Single crystal growth of superconducting UTe_2 by the molten salt flux method

H. Sakai, P. Opletal , Y. Tokiwa , E. Yamamoto, Y. Tokunaga , S. Kambe, and Y. Haga
Res. Gr. for Strongly Correlated Actinide Science, JAEA

Usually, superconductivity occurs when two electrons pair up with opposite spins to cancel out the spin component. However, there is a rare type of superconductivity called "spin-triplet" superconductivity, in which pairs of electrons have non-canceling spins. Scientists are studying this unique type of superconductivity as a potential candidate for topological superconductors. Various candidates for "spin-triplet" superconductivity have been found in uranium compounds.

In 2019, a research team from the National Institute of Standards and Technology (NIST) and the University of Maryland discovered a novel superconductivity with the "spin-triplet" superconducting feature in uranium ditelluride (UTe_2) [1]. Since it was known that UTe_2 crystals could be obtained through the chemical vapor transport (CVT) method, scientists were devoted to improving the existing CVT conditions. Then it was recognized that growing single crystals with superconducting properties was challenging. This is due to the difficulty of optimizing parameters like the mixing ratio of starting materials, temperature gradient, and amount of iodine used as a transport agent. Numerous research groups have encountered significant variations in the superconducting transition temperature (T_c), and some crystals fail to exhibit superconductivity. Scientists had assumed that regulating the amount of tellurium deficiency might be necessary to improve the T_c. However, our previous study [2] has shown that not tellurium but uranium deficiencies are the root cause of this issue. Hence, addressing this issue is a crucial initial step toward high-quality single crystals.

In this study [3], a molten-salt flux (MSF) method for growing single crystals without uranium deficiency is developed. The flux method is used in this development, which simplifies the synthesis conditions. The flux method involves growing crystals from a solution, like growing crystals of alum or salt dissolved in water. Instead of water, molten salt, a mixture of sodium chloride (NaCl) and potassium chloride (KCl), is used in this study. The MSF method is schematically illustrated in Fig. 1(a). A mixture of uranium and tellurium in varying ratios is packed in a graphite crucible with a salt mixture. The crucible is vacuum sealed in a quartz tube. The sealed quartz tube is then gradually cooled from 950°C to 650°C, the melting point of the salt mixture.

The optimization of the synthesis conditions in this method is relatively easy. Single crystals can be extracted when the "salt" is washed away with water from the "lump of UTe_2 and molten salt" formed after the heat treatment, as shown in Fig. 1(b). After several growth attempts with different ratios of materials, we have found synthesis conditions that produced single crystals with a higher T_c of 2.1 K and good reproducibility compared to the average T_c of 1.8 K grown by the conventional CVT method. As shown in Fig. 1(c), the residual resistivity ratio (RRR) of electrical resistivity, a measure of single-crystal quality, also reaches an order of magnitude higher value of 1000, far surpassing the previous maximum value reported as 88 [4]. The extremely high RRR means the uranium vacancies are eliminated as far as possible.

The newly developed MSF method, which can obtain high-quality single crystals with good reproducibility, is a significant breakthrough in studying exotic superconductivity features in this material. This research will accelerate fundamental research on topological superconductivity that holds potential for application in next-generation quantum computers and contributes to developing new materials.

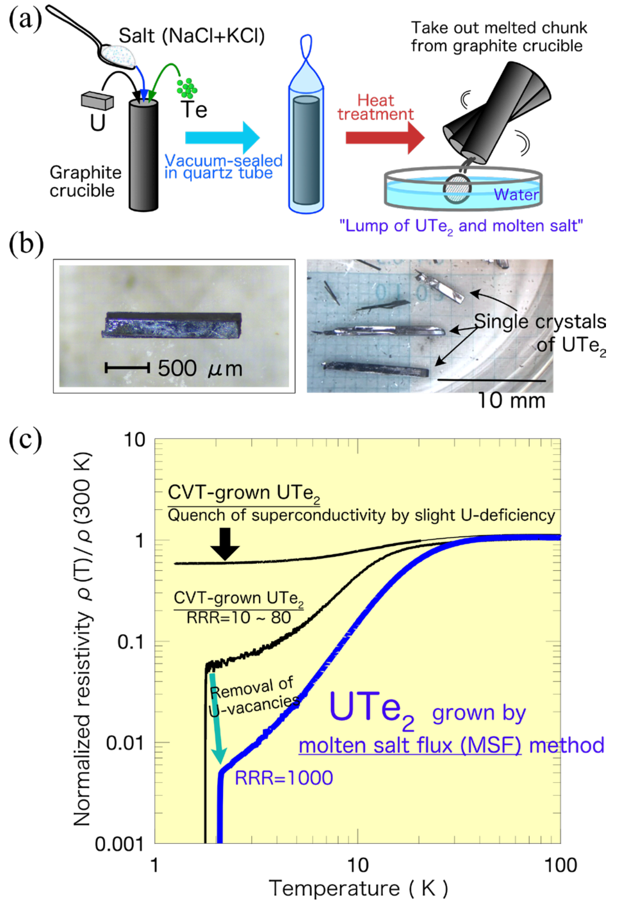

Fig. 1 (a) Schematic procedure of single crystal growth by the molten salt flux method. (b) Photographs of the obtained single crystals of UTe_2.
(c) Temperature dependence of normalized resistivity ρ(T)/ρ(300 K) for the CVT-grown crystals and the MSF-grown crystal of UTe_2.

This study was partially supported by JSPS KAKENHI (JP20K20905) and by the JAEA Fund for Exploratory Researches (Houga fund).

References

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