Magnetic force microscopy of epitaxial Fe_2CoAl and Co_2FeAl Heusler alloy films and microstructures

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The Heusler alloys have many unique properties. Among them, it is a high level of spin polarization achieving 100% [1]. In work [2], by means of ab initio calculations it was shown that some of these alloys, in particular Co_2FeAl possess the large constant of anisotropy which more than by an order exceeds that for iron. This makes it possible to use Heusler alloys as materials for permanent magnets that do not have rare earth elements in their composition, as fixed layers in spin valves and also as an effective spin injector. In the same work, it was shown that the electronic structure of these alloys varies greatly with the change of lattice type from cubic to tetragonal. In the process of epitaxial growth due to the mismatch between the growing film and the substrate crystal structure, such a transition can occur, leading to a change in the spin polarization of the alloy and its magnetic anisotropy.

The films of Heusler alloys Fe_2CoAl and Co_2FeAl were grown epitaxially by pulsed laser deposition in ultrahigh vacuum on the R - and A - planes of sapphire with a 20 nm thick W(001) or Mo (001) seed layer that was preliminary grown at 450 °C on the substrate. From the grown films, by application of subtractive microstructurization the microstructures of different sizes and shapes – circles, quadrates, rectangles and crosses, were fabricated.

Magnetic force microscopy (MFM) supported by micromagnetic calculations using OOMMF [3] was applied to study their magnetic structure. MFM measurements and micromagnetic calculations have shown that the microstructures of Fe_2CoAl have an in-plane uniaxial anisotropy with an easy magnetization axis directed at an angle close to 45° to the base cutoff of the R-plane sapphire substrate. After annealing these microstructures at a temperature of 600 °C, the in-plane anisotropy of the films becomes biaxial (Fig. 1).

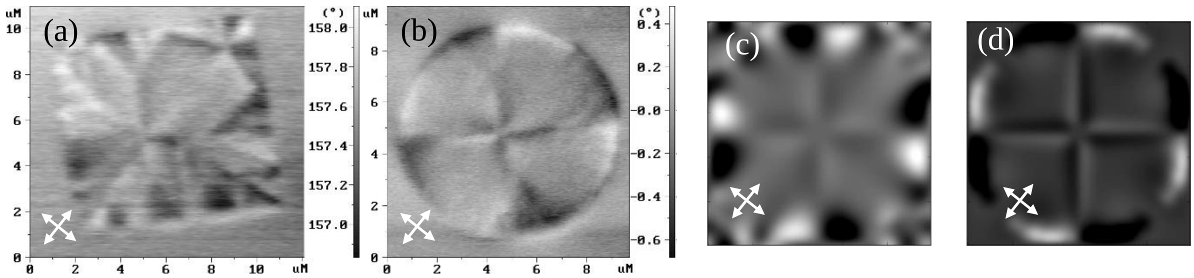

Figure 1. MFM images (a), (b) and their simulation (c), (d) for a quadrate and circle of Fe_2CoAl after annealing. The arrows indicate the easy axes of magnetization.

