Spin splitting of EuO/Si spin filter junctions with atomically sharp interface

R. Ohsugi[1], H. Omi[1,2], Y. Krockenberger[1], and A. Fujiwara[1]

NTT Basic Research Lab. [1], NTT Nano Photonics Center [2],

E-mail: rento.oosugi.yf@hco.ntt.co.jp

Spin injection into Si is the fundamental process for operations of Si-based spintronic devices. An effective way for the spin injection is the use of spin-filtering effect working at the interface between ferromagnetic oxides and Si. It is because the spin filtering effect arising from spin-dependent tunnel probabilities of ferromagnetic oxides on Si [1] can avoid the conductivity mismatch problem [2] which decreases the spin polarization (P) at the ferromagnetic metal/semiconductor junctions. However, to realize an efficient spin-filtering, the ferromagnetic materials have to be grown on Si with atomically sharp interfaces. This is because efficiency of the spin-filtering is suppressed by interfacial defect, e.g. intermixing and dangling bonds. Recently, we have reported that ferromagnetic europium oxide (EuO) has been epitaxially grown on Si(111) [3, 4] and (001) [5] substrates with atomically sharp interfaces. Here, we fabricated EuO tunnel junctions with the abrupt interfaces, and derived spin-splitting of tunnel barriers of EuO films on Si.

The spin-filter junctions [Fig.(a)] with layer structures shown in Fig.(b) were made by using a typical photolithography process. We first measured J-V curves of the devices in a measurement configuration shown in Fig.(b). Next, to obtain the temperature and thickness dependences of the tunneling barrier heights, the J-V curves were fitted using the spin-selective Simmons model [6]. The spin-dependent barrier heights ($\phi_\uparrow, \phi_\downarrow$) plotted in Fig.(c) show spin-splittings of tunnel barriers below the Curie temperature of 35 K. A spin polarization (P) of 97% (20 K) is calculated by using an equation [$P = (J_\uparrow - J_\downarrow)/(J_\uparrow + J_\downarrow)$], where $J_\uparrow$ and $J_\downarrow$ are current densities of up- and down-spins extracted by the J-V curve fittings. The EuO(111)/Si(111) structure with the atomically sharp interfaces can be used as an efficient spin-filter on Si.

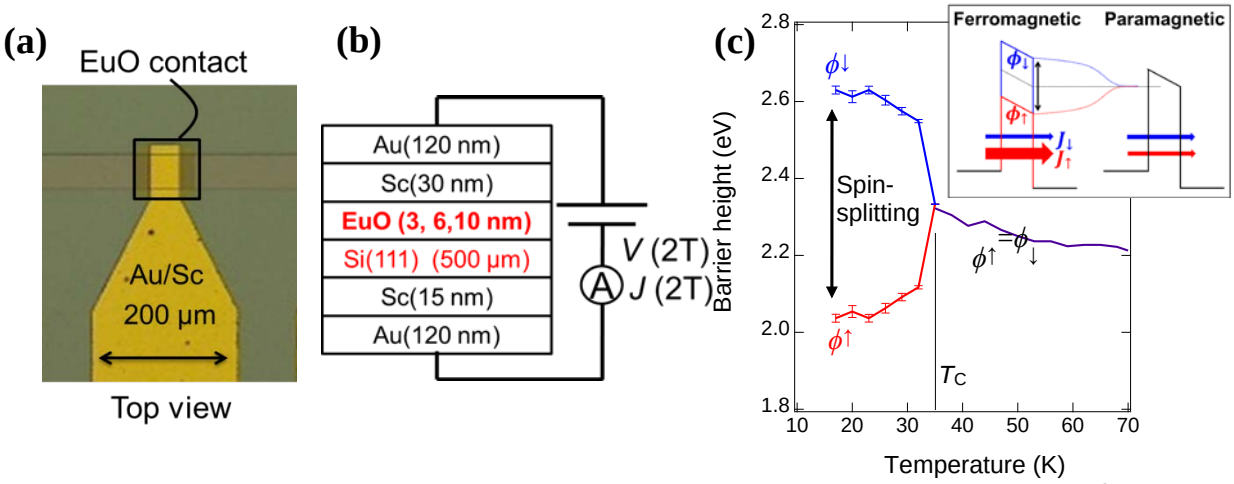

Fig. (a) The top view of a EuO/Si(111) tunnel junction. The contact areas are 100×100 μm^2. (b) The schematic of the measurement configuration and layer structure of the devices. Current densities and applied voltages are defined as J(2T) and V(2T), respectively. The measurements were performed from 17 to 80 K. (c) Temperature dependence of tunneling barrier heights of 6 nm-thick EuO films. The $\phi_\uparrow$ and $\phi_\downarrow$ show the spin-dependent barrier heights for up- and down-spins, respectively. The inset illustrates a barrier height change due to a magnetic phase transition.

[1] J. S. Moodera, *et al.*, J. Phys.: Condens. Matter **19**, 165202 (2007). [2] G. Schmidt, *et al.*, Phys. Rev. B **62**, R4790–R4793 (2000). [3] D. V. Averyanov, *et al.*, J. Magn. Magn. Mater. **459**, 136 (2018). [4] R. Ohsugi, *et al.*, Jpn. J. Appl. Phys. **57**, 110304 (2018). [5] D. V. Averyanov, *et al.*, Sci. Rep. **6**, 22841 (2016). [6] X. Hao, *et al.*, Phys. Rev. B **42,** 8235(1990)