Physica B 407 (2012) 4783–4786

Contents lists available at SciVerse ScienceDirect

Physica B

journal homepage: www.elsevier.com/locate/physb

Structure and magnetic properties of γ'-Fe_4N films grown on MgO-buffered Si (0 0 1)

Jing Li [a], Yinzhu Jiang [b,*], Tianyu Ma [a], Cong Lu [c], Yongbing Xu [c], Deren Yang [a], Mi Yan [a,**]

[a] State Key Laboratory of Silicon Materials, Department of Materials Science and Engineering, Zhejiang University, Hangzhou 310027, China
[b] Department of Materials Science and Engineering, Zhejiang University, Hangzhou 310027, China
[c] York Laboratory for Spintronics and Nanodevices, Department of Electronics, University of York, YO10 5DD, United Kingdom

ARTICLE INFO

Article history:
Received 28 February 2012
Received in revised form
13 August 2012
Accepted 5 September 2012
Available online 15 September 2012

Keywords:
γ'-Fe4N films
MgO buffer
Growth temperature
In-plane magnetic anisotropy
Biaxial texture
Pulsed laser deposition

ABSTRACT

γ'-Fe_4N thin films were grown on MgO-buffered Si (1 0 0) by pulsed laser deposition technique. Different crystallographic orientations and in-plane magnetic anisotropies were achieved by varying the growth temperature of the MgO buffer layer. When the MgO buffer layer was grown at room temperature, the γ'-Fe_4N film shows isotropic in-plane magnetic properties without obvious texture; while in-plane magnetic anisotropy was recorded for the γ'-Fe_4N films deposited on a 600 °C-grown-MgO buffer due to the formation of a (1 0 0)-oriented biaxial texture. Such a difference in in-plane magnetic anisotropy is attributed to the epitaxial growth of γ'-Fe_4N film on an MgO buffer with relaxed strain when the MgO layer was grown at a high temperature of 600 °C.

1. Introduction

Spin injection from a ferromagnetic (FM) metal into a semiconductor (SC) has been a crucial issue for the applications of spin-based electronics [1–4]. The spin injection efficiency is one of the key factors for the realization of spintronic devices. For a traditional FM/SC junction, the large conductivity mismatch between FM and SCs will severely hinder the spin injection and hence degrade the spin injection efficiency [5]. Recently, the insertion of an MgO tunnel barrier in FM/SC junction was demonstrated to effectively alleviate such conductivity mismatch and improve the spin injection efficiency [2,3,6]. Additionally, due to its good thermal and chemical stability even heated up to 800 °C, MgO was also confirmed as an excellent diffusion barrier for FM/SC interface [7]. Therefore, efficient spin injection can be expected by using a crystalline FM/MgO/SC system due to the high tunnel spin polarization [8–9]. For this purpose, FM/MgO/Si systems have attracted much attention because Si plays a primary role in electronics and possesses a long spin relaxation time [10–12]. γ'-Fe_4N has been considered to be one of the most promising FM materials with large magnetic moments for spintronic devices both theoretically and experimentally [13–16]. However, there have been no reports about the growth and properties of the γ'-Fe_4N/MgO/Si-based heterostructures so far.

In such γ'-Fe_4N/MgO/Si-based heterostructures, magnetic anisotropy will have a marked effect on the switching behaviors of the spin injection and magneto-tunneling devices. Crystal quality and surface morphology of the MgO buffer layer, largely determined by the deposition temperature, would play crucial roles in the growth of the γ'-Fe_4N films and corresponding magnetic anisotropy of γ'-Fe_4N/MgO/Si system. Therefore, we present here the texture formation and in-plane magnetic anisotropy in γ'-Fe_4N films with the MgO buffer grown at different temperatures on Si substrates.

