Large spin-dependent magnetoresistance and output voltage in the nanoscale Si spin-valve devices

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The silicon (Si) based spin-MOSFET [1] is considered to be the building block of low-power-consumption electronics because of its high compatibility with the CMOS technology and long spin lifetime in Si. In fact, spin injection into micron-scale 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; however, the spin-valve ratio is very low (~ 0.1%) and the spin-dependent output voltage is smaller than 1 mV. Recently, we have fabricated 20 nm-long Si channel spin-valve devices with an MgO/Ge double layer tunnel barrier as shown in Fig. 1(a), in which we observed a clear spin-valve effect up to -3.0% and spin-dependent output voltage of 20 mV [4,5]. In this work, by investigating the spin-valve effect in various nanoscale spin-valve devices with different MgO tunnel barrier thicknesses (t_{MgO}), we have improved the spin output voltage to 25 mV at the bias voltage of 1.1 V for a sample with $t_{\mathrm{MgO}} = 1.5$ nm, as shown in Fig. 1(b) and 1(c). Furthermore, by inserting an ultrathin (1 nm) Mg layer between the tunnel barrier MgO and the Fe electrode to prevent the formation of a magnetically-dead layer, we have increased the spin-valve ratio to $\Delta R/R = -3.6\%$ as shown in Fig. 1(d). 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 (AMR) of the Fe ferromagnetic electrodes, or the tunneling anisotropic magnetoresistance (TAMR) at the Fe/MgO interface, but it is caused by the spin transport through the nanoscale Si channel. The spin-valve ratio and the spin-dependent output voltage in this study are the highest values reported so far in lateral Si spin-valve devices. Our result is an important step towards the realization of nanoscale Si spin-MOSFETs.

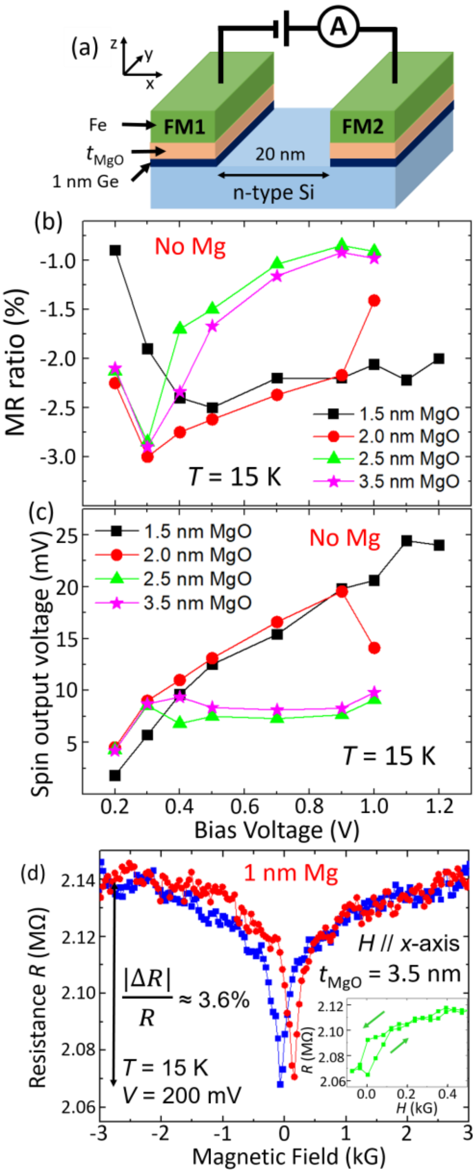

Fig. 1. (a) Schematic device structure examined in this study. (b) Dependence of the MR ratio ($\Delta R/R$) on the bias voltage of various spin-valve devices with different MgO thicknesses at 15 K. (c) Bias voltage dependence of the spin-dependent output voltage ΔV. (d) Large MR signal of a device with a 1 nm Mg layer inserted between the Fe and MgO layers, measured at 15 K with a bias voltage of 200 mV. Inset shows the minor loop MR.

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