An effect of gate voltage on thermally generated spin signals in Si spin-MOSFET

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A spin metal-oxide-semiconductor field effect transistor (MOSFET) is expected to pave a new way for future electronics, and enables to develop such as a reconfigurable logic circuit [1]. In addition, spin MOSFET has possibility to solve the waste heat issue of a conventional MOSFET, which is now quite serious for minimization of MOSFET and in suppression of energy consumption in electronics. Recently, it is reported that spin current can be generated by the Joule heating [2], which allows utilization of heat for generating spin signals. Since our group realized a room temperature operation of a Si-based spin MOSFET [3], thermally generated spin current in the spin MOSFET is potential to solve the waste heat problem in a Si-based conventional MOSFET. The purpose of this study is to detect the thermally generated spin signals and to realize its gate-induced modulation in a Si-based spin MOSFET.

A schematic image of a sample and a measuring scheme in this study is shown in Figure 1. Fe and Al electrodes were equipped on a P-doped non-degenerate n-type silicon-on-insulator substrate (the doping concentration was 2×10^{18} cm^{-3}). The gap length of these two Fe electrodes was 2.0 μm. There were tunnel barriers made of MgO at the interface of the Fe and the Si. The thickness of the tunnel barriers was 0.8 nm. The gate voltage was applied from the backside of the substrate. The local 3-terminals magnetoresistance (MR) method was introduced [4]. We used an ac lock-in technique for detecting the thermally generated spin signals as the 2nd harmonic voltage, because the Joule heating is proportional to the square of an electric current, I^2.

The magnetoresistance effect due to the thermally generated spin current under the gate voltage application of +60 V is shown in Figure 2. The magnitude of the thermally generated spin signals was 0.04 mV. Figure 3 shows gate voltage dependence of the thermally generated spin signals, where the spin signals were nicely modulated by the gate voltage. The gate voltage dependence is similar to that of the spin MOSFET [2]. This result indicates that the spin MOSFET operation by the Joule heating.

References:
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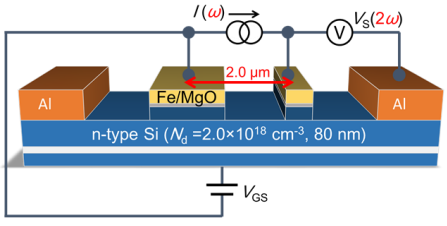

Fig. 1: Schematic image of a sample and local 3-terminals method

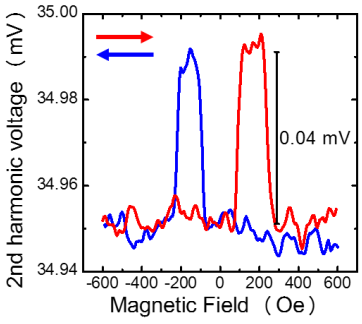

Fig. 2: Thermally generated spin signals in the local 3 terminals measurement with an applied voltage of +60 V

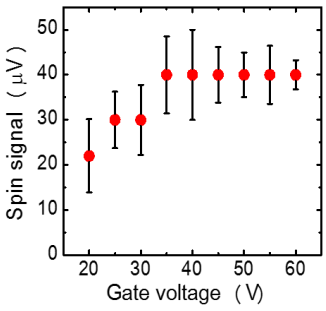

Fig. 3: The gate voltage dependence of the thermally generated spin signals