Inverse spin valve effect in nano-scale Si-based spin-valve devices

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The silicon (Si) based spin-MOSFET [1] is considered to be one of the most promising candidates for spintronics device. In fact, spin injection into microns of Si channels by using the three terminal Hanle effect [2] or the four-terminal spin-valve effect [3] has been demonstrated up to 150 K with a small spin-valve ratio (~ 0.1%) and a small spin-dependent output voltage below 1 mV. Recently, we have fabricated 20 nm-long Si channel spin-valve devices with an MgO/Ge double tunnel barrier, in which we observed a clear spin-valve effect up to 0.8% and spin-dependent output voltage of 13 mV, by using electron beam (EB) evaporation [4]. In this work, by using molecular beam epitaxy (MBE) to grow a Fe/MgO/Ge stack as structure in Fig. 1(a), we have significantly improved the spin-valve effect signal and the spin output voltage. We observed a large spin-valve effect with ΔR up to 57 kΩ, corresponding to $\Delta R/R$ = 3%. By systematically investigating the bias dependence, temperature dependence, and magnetic field direction dependence of the magnetoresistance (MR), we have confirmed that the observed signal is not caused by the anisotropic magnetoresistance of the Fe ferromagnetic electrodes, or the tunneling anisotropic magnetoresistance at the Fe/MgO interface, but it is caused by the spin transport through the nano-scale Si channel. We found that the sign of the spin-valve effect is reversed at low temperatures, suggesting the possibility of the spin-blockade effect of defect states in the MgO/Ge tunneling barrier. The highest spin-dependent output voltage is 20 mV at the bias voltage of 0.9V at 15 K, which is the highest value reported so far in lateral spin-valve devices. The MR ratio decreases with increasing the channel length, but remains higher than 1% even when the channel length is as long as 6 μm. Our result is an important step towards the realization of nano-scale spin-MOSFETs [5].

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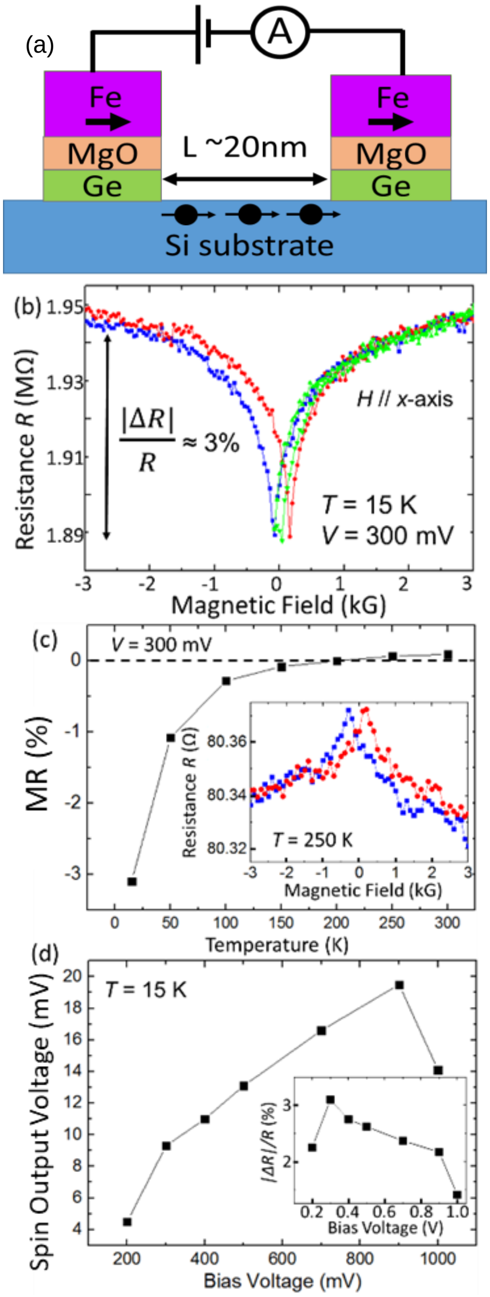

Fig. 1. (a). Schematic device structure examined in this study (b) MR characteristics of the device measured at 15 K with a bias voltage of 300 mV. The green curve is the minor loop. (c) Temperature dependence of ($\Delta R/R$). Inset: the MR curve at 250 K. (d) Bias voltage dependence of the spin-dependent output voltage ($\Delta R/R$)V at 15 K. Inset: the bias voltage dependence of the MR.