Spin-injection as a base of the spin-charge coupled electronic devices

Yoshishige Suzuki[1], Research Director of CREST
Materials Science Division, Electrotechnical Laboratory

In most of electronic devices, two aspects of an electron, namely, electron charge and spin have been used separately, as an electric current and a ferromagnetic momentum, respectively. Findings of giant magneto-resistance effect (GMR) and tunneling magneto-resistance effect (TMR)[1], however, make it possible to couple those two freedoms in an electronic device and opened a new field of research where one can explore new electronic devices based on spin-charge coupling. Imagine a junction of two ferromagnetic metals having each magnetic moment with different directions (Fig. 1). An electric current passing through the interface forces to inject electrons in the left side metal to the right side metal. Spin dependent scattering at interface causes an additional spin-dependent resistance, and exchange interaction between injected electrons and host spin system would cause rotation of total magnetic moment of the right side metal. Other effects like spin-injection assisted magnetic phase transition are also expected. The concept of spin injection provides the great variety of interesting new phenomena that will be useful in new solid state devices.

In this project, in order to establish a new technique to utilize an electron spin freedom together with charge freedom, we attempt to inject spin-polarized current into solid and examine its diffusion and interactions inside solids. The concrete targets of this project are, (1) electric switching effect due to spin injection and/or spin dependent transport, (2) magnetic switching and magnetic phase transition due to the spin injection, (3) high density spin injection using micro-probe technique, and (4) development of high quality TMR devices. This series of studies will hopefully lead to a new paradigm of read and write techniques applicable for a next generation magnetic random access memory (MRAM).

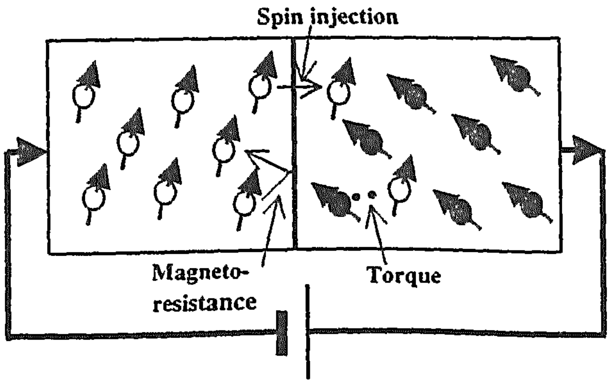

Fig. 1 Spin-injection. Current passing through an interface between two ferromagnets brings charge and spin at the same time. Additional spin-dependent scattering at the interface causes spin-dependent resistance, and exchange interaction of injected electrons results torque on the electron spin system in the right side material.

(1). Electric switching

To realize electric switching, the spin dependent tunneling effect will be used. Especially, we attempt to investigate spin dependent resonant tunneling

[1] e-mail: *suzukiy@etl.go.jp*

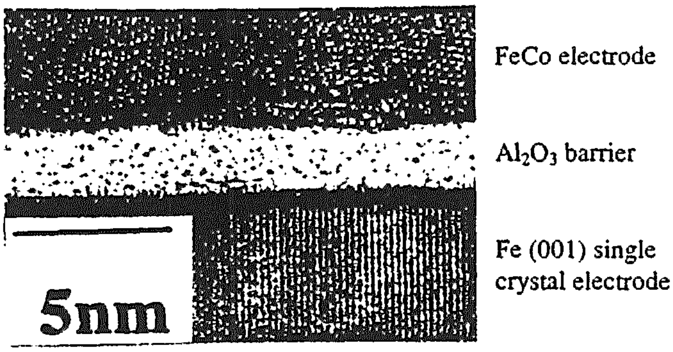

Fig. 2 Tunneling junction having a single crystal counter electrode [2].

effect by making single crystal tunnel junctions. Cross-section of a single crystal ferromagnetic metal tunnel junction, which has been realized first in our group [2], is shown in Fig. 2. By combining a technique to control quantum well states in ultrathin ferromagnetic films [3] to the fabrication technique of the TMR device, we try to realize a spin dependent electric switching device.

(2) Magnetic switching and magnetic phase transition

This approach consists of following three topics ; *i)* basic study on spin diffusion properties (Fig. 3), *ii)* a spin injection induced magnetization reversal, and *iii)* a spin injection induced magnetic phase transition. The final goal is to gain the insight which leads to a new paradigm of magnetization reversal mechanism applicable for a next generation magnetic random access memory (MRAM).

