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Program Title (English)　　:Spin-dependent transport phenomena in nano-scale spin transistors
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1. 概要（Summary）

We investigated the spin transport in nanoscale silicon (Si)-based spin-valve devices with a 20 nm Si channel and a Fe/(Mg)/MgO/Ge stack as the spin injector/detector. By optimizing the MgO barrier thickness, we achieved a large spin-dependent output voltage of 25 mV at 15 K. Furthermore, by inserting an ultrathin (1 nm) Mg layer in between the tunnel barrier MgO and the Fe electrodes to prevent the formation of a magnetically-dead layer, we have increased the spin-valve ratio up to –3.6% at 15 K. These are the highest values reported in lateral Si-based spin-valve devices.

2. 実験（Experimental）

【利用した主な装置】

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【実験方法】

The devices in this study were fabricated on a highly doped n-type Si (100) substrate with an electron density n = 1×10^{18} cm^{-3}. The Si substrates were cleaned by the standard cleaning with H_2SO_4/H_2O_2 solution, dipped into diluted hydrofluoric acid solution to remove the native oxide layer, and then rinsed in de-ionized water. After that, the samples were introduced into a MBE chamber with the base pressure of 1×10^{-9} Pa. We grew successively a 1 nm-thick Ge layer, a 1.5–3.5 nm-thick MgO layer, a 1 nm Mg layer, and a 10 nm-thick Fe layer. Here, an Mg thin layer was inserted between the Fe electrodes and the MgO barrier to prevent oxidation of the Fe electrode (Figure 1(a)) and to enhance the spin injection efficiency to the Si channel.

3. 結果と考察（Results and Discussion）

In this study, by optimizing the MgO thickness, we have succeeded in improving the spin-dependent output ΔV to the maximum value of 25 mV for the device with a 1.5 nm MgO barrier, which is the highest value reported so far in lateral Si-based spin-valve devices. Furthermore, by inserting an ultrathin (1 nm) Mg layer between the Fe electrode and the MgO barrier, we have succeeded in improving the local MR ratio up to $|\Delta R| \sim 75$ kΩ and $|MR| = 3.6\%$ (Figure 1(b)).

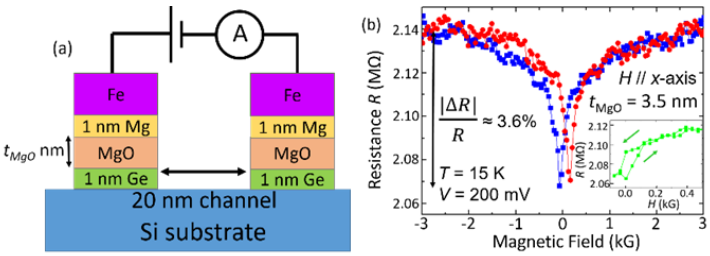

Figure 1. (a) Schematic device structure of a spin-valve devices. The MgO thickness t_{MgO} is varied from 1.5 nm to 3.5 nm. The thickness of the Mg insertion layer is fixed at 1 nm. (b) Local magnetoresistance (MR) of the device with a 1 nm-thick Mg insertion layer and 3.5 nm-thick MgO barrier layer, measured at 15 K with a bias voltage of 200 mV. Inset shows the minor loop MR.

4. その他・特記事項（Others）

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5. 論文・学会発表（Publication/Presentation）

(1) Duong Dinh Hiep, Masaaki Tanaka, Pham Nam Hai. “Lateral Silicon spin-valve devices with large spin-dependent magnetoresistance and output voltage”, Adv. Nat. Sci.: Nanosci. Nanotechnol., accepted.
(2) Duong Dinh Hiep, Masaaki Tanaka, Pham Nam Hai. “Large spin-dependent magnetoresistance and output voltage in the nanoscale Si spin-valve devices”, The 66th JSAP Spring meeting, Mar. 2019.

6. 関連特許（Patent）

N/A