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研究課題名（和文）原子レベルシミュレーションによる新奇六方晶機能製材料の設計

研究課題名（英文）Design of novel hexagonal functional materials by atomic level simulation

研究代表者
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研究成果の概要（和文）：本プロジェクトは、デバイス応用をにらんで、大きな磁化と新奇な電気磁気相互作用を持つ六方晶YMnO3型または類似構造を持つ酸化物磁性体を探索した。具体的な成果は以下の通りである。１LuFeO3型システムにおいて、電場誘起スピン再配列と180°の電気磁気スイッチングを起こす、新しいコリニア型フェリ磁性を実現する方策を立案した。２(LuFeO3)m/(LuFe2O4)超格子の室温マルチフェロイック挙動の微視的なメカニズムを提案した。３.Co置換BiFeO3のスピン状態と強磁性発現の関係を提唱した。４．斜方晶鉄酸化物、クロム酸化物におけるスピン再配列の微視的モデルを提唱した５．室温極性金属を設計した。

研究成果の学術的意義や社会的意義
Our research provides a possible answer to the present quest for the multiferroic and Magnetoelectric system that can exhibit large magnetization and efficient magnetization control by the external means, for the potential application in novel devices such as voltage-controllable magnetic memories.

研究成果の概要（英文）：The project aims to design magnetic materials with large magnetization and novel magnetoelectric (ME) coupling using computational simulations by exploring YMnO3 type hexagonal oxides and systems having related crystal structures. The findings are as follows; 1.An idea to realize novel non-collinear ferrimagnetic orders with potential electric field-controlled spin-reorientation (SR) transitions and 180° ME switching in LuFeO3 type systems (Under review, arXiv:2203.03841). 2.A probable microscopic mechanism to explain the RT multiferroic (MF) behavior of the (LuFeO3)m/(LuFe2O4)1 superlattices (Nat Commun 11, 5582 (2020)). 3.A predicted correlation between the spin-state and the MF properties of Co-doped BiFeO3 (Phys. Rev. Materials 6, 064401 (2022)). 4.Microscopic models of SR transitions in orthoferrites and orthochromites (Phys. Rev. Materials 5, 124416 (2021),Nat Commun 12, 1917 (2021)). 5. Design of prospective RT magnetic polar metals (Chem. Mater.33, 1594 (2021)).

研究分野：Condensed matter theory and materials physics

キーワード：Magnetoelectric effect　Condensed matter theory　Magnetism　Spintronics　Transition metal oxides

概要：原子レベルシミュレーションによる新奇六方晶機能製材料の設計

本プロジェクトは、デバイス応用をにらんで、大きな磁化と新奇な電気磁気相互作用を持つ六方晶 $YMnO_3$ 型または類似構造を持つ酸化物磁性体を探索した。具体的な成果は以下の通りである。１．$LuFeO_3$ 型システムにおいて、電場誘起スピン再配列と 180°の電気磁気スイッチングを起こす、新しいコリニア型フェリ磁性を実現する方策を立案した。２．$(LuFeO_3)_m/(LuFe_2O_4)$超格子の室温マルチフェロイック挙動（*Nat Commun* ***11****, 5582 (2020)*）の微視的なメカニズムを提案した。３．Co 置換 $BiFeO_3$ のスピン状態と強磁性発現の関係を提唱した（*Phys. Rev. Materials* ***6****, 064401 (2022)*）。４．斜方晶鉄酸化物、クロム酸化物におけるスピン再配列の微視的モデルを提唱した（*Phys. Rev. Materials* ***5****, 124416 (2021), Nat Commun* ***12****, 1917 (2021)*）５．室温極性金属を設計した（*Chem. Mater.* ***33****, 1594 (2021)*）。

