Logic operation using electron spins in silicon

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Logic gates using electron spins in silicon are expected to realize beyond complementary metal-oxide-semiconductor (CMOS) architectures with a superior switching energy, a high logic density, and a nonvolatile function. Here we focus on the semiconductor-based universal magnetologic gate (MLG) where the operand of logic operation is the magnetization direction [1]. The MLG consists of five ferromagnetic (FM) electrodes with parallel easy magnetization axes (Fig. 1(a)). The two collinear easy axes, $+y$ and $-y$, are defined as the binary states "1" and "0", respectively. The two outmost FM electrodes are input terminals and the center electrode is the output terminal. The other electrodes are configuration terminals that define the gate operation such as NAND or OR. By applying charge currents, spin accumulation is generated in the semiconductor channel, whose amplitude beneath the output electrode is represented by NAND or OR. Any binary logic operation can be realized by using a finite number of MLGs. Furthermore, the reconfigurable logic gates at a clock frequency provides flexibility in logic circuit design. An MLG consists of two exclusive or (XOR) gates. Therefore, logic operation of one XOR gate using three ferromagnetic electrodes (Fig. 1(b)) is a fundamental technique to realize MLG operation.

Here we present room temperature operation of a spin exclusive or (XOR) gate in lateral spin valve devices with nondegenerate silicon (Si) channels [2, 3]. The device for the spin XOR gate consists of three iron (Fe)/cobalt (Co)/magnesium oxide (MgO) electrodes. The spin drift effect was controlled by a lateral electric field in the Si channel to adjust the spin accumulation voltages detected by FM-M under two different parallel configurations of FM-A and FM-B, corresponding to (1, 1) and (0, 0), so that they exhibit the same value. As a result, the spin accumulation voltage detected by FM-M exhibited three different voltages, represented by an XOR gate in MLG as shown in Fig. 1(c). The one-dimensional spin drift-diffusion model clearly explained the obtained XOR behavior. Charge current detection of the spin XOR gate was also demonstrated. The detected charge current was 1.67 nA. Furthermore, gate voltage modulation of the spin XOR gate was also demonstrated, which enables operation of multiple MLG devices.

In the presentation, we will also report recent progress of the spin logic operation using spins in silicon.

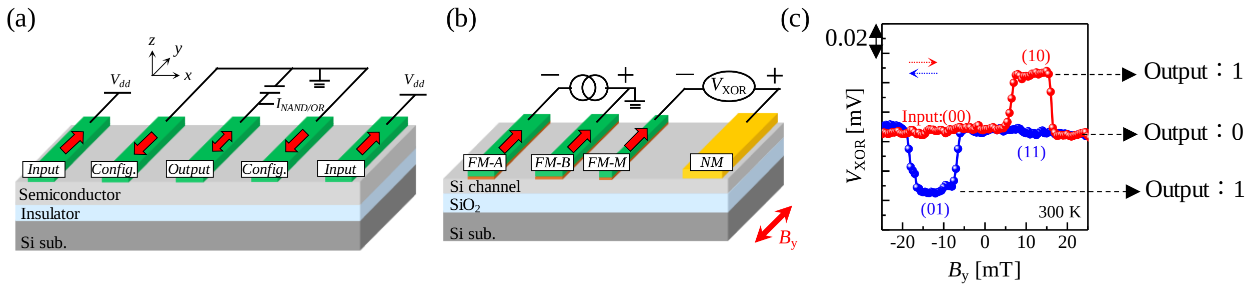

Figure 1 (a) Schematic illustration of the semiconductor-based MLG device proposed by Dery et al. [1]. (b) Schematic illustration of the silicon-based multiterminal lateral spin valves for the XOR operation. (c) A typical V_{XOR}-B_y curve in the XOR operation.

Reference

1) H. Dery, P. Dalal, Ł. Cywiński, and L. J. Sham, Nature **447**, 573 (2007).

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