# Perpendicular magnetic anisotropy and the crystal structure of *C*38-type MnGaGe films

Mingling Sun [1, 2], Takahide Kubota [1, 3], Yoshiaki Kawato [4], Yoshiaki Sonobe [4], Koki Takanashi [1, 3]
(Institute for Materials Research, Tohoku University [1], School of Engineering, Tohoku University [2],
Center for Spintronics Research Network, Tohoku University [3], Samsung R&D Institute Japan [4])

## Introduction

It has been a consensus in industry and academia that magnetoresistive random access memory (MRAM) is one of promising memories in the near future. From the viewpoint of materials development, the exploration of materials possessing small saturation magnetization ($M_s$) and perpendicular magnetization with high uniaxial magnetocrystalline anisotropy energy ($K_u$) are necessary for increasing the capacity of the core of MRAM called magnetic tunnel junction (MTJ) [1]. So far, the most successful case is CoFeB/MgO/CoFeB perpendicularly magnetized MTJs, which has achieved tunnel magnetoresistance (TMR) ratio of over 120% at room temperature [2]. Meanwhile, some other hopeful materials were also attempted, such as $L1_0$-FePt alloys with extremely large $K_u$ [3] and Co-based Heusler alloy utilizing interface magnetic anisotropy [4]. However, $M_s$ values of all those materials are relatively high. Here, we focus on *C*38-type perpendicularly magnetized MnGaGe films. MnAlGe which has a similar crystal structure with MnGaGe was deposited on a single-crystal (001) MgO substrate successfully [5]. Relatively small $M_s$ of about 250 emu/cm$^3$ and moderate $K_u$ of about 5 × 10$^6$ erg/cm$^3$ are of the interest for the application to MTJs. For giga-bit-class MRAMs, the reported $K_u$ for the MnAlGe film is still small, and the study of *C*38-type perpendicularly magnetized film is still limited. Therefore, in this work, we have determined to study perpendicular magnetization of epitaxially grown MnGaGe films.

## Experimental

All the metallic layers were deposited by using an ultrahigh-vacuum magnetron sputtering system. The MgO layer was deposited by using an electron beam evaporation system. MnGaGe layer with a thickness of 100 nm was deposited on MgO (001) substrate directly by co-sputtering technique using a MnGa target and a Ge target. The surfaces of the samples were capped by MgO (2 nm)/Ta (5 nm) layers. By adjusting output power of MnGa and Ge targets or changing Ar gas pressure, 5 series of samples were fabricated, which were: $Mn_{26}Ga_{23}Ge_{51}$, $Mn_{28}Ga_{38}Ge_{34}$, $Mn_{30}Ga_{37}Ge_{33}$, $Mn_{33}Ga_{36}Ge_{31}$ and $Mn_{35}Ga_{32}Ge_{33}$. Subsequent annealing processes were carried out using a vacuum furnace at 300 °C, 400 °C and 500 °C. After the preparation, vibrating sample magnetometer (VSM) and x-ray diffraction (XRD) measurements were carried out to characterize the magnetic properties and crystal structures, respectively.

## Results and discussions

Composition dependence of MnGaGe thin film was investigated systematically. Except the $Mn_{26}Ga_{23}Ge_{51}$ films, the $M_s$ values were close to that of the bulk sample [6] after annealing at the temperature higher than 300 ºC. In addition, the $Mn_{33}Ga_{36}Ge_{31}$ thin films exhibited perpendicular magnetization for the post-annealing temperature ranging from 300 ºC to 500 ºC. Furthermore, from the results of XRD measurements, epitaxial growth with (001)-orientation was observed in the $Mn_{33}Ga_{36}Ge_{31}$ films with annealing. On the other hand, (110)-orientation also appeared in other samples most of which exhibited in-plane magnetization. It is proposed that the stoichiometry is crucial for the epitaxy of MnGaGe film onto MgO substrate and the perpendicular magnetization.

## Reference

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