論文 / 著書情報
Article / Book Information

題目(和文)	Co置換BiFeO3の弱強磁性の起源および磁化反転の検出
Title(English)	Origin of Weak Ferromagnetism and Detection of Magnetization Reversal in Co-substituted BiFeO3
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出典(和文)	学位:博士(工学), 学位授与機関:東京科学大学, 報告番号:甲第301号, 授与年月日:2025年3月26日, 学位の種別:課程博士, 審査員:東 正樹,舟窪 浩,大場 史康,片瀬 貴義,笹川 崇男,山本 隆文
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Institute of Science Tokyo, Report number:甲第301号, Conferred date:2025/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

博士課程）
Doctoral Program

論 文 要 約

THESIS OUTLINE

Koomok Lee

論文題目：

Origin of Weak Ferromagnetism and Detection of Magnetization Reversal in Co-substituted $BiFeO_3$
(Co 置換 $BiFeO_3$ の弱強磁性の起源および磁化反転の検出)

Along with the development of information technology, the amount of data processing is exploding, and material design to sustain low-power electronics become indispensable. $BiFeO_3$ (BFO) is renowned for room temperature single phase multiferroic material having spontaneous electric polarization (P ~ 100 μC/cm^2) and non-collinear G-type antiferromagnet. Electric field (E) control of magnetization (M) is expected to be utilized for energy-efficient nonvolatile magnetic memory application. In BFO, macroscopic M is suppressed due to the spin cycloidal modulation of Fe^{3+} (S = 5/2) with 63 nm period. By partial substitution of Co for Fe, it was confirmed that spin structure changes from cycloidal structure to canted collinear one with weakly ferromagnetic moment of M ~ 0.03 μ_B/f.u. perpendicular to the P. In $BiFe_{0.9}Co_{0.1}O_3$ (BFCO) thin films, stripe pattern structure was observed in both ferroelectric and ferromagnetic domains and room temperature E-induced M reversal by P switching was demonstrated. Further reducing the geometry of BFCO into nanoscale size (~100 nm), both ferroelectric and ferromagnetic domain structures were revealed from multidomain (190 nm) to single domain (60nm) applicable for magnetic memory bit. The main purpose of this thesis is to clarify the origin of spontaneous M of BFCO and to develop elemental technologies toward BFCO based magnetic memory devices.

In chapter 2, the microscopic origin on the appearance of spontaneous M by Co substitution was investigated to achieve material deign guideline to enhance the weak M by chemical substitution. By employing density functional theory (DFT) and Monte Carlo simulation based on the spin Hamiltonian analysis, it is elucidated that substitution with high spin (HS) Co^{3+} with strong spin-orbit coupling plays a key role in stabilizing the spin canted collinear structure over cycloidal one. Moreover, the presence of HS Co^{3+} in $BiFe_{0.8}Co_{0.2}O_3$ was experimentally confirmed by Co $K\beta$ synchrotron X-ray emission spectroscopy. These results propose that substitution with magnetic ions with strong spin-orbit coupling is effective for designing weakly ferromagnetic behavior in BFO system.

In chapter 3, E-induced M reversal by P switching in BFCO nanodots with 190 nm diameters was investigated. By applying E using Piezoresponse Force Microscopy (PFM), ferroelectric topological domain change from downward center-convergent to upward center-divergent structure was induced referred to as 180° P switching distinct from that of thin film with stripe patterned ferroelectric domain accompanying 71° P switching upon electric poling. On top of that, observation of the ferromagnetic domain change on the same region was conducted using highly-sensitive scanning diamond nitrogen-vacancy center magnetometer (SNVM). As a result, both in-plane and out-plane *M* reversal by 180° *P* switching was demonstrated paving the way for the design of new type of voltage-write magnetic-read memory device.

In chapter 4, magnetic sensor for the electrical detection of *M* reversal (< 1mT) of BFCO memory was fabricated. As a sensor material, InSb was selected exhibiting the highest electron mobility (~10^5 cm^2/Vs) among III-V semiconductors widely applied for highly-sensitive Hall sensor. Despite the large lattice mismatch up to 17.8 %, epitaxial growth of (111)-oriented InSb on $SrTiO_3$ (STO) (6.3 nm)/BFCO (80 nm) /STO (001) thin film was confirmed using pulsed laser deposition method. From Hall effect measurement, InSb thin film showed electron mobility of ~10^2 cm^2/Vs at room temperature and external magnetic field down to 0.1 mT was electrically detected. This demonstrates that InSb Hall sensor is highly promising for the electrical detection of *M* reversal of BFCO based memory.