Spin-dependent transport and current modulation in a current-in-plane spin-valve field-effect transistor

Toshiki Kanaki¹, Tomohiro Koyama², Daichi Chiba², Shinobu Ohya¹,³, and Masaaki Tanaka¹,³

¹Department of Electrical Engineering and Information Systems, The University of Tokyo,
²Department of Applied Physics, The University of Tokyo,
³Center for Spintronics Research Network, The University Tokyo

E-mail: kanaki@cryst.t.u-tokyo.ac.jp

A spin metal-oxide semiconductor field-effect transistor (spin MOSFET), in which the source and drain electrodes are composed of ferromagnetic materials, has been intensively studied, aiming at future electronics applications [1,2]. Some experimental demonstrations of lateral and vertical spin MOSFETs have been reported thus far [3-6]; however, for both lateral and vertical spin MOSFETs, there still remain problems to overcome towards practical applications in the present status.

Here, we propose an alternative device, a current-in-plane spin-valve field-effect transistor (CIP-SV-FET), which comprises a ferromagnet / nonmagnet / ferromagnet trilayer and a gate electrode as shown in Fig. 1(a). This device can offer a functionality similar to that of spin MOSFETs due to the spin-valve effect and current modulation using a gate electric field. Also, the device performance is not affected by spin relaxation in the channel transport, which is a crucial issue in spin MOSFETs.

We fabricated a ferromagnetic-semiconductor GaMnAs-based CIP-SV-FET. The trilayer structure was grown on a lattice-relaxed In₀.₁₇Al₀.₈₃As buffer layer [Fig. 1(b)], and thus the magnetic easy axes of the GaMnAs layers are perpendicular to the film plane. We measured the Hall resistance ($R_{\text{Hall}}$) and sheet resistance ($R_{\text{sheet}}$) under an external magnetic field $\mu_0H$ applied perpendicular to the film plane. As shown in Figs. 1(c) and 1(d), $R_{\text{sheet}}$ was modulated both by the magnetization configuration through the spin-valve effect (0.17%) and by the gate voltage (14%) at 36 K. Furthermore, we successfully demonstrated electric-field-assisted magnetization reversal of the upper GaMnAs layer [7].

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FIG. 1. (a)(b) Schematics of the current-in-plane spin-valve field-effect transistor (CIP-SV-FET) (a) and the heterostructure used in this study (b). (c) $R_{\text{Hall}}$ (solid curve, left axis) and $R_{\text{sheet}}$ (circles, right axis) vs. $\mu_0H$. The gate voltage $V_G$ is 0 V. (d) $R_{\text{sheet}}$ vs. $V_G$. All data were taken with a bias current of 10 $\mu$A at 36 K.