Single-crystal rings of NbSe$_3$: a system for CDW interference?

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Abstract

We have produced new ring- and tube-shaped crystals of NbSe$_3$ and found reproducible synthesizing conditions. We have confirmed that the ring is a single-phase NbSe$_3$ crystal from X-ray diffraction, and that a charge-density wave (CDW) transition takes place near 140 K by observing satellites of electron diffraction peaks. The position of the satellites coincides with that of the conventional NbSe$_3$ at the CDW transition. Non-linear conduction due to the CDW sliding is also observed in the ring crystals. The threshold field is similar to the conventional ribbon-shaped NbSe$_3$ crystals. © 2000 Published by Elsevier Science B.V. All rights reserved.

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Macroscopic and mesoscopic topological matter such as a spherical and torus and Moebius strip have been the subject of much theoretical and experimental work for the sake of its wealthy physical phenomena. Persistent current in a metal ring threaded by a magnetic flux was proposed theoretically and observed experimentally [1]. Interference phenomena of electrons have also been investigated for a metal ring; the Aharonov–Bohm (AB) effect for thin gold rings [2] and the Altshuler–Aronov–Spivak (AAS) effect for tube-like Mg films in the weakly localized regime [3,4] and AAS-like effect for NbSe$_3$ with columnar defects [5]. Persistent current and interference phenomena can also be observed for the electronic condensate in superconductors of ring or tube shape. Can the persistent current exist also in ring- and tube-shaped charge-density wave (CDW) systems?

In order to observe those effects, it is necessary to obtain an ideal ring-shaped sample of a one-dimensional (1D) material, such as organic-conductors or CDW-NbSe$_3$ of MX$_3$ group systems. We have made ring- and tube-shaped crystals of NbSe$_3$, and found reproducible synthesizing conditions.

The samples were prepared by the chemical vapor transportation method. Single crystals of ring NbSe$_3$ were grown by using a solidification technique. This employs a stationary closed quartz tube inside a box furnace. Starting materials were composed of a mixture of bulk Se and Nb. The purity of all materials used in this work was 99.999%. The mixture was reacted at 740°C for three weeks in situ quartz tube and then cooled to 240°C at which temperature the oven was shut off. Fig. 1 is

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Fig. 1. Ring-shaped crystal of NbSe$_3$. Diameter of the ring is 100 μm.
Fig. 2. Satellites of CDW of ring-NbSe$_3$ by electron diffraction at 138 K, which is below the CDW transition temperature $T_1$. $\textbf{Q}_1 (0, 0.24, 0)$ is the wave vector of the CDW, $b^*$ the reciprocal lattice vector.

an optical microscope picture of a typical ring-shaped crystal of NbSe$_3$.

We ground up the samples of ring-shaped crystals in order to identify composition and crystal structure. The powder of the ring-shaped crystals shows a monoclinic NbSe$_3$ single phase by the measurements of the X-ray diffraction methods. We found the ring-shaped crystal is not a Nb$_3$Se$_4$, Nb$_2$Se$_4$, NbSe$_2$, Nb$_2$Se$_9$ or other binary compounds of Nb and Se. Lattice constants were $a = 10.01 \text{Å}$, $b = 3.48 \text{Å}$, $c = 15.63 \text{Å}$, $\beta = 108.5^\circ$, respectively. The ring-shaped samples were confirmed to be single crystals of NbSe$_3$.

Next, we performed electron-diffraction measurement of the ring-shaped NbSe$_3$ at 138 K (less than $T_1$, see below). Fig. 2 shows satellites due to the CDW wave vector of the ring-shaped NbSe$_3$ crystals. The CDW wave vector $\textbf{Q}_1$ is $(0, 0.24 \pm 0.01, 0)$, determined from the position of the satellites diffracted by superlattice reflection. The position of the satellites coincides with that of the conventional NbSe$_3$ at the CDW transition. We confirmed that a CDW transition takes place in this ring of NbSe$_3$ near 140 K. The CDW transition was also confirmed by the temperature dependence of the resistivity of a ring-shaped NbSe$_3$ (Fig. 3). For this crystal, the usual four-probe method was used. There are two resistivity anomalies both along the $a$- and $c$-axis, as in previous reports of temperature dependence of resistivity. They are caused by the CDW transitions at 145 K ($T_1$) and 54 K ($T_2$).

References