Fabrication and Characterization of Magnetic Superlattices - Epitaxial Co/Cr(100) and Co/Cr(211) superlattices


aInstitute of Physics, Academia Sinica, Taipei, Taiwan, ROC
bDepartment of Physics, National Cheng-Kung University, Tainan, Taiwan, ROC

Abstract — Epitaxial Co/Cr superlattices Co(1120)/Cr(100) on MgO (100) and Co(1100)/Cr(211) on MgO(110) have been grown by molecular beam epitaxy technique. Buffer layer of Mo or CrMo alloy was first deposited on top of the substrate which is crucial to prepare a smooth and well-ordered Cr surfaces and the following superlattices. The epitaxial orientation of Co/Cr(100) superlattices is Co[1120]//Cr[1 0 0]//MgO[1 0 0], Co[1100]//Cr[0 1 1]//MgO[0 1 0] and Co[0001]//Cr[011]//MgO[001], while that for Co/Cr(211) is Co[1100]//Cr[211]//MgO[1 1 0], Co[1120]//Cr[111]//MgO[1 1 0] and Co[0001]//Cr[011]//MgO[001]. Co x Cr y n superlattices with different Co thickness (x), Cr thickness (y) and number of layers (n) have been deposited. The maximum magnetoresistance of the Co/Cr(211) superlattices is 18% comparing with the 4.8% for Co/Cr(100) superlattices. The magnetization measurements also show that the antiferromagnetic coupling in Co/Cr(211) superlattices is stronger than in Co/Cr(100) superlattices. The magnetic properties are strongly influenced by the crystal orientation of the multilayers.

I. INTRODUCTION

The Co/Cr system attracts our attention because of its fascinating structural and magnetic properties, and technological applications as good media for perpendicular magnetic recording. Since the discovery of the giant negative magnetoresistance (MR) phenomena, ferromagnetic superlattices have attracted considerable attention [1-3]. Interestingly, Co/Cr superlattices have relatively small MR (less than 4%) [3-5] compared to the large MR of Fe/Cr superlattices (over 50%).

It is noted that the magnetic property may strongly be affected by the electronic structure, which in turn depends on their crystal structures. Herman et al [6] reported a theoretical model that each Cr(100) layer in a Cr crystal had non-zero magnetic moment but the Cr(211) layer had zero magnetic moment. Therefore the interlayer coupling in Co/Cr superlattices may be enhanced by replacing Cr(100) with Cr(211) in each Cr layer. Well-crystallized Co/Cr superlattices grown by molecular beam epitaxy (MBE) are most suitable for the study of the relationship between the structure and the magnetic property.

The MR ratio in superlattices is defined as \( \frac{R_0 - R_s}{R_0} \), where \( R_0 \) is the electrical resistance at saturated high magnetic field, and \( R_s \) is the electrical resistance when the field is removed. The maximum MRs of 2.5% and 2.72% of Co/Cr superlattices have been reported [5,7,8]. There was also lack of detail information about the influence of the crystal orientation on the magnetic property. This is the prime motivation for us to fabricate and study the magnetic properties of Co/Cr superlattices with different orientations.

In this paper, we report the successful growth of different crystal structures and magnetic properties of the epitaxial Co/Cr superlattices on MgO(100) and MgO(110) substrates by molecular beam epitaxy. We have obtained the maximum MRs of 18% for Co/Cr(211) superlattices and 4.8% for Co/Cr(100) superlattices. From the study of MR, we have also shown for the first time that distinct MR behavior exist between Co/Cr(100) and Co/Cr(211) superlattices.

II. EXPERIMENTAL

The crystal growth was carried out by a molecular beam epitaxy system (Eiko EL-10A), equipped with three independent electron beam evaporators. The base pressure of the MBE chamber is lower than 2x10^{-9} Torr. During deposition of the superlattices, the growth pressures were controlled at below 5x10^{-9} Torr, and the deposition rates were kept at ~0.1 Å/s. The film thickness and deposition rate were measured by a quartz crystal thickness monitor (Leybold Inficon XTC) and calibrated by ellipsometry and x-ray reflectivity analyses. To enable the growth of high quality samples, polished and epitaxial grade MgO substrates were chemically precleaned and rinsed in an ultrasonic cleaner. They were then outgassed at 900 to 1000 °C for at least 1/2 h under ultra high vacuum in the MBE system. Pure elements (99.99%) of Co, Cr and Mo were used. Mo or CrMo alloy graded buffer layer up to 300 Å thick was first deposited on top of the substrate in order to provide a smooth and well-ordered Cr surface. During the deposition of the Mo buffer layer, the substrate temperature was kept at 900 °C. For the growth of Co/Cr superlattices, the substrate temperature was kept between 300 and 350 °C to reduce the interdiffusion at the interfaces. The crystal structure of the film surface was in-situ examined throughout all the growth by a 15 KeV reflection high energy electron diffraction (RHEED). The crystal orientation was characterized by using Cu Ka radiation x-ray diffraction (XRD). The magnetic properties of all the samples were measured by using a superconducting-quantum-interference-devices (SQUID, Quantum design MPMS-5S) magnetometer.
Magnetization curves were measured with applied fields up to 5 tesla. The MR measurements were carried out by standard four probe technique in a magnetic field up to 5 T and with temperature at 10 K.

