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Microstructure and Magnetic Properties of Strontium Titanate Implanted with Iron

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Abstract—The magnetic phase composition of strontium titanate surface layers implanted with iron ions is studied by means of Mössbauer spectroscopy, and by measuring alternating current magnetic susceptibility. It is shown that the interaction between α-Fe nanoclusters at high concentrations of the implanted admixture produces ferromagnetic order in samples at room temperature.

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INTRODUCTION

Strontium titanate $SrTiO_3$ (STO) with perovskite structure has a unique combination of physical properties. First of all, it is a diamagnetic wide-bandgap semiconductor with distinctive optical properties: a high refractive index ($n = 2.5$) and transparency in the visible range of wavelengths and up to wavelengths of about 5 μm in the infrared range [1]. Second, pure STO is a quantum ferroelectric; however, strontium titanate samples containing the ^{18}O oxygen isotope display a paraelectric–ferroelectric phase transition at temperatures of around 25 K [2]. The temperature of the paraelectric–ferroelectric phase transition can also be greatly affected by mechanical stresses. For example, epitaxially grown and strongly strained STO layers exhibit ferroelectric properties even at room temperature [3]. Third, STO and materials based on it have the mixed ionic and electronic conductivity [4] that is responsible for the photocatalytic activity of STO and is used in some practical applications when designing oxygen sensors [5, 6] and memristor prototypes based on doped STO samples [7]. Finally, the crystalline structure of perovskite is suitable for growing epitaxial layers of high-temperature superconductors on an STO surface.

Introducing different impurities into STO is one way of obtaining new properties that are missing from the basic material. In light of present-day requirements for microelectronics and spintronics, atoms of transition metals (particularly iron atoms) are the most promising candidates for impurities. The scientific literature contains a number of results that show epitaxial STO layers heavily doped with iron can exhibit properties of a diluted magnetic semiconductor at room temperature [1]. In combination with quantum ferroelectric STO properties, we would expect the presence of the magnetoelectric effect in iron-doped strontium titanate, at least at low temperatures.

One widely used technique for doping materials is ion implantation. This doping procedure is based on the forced introduction (implantation) of an impurity with a given concentration into the crystalline structure of the basic material by irradiating its surface with high-energy ions of different chemical elements. An argument for expecting magnetoelectric properties in iron-implanted STO at room temperature is the estimated pressure in [8] of 6 GPa for the phase transition of pure STO with a change in the type of the crystalline lattice, in analogy with the phase transition in STO under atmospheric pressure and at a temperature of 105 K [9] (the cubic-to-tetragonal transition). Mechanical stresses comparable in magnitude can occur during ion implantation [10]. In addition, the forced introduction of iron ions into STO with a concentration exceeding the solubility limit of the impurity leads to its clusterization [11], which causes the formation of a nanocomposite film in the implanted surface layer of STO.

This work presents results from studying thin magnetic films obtained via the high-dose implantation of iron ions into single-crystalline STO substrates using conversion electron Mössbauer spectroscopy (CEMS) with elements of magnetic orientation Mössbauer spectroscopy (MOMS), and by measuring the alternating current magnetic susceptibility (ACMS).

EXPERIMENTAL

Our Fe-STO samples were obtained on the ILU-3 ion-beam accelerator at the Kazan Physical-Technical Institute. Single-charged iron ions with energies of