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## THE EQUILIBRIUM MAGNETIZATION DISTRIBUTION AND MAGNETIZATION REVERSAL PROCESSES IN MAGNETO-ELASTIC NANOSTRUCTURES

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The results of an experimental study of the equilibrium magnetization distribution and magnetization reversal processes of magnetoelastic nanostructures in the form of strips of constant or variable width are presented. It is shown that the symmetry breaking of the stable magnetization states of in the nanostrip can be realized by a static magnetic field applied perpendicular to the light axis of the ferromagnetic. Further change of magnetization states allows their manipulation (for example, the movement of the domain boundary) by means of homogeneous mechanical effects induced by the application of an electric field to the piezoelectric substrate. The results are of interest for the development of energy-efficient logic and memory spintronics.

A number of recent studies have shown that the magnetization state of magnetic films and plates can be controlled with very low energy amount [1-3]. These results make it possible to predict the possibility of creating spintronic nanodevices with record low energy amount – at the level of tens or even few of attojoules per one operation to switch the magnetization state [1-4], which is several orders of magnitude less than in traditional electronics devices. One of the promising directions of energy-efficient devices creation for storage and processing of information is reflected in the work on the study of processes in magnetic nanostructures with controlled magnetoelastic properties [1, 5-7]. In this case, elastic stresses induced by the piezoelectric layer are used to switch the state of the elements.

Recently, the possibility of domain-wall manipulating in magnetoelastic nanostripes by means of homogeneous mechanical stresses has been theoretically demonstrated [8,9]. Interest in the study of the motion of domains and domain walls is largely due to the development of spintronics devices with nanometer element sizes. Domain walls are considered as key elements of information processing devices, including nonvolatile solid-state memory devices [4, 9-15]. Such memory will potentially provide a much higher write density than modern hard drives, which together with a high read/write speed makes it possible to consider it as a possible universal memory.

Control of the position or speed of the domain wall in nanostripes of a certain shape on piezoelectric substrates is possible in case of violation of magnetic states symmetry in one-dimensional ferromagnets. This approach gives unusual configurations of domain walls and the velocity of domain walls of the same order of magnitude [9] as when action by magnetic fields or spin-polarized currents, and the energy consumption required to move the domain wall is significantly reduced.

In this paper, an experimental study of the equilibrium magnetization distribution and the processes of magnetization reversal of magnetoelastic nanostructures in the nanostripes of constant or variable width is carried out (Fig. 1). Multilayered magnetostrictive films of TbCo<sub>2</sub>/FeCo composition with thickness of ~20 nm were deposited onto piezoelectric PMN-PT substrates by

RF sputtering using a Leybold Z550 equipment [16]. The deposition was made under a magnetic field generated by permanent magnets in order to induce a magnetic easy axis anisotropy in the desired direction in the plane of the multilayer film. Then, micro - and nanostructures of various shapes were formed in the films by lithography for experimental study of magnetization distribution, processes of magnetization reversal, formation and movement of domain walls in the films; Fig. 2 and 3 show nanostripes of parabolic profile.

Easy magnetization axis is directed along the long side of the strip in the studied nanostripes. It was shown earlier [9] by mathematical modeling that the domain wall in the nanostripe of the parabolic profile is in the center of the stripe in equilibrium position. When applying mechanical stress (as a result of the application of an electric field to the piezoelectric substrate), the domain wall shifts to a new equilibrium position, which can be used in logical and storage devices of nanospintronics.

The data on the magnetic structure of a parabolic-shaped nanostripe obtained by magnetic force microscopy (MFM) are presented on Fig. 3. The domain structure of nanostripes was studied using an atomic force microscope Smart-SPM (AIST-NT). This device has a built-in magnet with a program of mechanical adjustment of the magnetic field in the range of -2000 ... +2000 Oe. The technique similar described in work [17] was used for registration of a magnetic state: few hundred MFM-scans was ~~registered~~ with a small magnetic field step (1 ... 10 Oe), overlapping the magnetization reversal cycle of the sample. Further, the obtained images were used to form a film that allows to consistently observe the various stages of the process of changing the nanostripe's domain structure. Several MFM scans are presented on Fig. 3 to illustrate the most important changes in the magnetization of the magnetoelastic nanostripe.

PPP-LM-MFMR (Nanosensors) probes with reduced magnetic moment were used for MFM measurements. All experiments were performed in air at room temperature. To stabilize the device operation for a long time taking a series of images after each scan, the operation was automatically carried out to correct the amplitude and resonance frequency of the probe vibrations, as well as to compensate for the drift of the sample. The measurements were carried out on a separate nanostripe so that we can examine their domain structure, and arrays of such nanostripes (Fig. 2,b), to identify the variation of the magnetization reversal fields.

When a magnetic field  $H$  is applied along the easy magnetization axis, the nanostripe is usually magnetized to saturation and is in a monodomain state. When the magnetic field  $H$  is applied perpendicular to the easy magnetization axis and  $H$  significantly exceed the coercive force of the film (Fig. 3,  $H = \pm 680$  Oe), the magnetization vector in the nanostructure is oriented along the applied magnetic field. In smaller magnetic fields, depending on the prehistory of the magnetization/demagnetization of the nanostripe, there are two variants for the formation of an equilibrium magnetic structure – with asymmetric (Fig. 3,  $H = 140$  e) or symmetrical (Fig. 3,  $H = 40$  e) direction of the magnetization vectors at the edges of the nanostripe. Note that the second variant is close to the domain structure model proposed in [9] for a magnetoelastic nanostripe of variable width (Fig. 1).

