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Selective removal of atoms as a new method for fabrication of single-domain patterned magnetic media and multi-layered nanostructures

Boris Gurovich*, Evgenia Kuleshova, Evgenii Meilikhov, Konstantin Maslakov

Russian Research Center, Kurchatov Institute, 1. Kurchatov sq., Moscow 123182, Russia

Abstract

The paper demonstrates the practical opportunities of the new phenomenon of "selective removal of atoms" for producing nanoscale patterned media. We have experimentally demonstrated the direct variation of a solid state atomic composition under exposure to the low-energy ion beam which leads to radical changes of the material physical properties of separate layers in a multi-layered structure. Using this method we have produced patterned magnetic media consisting of single-domain elongated Co-magnetic elements in Co-oxide matrix with the bit sizes from $320 \times 1600\,\mathrm{nm}^2$ down to $20 \times 100\,\mathrm{nm}^2$ (with the areal density of about $60\,\mathrm{Gb/inch}^2$).
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Traditionally, the materials with various physical properties are those with various chemical compositions. We have experimentally demonstrated the possibility of direct alteration of a solid atomic composition under exposure to an accelerated ion beam of a specific energy.

The physical basis of the invented and patented by us method of "selective removal of atoms" is as follows. Let us consider a situation that arises during interaction of a monochromatic ion beam of energy E and mass m with a two-atomic crystal consisting of atoms of different masses M_1 and M_2. The maximum energy transferred by the ions to atoms of a crystal is [1]

$$E_{\max}^{(1,2)} = \frac{4mM_{1,2}}{(M_{1,2}+m)^2}E, \tag{1}$$

where $E_{\max}^{(1)}$ and $E_{\max}^{(2)}$ are maximum energies which could be transferred by the accelerated ions to atoms with masses M_1 and M_2.

So, varying the mass and the energy of ions, it is possible to achieve the situation in two- or a multi-atomic crystal when the higher energy would be transferred to the atoms of low or high masses. If the maximum transferred energy exceeds the threshold value E_d for atoms of only one kind then an opportunity appears of selective removal of only light (or only heavy) atoms from the two- or a multi-atomic crystal [2]. Thus one can reduce a concentration or to remove completely atoms of the desired kind in the proper layer of a crystal by selecting a necessary dose of irradiation. As a result, it is possible to get dramatic modifications of chemical and physical properties in the proper layer of a crystal or within a thin film. The potential of the proposed method is determined by the possibility of its using for the efficient, purposeful and spatially modulated modification of composition, structure, physical and chemical properties of materials. Such a modification of chemical composition can dramatically change the physical properties of thin material layer, e.g. to produce an insulator–metal transition, to change magnetic or optical properties and so on. Thus a possibility exists

*Corresponding author. Tel.: +7-095-196-9215; fax: +7-095-196-1701.

E-mail address: evgenia-orm@yandex.ru (B. Gurovich).

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to create the controlled volume "pattern" of the areas with different physical properties.

The process can be produced through the upper (relative to the beam) additional layer of another material if its thickness is less than the ion projective length in the layer. If, in addition, the threshold energy of atomic displacement in the additional layer is higher than the transferred energy from the ions, the directed displacement of atoms in that material does not occur. Otherwise, the atoms of material penetrate in the underlying layer and their transfer in the beam direction occurs over the distance comparable with the ion projective length in the "sandwich" considered.

It is important that selective removal of atoms allows one to change simultaneously the physical properties of separate layers in a multi-layered structure by ion irradiation through the same mask. This is a principal advantage of the proposed technique compared to any other known methods or physical principles. As a result it permits to produce simultaneously (in parallel) the structures with different shape and properties in various layers by ion irradiation through the same mask (for example, a magnetic pattern in some layer and electric wiring in another one). Such a procedure allows one to get an overlapping of the structure elements in various layers with an accuracy of about 1 nm that is a crucial point in the production of thin-film multi-layered nanostructures.

We demonstrated the practical opportunities of the new phenomenon of "selective removal of atoms" for producing nanoscale patterned media. Using the selective removal of oxygen atoms from Co-oxide we have produced patterned magnetic media consisting of single-domain Co-magnetic elements in Co-oxide matrix (Fig. 1). Single-domain nano-sized bits of elongated (magnetically anisotropic) form have been produced with the mask made by the electron lithography. Therewith, regular structure with the bit sizes from $320 \times 1600\,nm^2$ down to $20 \times 100\,nm^2$ were obtained (with the areal density of about $60\,Gb/inch^2$).

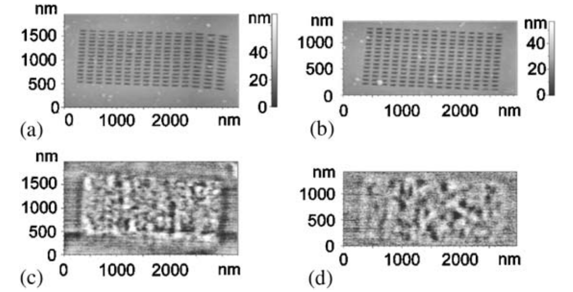

Fig. 1. Examples of patterned magnetic media with areal densities: $45\,Gb/inch^2$ (bit size—$25 \times 125\,nm^2$)—(a, c) and $57\,Gb/inch^2$ (bit size—$20 \times 100\,nm^2$)—(b, d). (a, b)—AFM topography images, (c, d)—magnetic force microscopy images.

Thus, our experiments have proved the efficiency of selective removal of atoms for producing nanoscale patterned magnetic media being of interest for various applications.

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