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Fan-out Value in a Current-Field Driven Spin Transistor

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1. Introduction

Spin transistor, which has functions of switching, amplification and nonvolatility, attracts a lot of attention since it has possibility to realize nonvolatile logic devices with ultra-low power consumption. Many kinds of spin transistor, such as Datta-Das type spin field effect transistor (spin-FET[1]), spin-valve transistor[2] and spin metal-oxide-semiconductor FET (spin-MOSFET[3]), have been proposed theoretically and some of them have been performed in experiments so far. However, power amplification property has never been realized in any structures at room temperature. Recently, we proposed a novel type of spin transistor driven by a current-induced magnetic field and we call this spin transistor "Current-Field Driven Spin Transistor"[4]. In this study, we investigated the power gain and fan-out properties of this device under an application of ac assist-fields.

2. General Instructions

Concept

A schematic diagram of an example of electrical circuit of current-field driven spin transistor is shown in Fig.1. It basically consists of a magnetic tunnel junction (MTJ) and an electrically isolated metallic wire (surrounded by a dotted-line frame in the Fig. 1). By applying current pulse to the wire-A, a current-induced magnetic field (current-field) is generated around the wire-A, leading to the magnetization switching of free layer in the MTJ-A. This principle is very similar to a conventional magnetoresistive random access memory (MRAM), however, the concept and the architecture are very different. Because of the resistance change in the MTJ-A, the power consumption in the wire-B, which is cascaded to the MTJ-A, is changed. If the current amplification property is realized, this can induce the magnetization switching of the free layer in the MTJ-B. We define the power gain in this device as,

$$\text{Power Gain} \equiv \frac{\Delta P_{\text{out}}}{P_{\text{in}}} = \frac{P_{\text{AP}} - P_{\text{P}}}{P_{\text{pulse}}} \qquad (1)$$

Here, ΔP_{out} is the change in the output power between the parallel and anti-parallel magnetization states and P_{in} is the power of the pulse consumed in the wire-A. Following equation (1), we obtain power amplification property if ΔP_{out} is larger than P_{in}. To obtain substantial amplification property, MTJ with low resistance area product (RA) is required. The current gain, which is another important parameter in this device, is defined similar to equation (1) (see Ref. 4 for details).

Experiment

The MTJ films were deposited on Si/SiO_2 substrates using a magnetron sputtering method(Canon ANELVA C7100). The film structure is as follows : buffer layers / PtMn (15) / CoFe (2.5) / Ru (0.85) / CoFeB (3) / MgO (1.05) / CoFeB (3) / Ru (1.5) / NiFe (2) / cap layers (nm in thickness). From current in-plane tunneling (CIPT) measurements, the RA and magneto-resistance ratio (MR) were evaluated to be 3.8 $\Omega\mu m^2$ and 110% respectively. The multilayer film was patterned into submicron-scale junctions using electron beam lithography, Ar-ion milling and lift-off techniques. Then, as an isolation layer, a thick SiO_2 layer(60 nm) was deposited on to the MTJ, except in a probe-contact area. Finally, a coplanar waveguide was fabricated on the SiO_2 layer. After the microfabrication, sample was annealed at 300 ºC for 2 hours with applying a magnetic field of 6 kOe.

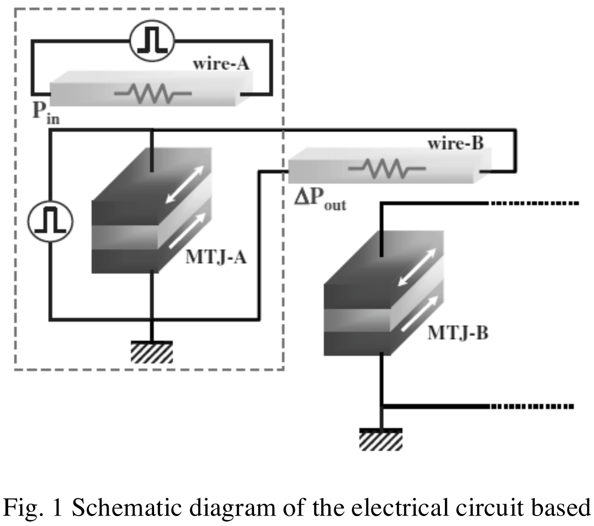

Fig. 1 Schematic diagram of the electrical circuit based on the "Current-field driven spin transistor".