1. Scientific background for the proposed research activity (研究開始当初の背景)

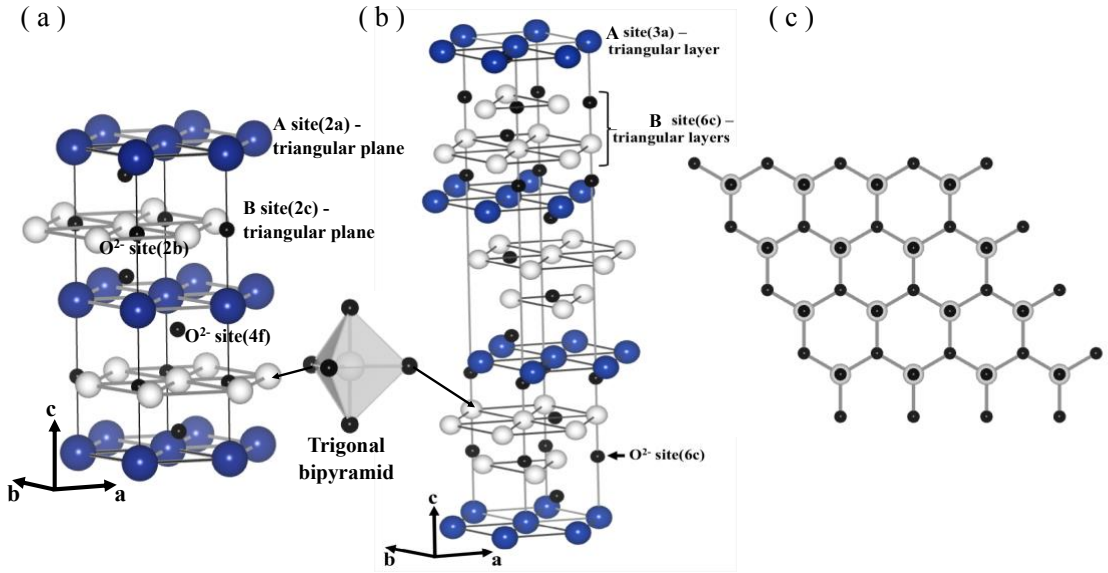

Figure 1 Undistorted high symmetry crystal structure of ABO_3($\boldsymbol{P6_3/mmc}$) (a) and AB_2O_4($\boldsymbol{R\bar{3}m}$) (b) transition metal oxides (A, B=cations). (c) Triangular arrangement of the B cations.

There has been considerable progress in the understanding of the microscopic mechanisms of the magnetoelectric (ME) coupling phenomenon which can enable the electric field control over magnetization (***M***). This topic of research is significant both from the fundamental and the applied physics points of view as large magnetization and strong ME coupling rarely coexist in a single-phase system at room temperature. The quest for effective microscopic mechanisms to realize this phenomenon is an active field of research. There has been increasing interest in the ABO_3 and AB_2O_4 (A, B = cations) transition metal (TM) oxides that crystallize in the hexagonal layered structures (see Figure 1) due to their potential to exhibit fascinating magnetic and electronic behavior, including room temperature multiferroic (MF) and ME behavior [*Nature* ***537****, 523 (2016)*], topological orders [*Nature* ***419****, 818 (2002), Nature Mater* ***13****, 163 (2014), Phys. Rev. Lett.* ***126****, 157601 (2021)*], giant magnetic anisotropy [*J. Phys. Soc. Jpn.* ***62****, 1723 (1993), Phys. Rev. Lett.* ***103****, 207202 (2009)*] and spin-liquid behavior [*Y. Shen et al., Nature* ***540****, 559 (2016), Nat. Phys.****15****, 262 (2019)*], thereby offering sufficient scope for designing potential materials with fascinating properties. As illustrated in Figure 1, the B-site cation is surrounded by a trigonal bipyramid arrangement of oxygen atoms and in the planes of the corner-sharing trigonal bipyramids the B cations form triangular lattice. These planes are layered with the triangular planes formed by the A-site cations. A common feature of these materials is that the spins are antiferromagnetically coupled in the triangular lattice (see Figure 1(c)) and hence, are **geometrically frustrated**. Also, the ABO_3 systems (R = Sc, Y, In, Dy-Lu and B = Mn, Fe) exhibit

