Field-induced superconductor-insulator transition in layered organics

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Abstract

A partially deuterated κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br salt, which is a superconductor situated near the Mott insulator, has been investigated by resistivity measurements under magnetic fields. The superconducting transition of this salt is replaced by the first-order metal-insulator transition by magnetic field. This field-induced transition fades away when the sample cooling around 80K is slowed down. The present findings lead us to bring to mind possible realization of the ideal electric switch controllable with the magnetic field.

Key words: Metal-insulator transition; First-order transition; Organic superconductors; Ideal switch

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The κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br (κ-Br) salt is a layered organic superconductor with T_c of $\sim$ 11.5K. The distinction of this superconductor is the strong electron-electron correlation characterized by comparatively large effective mass [1] and antiferromagnitic fluctuations in the normal state [2]. In addition, with the fact that the κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl (κ-Cl) salt is an antiferromagnetic insulator [3], another important character is known to be that this salt is situated near the superconductor(S)-insulator(I) phase boundary. To make a further approach to this remarkable boundary, the system must be tuned more finely than by the atomic substitution in the anion site. While application of pressure is a powerful method for the phase control in organic conductors, the isotope substitution of the constituent BEDT-TTF molecule is an effective way to tune the electronic phase of the κ-Br salt. Indeed the full deuteration of the κ-Br salt gives rise to the phase crossing to the S-I boundary: the antiferromagnetic ordering is observed in the insulating state of this salt [4] in common with the κ-Cl salt. Based on this fact, we further evolved this deuteration method. We recently reported that a series of progressively deuterated κ-Br salts showed systematic variation from superconductor to insulator, depending on the number of the constituent deuterium [5][6][7]. This finding lead us to the detailed characterization, including the check of the magnetic-field effect, of the electronic phase in the vicinity of S-I boundary at ambient pressure. Then, we uncovered a unique field-induced phenomenon in this series of deuterated salts.

In the present work, we demonstrate that the superconducting transition of the d4-κ-Br salt with a half of the totally eight protons in BEDT-TTF deuterated is replaced by the first-order metal-insulator transition by magnetic field. In addition, we show that the emergence of this phenomenon can be controlled by regulation of the cooling rate around 80K.

The details of synthesis of the partially deuterated salt, d4-κ-Br, were given elsewhere [7]. The electrical resistance with the currents injected in the in-plane direction was measured as functions of temperature, cooling rate, and magnetic field normal to the conducting layer.

Figure 1 shows the temperature dependence of the electrical resistance of the d4-κ-Br single crys-

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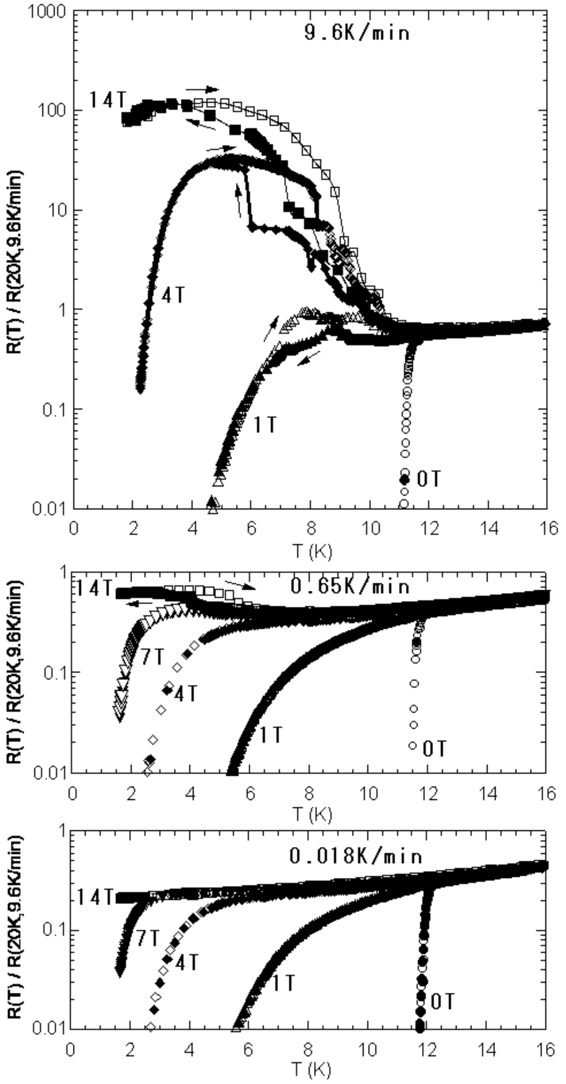

Fig. 1. The in-plane resistance of d-4-κ-Br salt. All the data are normalized by the values at 20K in cooling at a rate of 9.6K/min. Three panels distinguish the different cooling speed around 80K, as shown in the figure. The resistance is measured in descending (closed symbols) and ascending (open symbols) processes of temperature under magnetic fields normal to the conducting layer. The arrows show the existence of the hysteresis.

tal under several magnetic fields. The three panels distinguish the different cooling speed around 80K, which is known to influence the low temperature electronic phase. The superconducting state is, in general, changed into the metallic state by application of magnetic field in excess of the upper critical field. Indeed this behavior was observed in the extremely slow cooling case (0.018K/min), as seen in the bottom panel. In the case of the 9.6 K/min cooling (the top panel), however, application of an even low magnetic field of 1 T does not only suppress the superconducting transition to the lower temperature side but gives a sign of the metal-to-nonmetal transition with large hysteresis between the processes of ascending and descending temperature. With further increase of magnetic field, the nonmetallic state grows up with the hysteresis kept clear. Finally, under a high field of 14 T the low-temperature resistance amounts to two orders of magnitude larger than the normal state resistance at 20 K. Thus, the superconducting transition is replaced by the first-order metal-insulator transition by application of magnetic field. This is a unique field-induced S-I switching phenomenon.

The three panels represent that this S-I switching phenomenon shows a systematic fadeaway with the decrease of cooling speed. The d4-κ-Br salt is known to have a structural anomaly around 80K [8], which is inferred to have long relaxation time. So the cooling speed to pass through 80K is expected to control the averaged crystal structure below 80K. The previous systematic characterization at all the progressively deuterated salts suggests that the increase of the cooling rate lead a system to approach the S-I boundary from the S side [4][5][6]. Therefore the present result shows that this S-I switching phenomenon emerges only in the vicinity of the S-I boundary.

In summary, we observed a peculiar phenomenon in layered organics that is chemically modified and cooled with the regulated speed. That is the S-I switching controllable with magnetic field. This switching is the first-order transition and appears only in the vicinity of the S-I boundary. The present findings may open a way to the possible application to the molecular device such as an ideal electric switch.

Acknowledgements

This work was supported in part by Grant-in-Aid for Science Research from Ministry of Education, Science, Sports, and Culture, Japan. H.T. is indebted to the JSPS Research Fellowships for Young Scientists for financial support.

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