

Epitaxial layer of MgO (001) grown on Si(001) wafer by e-beam evaporation

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Abstract

MgO(001) has been growing successfully on Fe/Pd/Cu/Si(100) by e-beam evaporation as examined by X-ray diffraction and high resolution transmission microscope. We present the magnetic peculiarity of crystal structure Fe(001)/Pd(001)/Cu(001) on Si(001) substrate. The magnetic properties of the sample were measured by magneto-optical Kerr effect which shows an in-plane magnetocrystalline anisotropy. © 2006 Elsevier B.V. All rights reserved.

Keywords: Texture; MgO (001)

1. Introduction

Aluminum oxide used in magnetic tunneling junction (MTJ) exhibited magneto resistive ratio (MR) up to 60%, which was regarded as a promising material for magnetic random access memory (MRAM) industry [1]. The seeking for higher MR structure has not been stopped, and recently a report on using MgO(001) as the tunneling barrier in MTJ sets a new record in MR of 230% at room temperature [2,3]. Unlike the Al₂O₃, MgO has to be epitaxial for gaining high performance. Therefore, it is very selective about substrate or buffer materials. It is known that Cu(100)/Si(100) can be used as seed layer [4] to grow many transition elements epitaxially, such as Au, Fe, Ni, permalloy, Pt, Pd, etc. In this article we reported on the work of growing MgO(001). Since the surface mesh of MgO does not fit the Cu(100)/Si(100) and in order to reduce the mismatch, epitaxial layer of Fe(100)/Pd(100) was formed on top of the Cu(100)/Si(100).

2. Experiments

Samples of the textured structure MgO(001)/Fe(001)/Pd(001)/Cu(001) on Si(001) wafer were prepared by

using an e-beam evaporation system at room temperature. Before deposition, Si wafer was first cleaned by using acetone to degrease and then put into 16% HF solution for several seconds. Si wafer was then rinsed in deionized water (DI water) and dried by N₂. The base and working pressure were kept better than 3×10^{-7} Torr. During deposition, the evaporation rate was kept at about 0.1 nm/s without external applied field. The structure was characterized by X-ray diffractometer (XRD) and high resolution transmission microscope (HRTEM). The magneto-optical Kerr effect (MOKE) has been used to search magnetic peculiarity.

3. Results and discussion

The X-ray diffraction of samples Pd(5 nm)/MgO(35 nm)/Fe(20 nm)/Pd(15 nm)/Cu(15 nm)/Si(001) and Pd(5 nm)/Fe(20 nm)/MgO(35 nm)/Pd(15 nm)/Cu(15 nm)/Si(001) were shown in Fig. 1. It is not obvious that the Cu(002) diffraction peak appears at 51°. In Ref. [4], the e-beam evaporated Cu films were found to epitaxially grow on Si(001), and we used it to be a textured seed layer on Si(001) wafer. It is obvious that the Pd(002) diffraction peak appears at 47°, which means that the Pd could be deposited on Cu directly with good epitaxy. For sample

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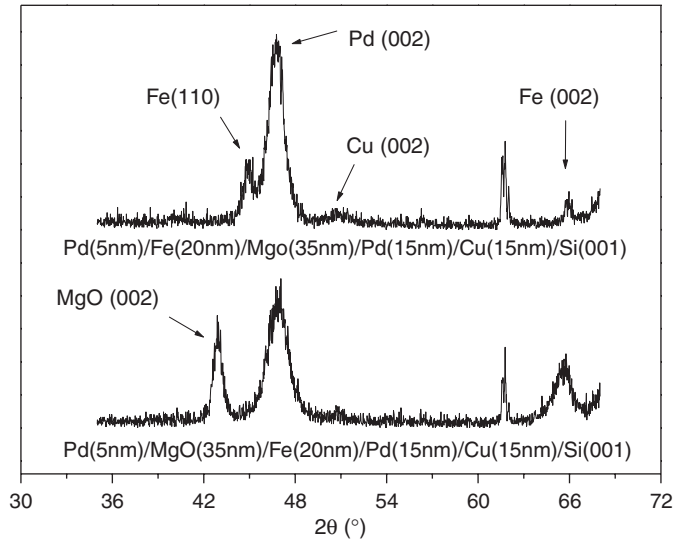


Fig. 1. The X-ray diffraction of samples Pd(5 nm)/MgO(35 nm)/Fe(20 nm)/Pd(15 nm)/Cu(15 nm) and Pd(5 nm)/Fe(20 nm)/MgO(35 nm)/Pd(15 nm)/Cu(15 nm)/Si(001).