ferroelectric behavior well above room temperature [*Acta Crystallographica* ***16****, 957 (1963)*], which is driven by the buckling of the BO_5 bipyramids and a subsequent trimerization of the A-site ions [*Nature Materials 3, 164 (2004), Phys. Rev. B* ***72****, 100103 (2005)*]. A ME coupling mechanism which can lead to the 180° ME switching phenomena and the formation of topologically protected ME domain structures was predicted in $LuFeO_3$[*Nat Commun* **5,** 2998 (2014)]. In addition to the structural complexity, various other factors contribute to dictate the electronic and magnetic behavior of these frustrated magnets, such as charge ordering, spin-orbit coupling and inter-triangular layer magnetic interactions. **The challenge, therefore, is to develop material-property guidelines to tailor and predict the properties of these materials. In particular, the bearing of the atomic order or disorder on the functional properties of these materials is least explored, which was the main objective of this proposed research activity. Further in depth understanding of the ferroelectricity and it's coupling with magnetism within this hexagonal and related frame of lattice would guide researchers to design new materials with novel magnetic and ME phenomena with potential memory applications.**

A polar Fe^{+2}/Fe^{+3} charge ordered state was reported to induce electric polarization (***P***) in $LuFe_2O_4$[*Nature* ***436****, 1136 (2005)*] and this finding initiated huge research activity. However, recent studies find that the ground state structure of $LuFe_2O_4$ is rather an antiferroelectric charge ordered phase [*Nature* ***537****, 523 (2016)*]. On the other hand, $LuFeCoO_4$ exhibits relaxor ferroelectric behavior [*J. Phys.: Conf. Ser.* ***320,*** *012084 (2011)*]. **Despite a large number of studies, ferroelectric behavior of these systems is far from understood.** Recently, strong ferroelectric distortions have been observed in the $LuFe_2O_4$ layer [*Nature* ***537****, 523527 (2016)*] induced by the robust geometric ferroelectric $LuFeO_3$ in $(LuFeO_3)_m/(LuFe_2O_4)_1$ superlattices. **$(LuFeO_3)_m/(LuFe_2O4)_1$ superlattices have been reported to show switching of the direction of *M* with the reversal of the direction of *P*. However, the mechanism that can lead to such coupling between the collinear ferrimagnetic *M* reported for these superlattices and FE *P* that can lead to 180^0 switching phenomena in these superlattices is not understood yet.**

2. **Purpose of the research project: (**研究の目的)The objectives of the proposed research program are,

I. To study the electronic and magnetic behavior of the hexagonal ferrites in the limit of strong magnetic anisotropy and Dzyaloshinskii-Moriya (DM) coupling. $LuFe_2O_4$ exhibits giant magnetic anisotropy, primarily originating from the degenerate $3d_{xz}$ electronic state of the Fe^{+2} ion under a trigonal bipyramid oxygen environment (associated Fe-3*d* level splitting is schematically presented in Figure 2). The magnetic and electronic properties of $LuFe_2O_4$ having equal concentrations of Fe^{+2} and Fe^{+3} ions are well explored [*Nature* ***537****, 523 (2016)*]. In the present study we have explored the effect of the formation of the Fe^{2+}/Fe^{3+} ordered structures in the magnetic and ME properties of the $LuFeO_3$ and $(LuFeO_3)_m/(LuFe_2O_4)_1$ superlattices. While in the former system the charge-ordered (CO) state can be formed due to the electron doping (by appropriate cation/anion substitutions), in the latter this phenomenon was controlled by the specific layering of the superlattices.

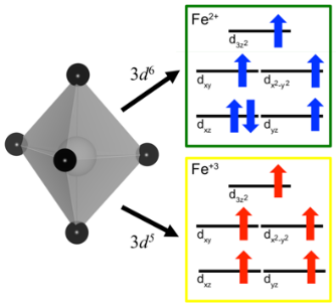

Figure 2The crystal filed splitting of the 3*d* states of Fe under the trigonal bipyramid oxygen environment.

II. To explore the stability of competing magnetic phases and spin-reorientation transition phenomena. Formation of multiple magnetic sublattices and strong interaction between them lead to the formation multiple magnetic phases and transitions like spin-reorientation (SR) transitions between them. The SR phenomenon has been observed in many ABO_3 type perovskite oxides systems. However, the underlying microscopic origin of this phenomenon using a material specific theoretical approach is less explored. In the present research activity, we have explored the microscopic origin of SR transitions considering both hexagonal and perovskite phases of ABO_3 oxides. We have also aimed is to develop mechanisms that lead to the efficient control over the SR transitions by the external means, such as electric field and optical stimuli [*Nat. Mater.* ***20****, 607-611 (2021)*].