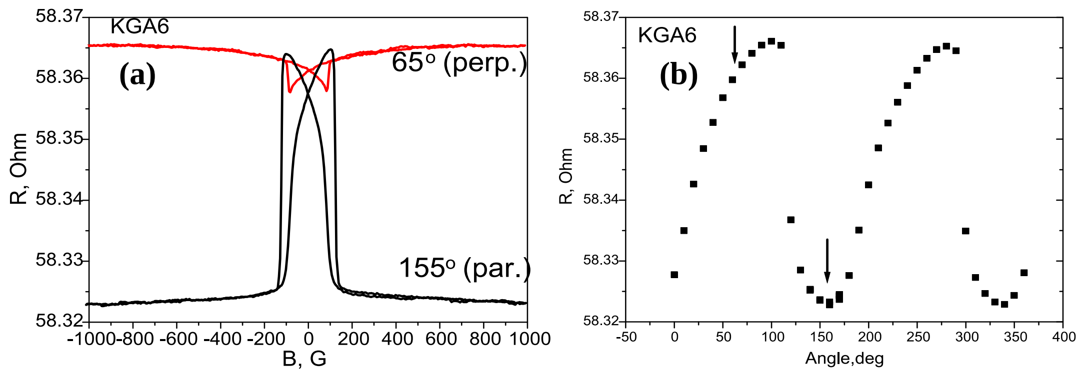

Figure 2. In-plane magnetoresistance of the bridge of Co_2FeAl for magnetic field directed parallel or perpendicular to the bridge (a) and the angular dependence of the resistance in a magnetic field with induction of 400 G, directed at different azimuthal angles (b). Arrows show field direction at which magnetoresistances were measured (numbers in (a) indicate the azimuthal angles).

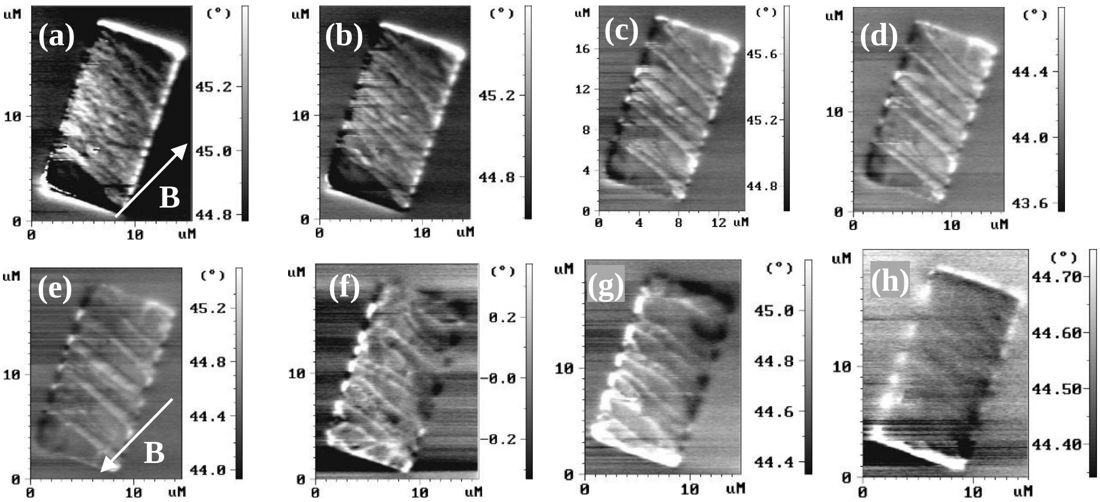

Figure 3. MFM images of rectangular Co2FeAl microstructure in an external magnetic field with induction of -600 (a), -300 (b), -130 (c), -57 (d), 12 (e), 150 (f), 272 (g) and 511 G (h). The field direction is depicted by the arrows (the inserts (a) and (e)).

The Co_2FeAl films grown on the A-plane sapphire showed unusual both field dependent and azimuthal-angle dependent magnetoresistances (Fig. 2). The field dependent magnetoresistance (Fig. 2a) exhibits an increase in the case when the current is parallel to the field and a decrease when it is perpendicular to the field. Usual behavior of anisotropic magnetoresistance should be vise versa. The angular dependence of magnetoresistance (Fig. 2b) has a form other than the sine wave.

To explain found dependences, the magnetic states of microstructures fabricated from grown epitaxial films were studied by MFM with application of external magnetic field (Fig. 3). MFM measurements showed that for the fields ranged from -800 G to -600 G the magnetic contrast is virtually unchanged and is typical to that shown in the Fig. 3a. At lower fields, the domain structure appears (Fig. 3b), which under further decrease of the field evolves to a state with residual magnetization (Fig. 3c). With a gradual increase of the field into the opposite to initial direction, significant changes in the magnetic structure occur under the field of about 150 G (Fig. 3f). It practically unchanges till the fields of 500 G (Fig. 3h), and the magnetic contrast is smeared at higher fields. The magnetic structure can be interpreted as a strip domain structure with the strips directed along the axis of easy magnetization that forms an angle against the base cutoff of the substrate. This can explain the results of measurements of magnetoresistance.

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