2. Experimental

γ'-Fe_4N films were deposited on Si (1 0 0) substrates by pulsed laser deposition (PLD) with a KrF (Coherent, COMPerPro201, λ=248 nm) excimer laser system. The Si (1 0 0) substrates were cleaned chemically by standard procedures followed by dipping in dilute HF acid solution to get hydrogen terminated oxide-free Si (1 0 0) surface, immediately, before loading into the high vacuum chamber. After the stainless-steel vacuum chamber was evacuated to the order of 10^{-7} Torr, the in-situ deposition of the MgO buffer layer was carried out at room temperature (RT) and 600 °C, respectively. The MgO buffer layer is prepared by ablating a sintered MgO target without additional oxygen gas. In order to

* Corresponding author. Tel./fax: +86 571 87952366.
** Corresponding author.
E-mail addresses: yzjiang@zju.edu.cn (Y. Jiang), mse_yanmi@zju.edu.cn (M. Yan).

0921-4526/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physb.2012.09.020

simplify the description, we use the terms "MgOrt" and "MgO600" to denote MgO buffer grown at RT and 600 °C throughout the paper. The γ′-Fe_4N films were then grown on the top of the MgO buffer layer at 150 °C by ablating high pure (99.95%) iron target at a nitrogen pressure of 1.8×10^{-3} Torr. The target-to-substrate distance was kept at 60 mm for both the MgO ceramic target and the iron metal target. The focused laser fluence was set at 3 J/cm^2 and 5 J/cm^2 for MgO buffer layers and γ′-Fe_4N thin films, respectively. The laser frequency was kept at 10 Hz for both films. Structural analysis was performed by x-ray diffraction (XRD, PANalytical X'Pert Pro) with a Cu K_α radiation. Film thickness was determined under a Hitachi S-4800 scanning electron microscope (SEM). It has been measured that the layer thickness of the γ′-Fe_4N and MgO buffer are about 200 nm and 50 nm, respectively. Transmission Electron Microscopy (TEM, FEI Tecnai G2 F20) was used to observe the cross-sectional microstructures. Magnetic properties were measured by a superconducting quantum interference device (SQUID) magnetometer (Quantum Design MPMS) and magneto-optic Kerr effect (MOKE) with the applied magnetic field parallel to the film plane at room temperature.

3. Results and discussion

The x-ray diffraction θ–2θ scans was used to investigate the effect of MgO growth temperature on the structure of γ′-Fe_4N films employing the same deposition parameters. Fig. 1 shows XRD patterns of γ′-Fe_4N films deposited on the MgO buffer grown at RT (MgOrt) and 600 °C (MgO600), respectively. In both cases, only two peaks from γ′-Fe_4N (2 0 0) and γ′-Fe_4N (1 1 1) can be observed except for the (2 0 0) peak from the MgO buffer, which indicates the single-phase γ′-Fe_4N is obtained for the films. For MgOrt, a weak MgO (2 0 0) peak is shifted to the left which implies that the misfit tensile strain exists in the MgO buffer. As the growth temperature increases to 600 °C, the tensile-strained MgO becomes relaxed with the in-plane lattice constant of 4.214 Å, which is consistent with its bulk value. It can be found that the γ′-Fe_4N film grown on MgO600 is mainly (1 0 0) oriented while the γ′-Fe_4N film grown on MgOrt exhibits both strong (1 1 1) and (2 0 0) peaks. This different crystal orientation of the γ′-Fe_4N films can be attributed to the underlying misfit strain in the MgO buffer determined by the growth temperature. Furthermore, the lattice constant of the γ′-Fe_4N for both samples was calculated to be $c=3.81$ Å utilizing the observed (2 0 0) diffraction, which is a little larger than the bulk value of 3.795 Å, indicating tensile strain existed in γ′-Fe_4N layer probably due to the lattice mismatch between γ′-Fe_4N and MgO. Based on these results, the MgO growth temperature is a key experimental parameter which determines the underlying misfit strain, leading to the different crystal orientation of the γ′-Fe_4N films.

Fig. 2 shows the in-plane M–H curves of γ′-Fe_4N films grown on MgOrt and MgO600 as measured by the SQUID magnetometer at 300 K. Distinct square-like hysteresis loops with large remnant magnetization and small coercive fields were obtained for both samples. The γ′-Fe_4N film on MgOrt exhibited a low coercivity of 10 Oe, while a lower coercivity of 5 Oe was recorded when growing γ′-Fe_4N film on MgO600. The saturation magnetization (M_s) of the γ′-Fe_4N films on both MgOrt and MgO600 is about 1250 emu/cm^3, the value of which is comparable with those reported previously [15]. The M_s value was calculated by careful volume calibration of the thin films using cross-sectional TEM measurement. It seems that the deposition temperature of the MgO buffer makes a little effect on the M_s of γ′-Fe_4N films.