Thus, the quasi-static processes of magnetization reversal of magneto-elastic parabolic-shaped nanostripes were experimentally studied. It is shown that the symmetry breaking of the stable magnetization states in the nanostripe can be realized by a static magnetic field applied perpendicular to the light axis of the ferromagnetic. In this case, it is possible to split a parabolic nanostripe into two domains; the domain wall in the equilibrium state is in the center of the nanostripe, in its narrow part. Further change of magnetization states allows their manipulation (for example, the movement of the domain wall) by means of homogeneous mechanical effects induced by the application of an electric field to the piezoelectric substrate.

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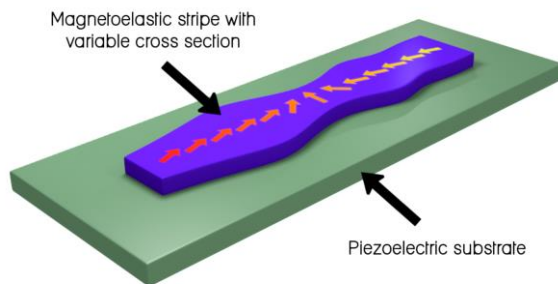


Fig. 1. Model of domain structure in a magnetoelastic nanostripe of variable width.

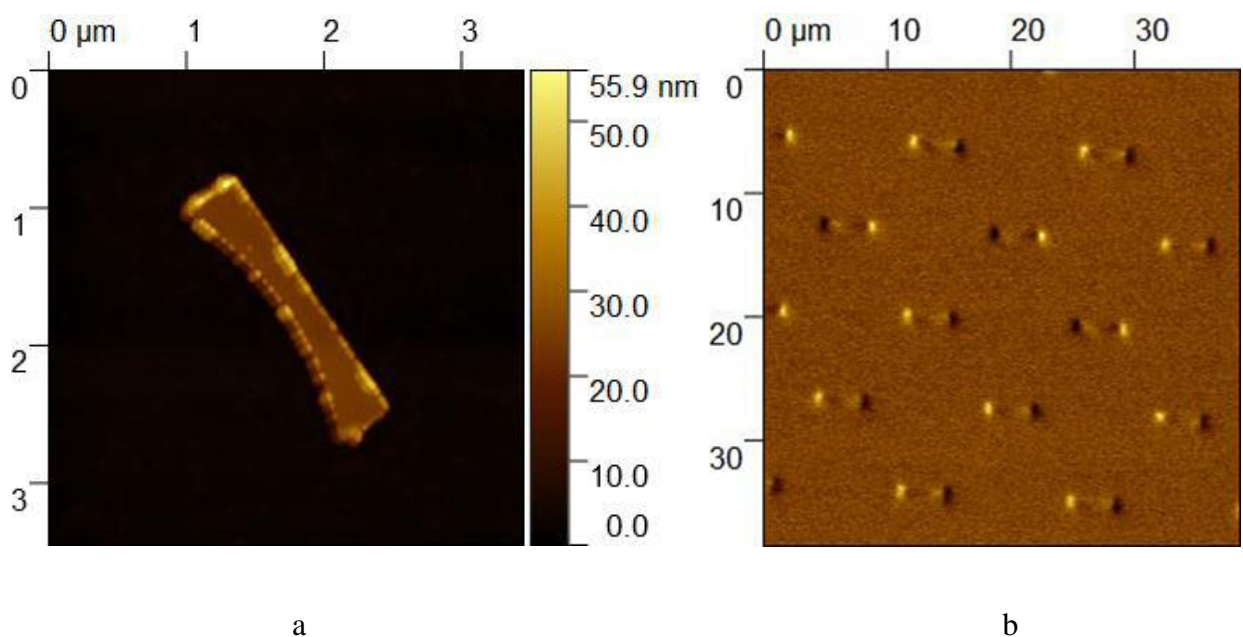


Fig. 2. Topography of magneto-elastic parabolic-shaped nanostripe (a, AFM) and an array of such nanostripes on a piezo-substrate (b, MFM).

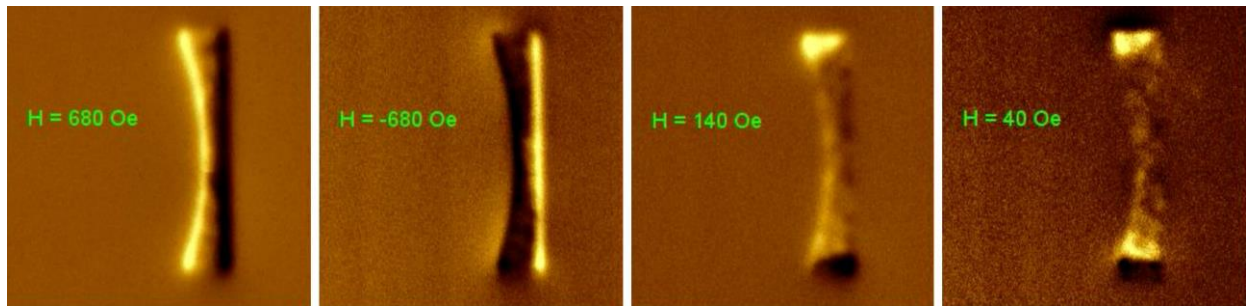


Fig. 3. Magnetic parabolic-shaped nanostripe in the presence of an external magnetic field directed in the film plane perpendicular to the long side of the stripe (MFM, magnetic field is indicated on the scans).