III. RESULTS AND DISCUSSION

The initial Mo (or MoCr graded alloy) buffer layers were first deposited on MgO(100) and MgO(110) substrates simultaneously. Mo(100) and Mo(211) are the crystal surfaces of the Mo films on top of MgO(100) and MgO(110) respectively. The first Cr layer was deposited on top of Mo and followed by the Co/Cr superlattices. Cr(100) and Cr(211) layers follow the underlying Mo(100) and Mo(211) buffer layers. Co(1120) and Co(1100) and the subsequent superlattice grow rather well on top of the Cr(100) and Cr(211) surfaces, respectively. Different thickness of Co (x=5 to 40 Å) and Cr (y=1 to 60 Å) layers in the superlattices with different periods (n=10 to 70) have been deposited in this study. In Co/Cr(100) superlattices, the unit cell of Co(1120) is a rectangle with dimensions of 4.07Å and 4.34Å which matches with the square cell of Cr(100) with dimension 4.08Å. The fit is good in one direction but off by about 6% in the other. In Co/Cr(211) superlattices, the unit cell of Co(1100) is also a rectangle with dimensions of 4.07 Å and 5.01 Å which matches almost perfectly with rectangle Cr(211) cell (4.07 Å and 5.0 Å). From the crystal growth point of view, Co/Cr(211) superlattices have better lattice match than Co/Cr(100) superlattices. The orientation of Co/Cr(100) superlattices has been reported previously [7, 8]. The XRD and RHEED measurements all confirmed the following orientation relationships of Co/Cr(211) superlattices:

Co(1100)//Cr(211)//Mo(211)//MgO(110),
Co(1120)//Cr(111)//Mo(111)//MgO[110],
Co[0001]/]/Cr[011]/Mo[011]/MgO[001],
as illustrated in Fig. 1 and Fig. 2.

Both magnetoresistance and magnetization measurements were carried out with H/Co(1120) (hard axis) on Co/Cr(211) superlattices and H/Co(1100) (hard axis) on Co/Cr(100) superlattices. The MR ratio of different Co/Cr superlattices with different Cr or Co thickness on MgO(110) or MgO(100) substrates have been measured. The maximum MR ratio at 10 K is 18% for (Co40Å/Cr15Å)20/MgO (110) compared with the maximum MR ratio of 4.8% measured on (Co40Å/Cr5Å)20/MgO(100) at 10 K, as shown in Fig. 3(a) and (b). Typical magnetization hysteresis loops of Co/Cr(211) and Co/Cr (100) superlattices were shown in Fig. 4(a) and (b), with applied fields up to 5 tesla at 10 K. The antiferromagnetic feature was clearly shown in (Co40Å/Cr15Å)20/MgO (110) superlattices in contrast to the ferromagnetic behavior shown in (Co40Å/Cr5Å)20/MgO(100) superlattices.

Fig. 1. The θ-2θ x-ray spectra of (Co40Å/Cr45Å)12/Mn50Å/MgO(110).

Fig. 2. The RHEED patterns of Co/Cr(211) superlattices show (a) Cr(211) viewed along [111], (b) Co(1100) viewed along [1120].
We have reported the novel epitaxial growth of Co/Cr superlattices with different orientations of Co and Cr prepared on single crystal MgO(100) and MgO(110) substrates. Co(1120)/Cr(100)/Mo(100)/MgO(110) and Co(1100)/Cr(211)/Mo(211)/MgO(110) are the epitaxial orientations of two kinds of samples. The maximum MR is 18% for the Co(1100)/Cr(211) superlattices and 4.8% for the Co(1120)/Cr(100) superlattices. The MR is about four times larger in the Co(1100)/Cr(211) superlattices than in the Co(1120)/Cr(100) superlattices. The magnetization measurements show that the Co(1100)/Cr(211) superlattices have stronger antiferromagnetic behavior than in the Co(1120)/Cr(100) superlattices. This demonstrates that the magnetic and magnetotransport properties of Co/Cr superlattices are strongly influenced by the crystal orientation of the multilayers.

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