

Spin-dependent transport in ferromagnet-germanium structures for spintronic applications

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Although spintronic technologies in both *n*-type and *p*-type Ge based structures should be explored for novel information storage and logic devices [1], there are few studies of reliable experiments on the electrical spin injection, spin transport, and spin manipulation in Ge [2]. In particular, the detection of the two-terminal local magnetoresistance effect in ferromagnet-Ge structures has not been reported yet.

For laterally configured structures, we utilized one of the ferromagnetic alloys, $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}$, as ferromagnetic contacts [Fig. 1(a)]. To demonstrate tunneling conduction of electrons at the $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}/\text{Ge}$ interface, we inserted phosphorus delta-doped n^+ -Ge layer between $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}$ and Ge.

Using nonlocal four-terminal magnetoresistance measurements in lateral spin devices with n-Ge, hysteretic resistance changes were detected even at room temperature [3]. Under applying out-of-plane magnetic fields, nonlocal Hanle-effect curves were also seen even at room temperature. From the analyses of the Hanle curves, we obtained a room-temperature spin lifetime and spin diffusion length of 0.25 ns and $\sim 0.44 \mu\text{m}$ [3], respectively. Using the same device structures, we can obtain two-terminal local magnetoresistance effect even at room temperature [Fig. 1(b)]. Unfortunately, the magnetoresistance ratio is quite small ($\sim 0.001\%$ at 303 K) compared to conventional magnetic tunnel junctions. We also obtained similar magnetoresistance effect through a 20-nm-thick p-Ge layer in vertically stacked ferromagnet/p-Ge/ferromagnet structures even at room temperature [4]. These technologies for n-Ge and p-Ge will pave a way for integration of the nonvolatile memory effect in ferromagnetic materials with Ge electronics.

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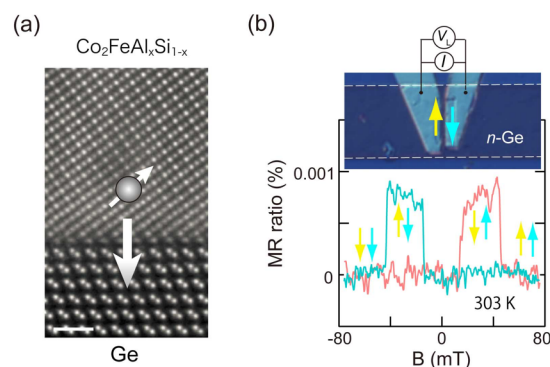


Fig.1. (a) HAADF-STEM image of a $\text{Co}_2\text{FeAl}_x\text{Si}_{1-x}/\text{Ge}$ heterostructure. (b) Optical micrograph of a fabricated lateral spin device and local magnetoresistance data at room temperature.