

シリコンスピンドバイスの微小電流駆動

Low current operation of silicon spin devices

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Steady progress has been made in silicon(Si)-based spintronics, including the room temperature demonstration of spin FET^[1] and spin XOR logic devices^[2], and spin transport in the inversion layer^[3]. Since these devices are expected to operate at room temperature, the creation of spin functions at room temperature is a key. Another promising device using spins in Si is quantum computation technology based on Si quantum dots^[4]. Recently, a considerably high fidelity has been reported^[5], accelerating research and development of Si-based quantum computing. The bottleneck is the detection of the spin state. Currently, Zeeman energy from an external magnetic field is used, but the energy difference that can be formed is small (several tens of μeV) and thus, vulnerable to thermal disturbances. If the ferromagnetic tunnel contacts, established in spin FET, can be used, it will be possible to achieve a high tolerance to thermal disturbances. The differences in the spin detection technologies between spin FET and quantum dot are the operation temperature, number of spins, and the amount of injection/detection current. Therefore, in this study, we investigated the applicability of the ferromagnetic tunnel contacts to the quantum technology.

Since the injected current is very small (0.5~50 μA), superimposition of spurious signals such as anisotropic magnetoresistance is inevitable in the MR measurements involving magnetization reversal. Therefore, the three-terminal Hanle measurement was employed, which does not require the magnetization reversal. In this measurements, a current is applied between two ferromagnetic tunneling contacts, and a voltage drop is detected only at the electrode under the spin extraction. The measurement was carried out at 30 K, because the carrier freezes out was taken place below 20 K.

The results for $I = 50$ and $2 \mu\text{A}$, more than two-orders of magnitude smaller than that of typical value in spin FET, are shown in Fig. 1. The results were obtained by subtracting the signal of the parallel configuration from the that of the anti-parallel configuration. A clear Hanle signal was obtained at $I = 50 \mu\text{A}$. For $I = 2 \mu\text{A}$, although the signal-to-noise ratio was poor, a Hanle signal was still recognized. Since the electrode size is $6.3 \mu\text{m}^2$, detection of spin signal is expected to be possible even less than 1 nA, if the ferromagnetic tunneling electrode is fabricated to the size required for application to the quantum dot (approx. $50\text{nm} \times 50\text{nm}$).

[1] T. Tahara et al., Appl. Phys. Express. **8**, 113004(2015), [2] R. Ishihara et al., Phys. Rev. Appl. **13**, 044010(2020), [3] S. Sato et al., Phys. Rev. B **102**, 035305(2020), [4] K. Takeda et al., Nature **608**, 682 (2022). [5] J. Yoneda et al., Nat. Commun. **12**, 4114(2021).

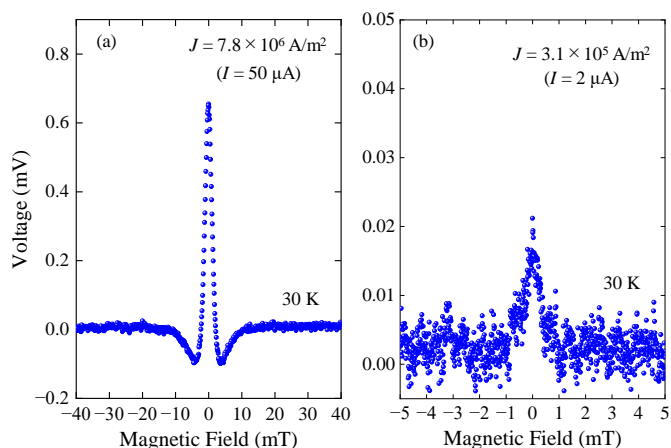


Figure 1 Difference in the three-terminal Hanle signal between the antiparallel and parallel configurations measured at 30K. Injection current is (a) 50 μA and (b) 2 μA , respectively.