(3) High density spin injection using micro-probe technique

High density spin injection and nano-scale device characterization will be tried using two types of micro-probe technique (Fig. 4). One is conductive atomic force microscopy (AFM). A conductive tip scans on an insulator with an applied voltage between the bottom metal layer and the tip, and the electrical current image would correspond to the barrier character. The other is spin-dependent scanning tunnel microscopy (STM). Basic injection process will be examined by the measurements of high density spin injection into local area and the tunneling spectra.

(4) Development of high quality TMR devices

Development of high quality insulators and large magnetoresistance for ferromagnetic tunnel junctions will be attempted. A special sputtering system including a fabrication

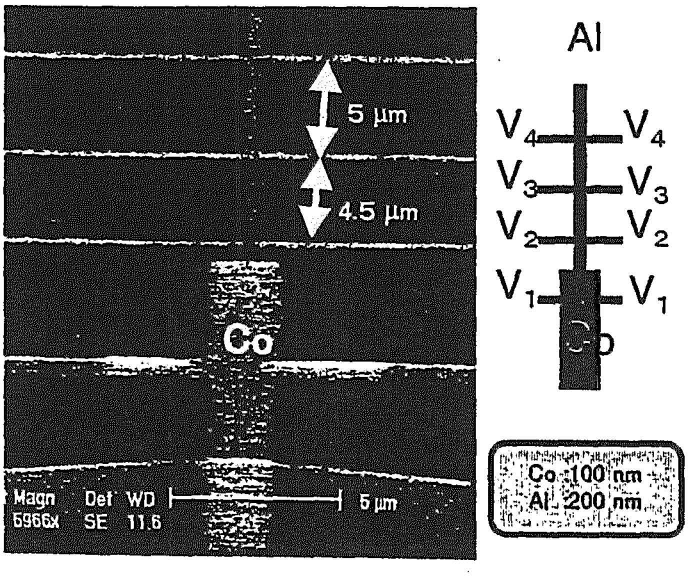

Fig. 3 Aluminum Hall bars connected to a Co spin injection source. The purpose of the study is to investigate the spatial distribution of the extraordinary Hall effect associated with the spin injection induced non-equilibrium magnetization with using position variable Al Hall bars[4].

chamber with six inductively coupled plasma (ICP) cathodes, an oxidation chamber with one ICP cathode and load-lock chamber will be provided for this purpose. Plasma oxidation using ICP is useful for preparing the very thin insulator because the ions do not strike strongly against the substrate. In order to analyze the quality of the insulator and devices, *in-situ* micro-analysis will be attempt.

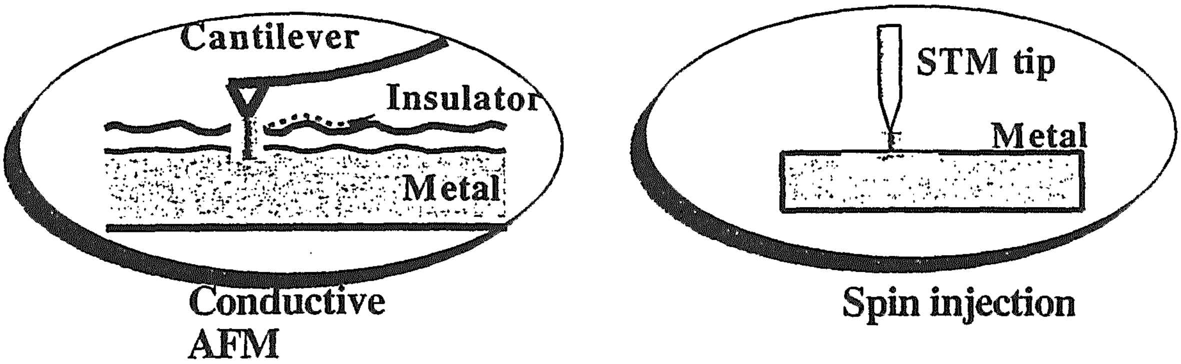

Fig. 4 Usage of micro-probe technique.

References
[1] T. Miyazaki and N. Tezuka, J. Magn. Magn. Mater., **139** (1995) L231.
[2] S. Yuasa, T. Sato, E. Tamura, Y. Suzuki, H. Yamamori, K. Ando, and T. Katayama, Europhysics Letter, in press.
[3] Y. Suzuki, T. Katayama, P. Bruno, S. Yuasa, and E. Tamura, Phys. Rev. Lett., **80**, (1998) 5200.
[4] Y. Otani, T. Ishiyama, S. G, Kim, and K. Fukamichi, J. Appl. Phys. **87** (2000) 6995.