REALIZATION OF HIGH QUALITY EPITAXIAL CURRENT-PERPENDICULAR-TO-PLANE GIANT MAGNETORESISTIVE PSEUDO SPIN-VALVES ON Si(001) WAFER USING NiAl BUFFER LAYER

Jiamin CHEN[1,2], J. LIU[2], Y. SAKURABA[2], H. SUKEGAWA[2], S. LI[2] and K. HONO[2,1]

[1]University of Tsukuba, Tsukuba, Japan
[2]National Institute for Materials Science, Tsukuba, Japan
E-mail address: chen.jiamin@nims.go.jp

I. INTRODUCTION

Spintronics is one of the research fields that have rapidly developed in these two decades. However, only a few applications reached to the practical level so far, i.e. there is still large gap between fundamental studies and practical applications in spintronics field. Although many previous studies on epitaxial current-perpendicular-to-plane giant magnetoresistive (CPP-GMR) devices reported excellent device performances, they are always regarded as fundamental studies because unpractical MgO single crystalline substrate is needed.[1] In this study, we report to use NiAl buffer layer as a template for the integration of epitaxial CPP-GMR devices on a Si(001) single crystalline substrate. We confirmed by a careful microstructure analysis that the epitaxial CPP-GMR devices with half-metallic $Co_2FeGa_{0.5}Ge_{0.5}$ (CFGG) Heusler electrode grown on the buffered Si(001) substrate have a very flat and sharp interface structures. Excellent magnetoresistive (MR) output that is comparable with the devices grown on an MgO(001) substrate were clearly observed in the device on Si substrate, demonstrating the possibility of epitaxial spintronic devices with NiAl template for practical applications.[2]

II. EXPERIMENT DETAIL

A fully epitaxial multi-layer stack of NiAl(50)/CoFe(0 or 10)/Ag(50)/CFGG(10)/Ag(5)/CFGG(10)/Ag(5)/Ru(8) (thickness in nm) was deposited onto Si(001) single-crystalline substrates using the ultrahigh vacuum magnetron sputtering system. Crystal structure, surface roughness, magneto-resistance property and microstructure were analysed by XRD, RHEED, AFM, direct current four-probe method and TEM, respectively.

III. EXPERIMENT RESULT

Figure 1 shows the XRD patterns accompanied with RHEED patterns for samples with single 50 nm thick NiAl layers deposited on a Si(001) substrate at different temperatures. At the deposition temperature of T_s=300°C, NiAl(011) and NiAl(022) peaks appear, indicating the NiAl layer grows with the (011) orientation in the out-of-plane direction, which is different from the (001) orientation of Si substrate. A very broad NiAl(011) peak shown in the two dimension XRD image suggests that the crystallinity is low at this deposition temperature. A RHEED pattern taken along the NiAl[100] azimuth gives a rings-centered pattern, which means a polycrystalline growth of the NiAl layer. When deposition temperature increases to T_s = 400°C, the NiAl(011) and NiAl(022) peaks disappear; instead, the NiAl(001) and NiAl(002) peaks appear. The appearance of NiAl(001) peak suggests that the NiAl has B2 ordered structure and its crystal orientation becomes (001) to the out-of-plane direction.

Figure 2 shows the stacking structure of multilayer for the whole CPP-GMR devices and the RHEED patterns for each layer. The sharp streaks in RHEED patterns for each layer demonstrate a nice epitaxial growth of CPP-GMR devices on a Si(001) single-crystalline substrate using NiAl as a buffer material. The epitaxial relationship of Si(001)[110]//NiAl(001)[110]//CoFe(001)[110]//Ag(001)[100]//CFGG(001)[110] can be confirmed for all the layers. The usage of NiAl buffer layer successfully overcomes the difficulty of growing high quality epitaxial ferromagnetic (FM) films on Si.

