# Optimization of growth temperature of $Mn_4N$ thin films on LSAT(001) grown by molecular beam epitaxy

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**[Introduction]** $Mn_4N$ is a promising material for current induced domain wall motion devices because of its perpendicular magnetic anisotropy (PMA) with a large uniaxial anisotropic constant ($K_u$~$10^2$ kJ/$m^3$) and a small spontaneous magnetization ($M_S$~100 kA/m) [1]. Besides, it consists of only light and abundant elements. We recently achieved an ultrafast domain wall motion ($v_{DW}$ = 900 m/s) at a current density of approximately $10^{12}$ A/$m^2$ for $Mn_4N$ nanowires driven by only spin transfer torque without any external magnetic field [2]. We anticipate that the in-plane tensile distortion of $Mn_4N$ films causes the PMA [3]. (La, Sr)(Al, Ta)$O_3$ (LSAT) has a larger lattice constant than $Mn_4N$, and thus we expect in-plane compressive distortion in $Mn_4N$ films when grown on an LSAT substrate. However, no group has reported the epitaxial growth of $Mn_4N$ films on LSAT(001) substrates.

**[Experiment]** 30-nm thick $Mn_4N$ films were grown on LSAT(001) substrates by molecular beam epitaxy (MBE) using a solid Mn and a radio-frequency $N_2$ plasma at various substrate temperatures ($T_S$) of 450–800°C. After the growth, Ti cap layers were deposited *in-situ* on the $Mn_4N$ films to prevent oxidation. The crystalline quality of grown films was evaluated by reflection high-energy electron diffraction (RHEED) and out-of-plane and in-plane X-ray diffraction (XRD) measurements. The film thickness was evaluated by X-ray reflectivity. Magnetic properties were measured by vibrating sample magnetometer at room temperature (RT). Anomalous Hall effect (AHE) measurement was performed by physical properties measurement system at RT to evaluate $K_u$.

**[Result & Discussion]** Streaky RHEED patterns and Kikuchi lines along LSAT[100] azimuth were observed for the samples grown at $T_S$ = 700–800 °C in Fig. 1. On the other hand, the samples grown at $T_S$ < 650 °C showed the ring patterns, indicating poly-crystalline structures in their surfaces. Figure 1 also shows the out-of-plane XRD profiles. Epitaxial growth of $Mn_4N$ was confirmed for samples grown at $T_S$ = 700–800 °C. The presence of tensile distortion was confirmed even in $Mn_4N$ films on LSAT(001) from out-of-plane and in-plane (not shown) XRD patterns. Figure 2 shows the $T_S$ dependence of $M_S$ and $K_u$. The samples grown at $T_S$= 700–800 °C showed PMA. Based on these results, we succeeded in the epitaxial growth of highly *c*-axis oriented $Mn_4N$ films with PMA on LSAT(001) substrates at $T_S$ = 700, 750 and 800 °C. Especially, $K_u$ becomes the largest at $T_S$= 750 °C. We plan to investigate the relationship between $K_u$ and the ratio of lattice constant *c/a*.

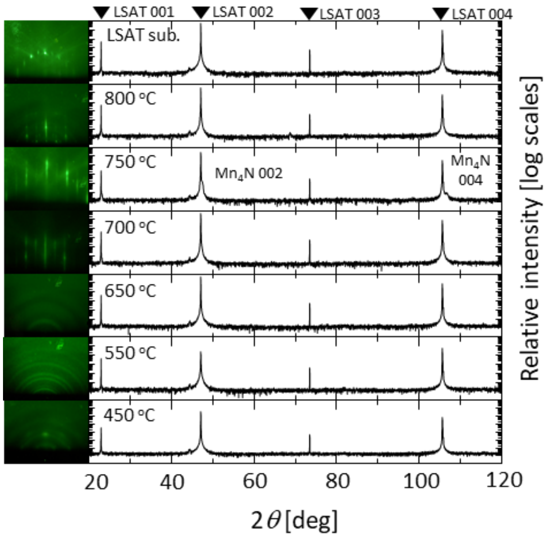


Fig.1. RHEED patterns along LSAT[100] azimuth (left) and $\omega$-2$\theta$ XRD profiles (right) of the samples on LSAT(001) at $T_S$ = 400–800 °C .

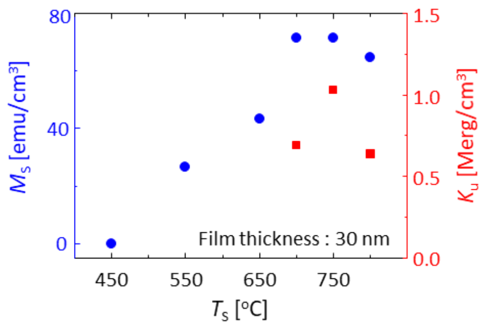


Fig. 2. $T_S$ dependence of $M_S$ and $K_u$ of $Mn_4N$ films on LSAT(001) substrates at RT.

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**[Reference]**
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