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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.

Keywords: Charge-density wave; Quantum interference; Ring; Topology

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

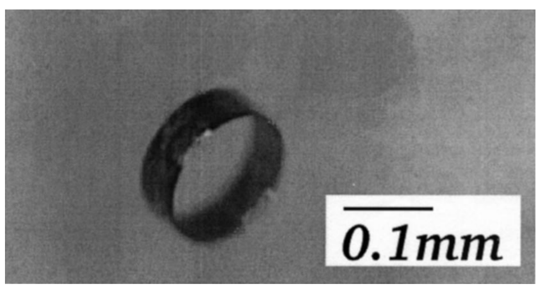

Fig. 1. Ring-shaped crystal of $NbSe_3$. Diameter of the ring is 100 μm.

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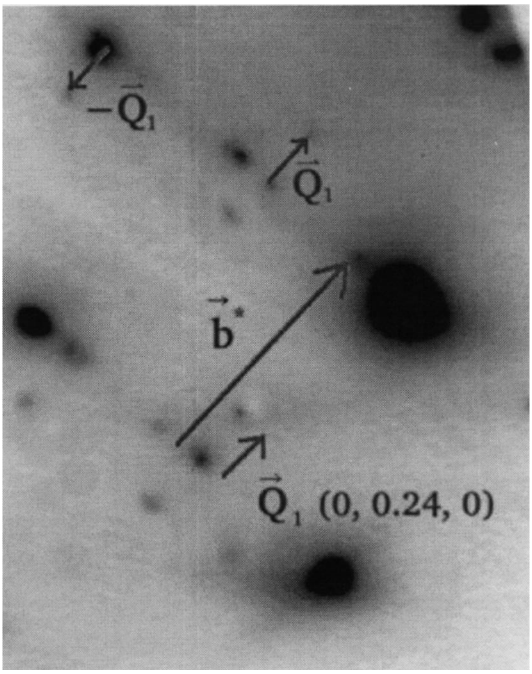

Fig. 2. Satellites of CDW of ring-$NbSe_3$ by electron diffraction at 138 K, which is below the CDW transition temperature T_1. $\boldsymbol{Q}_1$ (0 0.24 0) is the wave vector of the CDW, $\boldsymbol{b}^*$ the reciprocal lattice vector.

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_3Se_4, Nb_2Se_3, $NbSe_2$, Nb_2Se_9 or other binary compounds of Nb and Se. Lattice constants were $a = 10.01$ Å, $b = 3.48$Å, $c = 15.63$ Å, $\beta = 108.5°$, 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 $\boldsymbol{Q}_1$ 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).

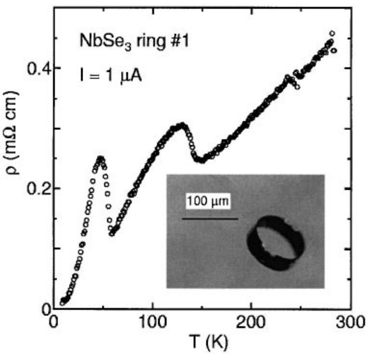

Fig. 3. Temperature dependence of resistivity of the ring-shaped crystal along the circumference of $NbSe_3$.

References

[1] L.P. Levy et al., Phys. Rev. Lett. 64 (1990) 2074.
[2] V. Chandrasekhar et al., Phys. Rev. Lett. 67 (1991) 3578.
[3] D.Yu. Sharvin, Yu.V. Sharvin, Pis'ma Zh. Eksp. Teor. Fiz. 34 (1981) 285.
[4] D.Yu. Sharvin, Yu.V. Sharvin, JETP Lett. 34 (1981) 272.
[5] Y.I. Latyshev, O. Laborde, P. Monceau, S. Klaumunzer, Phys. Rev. Lett. 78 (1997) 919.