Pd(5 nm)/MgO(35 nm)/Fe(20 nm)/Pd(15 nm)/Cu(15 nm)/Si(001), the Fe(002) diffraction peak can be seen at 66° . It means that we can deposit the textured Fe(001) on Pd(001) directly, and this Fe layer can be the bottom ferromagnetic electrode of MTJs. The MgO(002) diffraction peak appears at 43° . It means that MgO(001) has good texture which was deposited on Fe(001) directly. However, for sample Pd(5 nm)/Fe(20 nm)/MgO(35 nm)/Pd(15 nm)/Cu(15 nm)/Si(001), the Fe(002) diffraction peak decreases, the MgO(002) diffraction peak disappears, and the Fe(110) diffraction peak appears at 45° . It means that MgO(001) could not be deposited with good texture on Pd(001) directly, because the mismatch between MgO and Pd was too large (8%), and Fe(001) could not be formed on this non-crystal MgO thin film. Since the diffraction peak at 62° was the single of Si substrate, we could deposit crystal MgO(001) on Si(001) wafer with selecting small mismatch structure of Fe(001)/Pd(001)/Cu(001).

Fig. 2(a) shows the schematic diagram of Fe(001)/Pd(001)/Cu(001)/Si(001) structure. First, we used the HF solution to remove the silicon-oxide on the Si(001) wafer surface, and it forms a “two by one” structure [5]. The lattice constant of Si is 3.84 Å or so. Second, we deposit the FCC-Cu(001) with lattice constant 3.61 Å on this “two by one” Si(001) surface with the rotating of 45° in-plane [4], and the mismatch between Si and Cu was 6%. Then, we deposit the fcc-Pd(001) (lattice constant 3.89 Å) on the Cu(001) with 7% mismatch, with an aim to reduce the mismatch between Fe(001) and Cu(001). Finally, we deposit the BCC-Fe(001) (lattice constant 2.87 Å) on the Pd(001) with the rotating of 45° in-plane as schematic diagram, and the mismatch between Fe(001) and Pd(001) was 4%. Fig. 2(b) shows the schematic diagram of MgO(001)/Fe(001). It is obvious that the process of

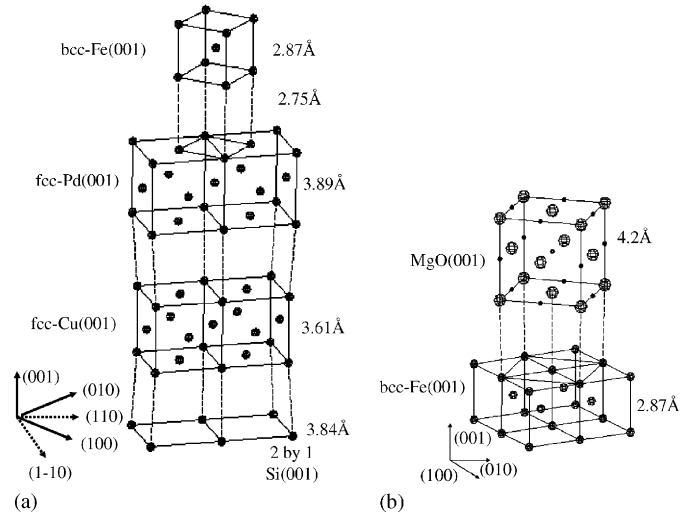


Fig. 2. (a) The schematic diagram of Fe(001)/Pd(001)/Cu(001)/Si(001). (b) The schematic diagram of MgO(001)/Fe(001).

