Observation of ferromagnetic order in Ga-based icosahedral quasicrystal

Farid Labib [A], Kazuhiro Nawa [B], Yoichi Ikeda [B], Yusuke Nambu [C, D], Taku J. Sato [B, E] and Ryuji Tamura [A]

[A] Tokyo Univ. of Science, [B] Tohoku Univ., [C] Kyoto Univ., [D] FOREST, [E] Univ. of Tokyo

Ferromagnetism is well established in both periodic crystals and amorphous materials [1,2], yet its realization in quasicrystals (QCs), i.e., solids with long-range quasiperiodic order and non-crystallographic rotational symmetry [3], remained elusive for decades. Magnetic QCs were long believed to support only short-range correlations or glassy states, until the recent discovery of ferromagnetic and antiferromagnetic orders in Au-based icosahedral QCs [4–6]. To date, however, all magnetically ordered QCs have been confined to Au-based alloy systems. Recent theoretical studies, on the other hand, have shown that crystal electric field-induced single-ion anisotropy, determined by the local ligand environment of the rare-earth ions, can stabilize a variety of noncollinear and noncoplanar spin configurations in QCs [7]. This means that the discovery of new magnetic QCs in non-Au-based systems could not only expand the known magnetic QCs, but also provide access to magnetic textures not yet realized experimentally.

Using the heterovalent elemental-substitution strategy introduced elsewhere [8], a new polycrystalline QC is recently synthesized by rapidly quenching an arc-melted alloy with the nominal composition $Ga_{32}Au_{32.6}Pt_{20}Tb_{15.4}$. Bulk magnetization measurements revealed ferromagnetic ordering with a Curie temperature of 5.7 K, a Curie–Weiss temperature of 2.10 K, and an effective magnetic moment of 9.39 μ_B.

To gain further insight into the nature of the magnetic order, powder neutron diffraction measurements were performed using the high-resolution diffractometer HERMES with a neutron wavelength of 2.1964(2) Å. A 3.05 g polycrystalline sample was powdered and loaded into a 6-mm-diameter vanadium can under a helium exchange-gas atmosphere. A Cd absorber was placed at the bottom of the can to centre the sample in the neutron beam. Diffraction patterns were collected at 2 and 15 K and are compared in Fig. 1. Magnetic reflections, including (221001), (211111), and (111000), emerge at positions coincident with the nuclear Bragg reflections, consistent with a propagation vector of k = 0 and ferromagnetic order. The reflections were indexed in six-dimensional reciprocal space using the Elser indexing scheme. Refinement of the magnetic structure was not possible because a suitable higher-dimensional framework for modelling and refining magnetic order in quasicrystals is not yet available.

[1] J. H. Belo, Appl. Phys. Lett. **100**, 1 (2012).
[2] P. Duwez, J. Appl. Phys. **38**, 4096 (1967).
[3] D. Shechtman, Phys. Rev. Lett. **53**, 1951 (1984).
[4] R. Takeuchi, Phys. Rev. Lett. **130**, 176701 (2023).
[5] R. Tamura, J. Am. Chem. Soc. **143**, 19938 (2021).
[6] R. Tamura, Nat. Phys. **21**, 974 (2025).
[7] S. Watanabe, Proc. Natl. Acad. Sci. **118**, 1 (2021).
[8] F. Labib, J. Am. Chem. Soc. **147**, 33424 (2025).
[9] R. Tamura, Mater. Trans. **62**, 297 (2021).

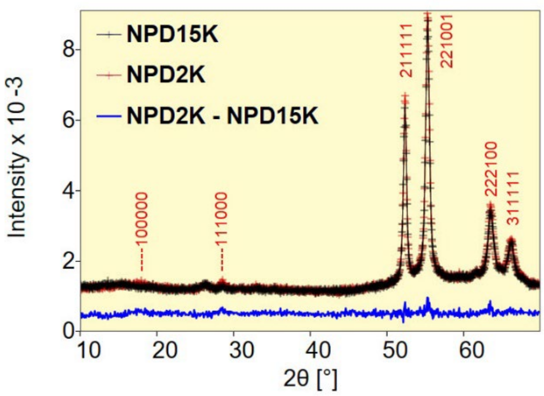

Fig. 1. Powder neutron diffraction patterns of $Ga_{32}Au_{32.6}Pt_{20}Tb_{15.4}$ QC measured at 2 and 15 K.