Increase of tunneling magnetoresistance in trilayer structures composed of group-IV ferromagnetic semiconductor $Ge_{1-x}Fe_x$, MgO, and Fe

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Group-IV ferromagnetic semiconductor (FMS) $Ge_{1-x}Fe_x$ (GeFe) is a promising material for spin injectors and spin detectors for Si and Ge [1-3]. GeFe can be epitaxially grown on Si and Ge substrates by low temperature molecular beam epitaxy (LT-MBE) and its conductivity can be controlled from metallic to insulating by boron (B) doping [4]. Recently, tunneling magnetoresistance (TMR) has been observed in Fe/MgO/$Ge_{0.935}Fe_{0.065}$ magnetic tunnel junctions (MTJs) for the first time in MTJs with group-IV FMS, confirming the presence of spin-polarized carriers at the Fermi level in GeFe [5]. However, the TMR ratio reported in Ref. [5] was only 0.27%. Thus, it is necessary to improve TMR in Fe/MgO/GeFe. Here, we show that the TMR ratio is increased up to 1.5% by decreasing the size of the mesa diodes and by increasing the Fe concentration x of $Ge_{1-x}Fe_x$.

We have grown Fe / MgO (3 nm)/ $Ge_{1-x}Fe_x$ (x = 6.5%, 10.5%, 14%, 17.5%) / Ge:B (B: 4×10^{19} cm^{-3}) on p^+ Ge (001) substrates by MBE. When $x \geq 10.5\%$, although the reflection high energy electron diffraction (RHEED) pattern of the MgO layer became broader with increasing x, the RHEED patterns of other layers were streaky. The observed RHEED patterns indicated that the MgO and Fe layers were epitaxially grown on $Ge_{1-x}Fe_x$ with the epitaxial relationship of Fe[100](001) // MgO[110](001) // $Ge_{1-x}Fe_x$[100](001) [2].

After the growth, an Al layer was deposited on the samples as a top electrode. We patterned mesa diodes with a diameter φ of 15, 60, and 150 μm using photolithography and Ar-ion etching. SiO_2 was deposited for passivation. Figure 1 shows the TMR curves observed in the tunnel junction with x = 10.5%. The jumps of the resistance at $\mu_0 H = \pm 0.024$ T correspond to the inversion of the magnetization direction of the Fe layer. Figure 2 shows the x dependence of the TMR ratio. Compared with Ref. [5], the TMR ratio was increased by changing the shape and size of the mesa diodes from a square with the size of 700×700 μm^2 to the circle with φ = 60 μm when x = 6.5%. The TMR ratio became maximum at x = 10.5%, which is probably due to the enhancement of the ferromagnetic ordering in GeFe. The decrease in the TMR ratio at higher x can be attributed to the degradation of the crystallinity of the MgO layer by the increase in x.

This work was partly supported by Giants-in-Aid for Scientific Research including Specially Promoted Research, Project for Developing Innovation Systems of MEXT, and Spintronics Research Network of Japan (Spin-RNJ).

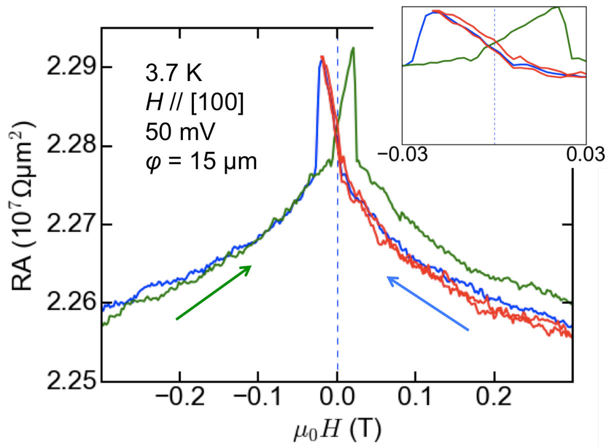

Fig. 1 TMR curves observed in the tunnel junction with x = 10.5% when the bias voltage was 50 mV. The blue and green curves express the major loops. The red curve is the minor loop.

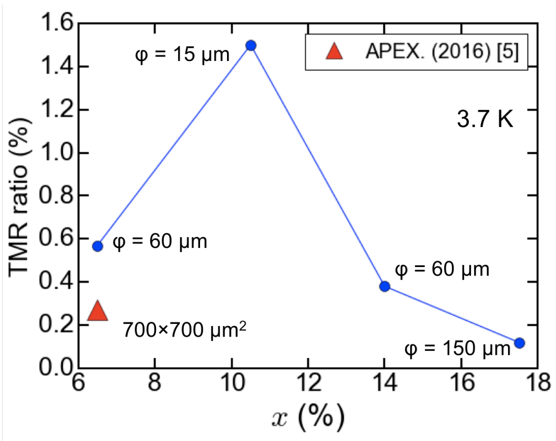

Fig. 2 Fe content (x in $Ge_{1-x}Fe_x$) dependence of the TMR ratio. The red point corresponds to the TMR ratio reported in Ref. [5].

References

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