

## Research Group for Nanoscale Structure and Function of Advanced Materials

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A macroscopic matter is assembly of microscopic ones and the functional materials whose characteristics are exposed by investigation of both local and whole state. An experimental technique that can be used to selectively investigate a local state can extend the field of materials research. Existing technical developments enable us to efficiently produce high-intensity beams of muons, positrons, neutrons, and ions, which are useful for studying various atomic structures and dynamics of functional materials at the length scale of advanced beams. In addition, experiments that can obey local states at surface, interface, or around impurity have been developed as well, and they can be used to obtain new scientific insights. Our objectives are to study the nanoscale structures and functions of materials, and develop advanced measurement technologies.

### Polaronic nature of a hydrogen-related paramagnetic center in SrTiO<sub>3</sub> revealed by muon spin spectroscopy [1]

Electron-doped strontium titanates (SrTiO<sub>3</sub>) are promising materials for emerging oxide electronics, which show exceptionally high electron mobilities for transition metal oxides with d-like conduction bands. Metallic conductivity of these compounds indicates that the excess electrons predominantly have an itinerant character. On the other hand, a deep single-particle state in the band gap together with a coherent state near the conduction band minimum for H-doped [2], Nb-doped, and La-doped n-type sample, is detected by photoemission spectroscopy (PES). This suggests that a localized electron state coexists with the itinerant state in electron-doped SrTiO<sub>3</sub>. However, the origin of the localized state remains unclear.

We performed muon spin rotation ( $\mu^+$ SR) measurements on SrTiO<sub>3</sub> to elucidate the nature of the localized state in H-doped SrTiO<sub>3</sub>. Positive muons ( $\mu^+$ ) implanted into SrTiO<sub>3</sub> behave as a radioactive isotope of H at an interstitial site in the dilute doping limit and provide microscopic insight into excess electrons brought in with the H-like  $\mu^+$  dopants. We observed a

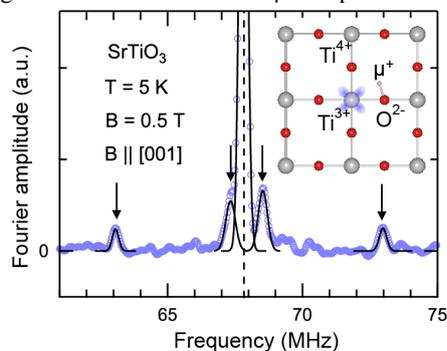


Fig. 1  $\mu^+$ SR frequency spectrum at 5 K in a field of 0.5 T applied along the [001] direction. The satellite peaks indicated by arrows correspond to a  $\mu^+$ -Ti<sup>3+</sup> complex.

paramagnetic signal at cryogenic temperatures (Fig. 1), which indicates localization of an electron near interstitial  $\mu^+$ . Based on a dipolar character of hyperfine interactions between  $\mu^+$  and the localized electron, we concluded that the electron stays at the Ti site adjacent to  $\mu^+$  to form a  $\mu^+$ -Ti<sup>3+</sup> complex. This result suggests that the in-gap state observed in H-doped SrTiO<sub>3</sub> may be associated with a Ti<sup>3+</sup> polaron stabilized near an ionized H<sup>+</sup>.

### High-temperature short-range order in Mn<sub>3</sub>RhSi [3]

Conventional phase transitions are well understood in terms of the order parameter, based on the Landau–Ginzburg–Wilson theory. However, the unconventional magnetic orders of conduction electrons in the metallic phase has been observed for high temperature superconductors and heavy fermion compounds. These unconventional magnetic orders have been limited to relatively low temperatures as quantum phase transitions. Here high-temperature magnetic short-range order is observed as one of the unconventional magnetic orders at temperatures up to 720 K in a noncentrosymmetric intermetallic antiferromagnet Mn<sub>3</sub>RhSi with a well-ordered lattice as summarized in Fig. 2. This temperature is the highest record for the magnetic short-range order so far to our knowledge. The magnetic Mn ions form a hyperkagome network of corner sharing triangles, where the spins are geometrically frustrated. The spin network is equivalent to that of a spin liquid and non-Fermi-liquid material,  $\beta$ -Mn. Our observation indicates that a metallic phase with magnetic short-range order exists at high temperatures.

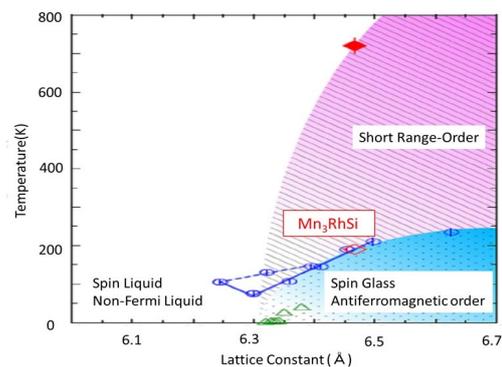


Fig. 2 Phase diagram of the family of compounds with the  $\beta$ -Mn structure as a function of the cubic lattice parameter, in addition to Mn<sub>3</sub>RhSi (open and closed diamonds).

### References

- [1] T. U. Ito *et al.*, *Appl. Phys. Lett.* **115**, 192103 (2019).
- [2] M. D'Angelo *et al.*, *Phys. Rev. Lett.* **108**, 116802 (2012).
- [3] H. Yamauchi *et al.*, *Commun. Mat.* **1**, 43 (2020).