Figure 3 summarizes the MR outputs of resistance change-area product (*ΔRA*) for the epitaxial CPP-GMR devices grown on a Si(001) substrate (red stars) as a function of annealing temperature. High MR output (*ΔRA* of 8.56 mΩ· μm^2 and MR ratio of 27.8%) are achieved using the CFGG Heusler alloy as ferromagnetic layers on Si(001) substrate. It is important to point out that by inserting CoFe as a diffusion barrier, MR output is further enhanced to 9.54 mΩ· μm^2 and 37%, which presents comparable MR output with those grown on an MgO(001) substrate. This means we can replace the expansive impractical MgO substrate with the Si substrate to achieve high performance epitaxial CPP-GMR devices for practical sensor applications, which is a great breakthrough. More importantly, by combining this epitaxial Si/NiAl/CoFe template with the wafer bonding technique,[3] various types of spintronic devices such as CPP-GMR, magnetic tunnel junctions, spin-field-effect transistors and lateral spin valves can be grown on a Si substrate and easily attached to other integrated circuits or magnetic shield layers, which is promising for next-generation spintronic applications based on epitaxial devices.

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IV. REFERENCE

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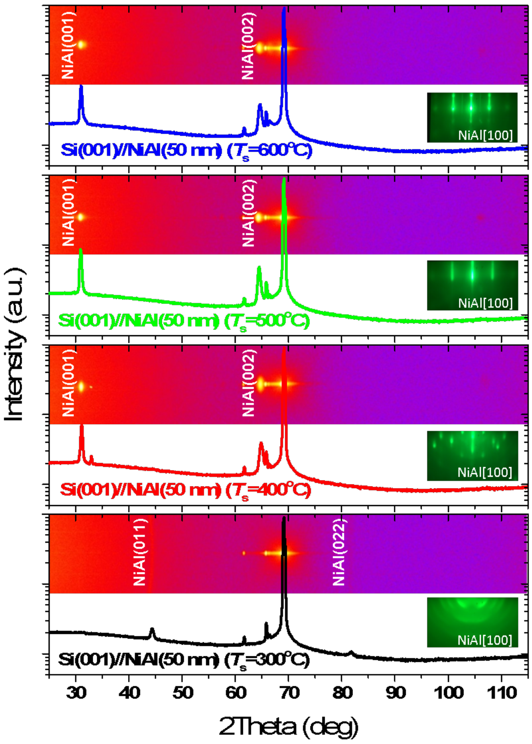

Fig.1 θ-2θ XRD profiles and corresponding two-dimensional diffraction images of 50 nm thick NiAl layer on Si(001) substrate with deposition temperature ranging from 300 to 600°C. Insets are RHEED patterns taken along <100> azimuth of each deposition temperature.

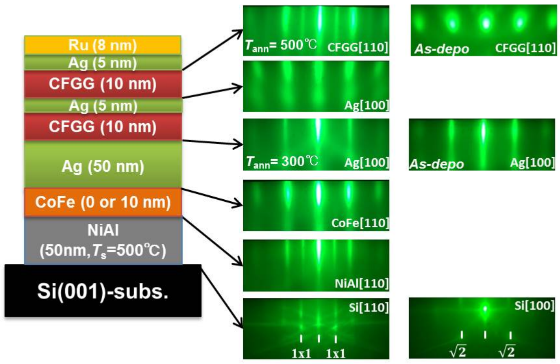

Fig.2 Structure illustration of whole CPP-GMR film stack and corresponding RHEED patterns for each layer.

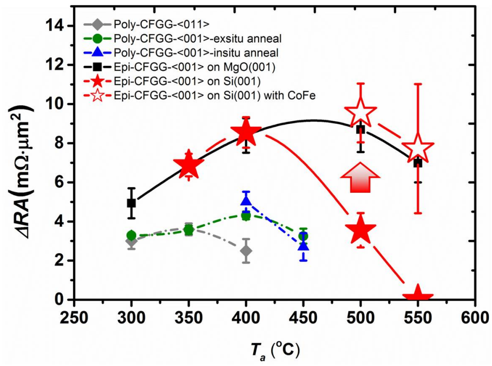

Fig.3 Annealing temperature dependence of ΔRA for various CPP-GMR devices.