III. To understand and predict the electronic and magnetic behavior of the binary $A(BB')O_4$ systems (where B, B′ = 3*d* TM ions) as a function of TM *d*-level occupancy. While the hexagonal phase has been synthesized for numerous 3*d*–3*d* transition metal combinations [*Progress in Solid State Chemistry* ***43****, 37 (2015)*], the electronic and magnetic properties of these materials are less explored. One of the most studied materials of this family is $LuFe_2O_4$, which is a robust insulator with a large band gap [*Phys. Rev. Lett.* ***101****, 227602 (2008)*]. In the proposed research efforts, we have investigated and attempted to predict the relation between crystal structure and the functional properties of the $LuB_xB'_{1-x}O_4$ systems through detailed investigation of the structural, electronic and magnetic phase stabilities as functions of the TM 3*d*–level occupancy.

３．**Research method** (研究の方法)

Ground state calculations (Density Functional Theory (DFT)): We used a combination of theoretical tools, such as DFT based electronic structure calculations, group theory, microscopic models and finite temperature Monte Carlo simulations to achieve our research goals. We conducted various levels of DFT calculations, such as energies of various structural and magnetic phases, equilibrium crystal structures, phonon dispersions, dielectric properties and electric polarization using Berry phase method, which is the most computationally heavy component of the present research activity. In order to conduct DFT calculations, we currently have two computational facilities, (1) a group private computer cluster and (2) access to Tokyo Tech supercomputer TSUBAME. The group also has the licensed access to DFT based Fortran code VASP and Wien2k.The cation ordered configurations were determined by using CASM (https://prisms-center.github.io/CASMcode_docs/) and the cation disordered phases were modeled by creating the special quasi-random structures (SQS) (ATAT).

Spin models to study the magnetic properties at finite temperature: In these frustrated magnetic systems, the relevant magnetic interactions are between TM magnetic moments and can be described through a Heisenberg spin model Hamiltonian, $H = \sum_{i,j} J_{ij}\vec{S}_i \cdot \vec{S}_j + \sum_{i,j} \vec{D}_{ij} \cdot \vec{S}_i \times \vec{S}_j + \sum_i \vec{S}_i \cdot \hat{\tau}_i \cdot \vec{S}_i$, where J_{ij} represents the symmetric isotropic exchange interactions, $\vec{D}_{ij}$ represents the DM interactions and $\hat{\tau}_i$ is the single-ion anisotropy. The relevant interactions were considered through group theoretic symmetry analysis. The values of the magnetic interactions were estimated by performing total energy calculations for finite number of collinear and non-collinear spin structures. Suchan approach not only explains ground state spin structure, but also can be used for finite temperature analysis through Monte Carlo (MC) simulations [*Nat Commun* **5,** 2998 (2014)*, Nature* ***537****, 523527 (2016)]*.

４．**Research results**（研究成果）

Designed non-collinear ferrimagnetism and its coupling with the ferroelectric order in $LuFeO_3$ (Under review, arXiv:2203.03841): Here, we have endeavored to design hitherto unobserved non-collinear ferrimagnetic orders characterized by high ***M*** and have coupled them with an improper ferroelectric (FE) order in the hexagonal $LuFeO_3$ that exhibits interesting topological orders. In our proposed model, the DM interactions between the magnetic ions and their coupling with the FE order is at the root of these magnetic and magnetoelectric (ME) phenomena. The proposed two-sublattice magnetic system, generated by a specific Fe^{2+}/Fe^{3+}charge-ordered (CO) state, forms multiple energetically close, non-collinear ferrimagnetic orders, thereby enabling the manipulation of the microscopic magnetic interactions and the triggering of SR transitions by various efficient means. The two-sublattice structure was realized in the hexagonal phase of $LuFeO_3$ doped with electrons. This electron doped system is characterized by $P \sim 15\ \mu C/cm^2$, $M \sim 1.1\ \mu_B$/Fe and magnetic transition near room temperature (~ 290 K). Based on the coupling between the magnetic interactions and the FE primary order parameter observed in this system, microscopic mechanisms to achieve electric field ***E*** induced SR transitions and 180° switching of the direction of ***M*** are proposed.

