# Sb δ-doping of non-degenerate Ge(001) for a spin-FET with a high-mobility channel

T. Takada[1,2], H. Saito[1], A. Spiesser[1], R. Jansen[1], S. Yuasa[1], and N. Miura[2]
( [1]AIST, Spintronics Research Center, [2]Meiji Univ.)

## Introduction

Spin-dependent transport in a lateral semiconductor (SC) channel with two ferromagnetic (FM) contacts is the fundamental operation principle of the spin field-effect-transistor (spin-FET). For an effective transport of the spin-polarized carriers, the use of a non-degenerate SC is desirable because longer spin lifetimes are expected. The major requirement to employ a non-degenerate SC channel is to suppress the thermionic emission current and enhance the tunneling transport across the FM/SC contact by reducing the depletion region width in the SC region [1]. Recently, Hamaya and his co-workers have developed low-resistance FM tunnel contacts on *n*-type non-degenerate Ge(111) using the Sb δ-doping and low-temperature Ge homoepitaxy [2, 3]. On the other hand, Ge(001) is also a promising candidate as a channel of the spin-FET since epitaxial FM/MgO(001) tunnel barrier can be easily grown, providing a canonical spin injector/detector. Here, we have investigated the effect of the Sb δ-doping on the electrical transport process of Fe/MgO/non-degenerate Ge(001) devices.

## Sample preparations

Films were grown by molecular beam epitaxy on *n*-type Ge(001) substrates (a carrier concentration of ~ 5 × $10^{16}$ $cm^{-3}$). Sb was evaporated at room temperature (RT), followed by a 10 nm-thick Ge layer. We prepared several samples with different sheet doping densities of Sb ($n_{Sb}$) and growth temperature ($T_g$) of the homoepitaxial Ge layer. Finally, Au(20 nm) / Fe(5 nm) / MgO(1.5 nm) layers were deposited at RT. Reflection high-energy electron diffraction (RHEED) image revealed that the MgO layers have (001)-oriented single-crystalline or textured structure depending on $T_g$ and $n_{Sb}$.

## Results

Figure 1(a) shows the current-voltage (*I-V*) characteristics of the devices grown at different $T_g$ with a constant $n_{Sb} = 2.0 \times 10^{14}$ $cm^{-2}$. The devices with $T_g$ = 400 °C and 350 °C reveal a clear rectifying behavior, showing that the thermionic emission is the dominant transport process. With decreasing $T_g$, the current under reverse bias dramatically increases, and the rectifying behavior finally disappears above $T_g$ = 250 °C. For the devices with $T_g$ = 250 °C and 200 °C, there is no large difference in the resistance-area products (*RA*) as plotted in Fig.1 (b). This indicates that tunneling becomes the major transport process for $T_g \leq 250$ °C.

## References

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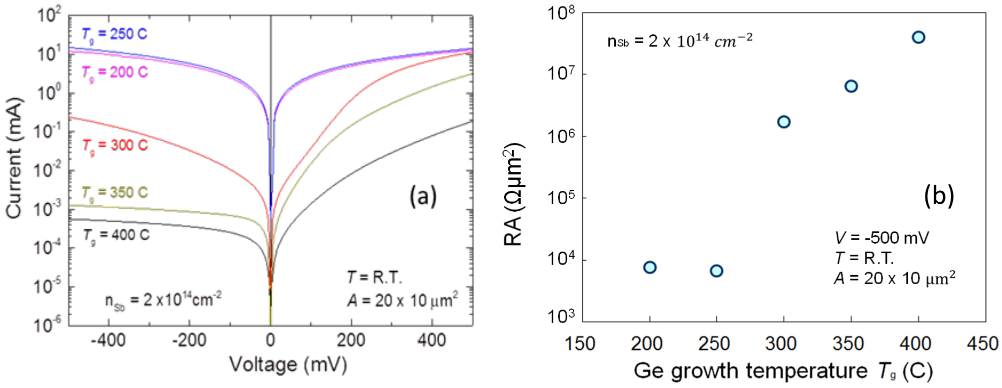

Fig.1 (a) Current-voltage characteristics of Fe/MgO/n-Ge(001) devices and (b) the corresponding *RA* at -500 mV as a function of $T_g$ measured at RT. The sheet Sb doping density $n_{Sb}$ is kept constant with a 2.0 × $10^{14}$ $cm^{-2}$.