Spin accumulation in a Si channel using a high-quality CoFe/MgO/Si spin injector

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Introduction: Understanding and controlling of spin injection and transport for Si channels are highly requested to realize Si-based spin devices [1]. The Hanle effect observed in three-terminal spin accumulation (3T-SA) devices has been widely used to investigate spin injection phenomena. However, Hanle-effect signals obtained from the 3T-SA technique need to be carefully verified. Our developed fitting technique of Hanle-effect signals is useful to distinguish signals due channel spin and trap spin components, and this technique can extract the intrinsic channel spin component from the other signals [2]. Recently, we investigated spin injection/extraction for a Si channel using CoFe/MgO/n-Si and CoFe/AlOx/n-Si tunnel contacts [3]. Hanle-effect signals originated from spin accumulation in the channel were successfully observed, and it was found that the spin injection ratio of the channel spin component to the trap spin component depended on the quality of their tunnel barriers. In this paper, we optimize the fabrication process of the MgO tunnel barrier and investigate spin injection behavior of a high-quality CoFe/MgO/n-Si tunnel contact.

Experimental procedure: An Al(100nm)/CoFe(30nm)/MgO tunnel-contact stack was formed on a highly P-doped n-type Si substrate (N_d=4x10^{19}cm^{-3}) using a multi-chamber (metal-sputter / radical-oxidation / MBD) system without breaking ultrahigh vacuum. The ultrathin MgO barrier layer was formed by the radical oxidation of an Mg thin film (0.5nm) deposited on the Si substrate at room temperature and then it was annealed under radical-oxygen exposure to improve the film quality. The annealing temperature and RF power of the annealing were optimized. The CoFe electrode was deposited on the MgO barrier layer using MBD technique. Spin injection behavior was evaluated employing the 3T-SA method shown in Fig. 1.

Results and Discussion: Figure 2 shows Hanle-effect signals observed using the 3T-SA device with a MgO tunnel contact fabricated by the optimized process. The Hanle-effect signals due to trap and channel spin components can be analyzed by curve fitting procedure using Lorentz and much sharper non-Lorentz functions, respectively [2]. The observed signals were closely fitted by the superposition of these two functions, as shown in Fig. 2. The trap spin component in the observed signals was suppressed by reducing bias voltage V_{bias}, and the signal exhibited only a single channel spin component for lower V_{bias}. Note that this single component was not able to be reproduced by a single trap spin component (Lorentz function). This behavior would relate energy distribution of the trap density. Possible mechanisms of this phenomenon will be presented at the conference.

References: [1] S. Sugahara, IEE Proc. Circuits Devices Syst. **152**, 355 (2005). [2] Y. Takamura, *et al.*, J. Appl. Phys. **115**, 17C307 (2014). [3] T. Akushichi, *et al.*, J. Appl. Phys. **117**, 17B531 (2015).

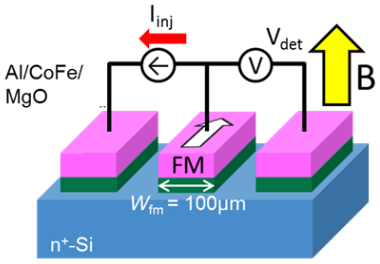

Fig. 1 3T-SA device

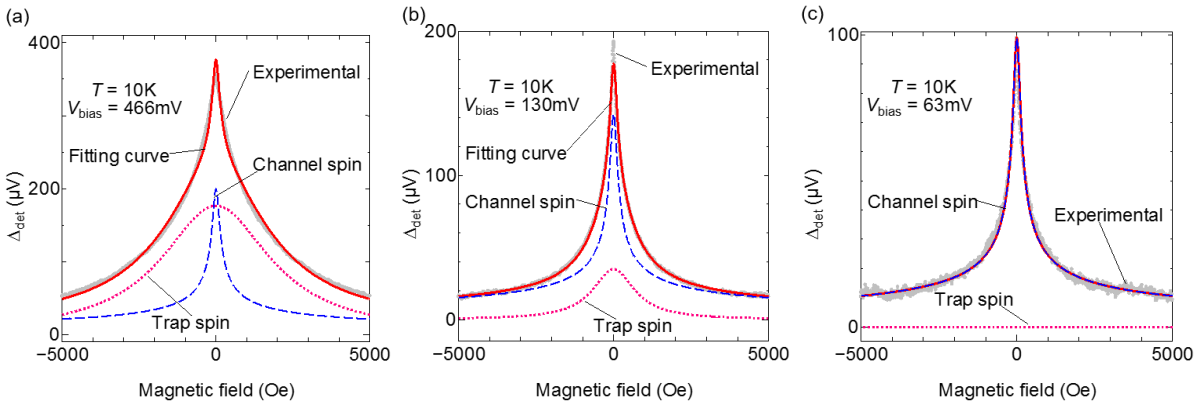

Fig. 2 Hanle-effect signals observed using the 3T-SA device with a high-quality CoFe/MgO/Si spin injector, measured at 10K with (a)V_{bias} = 466 mV, (b) V_{bias} = 130 mV, and (c) V_{bias} = 63 mV.