Electron spin lifetime and momentum lifetime in Si two-dimensional accumulation channels: Demonstration of spin MOSFETs at room temperature

Shoichi Sato[1], Mitsuki Ichihara[1], Masaaki Tanaka[1,2], and ◦Ryosho Nakane[1,3]

[1]*Dept. of Electrical Eng. and Information Systems,* [2]*Center for Spintronics Research Network (CSRN),*
[3]*Institute for Innovation in International Engineering Education,*
The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Silicon is known as a suitable material for the channel of spin functional semiconductor devices [1] owing to its long electron spin lifetime τ_S. However, it was reported that τ_S in Si two-dimensional (2D) channel is shorter than that in bulk Si materials [2,3], which is critical for device applications. To clarify the origin of the reduction in τ_S, we have experimentally investigated the relation between the electron spin lifetime τ_S and momentum lifetime τ in a 2D accumulation channel of Schottky-barrier spin metal-oxide-semiconductor field-effect transistors (spin MOSFETs) [4].

Figure 1 shows our spin MOSFET structure examined in this study, which has Fe/Mg/MgO/Si Schottky-tunnel junctions at the source/drain and a 15-nm-thick non-degenerated Si channel with a phosphorus donor doping concentration N_D of 1×10^{17} cm^{-3}. The device with various channel lengths L_{ch} (= 0.3 – 10 μm) show clear spin-valve signals at 295 K, as shown in Fig. 2(a). We have estimated the spin diffusion length λ_S in various gate voltages V_{GS} (= 40 – 100 V) from the decay rate of the spin-valve signals (Fig. 2(b)). From the experimental results of a Hall-bar-type MOSFET device (not shown) and self-consistent calculations using Poisson's and Schrödinger's equations [5], τ and the electron diffusion coefficient D_e in the 2D accumulation channel were estimated. Using the relation $\lambda_S = (D_e\tau_S)^{0.5}$, τ_S was estimated and plotted as a function of the effective gate electric field E_{eff} [5] in Fig. 3. In the same figure, the value $\tau\times14000$ is also plotted by the red curve. We found that the spin-flip probability τ/τ_S is almost constant (~1/14000) and unchanged by the gate voltage. This indicates that the Elliott-Yafet mechanism [6] is dominant in the Si 2D electron accumulation channel, and that both the spin-flip rates per one phonon scattering event and per one surface roughness scattering event are the same.

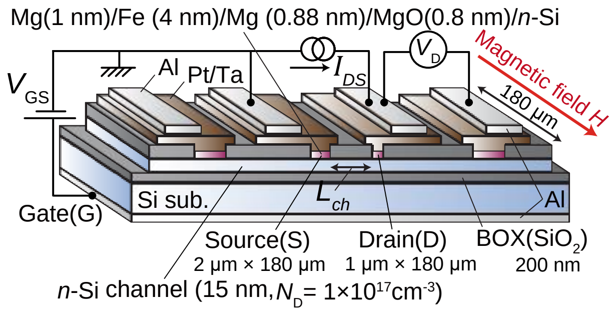

Fig. 1 Schematic illustration of our spin MOSFET and the measurement setup.

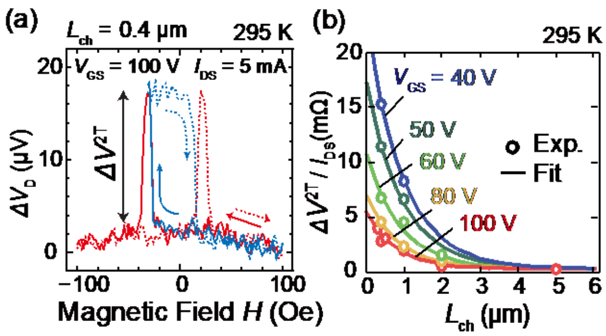

Fig. 2 (a) Spin-valve signal obtained in the sample with L_{ch} = 0.4 μm and V_{GS} = 100 V. (b) L_{ch} dependence of the spin-valve signal with various gate voltages V_{GS} = 40 – 100 V.

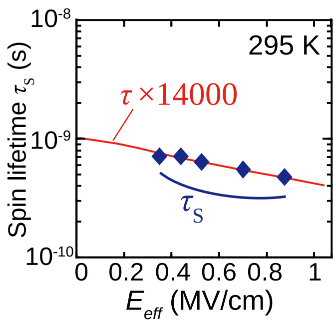

Fig. 3 Spin lifetime τ_S as a function of the effective gate electric field E_{eff}. Red curve is the value of the momentum lifetime τ multiplied by 14000.

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