$L1_0$-FeNi films with a large degree of order and uniaxial magnetic anisotropy fabricated by denitriding epitaxial FeNiN films

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Ferromagnetic materials possessing large uniaxial magnetic anisotropy energy (K_u) and composed of earth abundant elements are required in order to realize the next-generation permanent magnets. We have focused on the $L1_0$-ordered FeNi alloy as a rare-earth free high K_u ferromagnetic material [1]. Recently, the synthesis of polycrystalline $L1_0$-FeNi powder by denitriding FeNiN powder was reported, and a degree of order (S) of 0.71 was achieved [2]. However, the exact K_u value of $L1_0$-FeNi formed by the denitriding method is still unclear, and the evaluation of K_u using a single-crystal $L1_0$-FeNi is required. In this study, we grew epitaxial FeNiN films by molecular beam epitaxy and fabricated $L1_0$-FeNi films by nitrogen topotactic extraction, and characterized their S and K_u values.

20 nm-thick FeNiN films were grown on $SrTiO_3$(001) substrates at 200, 250, and 350 °C by supplying Fe, Ni, and radio-frequency N_2 plasma, simultaneously [3]. Denitriding was performed by *ex-situ* furnace annealing at 300 °C for 4 h under an H_2 gas flow rate of 1 L/min at ambient pressure. Structure of the samples was characterized by x-ray diffraction measurements using Cu-$K\alpha$ radiation and synchrotron radiation (hv = 7.11 keV), and cross-sectional scanning transmission electron microscope (STEM) measurements. Magnetization curves were measured by vibrating sample magnetometer at room temperature, and the K_u value was estimated by magnetic torque measurements.

The epitaxial $L1_0$-FeNi films oriented with the *a*-axis perpendicular to the film plane having two variants with the orthogonal in-plane *c*-axes are fabricated. For the sample grown at 350 °C, the S and K_u values are evaluated to be 0.87 and 5.9×10^5 J/m^3, respectively. In spite of the large S value exceeding those reported previously [1,2], the K_u value is modestly high. The exchange length of $L1_0$-FeNi (3.2 nm) is comparable to the variant sizes of our samples estimated by the STEM measurements. This strongly suggests that the obtained macroscopic K_u value is smaller than the actual K_u of each variant [4].

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