Effect of substrate temperature on the structural and magnetic properties of Fe/Ag superlattices

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Abstract

In the present work, Fe/Ag superlattices were grown by molecular beam epitaxy (MBE) on MgO(001) single crystal substrates maintained at room temperature or at 423 K during the deposition. The structural properties were carried out using small and high angle X-ray diffraction techniques. The magnetic hysteresis loops with the magnetic field applied parallel or perpendicular to the plane of the films were measured by a superconducting quantum interference device (SQUID) magnetometer in the temperature range 5-300 K. A comparison of the obtained results showed that the heating of MgO substrates leads to a strong interdiffusion and causes a significant modification of structural and magnetic properties of Fe/Ag superlattices.

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1. Introduction

A large number of magnetic multilayers and superlattices have been synthesized recently and investigated by many research groups [1-3]. The study of interfacial roughness and magnetism has received much attention because the magnetic and transport properties of these systems depend strongly on the change of the interface structure [4].

In this work, we present the results of the influence of growth temperature on the structural and magnetic properties of Fe/Ag superlattices epitaxially grown on MgO(001) substrates.

2. Experimental methods

The Fe/Ag superlattices were grown by sequential deposition of Fe and Ag layers by molecular beam epitaxy on single crystal MgO(001) substrates maintained either at room temperature or at an elevated temperature of 423 K.

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Twenty superlattice periods were deposited with Fe and Ag layers thicknesses fixed as 15 and 55 Å, respectively. Both the deposited rates, 1.3 Å/s for Fe and 0.6 Å/s for Ag, were controlled using a quartz crystal oscillator.

The structural characterization of the two samples was carried out by both high and small angle X-ray diffractions using CuKα radiation. The magnetic measurements were performed using a superconducting quantum interference device (SQUID) magnetometer in the range 5-300 K.

3. Results and discussion

Fig. 1a shows the small angle X-ray diffraction patterns of the sample prepared at room temperature, called S1, which had Kiessig fringes and Bragg peaks up to the sixth order. This indicated that S1 had a high quality layered structure and well-formed interfaces. In the case of the sample prepared at 423 K(Fig. 1b), called S2, the Kiessig fringes and Bragg peaks up to second order disappeared and the intensity of the other peaks was weaker than that of S1.

This may indicate the existence of a thicker diffused region at the interfaces and/or a large interfacial roughness, as suggested in a number of systems (e.g. Fe/Cr [1,5], Fe/Si [6], Fe/Ag [4]), induced by the substrate heating during the deposition.

High-angle X-ray diffraction patterns of sample S1and S2 (Fig.2 a,b) were obviously different. Both spectra showed intense peaks corresponding to MgO(002), Ag(002) and Fe(002) reflections.
S1 had many sharp satellite peaks, the appearance of those peaks confirmed the high period modulation and crystalline quality of Fe/Ag superlattices grown at room temperature. However, in the case of S2, the satellite peaks disappeared and the intensities of main peaks became weaker. This disappearance is attributed to a larger crystal plane roughness at the Fe/Ag interfaces [7,8], and one of the reasons for this weakening can be caused by a large intermixing at interfaces during the growth at elevated temperature. This confirms the obtained results of the small angle diffraction. The rocking curves measured across the fundamental Ag(002) peak (inset of Fig. 2a,b) had the full width at half maximum(FWHM) equal to 0.8° and 1.7° for S1 and S2, respectively. The increase of FWHM value from 0.8° to 1.7° means that the heating of the MgO substrate leads to the deterioration of the crystalline quality of the superlattice [2].

Fig. 3 shows the magnetization hysteresis loops of [Fe(15 Å)/Ag(55Å)]x20 superlattice prepared on unheated and heated MgO substrate with magnetic field applied perpendicular to the film plane. The easy magnetization direction of the two samples S1 and S2 was in the film plane, which indicates that the magnetic anisotropy was in the plane.

The magnetization of saturation decreases significantly when the growth is at high temperature (Ts=423K), this can be explained by the formation of interdiffused region at Fe/Ag interface. The X-ray diffraction curves (Figure 1.b and 2.b) is the evidence of the existence of this region. This region reduces the magnetic moments of iron atoms [6].

Fig. 3. Magnetic hysteresis loops recorded at 5 K (a) and 300 K (b) for [Fe(15 Å)/Ag(55Å)]x20 superlattices prepared at Ts=RT and 423 K.

4. Conclusion

Fe/Ag superlattices were epitaxially grown on MgO(001) substrates unheated and heated during the deposition. X-ray characterization revealed the influence of substrate heating on the interfacial roughness which well correlated with the decreasing of the magnetization measured from 5 to 300 K.

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