The in-plane magnetic anisotropies of the γ′-Fe_4N samples with buffer layers deposited at different temperatures were measured by MOKE. Fig. 3 shows the magnetic hysteresis loops of γ′-Fe_4N/MgO/Si structures with the magnetic field applied along the four major in-plane axes of the Si (1 0 0). For the γ′-Fe_4N film grown on the MgOrt, the hysteresis loops along four major directions show the very similar features with a squareness of 0.895, which indicates an in-plane magnetic isotropy (Fig. 3(a)). Oppositely, the γ′-Fe_4N film grown on the MgO600 exhibit an in-plane magnetic anisotropy (Fig. 3(b)) with the squareness close to 1 along both the [0 0 1] and [0 1 0] directions, which clearly reduced along both the [0 1 1] and [01$^-$1] directions, indicating the cubic anisotropy. The hysteresis loop squareness has been calculated along the [0 1 1], [0 0 1], [01$^-$1], and [0 1 0] directions and found to be 0.831, 0.939, 0.887, and 0.927, respectively. These values further suggest a dominant contribution of the cubic biaxial anisotropy superimposed by a uniaxial anisotropy component.

From the XRD results in Fig. 1, there is no difference of stress state in γ′-Fe_4N films with different MgO growth temperatures, the effect of stress anisotropy on the difference of this in-plane anisotropy can be excluded. As expected for bulk FCC-γ′-Fe_4N, the cubic easy axes are along [1 0 0], [0 1 0], etc. For γ′-Fe_4N film on MgO600, the cubic magnetic anisotropy component can be attributed to the high (0 0 1)-oriented texture as shown in Fig. 1(b). In our previous research, the γ′-Fe_4N films grown on Si (1 0 0) using an Fe buffer have shown an in-plane magnetic isotropy although it has a high (0 0 1)-oriented texture, which was attributed to the fiber texture caused by the amorphous interlayer at the interface of Fe/γ′-Fe_4N, as was confirmed by HRTEM research [17]. Generally, thin film textures may be categorized into two different types: (1) The so-called fiber textures, the orientation of a certain lattice plane is preferentially parallel to the polycrystalline or amorphous substrate in which the influence of the substrate is minor and the texture is formed mainly by anisotropic growth; (2) biaxial textures, the

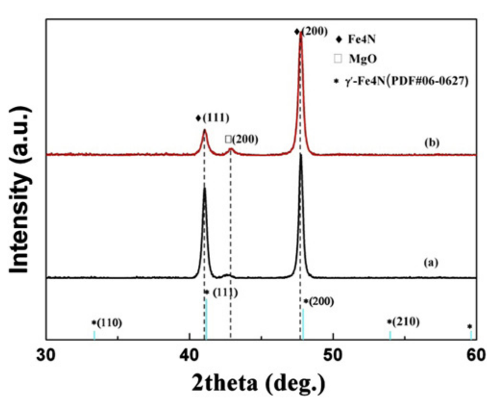

Fig. 1. XRD patterns of two γ′-Fe_4N/MgO/Si films with MgO buffer grown at (a) RT, (b) 600 °C.

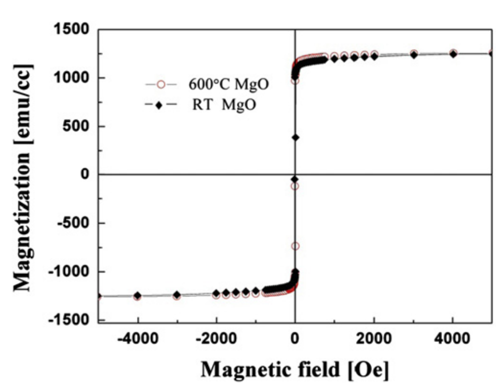

Fig. 2. In-plane magnetic hysteresis loops of the γ′-Fe_4N films on the MgO layer grown at RT and 600 °C.