Realization of high quality epitaxial current-perpendicular-to-plane giant magnetoresistive pseudo spin-valves on Si(001) wafer using NiAl buffer layer

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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. 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 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.[1]

Experiment detail

A fully epitaxial multi-layer stack of NiAl(50)/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.

Experiment result

Figure 1 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]//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 2 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 magnetoresistive ratio over 27% was achieved using the CFGG Heusler alloy as ferromagnetic layers. It is important to point out that for the post-annealing temperature up to 400°C, our CPP-GMR devices grown on a Si(001) substrate presents comparable MR outputs 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 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.

References

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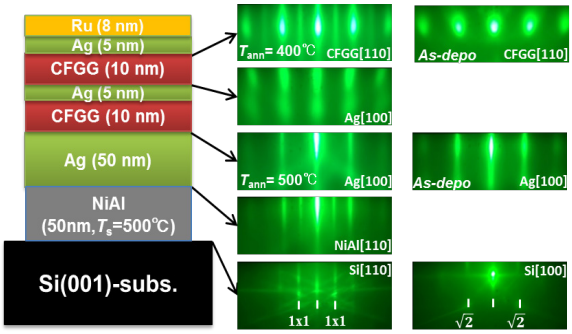

Fig.1 Structure illustration of whole CPP-GMR film stack and corresponding RHEED patterns for each layer.

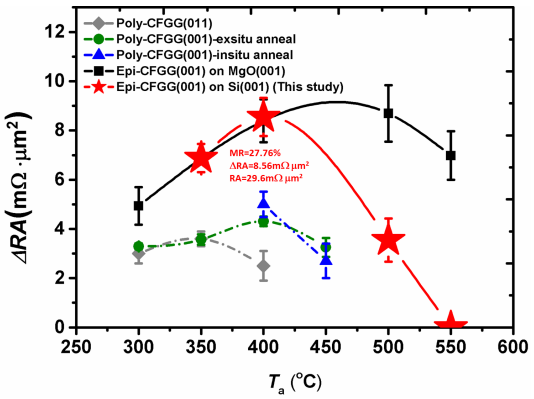

Fig.2 Annealing temperature dependence of ΔRA for various CPP-GMR devices.[2]