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Nanostructures defined by the local oxidation of the ferromagnetic GaMnAs layer

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ABSTRACT

The results of local anodic oxidation (LAO) on the thin GaMnAs layers are reported. The ferromagnetic GaMnAs layers were prepared by low-temperature molecular beam epitaxy (MBE) growth in a Veeco Mod Gen II machine. The LAO process was performed with the atomic force microscope (AFM) Smena NT-MDT placed in the sealed box with the controlled humidity in the range 45–80%. The oxide was grown in the semi-contact mode of the AFM. The sample was positively biased with respect to the AFM tip with the bias from 6 to 24 V. The conductive diamond-coated AFM tips with the radius 30 nm were utilized for the oxidation. The tip speed during the oxidation was changed from 400 nm/s to 1.5 μm/s. The tip force was also changed during the oxidation. The height of oxide nanolines increases with applied voltage from 3 to 18 nm. The width of these lines was approximately 100 nm at half-maximum. The magnetoresistance measurements of the sample with 1D lateral constriction by the LAO and the micromagnetic simulations of the structure with two lateral constrictions are presented.

1. Introduction

The fabrication and study of nanoelectronic devices demand the modification of metals and semiconductors on the nanometer length scale. Key elements for more complex structures such as transistors are narrow conducting wires and tunneling barriers. On the nanometer scale, proximal probe-based instruments, in particular the scanning tunneling microscope (STM) and atomic force microscope (AFM), have proven successful not only to image surfaces but also to modify them. AFM is a well-known instrument used for surface topography measurements. The principle of the method lies in monitoring of the tip motion above the inspected surface. The tip is fixed on the end of the elastic cantilever, which is deflected by attractive and repulsive forces between the surface and the tip. The deflection of the cantilever is optically scanned. Various approaches have been used to generate patterns by means of the AFM useful for device fabrication: mechanically modifying a resist layer, which then acts as an etch mask for pattern transfer, local anodic oxidation (LAO) and subsequent use of the oxide as the etch mask, and maskless techniques, i.e., those directly affecting the material's electron system by the proximal probe itself. This can be done again mechanically or by using the probe for locally inducing chemical reactions. Early work on STM and contact AFM-induced oxidation of Si was done by Dagata et al. [1]. If the substrate surface and the tip are electrically conductive and the tip is biased negatively to the surface, local oxidation proceeds under the tip (see Fig. 1). With this method it is possible to fabricate oxide lines of any shape. Height of these formations reaches several nanometers and their width at half of the maximum is about 100 nm. Oxide lines can be written to form desired patterns on the surface by translating the tip in a controlled fashion. Several research groups have demonstrated the viability of this technique in both contact and tapping AFM modes. However, when the LAO is performed in the contact mode, the tip apex tends to degrade readily since the tip stays in physical contact with the surface. This subsequently shortens the life-time of the tip and sacrifices the resolution of oxide patterns. For these reasons, the noncontact/tapping AFM mode is the most preferred to perform the LAO. The AFM tip oxidizes the surface and forms an energy barrier for electrons in a metal or in a heterostructure. The LAO patterning is broadly reported on Ti [2], Si [3] and GaAs layers [4,5]. Unsuccessful attempt has been realized with the LAO on the GaN layer [6].

This method could be advantageous, especially for laboratory experiments. The sample surface can be examined before the oxidation. Consequently, it is possible to create oxide lines on the selected location. Oxidation results can be immediately investigated. In this work, a conducting AFM tip is used in the tapping

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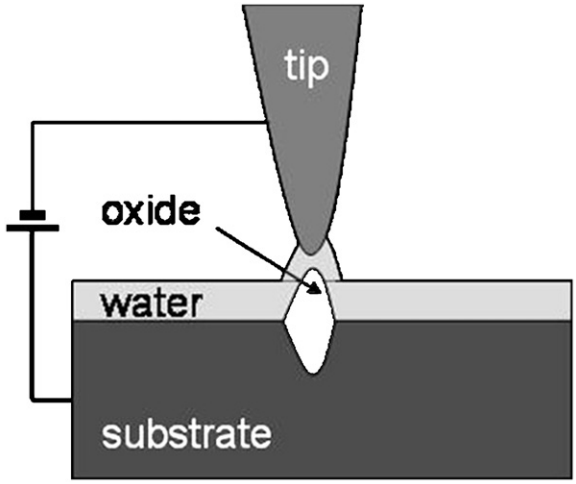

Fig. 1. LAO by the AFM tip.

mode to oxidize the GaMnAs surface producing nanometric constrictions in a thin ferromagnetic layer.

