Temperature dependence of spin transport properties in Si-based lateral spin valves

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Silicon (Si) is a pivotal material for the spintronics application because a long spin lifetime is expected due to the crystal inversion symmetry and the weak spin orbit interaction [1]. Recently, room temperature operation of the spin metal-oxide semiconductor field-effect transistor (MOSFET) using nondegenerate Si-based lateral spin valves (LSVs) has been reported by our group, a noteworthy progress for the Si spintronics [2]. In contrast, a fundamental research such as a detailed investigation of temperature evolution of the spin transport properties has not been performed to date. Such study provides a fruitful information e.g. spin scattering mechanism, origin of degradation in spin polarization due to temperature elevation, important for further progress of the Si spin devices. In this study, we investigated temperature dependence of spin transport properties such as spin lifetime, spin diffusion length and spin polarization in Si-based LSVs.

A schematic of the devices used in this study is shown in Fig. 1(a). Nonlocal four-terminal devices with Fe/MgO spin injector and detector were fabricated. The thickness and doping concentration of the silicon channel were 85 nm and 1×10^{20} cm^{-3}(phosphorus), respectively and center to center distance between two FM contacts was 1.85 μm. Spin transport properties were investigated by means of the nonlocal four terminal and the Hanle effect measurements. Electrical transport properties such as conductivity of the Si channel was measured by the conventional four terminal measurements. Measurements were carried out over the temperature range of 4 ~ 300 K.

The inset of Fig. 1(b) shows the Hanle effect signals measured at 4 K under antiparallel conditions. A clear Hanle signal was observed. The spin lifetime τ_s, was estimated to be 5 ns, three fold of that at 300 K. The main panel of Fig 1(b) shows the temperature dependence of τ_s. The τ_s was increased with decreasing the temperature and saturated around 10 K. assuming that the nonmagnetic impurity scattering in the degenerate Si is temperature independent is not temperature dependent as in a simple metal [3], we determined the total spin-flip scattering rate from the nonmagnetic impurities and phonons to be $\varepsilon_i\approx1.339\times10^{-5}$ and $\varepsilon_p\approx3.620\times10^{-6}$ through applying Matthinessen's rule to our experimental results. Detailed discussion is given in the presentation.

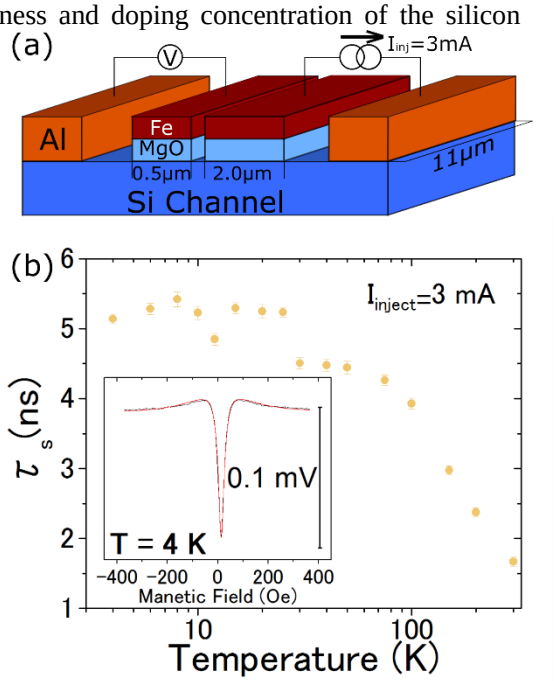

Figure 1. (a) A schematic of the Si based LSV. **(b)** Temperature dependence of spin lifetime obtained from nonlocal Hanle effect signals. The inset shows a typical Hanle effect signal at 4 K under antiparallel configuration.

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[2] T. Tahara et al., Appl. Phys. Express **8**, 113004(2015)
[3] J. T. Batley et al., Phys. Rev. B 92, 220420(R) (2015)