【Grant-in-Aid for Scientific Research (S)】

Broad Section D

Title of Project : Exploration of new functionalities in 4f-5d electron system via invention of rare earth monoxides

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Keyword : rare earth monoxides, epitaxial thin film, heterostructure, 5d electron, 4f electron

【Purpose and Background of the Research】

Chemically stable simple rare earth oxide is usually rare earth sesquioxides R_2O_3 (R: rare earth), which are high permittivity insulators. If electrically conducting rare earth oxides are available, they could be useful electronic and/or magnetic materials because of large spin-orbit coupling in 5d-4f electron of rare earth elements. Indeed, electrically conducting EuO, which is uniquely stable among rare earth monoxide, has been extensively studied as a spintronic material. Recently, we succeeded in the synthesis of rocksalt-type yttrium monoxide YO for the first time. By using thin film epitaxy with pulsed laser deposition, metastable YO phase can be obtained. Here, Y ion is not stable trivalent but metastable divalent, so that the d electron contributes to high electrical conduction in YO. The other rare earth monoxides, which were also successfully synthesized, mostly showed high electrical conduction, and some of them were new superconductor or ferromagnet. Simple rocksalt structure of the rare earth monoxides RO, in contrast with a complicated C-rare earth structure of R_2O_3, enables to fabricate the heteroepitaxial structures. Considering their various properties as a function of 4f electron number, further diverse properties can be expected in such heterostructures. Thus, purposes of this project are (1) synthesis of all rare earth monoxides and elucidation of their properties to reveal a potential as electronic, magnetic, and superconducting functional materials, and (2) exploration of new properties and functionalities via synthesis of solid solutions and heterostructures.

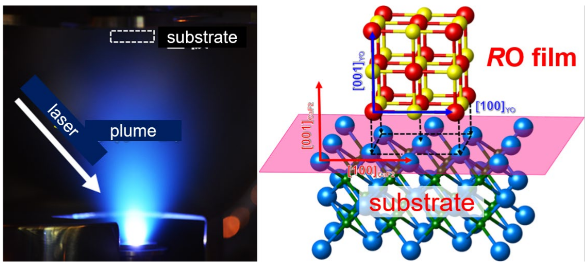

Fig. 1. UV laser (left) enables to synthesize rocksalt-type rare earth monoxide (right).

【Research Methods】

We conduct thin film synthesis of all rare earth monoxides, and measure optical, electric, and magnetic properties, in addition to the search for efficient carrier dopant of rare earth monoxides. The electronic states are also investigated in collaboration with synchrotron measurement groups. We also synthesize the solid solutions to examine systematic variation of the properties as a function of the composition.

As for the heterostructures, we explore their novel properties and functionalities such as two dimensional hole gas and triplet Cooper pair in various combinations of rare earth monoxides and normal metals. In addition, microscopic electronic states will be investigated by real space mapping of electronic and spin states at the interfaces with low temperature scanning tunneling microscope.

【Expected Research Achievements and Scientific Significance】

Rare earth monoxides have been known as the gas phases, while their solid phases have been so rare that their polycrystals were synthesized about 40 years ago. Since then, even their fundamental properties have not been studied except for EuO, in spite of their simple crystal structure and composition. However, the rare earth monoxides we synthesized exhibit remarkable electrical conduction and magnetism in contrast with well-known 3d transition metal monoxides, most of which are antiferromagnetic insulators. The simple rocksalt structure is beneficial to synthesize solid solutions and heteroepitaxial structures. Their various properties and functionalities would make rare earth monoxides new electronic, magnetic, superconducting, spintronic, and topological materials. In addition, we could obtain useful information concerning both fundamentals and applications contributing to various fields, because rare earth monoxides are a systematic series of electrically conducting 4d-5f electron system compounds.

【Publications Relevant to the Project】

- T. Yamamoto *et al.*, “Rock-salt structure GdO epitaxial thin film with a high ferromagnetic Curie temperature”, Appl. Phys. Lett. **117**, 052402 (2020).
- K. Kaminaga *et al.*, “Superconductivity of rock-salt structure LaO epitaxial thin film”, J. Am. Chem. Soc. **140**, 6754–6757 (2018).
- K. Kaminaga *et al.*, “A divalent rare earth oxide semiconductor: Yttrium monoxide”, Appl. Phys. Lett. **108**, 122102 (2016).

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