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## Highly efficient detection of pure spin currents in *n*-Ge using *L*2<sub>1</sub>-Co<sub>2</sub>FeSi Heusler-compound electrodes

°Y. Fujita<sup>1</sup>, K. Kasahara<sup>1</sup>, S. Yamada<sup>1</sup>, K. Sawano<sup>2</sup>, M. Miyao<sup>1</sup>, and K. Hamaya<sup>1</sup>

Department of Electronics, Kyushu Univ.<sup>1</sup>, Tokyo City Univ.<sup>2</sup>

E-mail: y\_fujita@nano.ed.kyushu-u.ac.jp

To date, generation and detection of pure spin currents in *n*-Ge have been reported up to ~200 K.<sup>[1,2]</sup> Unfortunately, the nonlocal four-terminal Hanle-effect curves could not be observed above 100 K although Fe/MgO tunnel-barrier contacts were used as a spin injector and detector.<sup>[1]</sup> In this study, we achieve large enhancement of spin generation efficiency in *n*-Ge using  $L2_1$ -Co<sub>2</sub>FeSi Heusler-compound electrodes with high spin polarization ( $P \ge 0.5^{[3]}$ ), and clearly observe nonlocal Hanle-effect curves at 150 K.

We fabricated four-terminal lateral spin-valve devices (LSVs) consisting of a phosphorous-doped n-Ge(111) channel (~50 nm,  $n \sim 2.5 \times 10^{18} \text{ cm}^{-3}$ ) formed by an ion implantation technique and Co (20 nm)/ $L2_1$ -Co<sub>2</sub>FeSi(10 nm)/ $n^+$ -Ge (5 nm,  $n \sim 10^{19} \text{ cm}^{-3}$ ) Schottky tunnel contacts. A high quality  $L2_1$ -Co<sub>2</sub>FeSi film (10 nm) was grown on  $n^+$ -Ge(111) by room-temperature molecular beam epitaxy.<sup>[4]</sup> Conventional processes were used to fabricate four-terminal LSVs as schematically illustrated in Fig. 1.

Figure 2 shows nonlocal Hanle-effect curves measured at I = 1.0 mA at 150 K for parallel ( $\uparrow\uparrow$ ) and anti-parallel ( $\uparrow\downarrow$ ) magnetization configuration between the two Co<sub>2</sub>FeSi electrodes. By fitting the Hanle-effect curves with the one-dimensional spin drift diffusion model, the spin lifetime ( $\tau_s$ ) and the diffusion constant (*D*) for the *n*-Ge channel were estimated to be ~420 psec and ~8.3 cm<sup>2</sup>s<sup>-1</sup>,<sup>[5]</sup> respectively.

We can also estimate the spin generation efficiency  $(P_{inj} \times P_{det})^{1/2}$  at ~ 0.12, where  $P_{inj}$  and  $P_{det}$  are spin polarization at injector and detector, respectively. This value is about two orders of magnitude larger than that for the previous Fe/MgO/Ge devices.<sup>[1]</sup>

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Fig.1 Schematic of a device structure.



Fig.2 Nonlocal Hanle-effect curves at 150 K. The solid curves are fitting results.