28a-A7-2

Highly efficient spin injection into silicon using ferromagnetic tunnel contact with radical-oxidation-formed MgO barrier

ISEL, Tokyo Inst. of Tech. [1], CREST, JST [2], °A. Sadono[1], T. Akushichi[1], T. Okishio[1], Y. Shuto[1,2], S. Sugahara[1,2]
E-mail: sadono.a@isl.titech.ac.jp

Introduction: Spin-functional MOSFETs such as a spin-MOSFET [1] possess promising functionalities for low-standby-power logic circuits, owing to their magnetization-configuration-dependent output characteristics [2]. Understanding and controlling spin injection and transport for Si channels are necessary to realize these devices. CoFe/MgO/n-Si tunnel junctions would be useful to achieve spin injection/detection for Si channels at room temperature [3-5]. In the previous reports, the MgO tunnel barrier was formed by electron beam evaporation or MBE. In this paper, we investigated spin injection into a Si channel using a CoFe/MgO/n-Si tunnel junction whose MgO barrier was formed by radical oxidation of an Mg thin film. We found that the radical oxidation technique improved the quality of the tunnel junction and that highly efficient spin injection was made possible by the junction, which were beneficial in revealing spin injection dynamics.

Experimental procedure: An Al(100nm)/CoFe(30nm)/MgO tunnel-contact stack was formed on a highly P-doped n-type Si substrate (N_d=5x10^{19}cm^{-3}) using a multi-chamber sputter/radical-oxidation/MBE system without breaking ultrahigh vacuum. The ultrathin MgO barrier layer was formed by radical oxidation of an Mg thin film (1.5nm) deposited on the Si substrate at room temperature and then annealed at 400^{o}C for 30 minutes. The CoFe electrode was deposited on the MgO barrier layer using MBE technique. Spin injection behaviors were evaluated employing the three-terminal spin accumulation method shown in Fig. 1.

Results and Discussion: Figure 2 shows observed Hanle-effect signals in a temperature range from 10 to 150K, in which the current bias was fixed at 10mA and its polarity was changed for spin injection and extraction measurements. The signals was not able to be fitted by single Lorentz function, and at least two Lorentz functions having different FWHMs were required to fit the observed signals. A similar result has also been reported recently [3]. We analyzed the Hanle-effect signals using two Lorentz functions with narrower and broader FWHMs, in which the least square method was used for the deconvolution. The amplitude and FWHM of the narrower Lorentz-function component decreased with increasing temperature. However, the FWHM of the broader component had only slight temperature dependence. Figure 3 shows the bias dependence of spin lifetime at 10K. The spin lifetime evaluated from the narrower component decreased with increasing bias voltage. On the other hand, the spin lifetime evaluated from the broader component had little dependence on the bias voltage. The amplitude of these components increased with increasing bias. These findings were somewhat different from previously reported behavior [3]. Nevertheless, the narrower component would be likely to reflect the spin injection phenomenon.

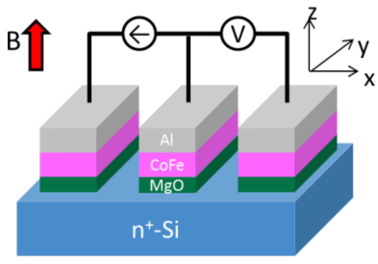

Fig.1 Device structure and measurement setup for three-terminal spin accumulation method.

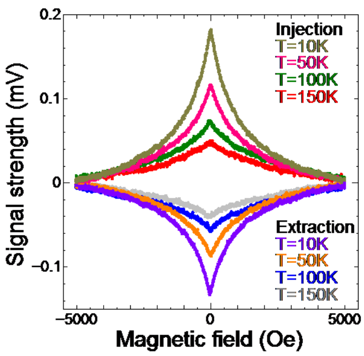

Fig.2 Hanle-effect signals at 10-150K for spin injection and extraction measurements.

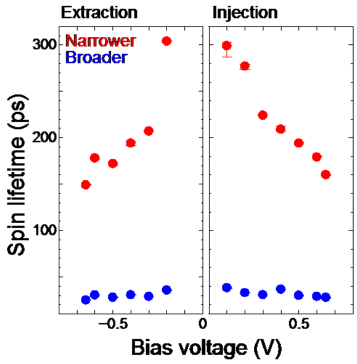

Fig.3 Spin lifetime as a function of bias voltage at 10K for spin injection and extraction measurements.

References: [1] S. Sugahara, IEE Proc. Circuits Devices Syst. **152**, 355 (2005). [2] S. Yamamoto, *et al*, Electronics Lett. **47**, 1027 (2011). [3] A. Yasunori, *et al*, Phys. Rev. B **86**, 081201(R) (2012). [4] M. Ishikawa, *et al*, Appl. Phys. Lett. **100**, 252404 (2012). [5] K. R. Jeon, *et al*, Appl. Phys. Lett. **98**, 262102 (2011).