3. Results

Figure 2 shows a representative TMR curve of the MTJ (0.3×0.9 μm^2 in size) measured by two terminal measurement. Because of the parasitic resistance (evaluated to be about 8.3 Ω) in the electrodes and contact resistance, apparent MR ratio is reduced to be 50 %. All measurements were performed under the static external field of Hex = 46 Oe (at the center of the hysteresis curve). Additionally, in order to enhance the efficiency of the pulse-induced switching, an assisting ac magnetic field (~50 Oe) with frequency of 2 Hz was also applied. Under this condition, successive square current pulses (1.4 mA in amplitude and 500 ms in duration time) were applied into the coplanar waveguide. We could observe clear transition of the resistance between low and high resistance states, corresponding to the switching in the free layer(not shown here).

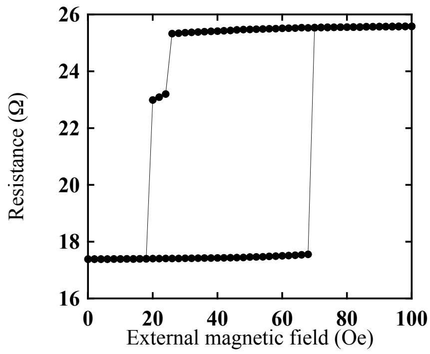

Fig.2 A representative TMR curve (0.3×0.9 μm^2 in size)

The output power and current significantly depends on the bias voltage (V_{bias}) applied to the MTJ. In Fig. 3, bias voltage dependences of the resistance both in parallel and anti-parallel states (gray lines) are shown. Following to equation (1), we estimated the power gain as a function of the bias voltage (black line) Here, we assumed an ideal resistance for the wire-B to evaluate the inherent power gain. High power gain of up to 70 was obtained at V_{bias} = 0.4 V. Figure 3(b) shows the calculated fan-out, which is defined as number of MTJs that can be driven by an output from a single MTJ, as a function of bias voltage. Here, the power consumed for the ac fields application was neglected. We obtained fan-out of 1.2 under the bias voltage of 0.4 V. This indicates that we can drive the MTJ-B in the Fig. 1 by the current-field application to the wire A.

4. Summary

We investigated the power gain and fan-out property of the current-induced spin transistor under the application of ac assit-magnetic fields. We obtained the power gain of 74 and fan-out of 1.2 in proposed device at room temperature. This result implies that the current-field driven spin-transistor has a possibility to be a basic element for the nonvolatile logic device.

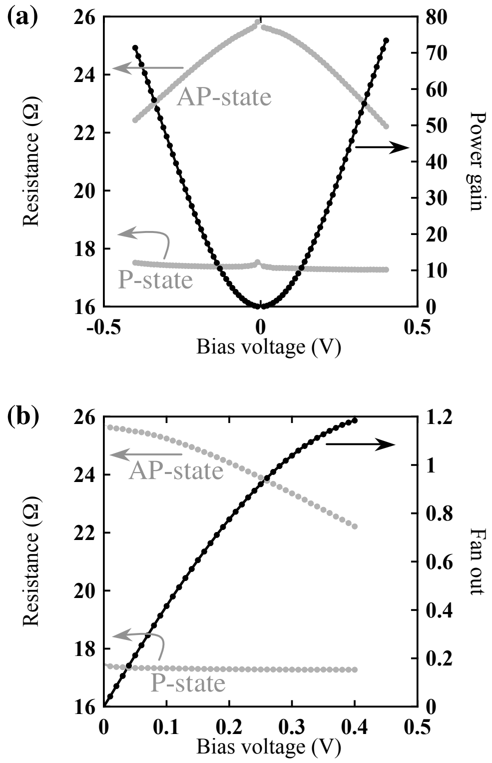

Fig. 3 Bias voltage dependence of the (a) power gain and (b) fan-out properties of the current-field driven spin transistor

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