РАЗДЕЛ XVII. ФИЗИКА

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Magnetic ordering in Fe/MgO/Cr/MgO/Fe heterostructures

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Abstract

We report on the fabrication and characterization of layered heterostructures Fe(10nm)/MgO(1.5)/Cr(t)/MgO(1.5nm)/Fe(7nm) ($t = 0.9, 1.8\text{nm}$). The coupling of the Fe moments in this model system is mediated both by metallic Cr and insulating MgO layers. High structural quality of the samples was confirmed with X-ray diffraction and reflectometry. The macroscopic magnetic properties of both samples observed by vibrating sample magnetometry look similar with characteristic steps in the hysteresis curves. Magnetization reversal is found to go in different ways for these two samples when magnetic field is applied along hard magnetization axis.

Keywords: Layered magnetic nanostructures, magnetic ordering.**Аннотация**

Мы представляем результаты об изготовлении и характеристике слоистых гетероструктур Fe(10nm)/MgO(1.5 nm)/Cr(t)/MgO(1.5nm)/Fe(7nm) ($t = 0.9, 1.8\text{nm}$). Связь магнитных моментов Fe в этой модельной системе осуществляется посредством слоёв металлического Cr и изолирующего MgO. Высокое структурное качество образцов подтверждается рентгеновской дифракцией и рефлектометрией. Макроскопические магнитные свойства обоих образцов, исследуемые с помощью вибрационной магнитометрии, имеют похожую ступенчатую форму кривых гистерезиса. Когда внешнее магнитное поле направлено вдоль оси трудного намагничивания, обнаружено, что разворот намагничивания происходит по-разному для этих двух образцов.

Ключевые слова: слоистые магнитные наноструктуры, магнитное упорядочение.**Introduction**

Fe/MgO/Cr/MgO/Fe is a novel system where the Fe magnetic moments are coupled both across insulating and metallic spacing layers. Magnetic and magnetotransport properties of magnetic multilayer structures with metal/metal and metal/insulator interfaces have been studied in depth, whereas systems including both metal and dielectric spacing layers were much less investigated. In particular, physically interesting Fe/MgO/Cr systems are studied in very limited number of publications [1,2].

In the present study we report on structure and magnetic properties of Fe/MgO/Cr nanoheterostructures. In particular, we focused on the fabrication of samples, their magnetic behaviour, including macroscopic properties as well as layer-resolved magnetization reversal.

Experimental

Fe/MgO/Cr/MgO/Fe nanostructures were grown by UHV sputtering onto (100)MgO monocrystalline substrates without using a buffer layer. A Ta capping layer protects the system from oxidation. We have investigated two samples Fe(10nm)/MgO(1.5nm)/Cr(tnm)/MgO(1.5nm)/Fe(7nm)/Ta(5nm) with $t = 0.9\text{ nm}$ (sample 1) and $t = 1.8\text{ nm}$ (sample 2). These Cr thicknesses are known to provide antiferromagnetic and ferromagnetic ordering in Fe/Cr superlattices [3]. Metals were grown by DC magnetron

sputtering, the insulating MgO by RF sputtering. X-ray reflectometry (XRR) and diffraction (XRD) for structural characterization of the samples was performed on an Empyrean PANalytical diffractometer using $\text{CoK}\alpha$ radiation in parallel beam geometry. The magnetization was measured by vibrating sample magnetometry (VSM).

Results and Discussion

Representative XRR data and the best-fit model curve for the sample 1 are shown in Fig. 1.

Figure 1: XRR data for sample 1 (points), model structure and resulting fit (line).

The fit of samples shows that layer thicknesses are close to their nominal values, and that there is a well-defined layered structure with sharp interfaces except for Cr with a roughness corresponding to two atomic monolayers.

Figure 2: Magnetization curves for the sample 1 (left) measured for magnetic field applied at an angle of (c) 30° and (e) 45° relative to the Fe easy magnetization axis [110]; (b), (d) and (f) show similar data at the same rotation angles of the sample 2. Insets show the direction of magnetic moments of Fe(7nm) (black arrow) and Fe(10nm) (red arrow). The external field is directed horizontally from left to right.

Fig. 2 shows magnetic hysteresis loops measured by VSM for both samples, where the angle between the Fe easy magnetization direction [110] and the external magnetic field was set to 0° - 60° (остальные не приведены). The loops show steps, for example on the negative branch in the field range between $H=15$ Oe and 40 Oe. It is assumed that these steps are related to the reorientation of the magnetic moment in one or both Fe layers from negative to positive directions.

Conclusion

By using UHV sputtering we have grown high quality Fe/MgO/Cr/MgO/Fe nanoheterostructures, their structural properties were determined with X-ray diffraction and reflectometry. VSM magnetometry shows that magnetization reversal is featured by the presence of intermediate state. This non-collinearity can be controlled by applying small external field of several tens of Oersteds and sample orientation and it is also affected by the thickness of MgO spacer. The performed study may be useful for designing the spintronic devices for operation at room temperature and also at low temperatures, in superconducting spin-valves structures where non-collinearity is required to generate spin triplet condensate.

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