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Charge-density-wave sliding in ring-shaped crystals of $NbSe_3$

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Abstract

We report the first measurements of resistivity for a ring-shaped crystal of the quasi-one-dimensional conductor $NbSe_3$. The temperature dependence of resistivity and current–voltage characteristics clearly demonstrate that the one-dimensional chains are along the circumference of the ring and the charge-density wave (CDW) can slide along the ring above a threshold field. The ring crystal is suitable for the investigation of interference phenomena in the CDW system. We also find that the ring crystal cannot be regarded as two CDW conductors connected in parallel.

Keywords: Charge-density wave; Interference phenomenon; Ring

There are many topics in the physics of one-dimensional metallic rings, especially in the case of mesoscopic ones. The persistent current and the interference phenomena have been investigated experimentally and theoretically for a metal ring threaded by a magnetic flux. The charge-density wave (CDW) is a candidate which may show such phenomena. Theoretical work is reported on the CDW in a one-dimensional ring with electron–phonon interaction [1–6]. Recently, Latyshev et al. investigated the CDW sliding through the columnar defects in magnetic field using the quasi-one-dimensional conductor $NbSe_3$ [7]. They claimed that their observation was a manifestation of the Aharonov–Bohm effect on the sliding CDW. Single crystals of $NbSe_3$ are usually obtained in a form of whisker-shape with the longest direction along the one-dimensional axis. Quite recently, we have successfully synthesized ring- and tube-shaped crystals of $NbSe_3$ with good reproducibility [8]. Here we report the first measurements of resistivity in a ring-shaped crystal of $NbSe_3$.

Crystals of $NbSe_3$ were synthesized by reacting the elements in an evacuated quartz tube. We obtained several ring-shaped crystals from each of several batches. Details of sample preparation are described elsewhere [8]. The diameter of the ring crystal used in the present study is ~ 200 μm. For the resistivity measurements gold wires with diameter of 10 μm were attached using silver paste on the surface of the crystal. The arrangement of the electrical contacts is shown in the inset to Fig. 1. For measurements of the current–voltage characteristics, the voltages V_1 and V_2 across the voltage contacts were measured as a function of total current I in the constant current mode.

The temperature dependence of resistivity along the circumference of the ring crystal was very similar to that of the whisker crystals along the b-axis of $NbSe_3$, that is, the one-dimensional chains. The two increments due to the CDW transitions were clearly observed just below 140 and 56 K, which are very close to the transition temperatures in the whisker crystals. The resistivity at 300 K was very similar to that parallel to the b-axis of the whisker crystals. In Fig. 1(a), the voltage V_1 across the left arm and dV_1/dI measured at $T = 44.5$ K are plotted as a function of the total current I. The voltage V_1 showed a nonlinear behavior due to the CDW sliding above a threshold value of the total current $I_T \sim 1.8$ mA. This is fairly clear in the dV_1/dI versus I plot. Similar behavior was also observed for the voltage V_2 across the right arm and dV_2/dI around $I_T \sim 3.5$ mA, as shown in Fig. 1(b). The threshold field E_T for the nonlinear conduction is ~ 320 mV/cm for the left arm and ~ 285 mV/cm for the right arm, respectively. These values of E_T are similar to that for the whisker crystals. The present results clearly demonstrate that the ring crystal of $NbSe_3$ has the same

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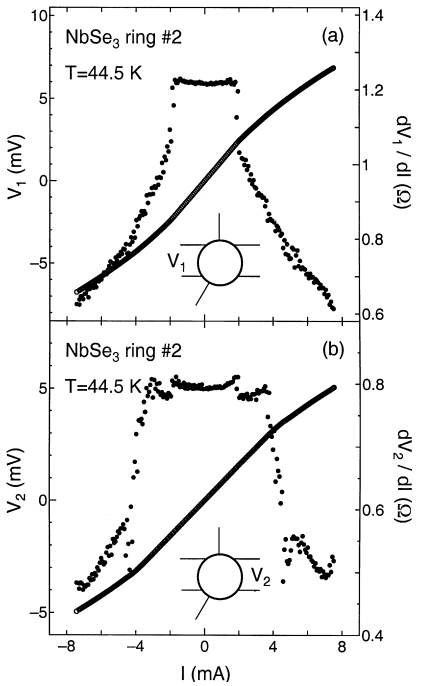

Fig. 1. Voltages V_1 and V_2 developed across the left (a) and right (b) arms of the ring-shaped crystal plotted as a function of the total current through the ring. Current derivative of V_1 and V_2 are also shown.

features as the whisker crystals and that the one-dimensional chains in the ring crystal are along the circumference of the ring. The coherence length of the CDW velocity in $NbSe_3$ is typically ~ 100 μm [9], which is comparable to the size of the present ring crystal. The ring crystal is suitable for the investigation of the interference phenomena in the CDW system.

As observed in Fig. 1(b), there is a jump around $I^* \sim 1.9$ mA in dV_2/dI for the right arm. The value of the total current I^* corresponds to the threshold value for the nonlinear conduction of the left arm due to the CDW sliding. We also observed structures in dV_2/dI around 4.8 and 7.2 mA. A ring crystal might be considered as two CDW conductors connected in parallel. From this point of view, we have simulated the measurements phenomenologically. Results of the simulations showed that the jump at I^* was due to decrease of the current flowing the right arm. However, dV_2/dI just above I^* abruptly decreased in the simulation, which differs from the measurements. The structures in dV_2/dI did not appear in the simulation. These differences between the measurements and the simulations indicate that the ring crystal cannot be regarded as two CDW conductors connected in parallel. The origin of the difference should be ascribed to the ring geometry of the present crystal.

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