Shubnikov-de Haas Oscillations in the Superconducting Fluctuation Region of κ-(BEDT-TTF)$_2$Cu(NCS)$_2$

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Abstract

Shubnikov-de Haas oscillations in an organic superconductor κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ are studied near the upper critical field. The oscillations suffer additional attenuation that is absent in a pressure of 2 kbar in which the upper critical field is suppressed as low as 1 T. This demonstrates that the additional attenuation at ambient pressure is caused by the superconductivity.

Key words: Shubnikov-de Haas oscillations; organic superconductor; pressure; superconducting fluctuation

Quantum oscillations, de Haas-van Alphen (dHvA) and Shubnikov-de Haas (SdH) effects, are caused by the orbital motion of quasiparticles in Landau levels at the Fermi surface. Since the quasiparticle spectrum changes due to an opening of the gap in the superconductivity state, quantum oscillations in the superconductivity state have drawn interests in terms of the symmetry of the superconducting gap [1]. In the case of κ-(BEDT-TTF)$_2$Cu(NCS)$_2$, oscillations caused by the two-dimensional pocket with period of 600 T are observed below the upper critical field H_{C2} above the irreversibility field [2–4]. An additional attenuation of the oscillation compared to the normal state is found. It is understood in terms of the superconductivity fluctuation effect near H_{C2} [3,5,6].

The dHvA oscillations are observed in the vortex liquid state in which we have finite resistance. It is possible that the SdH oscillation can also be observed [6,7]. The SdH measurement is easier to be carried out under pressure. In order to get insight into the additional attenuation near H_{C2}, SdH oscillations are measured at ambient pressure and at pressure of 2 kbar.

Single crystals of κ-(BEDT-TTF)$_2$Cu(NCS)$_2$ are grown with an electrochemical method described elsewhere. Four electrodes were attached with a small amount of graphite paste along the crystallographic b-axis. The magnetoresistance was measured by a standard lock-in technique with current amplitude of 5 to 50 μA. Data above 0.5 K were measured with ^{3}He cryostat and those at 0.06 K were measured with dilution refrigerator. Used frequency was 137 Hz for the former and 83 Hz for the latter. The external magnetic field was applied always perpendicular to the two-dimensional plane with field sweep rate of between 0.05 and 0.1 T/min. Pressure was applied using BeCu clamp cell equipped with the ^{3}He cyrostat.

In Fig. 1(a), we show magnetic field dependences of resistance at 0.06 K with three different measuring currents. Below c.a. 0.7 K, we find nonlinearity in resistance, possibly due to the superconductivity. The SdH effect is observed above 6 T. Temperature dependence of the oscillation at 8 T indicates that the effective mass is 3.5 times as large as bare electron

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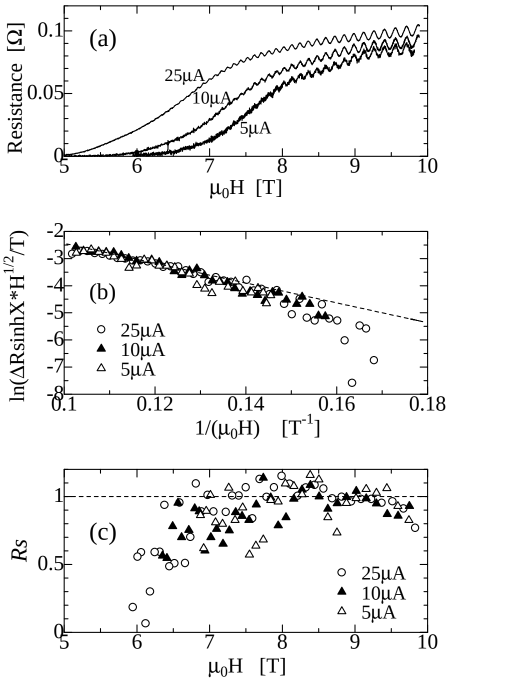

Fig. 1. (a) Magnetic field dependence of resistance with three different measuring currents at 0.06 K at ambient pressure. (b) The Dingle plot of the SdH oscillations. (c) The additional damping factor R_s of the oscillations.

mass, which agrees with former reports. By plotting $\ln\left[\Delta R \cdot \sinh\left(14.69 * 3.5 * T/(\mu_0 H)\right) * (\mu_0 H)^{1/2}/T\right]$ with respect to $1/(\mu_0 H)$, we find Dingle plots as shown in Fig. 1(b). The Dingle temperature in the normal state above 8 T is $T_D = 0.7$ K. In spite of the nonlinearity in the magnitude of the resistance, the Dingle plots are almost unchanged with the different measuring currents. Below 7.3 T, we find downward deviation of the Dingle plots from the straight line. The Dingle temperature $T_D(H)$ increases with decrease of magnetic field, indicating an appearance of the additional attenuation. The additional damping factor of the oscillations is evaluated by $R_s = \exp\left[-14.69 * 3.5 * (T_D(H) - T_D)/(\mu_0 H)\right]$, as shown in Fig. 1(c). The damping grows more rapidly with decrease of magnetic field below 7.3 T, compared to that of the dHvA oscillation [5]. This finding agrees with recent report by Sasaki *et al.* [6], indicating that the resistance is more strongly influenced by the fluctuation in the vortex liquid state since it is a nonequilibrium quantity.

In Fig. 2(a), we show magnetic field dependences of resistance in a pressure of 2 kbar at 0.7 K with measuring current of 10μA. Here we have no nonlinearity. Above 5.7 T, we see SdH oscillations. At this pressure, H_{C2} is suppressed as low as 1 T. By the analysis of the temperature dependence, the effective mass is deduced

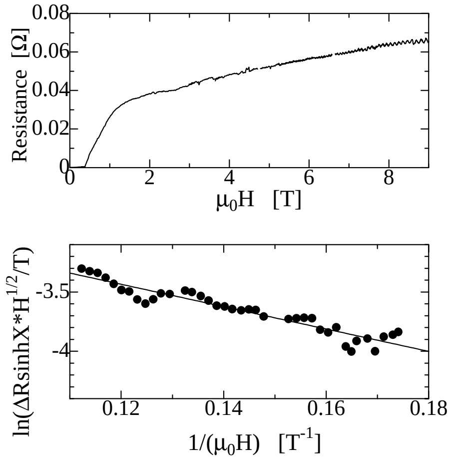

Fig. 2. (a) Magnetic field dependence of resistance at 0.7 K in a pressure of 2 kbar. SdH oscillations are observed above 5 T. (b) The Dingle plot of the SdH oscillations.

2.6 times as large as bare electron mass, which agrees with the former work [8]. The Dingle analysis is carried out as shown in Fig. 2(b), and we obtain a straight line, indicating that the Dingle temperature is independent of magnetic field. We have no additional damping down to 5.7 T. This demonstrates unambiguously that the additional attenuation below 7.3 T observed at ambient pressure is indeed caused by the superconductivity.

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