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Formation of anisotropic ferromagnetic response in rutile (TiO_2) implanted with cobalt ions

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Abstract

The (1 0 0)- and (0 0 1)-monocrystalline plates of rutile (TiO_2) were implanted by 40 keV Co^+ ions with fluences in wide range of 0.15–1.5×10^{17} ion/cm^2 to study the development of ferromagnetism in the diamagnetic TiO_2. With increase of fluence the implanted rutile plates reveal sequentially paramagnetic, superparamagnetic, weak ferromagnetic and, eventually, strong anisotropic ferromagnetic response at room temperature. The thermo-magnetic analysis shows that the ferromagnetic samples exhibit two magnetic transitions with temperatures of the ferromagnetic ordering $T_{C1} \sim 700$ K and $T_{C2} \sim 850$ K, correspondingly. Heating of the samples in air strongly suppresses the ferromagnetic phases if the temperature of heating exceeds the corresponding transition temperature. Subsequent high-vacuum annealing restores only the low-temperature ferromagnetic phase. The origin of the two magnetic phases and anisotropy of the ferromagnetism in the Co-implanted rutile are discussed in the model of two cobalt-rich layers with different concentration and valence states of the implanted cobalt.

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Keywords: Magnetic semiconductors; Ion implantation; Spintronics

1. Introduction

Recently [1–3] we have shown that monocrystalline plates of rutile (TiO_2) implanted with cobalt ions to high fluences of 1.5 or 2.0×10^{17} ion/cm^2 reveal strong anisotropic ferromagnetism with a ferromagnetic transition temperature as high as 700 K. However, the origin of the ferromagnetism in Co-implanted TiO_2 has not been clarified yet. In the context of the problem, we have implanted the rutile plates with various fluences of cobalt ions to study development of the ferromagnetic response in the diamagnetic TiO_2. In the paper we show strong influence of the cobalt fluence and post-implantation thermal treatment on the magnetic properties of rutile. For the first time, we report on two ferromagnetic phases with different temperatures of magnetic ordering which may coexists in the Co-implanted rutile.

2. Experimental

The $15 \times 15 \times 1.5$ mm^3 monocrystalline plates of synthetic rutile (*Moscow Power Engineering Institute, Lab. of Prof. A. Balbashov*) were implanted with 40 keV Co^+ ions to fluences in the range of 0.15–1.5×10^{17} ion/cm^2 at an ion flux of 8–9 μA/cm^2. The sample holder was water cooled to prevent samples from overheating. Both (0 0 1)- and (1 0 0)-face oriented rutile plates were implanted in a single run of an *ILU-3* ion beam accelerator kept at residual vacuum of 10^{-5} Torr.

Element composition and element depth distribution, as well as crystal phase identification and surface morphology

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