Magnetic tunnel junctions epitaxially-grown on Si(111) and Al2O3(0001) substrates

Sung-Jin Ahn*, H. Kubota, Y. Ando, T. Miyazaki
Department of Applied Physics, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan

Introduction

Since the discovery of a large magnetoresistance ratio at room temperature [1,2], magnetic tunnel junctions (MTJs) have been a subject of intense research due to their fertile physics and potential applications. However, one of the main shortcomings in MTJ is the dramatic decrease of magnetoresistance effect with bias voltage [2]. It is reported that the steepness of Tunnel magnetoresistance (TMR) decay with bias voltage is reduced in high quality junctions [3], but part of it is due to intrinsic mechanism such as electronic structure of ferromagnetic (FM) electrode and excitation of magnons at the metal-barrier interface. In the other words, the bias voltage dependence of TMR is strongly related not only with the quality of the interfaces and barrier but also with the FM electrode.

Therefore, in our work, we aims at improvement of bias voltage dependence through epitaxially-grown FM electrode, which also means the high quality of Al-O layer.

Experimental details

MTJs were prepared by magnetron sputtering on Si(111) and Al2O3(0001) substrates. The structures were Si(111) /Cu(111) 20nm/Ni80Fe20(111) 50nm/Al 1.6nm-O(t sec)/Co75Fe25 4nm/IrMn 10nm/Ni80Fe20 30nm and Al2O3(0001)/Pt(111) 20nm/Ni80Fe20(111) 50nm/Al 1.6nm-O(t sec)/Co75Fe25 4nm/IrMn 10nm/Ni80Fe20 30nm, respectively.

Si(111) wafers were first cleaned in H2SO4+H2O2 solvent and then immersed in NH4F solution to remove the native SiO2 and to obtain a hydrogen-terminiated surface. Al2O3(0001) substrates were heated up to 850℃ to rearrange the surface and a Pt buffer layer was deposited at 300℃. All the deposition processes were done at a base pressure of about 3× 10-6Pa without breaking vacuum. The buffer layers (Pt, Cu) and the bottom FM electrode (Ni80Fe20) were sputtered at slow rate of 0.06nm/sec and 0.03nm/sec respectively to obtain epitaxially-grown films. After sputtering of ultra-thin Al layers, the surface was oxidized by inductively coupled plasma (ICP) in a mixed atmosphere of 0.25Pa Ar and 0.74Pa O2. Tunnel junctions were fabricated using micro-fabrication process combined with Ar ion-beam etching and CHF3 reactive ion etching.

Results and discussions

Fig. 1 shows X-ray diffraction -scans and LEED patterns of the Al2O3(0001)/Pt(111) 20nm/Ni80Fe20(111) 20nm/Al 1.6nm. From the peak positions of Pt(111) and Ni80Fe20(111) with respect to those of Al2O3(0001) , it was confirmed that Pt(FCC) and NiFe(FCC) grows epitaxially on Al2O3(0001) (Corundrum). But, 6-fold symmetry patterns from Pt(111) and Ni80Fe20(111) observed indicate twin epitaxy with some grains rotated by 180° about the [111] pole with respect to others [4].

TMR ratios measured at as-deposited state were 32% for Si(111) substrate and 28% for Al2O3(0001) substrate when plasma oxidation time is 180sec. Fig. 2 represents the normalized TMR ratio versus DC bias voltage curves measured at as-deposited state. The curves are slightly asymmetric with respect to zero DC bias voltage irrespective to plasma oxidation time. In general, TMR decay can be evaluated with the voltage V1/2 at which the zero bias TMR value is halved. In this work, all of the MTJs prepared show large values of V1/2. V1/2 of the MTJs prepared on Si(111) are slightly larger than those of the MJJs on Al2O3(0001). After annealing, V1/2 increases slightly in case of both Si(111) and Al2O3(0001) substrates, as shown in Fig. 3. As the annealing temperature increases up to 250℃, an average barrier height () increases up to about 3eV and the difference between bottom barrier height (1) and top barrier height (2) decreases, which means that the barrier shape becomes near to a rectangular potential barrier after annealing. The effective barrier thickness decreases from 1.0nm to 0.9nm, which suggests homogeneity of Al-O layer and sharpening of the FM/I interfaces due to annealing.

Conclusion

Expitaxally-grown tunnel junctions were fabricated on Si(111) and Al2O3(0001) substrates using UHV sputtering and lithography process. The large values of V1/2 (~700mV) and barrier height (~3eV) were obtained after annealing at 250℃.

This study was supported by the IT program of Research Revolution 2002 (PR2002) Development of Universal Low-Power Spin Memory from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] T. Miyazaki and N. Tezuka, J. Magn. Magn. Mater. 139 L231 (1995)
[2] J. S. Moodera, L. R. Kinder, T. M. Wong, and R. Meservery, Phys. Rev. Lett. 74, 3273 (1995).
[3] J. S. Moodera, J. Nowak, and R. van de Verdonk, Phys. Rev. Lett. 79, 3744 (1997)
[4] R. F. C. Farrow, G. R. Harp, R. F. Marks, T. A. Rabedeau, M. F. Toney, D. Weller and S. S. P. Parkin, J. Crystal. Growth. 133, 47 (1993).