Room-temperature germanium spintronics developed by atomically controlled heterointerfaces

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Semiconductor (SC) spintronics is expected for the achievement of novel logic and memory architectures with low power consumption in future electronics[1]. In particular, because of the compatibility with CMOS technologies and optical communication on the silicon platform (Si-photonics), germanium (Ge)-based spintronic technologies have so far been developed[2]. To operate Ge spintronic devices with nonvolatile memory effect above room temperature, it is essential to obtain sufficiently large local two-terminal magnetoresistance (MR) signals. Unfortunately, the value of room-temperature MR ratio in *n*-Ge-based lateral spin-valve devices has been less than 0.001 % [3,4].

In this talk, we introduce a new method for enhancing room-temperature MR ratio in Ge spintronic devices. Here, we utilize an atomic-layer termination technique in addition to our unique technology with ferromagnetic (FM) Heusler alloy/Ge Schottky-tunnel contacts on Si substrates[2]. When we insert five-six Fe atomic layers between the Heusler-alloy spin injector and the Ge layer, the quality of the Heusler alloy near the interface is significantly improved [5], As a result, even at room temperature, we can obtain a large MR ratio of 0.04 % [5], two orders of magnitude larger than those in previous works[3,4]. For obtaining the highest MR ratio, we can reduce the electric power down to ~ 0.12 mW, one order of magnitude lower than that (~ 1.15 mW) in Si-based devices with MgO tunnel barriers[6]. Because the MR ratio at 8 K reaches 0.43 % for above devices [5], we also explore the degradation mechanism of the MR ratio with increasing the temperature (T). From the analyses based on the standard one-dimensional spin-diffusion model[7], we can verify the temperature dependence of the FM/Ge interface spin polarization (P). As consequences, the decay mechanism of the FM/SC interface P with increasing temperature can be interpreted in terms of the $T^{3/2}$ law meaning a model of the thermally excited spin waves in the FM electrodes[8]. Also, we confirm that the temperature-dependent magnetization of the ultra-thin FM layer just on top of Ge is strongly related to the degradation of the MR ratio[8]. Therefore, the strong ferromagnetism of the FM layer near the interface is essential for high-performance Ge spintronics devices above room temperature.

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