Several spin-valve and spin-filtering effects have been reported in the ferromagnetic nanostructures with the domain-wall pinning on the nanoconstrictions. The giant magnetoresistance (GMR) up to several hundred % is produced by the opposite magnetization of adjacent domain walls; the tunnel magnetoresistance (TMR) appears, when the constrictions are very narrow (below 10 nm), producing up to several thousand % [7]. Tunneling anisotropic magnetoresistance (TAMR) is present in the nanoconstricted structures with the strong spin–orbit coupling [8]. Application of the external magnetic field in the different directions produces both positive and negative magnetoresistance. Most of the nanoconstricted ferromagnetic structures are based on the GaMnAs layers patterned by the electron-beam lithography. The LAO by AFM is attracting attention because of its relatively low cost and high resolution. Very few reports are presented about the LAO on the ferromagnetic GaMnAs layers.

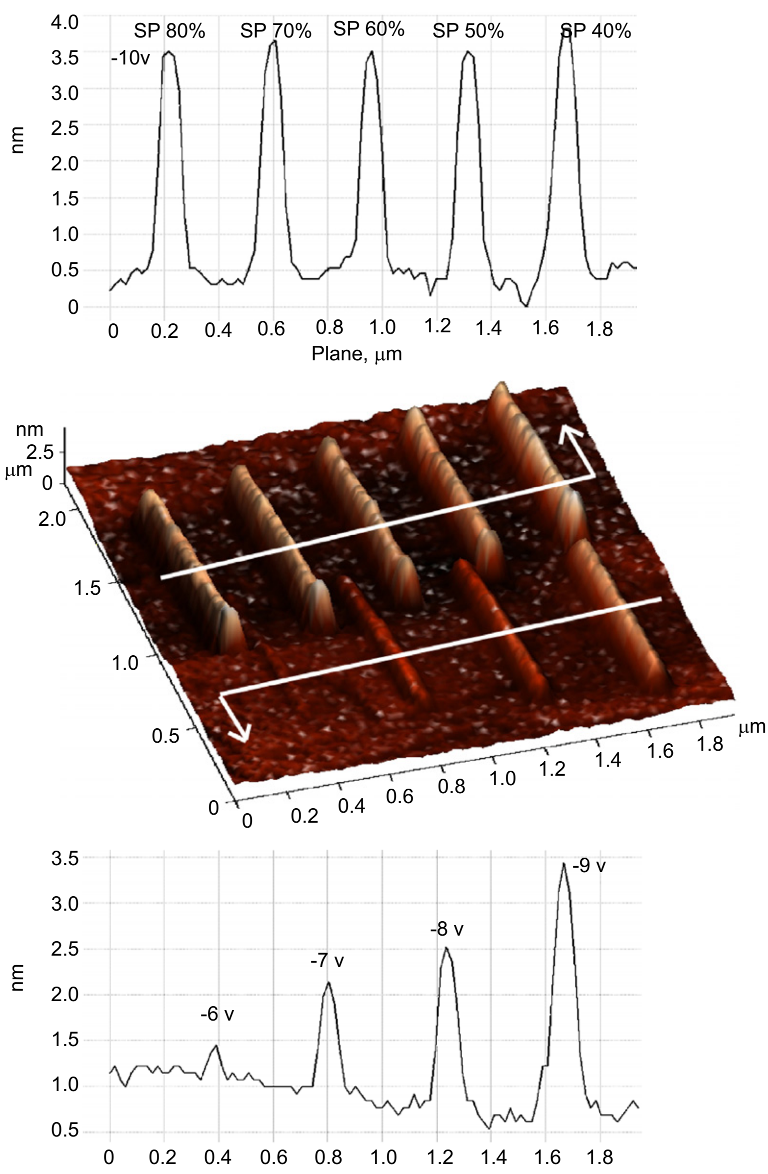

Fig. 2. The 3D picture of the oxide lines prepared by LAO in the GaMnAs layer using the semi-contact mode. Set point was lowered to 40% of the original value, increasing the force applied on the tip. Humidity was 75%. Tip velocity during LAO was 400 nm/s. Negative bias applied on the tip was 5, 6, 7, 8 and 9 V (from the left) for bottom lines and 10 V for upper lines, where the tip force was varied without significant effect.