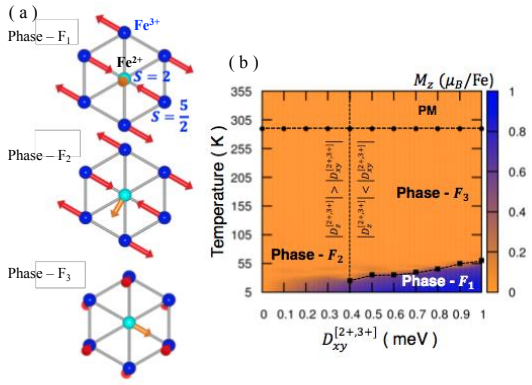

Figure 3 (a) Identified non-collinear ferrimagnetic orders F_1, $F_2$and F_3. Red and orange arrows represent Fe^{3+} and Fe^{2+} spins, respectively. (b) Observed stable magnetic phases as a function of temperature and inter-sublattice DM interactions ($D_{xy}^{[2+,3+]}$).

Predicted charge and ferrimagnetic order in $(LuFeO_3)_m/(LuFe_2O_4)_1$ MF and ME superlattices (*Nat Commun 11, 5582 (2020)*): In $LuFeO_3$, an improper FE behavior with an electric polarization of $P\sim$ 6.5 $\mu C/cm^2$ below $\sim$ 1040 K and canted antiferromagnetic (AFM) order with induced $M\sim$ 0.03 μ_B/Fe below ~ 147 K were reported. On the other hand, $LuFe_2O_4$ exhibits a coupling between charge and magnetic order which leads to the formation of collinear ferrimagnetic behavior with considerably high $M\sim$0.8-1.4μ_B/Fe below ~ 240 K. Atomically engineered superlattices of $LuFeO_3$ and $LuFe_2O_4$ reportedly exhibited near room temperature MF and ME behavior [*Nature **537**, 523 (2016)*]. Both the magnetic transitional temperature and $\boldsymbol{M}$ were found to be enhanced in these superlattices. Employing DFT calculations and finite temperature MC simulations, we showed that with an increase in the thickness of the FE $LuFeO_3$ layer there was a reduction in the magnetic frustration in the ferrimagnetic $LuFe_2O_4$ layer and a subsequent rise in the magnetic transition temperature. Moreover, we showed that the formation hole doped and Fe^{2+}/Fe^{3+} CO non-polar ferrimagnetic layer can contribute to enhance the magnitude of $\boldsymbol{M}$. A comparative analysis of the experimentally observed and calculated Magnetic circular dichroism (MCD) spectra furnished further evidences in support of this theoretical prediction.

Proposed microscopic mechanism of SR transitions in various perovskite phase of ABO_3 transition metal oxides (*Phys. Rev. Materials 5, 124416 (2021), Nat Commun 12, 1917 (2021)*): Spin reorientation (SR) transitions and other related magnetic phenomena, originating out of the complex interplay between multiple magnetic sublattices, are scientifically interesting and have a wide variety of commercial applications. By means of DFT calculations and finite temperature MC simulations, we explored the possible origins of SR transition of Cr spins in $NdCrO_3$. We show that at the root of the observed SR transition in $NdCrO_3$, is a delicate balance between Nd−Cr magnetic isotropic exchange interactions, single ion anisotropy of Nd and Cr ions. As shown in Figure 4, the $\mathbf{G_y}$-$\mathbf{G_z}$ SR transition strongly depends on the relative strength of Nd-Cr isotropic exchange interaction γ with respect to Cr-Cr interactions. Our results also propose a hitherto unobserved collective magnetic ordering in Nd sublattice. The detection of this ordering is, however, difficult as it is an extreme low temperature phenomenon. Therefore, further investigations are required before anything conclusive is said in this regard.