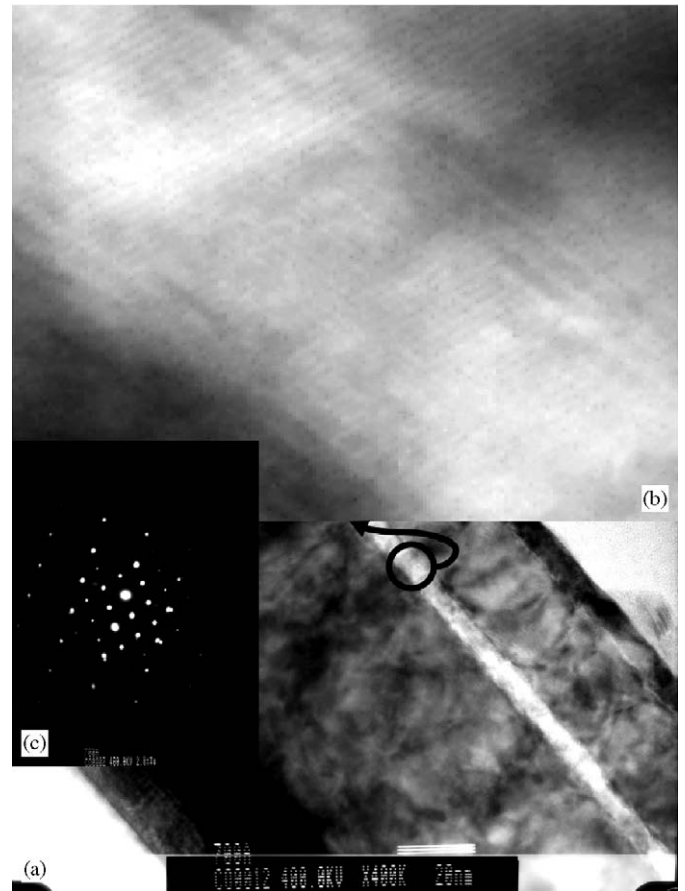


Fig. 3. (a) HRTEM image. (b) The partially enlarged picture of Fig. 3(a). (c) HRTEM electron diffraction pattern of Pd(5 nm)/Fe(20 nm)/MgO(35 nm)/Fe(50 nm)/Pd(15 nm)/Cu(15 nm)/Si(001).

deposition was similar to the deposition between Fe(001) and Pd(001). The MgO(001) with NaCl structure deposit on Fe(001) with the rotating of 45° , and the mismatch between MgO(001) and Fe(001) was 4%.

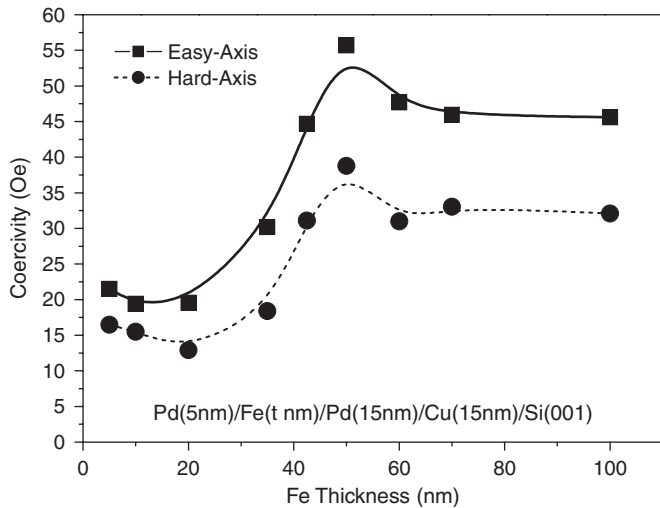


Fig. 4. The coercivity versus different iron thickness (t) of sample Pd(5 nm)/Fe(t nm)/Pd(15 nm)/Cu(15 nm)/Si(001).

Fig. 3(a) presents a cross section HRTEM image of Pd(5 nm)/Fe(20 nm)/MgO(35 nm)/Fe(50 nm)/Pd(15 nm)/Cu(15 nm)/Si(001) structure. It is not clear to see good crystal quality of MgO film, but the partially enlarged picture in Fig. 3(b) identified good crystal lattice on MgO. And the Fig. 3(c) identified HRTEM electron diffraction pattern on MgO layer.

Fig. 4 shows the coercivity versus different iron thickness(t) of sample Pd(5 nm)/Fe(t nm)/Pd(15 nm)/Cu(15 nm)/Si(001), and we define the Fe(100) direction as easy-axis and Fe(110) direction as hard-axis. For easy-axis, the minimum coercivity was about 20 Oe when iron

thickness was 20 nm. When iron thickness increased, the coercivity increased, too. It might be attributed to the competition of Neel wall and Bloch wall energy. The maximum coercivity was 55 Oe when iron thickness was 50 nm. When iron thickness exceeds 50 nm, the magnetic behavior shows bulk peculiarity, and the coercivity maintains a constant value about 50 Oe.

4. Summary

Crystal MgO(001) could be deposited with good texture on the structure of Fe(001)/Pd(001)/Cu(001)/Si(001) at room-temperature, and this structure shows an in-plane magnetocrystalline anisotropy. By using this structure, it is feasible to prepare the MTJ device at room-temperature.

Acknowledgements

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