Spin Signals in 3-Terminal Geometry of Tunnel Junctions with a Heat-Treated MgO/Si Interface

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Hanle effects provide a means indispensable for extracting the information of spin dynamics in semiconductors (SC). However, the interpretation of the Hanle signals of FM/I/SC in the 3-terminal geometry (3T) is still under debate[1-8]. Since the FM contact serving as both a spin source and a detector is voltage-biased in the 3T, tunneling currents bring about additional factors on the detected signals[4,8] and inelastic tunneling and impurity scattering are also detected via defects at the interface and within the tunnel barrier[6,7]. On the other hand, the author found that dipole strength at the MgO/Si interface reduced with annealing[9]. Effects of the heat-treated MgO/Si interface on Hanle signals have been studied in 3T devices.

Samples of FeCo(13 nm)/MgO/SOI were prepared by MBE method. In order to obtain the ordered Si(100)2×1 reconstruction for the surface-Si of the SOI substrate, a heat-treatment was carried out in the MBE chamber (< 2×10^{-8} Pa) after a wet process. Surface potential at the interface of MgO/Si was measured in the same MBE system by using the Kelvin probe method. 3T devices were fabricated by photolithography and wet-etching.

Figures 1a) and 1b) show results of Hanle and inverted Hanle measurements in the spin injection and extraction conditions, respectively, as a function of the annealing temperature for the MgO(1.4 nm)/Si interface. All observed Hanle signals showed the broad type of profile. Compared with ΔV in the spin extraction, ΔV in the spin injection increases by annealing at 500 °C as a notable feature. The strength of the interface dipole consisting of both negative charges in the Si side and positive charges in the MgO side was previously found to reduce by annealing[9]. Moreover, it was proved that reducing the dipole strength led to the increase of the spin polarization in the spin injection condition[10]. Therefore, it is safe to say that the increase in ΔV by annealing at 500 °C comes from the increase in the spin polarization of the injected current by the reduction of the dipole strength. On the other hand, the decrease in ΔV by annealing at 700 °C would be due to the formation of the defects in the MgO layer.

Figure 2 shows the MgO thickness dependence of ΔV in the devices with the heat-treated interface at 500 °C. Several papers reported the dependence of ΔV on the junction resistance[4,8]. The tendency in this study is similar to the reported claims. The origin of the increase in ΔV is thought to come from the sequential tunneling with finite tunnel resistances for the direct tunneling[1,3]. The details will be discussed in the conference.

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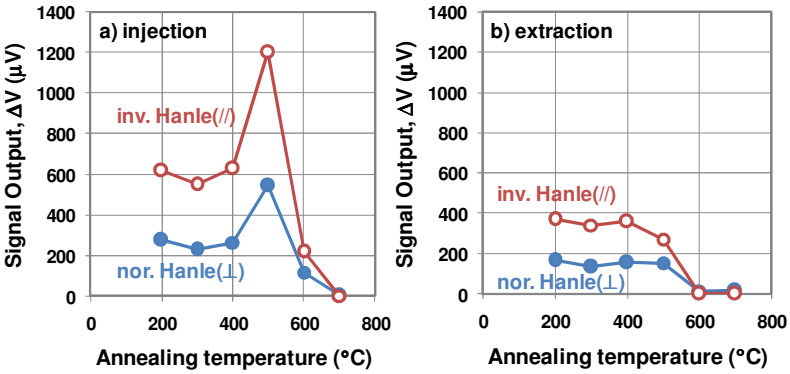

Fig. 1 Signal outputs as a function of annealing temperature, a) in the spin injection condition, and b) in the spin extraction condition. Measurement at room temperature, bias current=0.125 μA/μm^2, MgO=1.4 nm.

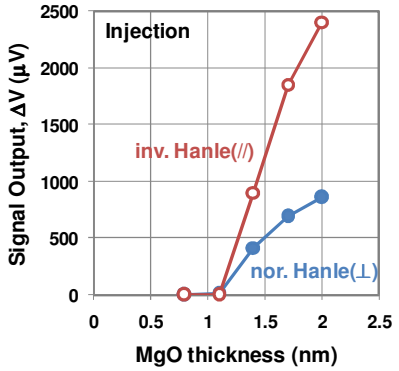

Fig. 2 Signal outputs in the spin injection condition as a function of MgO thickness. Annealing at 500°C, measurement at room temperature, bias current =0.083 μA/μm^2.