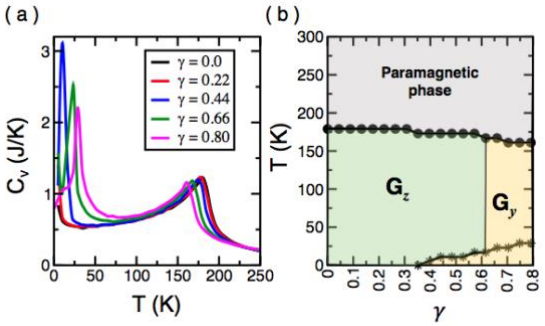

Figure 4 (a) calculated temperature dependence of specific heat for a choice of γ values. The second peak represents SR transition. (b) Magnetic phase diagram in T-γ plane. $\mathbf{G_z}$ and $\mathbf{G_y}$ represent G-type AFM order in Cr sublattice with spins orientated along *z* and *y* axes, respectively.

Recently, a non-trivial Pb^{2+}/Pb^{4+} CO state and a SR transition from a canted AFM order with Fe spins oriented along the crystallographic ***a***-axis ($\mathbf{G_a}$) to a collinear AFM structure with spin moments along the **b**-axis ($\mathbf{G_b}$) near 418 K was observed in $PbFeO_3$. We showed that the peculiar arrangement of the Pb ions leads to the creation of the two magnetic Fe1 and Fe2 sublattices with mutually competing magnetic anisotropy energies. While the former energetically favors the orientation of the spins along the **b** axis, the latter, in contrast, favors the **a**-axis spin orientation. At high temperatures, it is this which is expected to contribute to drive the SR transition. Our work is expected to introduce a unique opportunity of inducing magnetic phase transition ($\boldsymbol{M} = 0 \leftrightarrow \boldsymbol{M} \neq 0$) by driving a redistribution of Pb ions via an external electric $\boldsymbol{E}$ field and/or strain.

Other relevant research results funded by the present project (* corresponding author):

1. K. Lee,…,Hena Das* *et. al.* Phys. Rev. Materials **6**, 064401 (2022).
2. M. Shaikh,..,Hena Das* *et. al.* Chem. Mater. **33**, 1594-1606 (2021).
3. S.Wakazaki*et. al.*Inorg. Chem., **59**, 13390-13397 (2020).
4. K. Ohashi,…,Hena Das* *et. al.*, Chem. Mater. **32**, 9753-9760 (2020).

