys, for example, $Ni_{49}Fe_{18}Ga_{27}Co_6$ [3], have relatively high Curie point values, and the temperatures of their martensitic transitions can shift noticeably to higher temperatures when the crystal is deformed.

In the present work, the changes in the magnetic structure of $Ni_{49}Fe_{18}Ga_{27}Co_6$ alloy during forward and reverse martensitic transformation have been investigated by magnetic force microscopy (MFM). According to the data of differential scanning calorimetry, the transition temperatures of the sample under study are as follows $T_{AS}$ = 8.2 ºC, $T_{AF}$ = 14.5 ºC, $T_{MS}$ = 2.2 ºC, $T_{MF}$ = –10.9 ºC.

An atomic force microscope – probe nanolaboratory INTEGRA-AURA (NT-MDT, Russia) with MFM function was used for the experiments. Magnetic cantilevers with stiffnesses of 3.5 and 6 N/m and CoFe coating and a temperature-controlled cryostat for measurements in the range from +170°C to –30°C were used. The sample was mechanically polished beforehand. Before measurements, the residual magnetization of the sample was destroyed by an alternating field with an amplitude of 1 T.

Scanning was performed in semi-contact, dynamic (AC) mode using a two-pass technique. MFM maps were recorded at temperatures of 22 °C (initial austenitic state), 0 °C (below $T_{MS}$ in the direct transition), -20 °C (below $T_{MF}$ in the martensitic phase), 22 °C (reverse transition). The analysis of the obtained images was carried out using the NT-MDT Nova program. The evolution of the shape, size, and distribution of magnetic field inhomogeneities with temperature change was evaluated (Fig. 1).

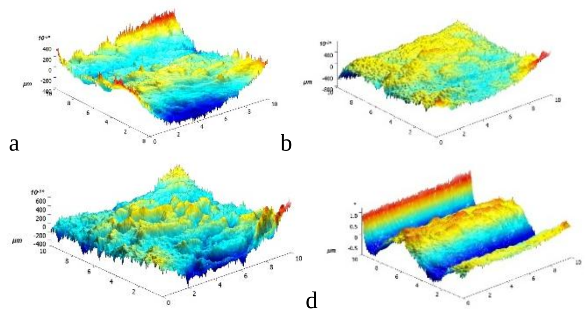


**Рис. 1.** Three-dimensional reconstructions of MFM maps of alloy $Ni_{49}Fe_{18}Ga_{27}Co_6$ at temperatures: (a) 22 °C, (b) 0 °C, (c) –20 °C, (d) 22 °C.

At 22 °C, the magnetic structure shows pronounced banding and local variations, (Fig. 1a). At 0 °C, small-scale magnetic fluctuations and weakening of contrast appear, indicating the initial signs of martensitic transition (Fig. 1b). At –20 °C, there is a complete destruction of the initial structure and the formation of chaotic small-scale magnetic regions (Fig. 1c). At 22 °C, a band structure with local variations of the magnetic field is restored (Fig. 1d).

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