５．主な発表論文等

〔雑誌論文〕　計9件（うち査読付論文　9件／うち国際共著　9件／うちオープンアクセス　2件）

１．著者名 Fan Shiyu、Das Hena、Rebola Alejandro、Smith Kevin A.、Mundy Julia、Brooks Charles、Holtz Megan E.、Muller David A.、Fennie Craig J.、Ramesh Ramamoorthy、Schlom Darrell G.、McGill Stephen、Musfeldt Janice L.	４．巻 11
２．論文標題 Site-specific spectroscopic measurement of spin and charge in (LuFe03)m/(LuFe204)1 multiferroic superlattices	５．発行年 2020年
３．雑誌名 Nature Communications	６．最初と最後の頁 5582
掲載論文のDOI（デジタルオブジェクト識別子） 10.1038/s41467-020-19285-9	査読の有無 有
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１．著者名 Ye X.、Zhao J.、Das H.、Sheptyakov D.、Yang J.、Sakai Y.、Hojo H.、Liu Z.、Zhou L.、Cao L.、Nishikubo T.、Wakazaki S.、Dong C.、Wang X.、Hu Z.、Lin Hong-Ji、Chen Chien-Te、Sahle C.、Efiminko A.、Cao H.、Calder S.、Mibu K.、Kenzelmann M.、Tjeng Liu Hao、Yu R.、Azuma M.、Jin C.、Long Y.	４．巻 12
２．論文標題 Observation of novel charge ordering and spin reorientation in perovskite oxide PbFe03	５．発行年 2021年
３．雑誌名 Nature Communications	６．最初と最後の頁 1917
掲載論文のDOI（デジタルオブジェクト識別子） 10.1038/s41467-021-22064-9	査読の有無 有
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１．著者名 Shaikh Monirul、Fathima Aafreen、Swamynadhan M. J.、Das Hena、Ghosh Saurabh	４．巻 33
２．論文標題 Investigation into Cation-Ordered Magnetic Polar Double Perovskite Oxides	５．発行年 2021年
３．雑誌名 Chemistry of Materials	６．最初と最後の頁 1594～1606
掲載論文のDOI（デジタルオブジェクト識別子） 10.1021/acs.chemmater.0c02976	査読の有無 有
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１．著者名 Ohashi Kotaro、Shigematsu Kei、Das Hena、Yamamoto Kazumasa、Tsukasaki Hirofumi、Mori Shigeo、Azuma Masaki	４．巻 32
２．論文標題 Lithium Ion Conduction in a Cation-Deficient Quadruple Perovskite LiCuTa309 Epitaxial Thin Film: Theoretical and Experimental Investigations	５．発行年 2020年
３．雑誌名 Chemistry of Materials	６．最初と最後の頁 9753～9760
掲載論文のDOI（デジタルオブジェクト識別子） 10.1021/acs.chemmater.0c03635	査読の有無 有
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1．著者名 Wakazaki Shogo、Nishikubo Takumi、Sakai Yuki、Shigematsu Kei、Das Hena、Zhang Depei、Zhang Qiang、Matsuda Masaaki、Azuma Masaki	4．巻 59
2．論文標題 Stabilized Charge, Spin, and Orbital Ordering by the 6s2 Lone Pair in Bi0.5Pb0.5MnO3	5．発行年 2020年
3．雑誌名 Inorganic Chemistry	6．最初と最後の頁 13390～13397
掲載論文のDOI（デジタルオブジェクト識別子） 10.1021/acs.inorgchem.0c01748	査読の有無 有
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1．著者名 Yuki Sakai, Takumi Nishikubo, Takahiro Ogata, Hayato Ishizaki, Takashi Imai, Masaichiro Mizumaki, Takashi Mizokawa, Akihiko Machida, Tetsu Watanuki, Keisuke Yokoyama, Yoichi Okimoto, Shin-ya Koshihara, Hena Das and Masaki Azuma	4．巻 31
2．論文標題 Polar−Nonpolar Phase Transition Accompanied by Negative Thermal Expansion in Perovskite-Type Bi1−xPbxNiO3	5．発行年 2019年
3．雑誌名 Chemistry of Materials	6．最初と最後の頁 4748-4758
掲載論文のDOI（デジタルオブジェクト識別子） 10.1021/acs.chemmater.9b00929	査読の有無 有
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1．著者名 Kei Shigematsu, Keisuke Shimizu, Kazumasa Yamamoto, Takumi Nishikubo, Yuki Sakai, Sergey A. Nikolaev, Hena Das, and Masaki Azuma	4．巻 1
2．論文標題 Strain Manipulation of Magnetic Anisotropy in Room-Temperature Ferrimagnetic Quadruple Perovskite CeCu3Mn4O12	5．発行年 2019年
3．雑誌名 ACS Appl. Electron. Mater.	6．最初と最後の頁 2514-2521
掲載論文のDOI（デジタルオブジェクト識別子） 10.1021/acsaelm.9b00547	査読の有無 有
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1．著者名 Das Hena、Rebola Alejandro F.、Saha-Dasgupta Tanusri	4．巻 5
2．論文標題 Exploring the possible origin of the spin reorientation transition in <mml:math xmlns:mml="http://www.w3.org/1998/Math/MathML"><mml:msub><mml:mi>NdCrO</mml:mi><mml:mn>3</mml:mn></mml:msub></mml:math>	5．発行年 2021年
3．雑誌名 Physical Review Materials	6．最初と最後の頁 124416
掲載論文のDOI（デジタルオブジェクト識別子） 10.1103/PhysRevMaterials.5.124416	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Lee Koomok、Shigematsu Kei、Das Hena、Azuma Masaki	4．巻 6
2．論文標題 Exploring the correlation between the spin-state configuration and the magnetic order in Co-substituted <mml:math xmlns:mml="http://www.w3.org/1998/Math/MathML"><mml:msub><mml:mi>BiFeO</mml:mi><mml:mn>3</mml:mn></mml:msub></mml:math>	5．発行年 2022年
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1．発表者名 Hena Das
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〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関