Development of AC susceptibility technique under high pressure and its application to organic superconductor

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Abstract

We developed an AC susceptmeter available under pressure. It was examined at the organic superconductor, κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br, and then we confirmed a satisfactry performance. A future possible application is presented.

Key words: organic superconductor; high pressure; phase diagram

Superconductivity of organic conductors is well known to be sensitive to pressure. The transition temperature of the ambient-pressure organic superconductors has large (negative) pressure coefficient and, with increasing pressure, immediately vanishes to the low temperature side not available[1]. Such a pressure dependence is usually researched by means of the pressurizing system based on the beryllium-copper (Be-Cu) piston-cylinder (below 1.5∼2 GPa) or the He gas compressor (below 0.1∼0.2GPa). On the other hand, a few of organic conductors such as (TMTTF)$_2$X (X=PF$_6$, Br) salts show the emergence of superconductivity at far higher pressure than 2GPa[2]. In addition, there is an exceptional case that the superconductivity disappears at above 2GPa, as seen in a κ-(BEDT-TTF)$_4$Hg$_{2.89}$Br$_8$ salt[3]. To study the superconductivity of these compounds, we need to extend the measurements of the physical properties to further high pressure-range.

Meanwhile, most of the studies about the pressure dependence of the physical properties are made by the electrical resistivity measurement. However, only an experiment about the transport properties is not enough to achieve the detailed characterization of the superconducting state. For example, one can never exclude the possibility that a sample has a local superconducting state in all cases and can hardly conclude to include it in some cases. In this sense the method that can evaluate the bulky coherence of superconductivity is required even under pressure.

As for the organic crystal, there is another problem. The resistivity of the organics often shows adventitious jumps in the descending process of temperature and, in some particular cases, becomes to be unmeasurable. Indeed we encountered this phenomenon in some of the reisistivity measurements of κ-(BEDT-TTF)$_4$Hg$_{2.89}$Br$_8$ salt in ambient pressure. The alternative method is required for such a salt.

From these three kinds of requirements, we tried to develop the system that gave the bulky information under higher pressure than 2GPa. In the present work, we show the structure and the performance of our high-sensitivity AC susceptmeter available under high pressure. In addition, the test result for the representative organic superconductor is presented.

Figure 1 shows cross-sectional view of the pressure cell combined with AC susceptmeter. This pressure cell is a hybrid system of the MP35N[4] inner cylinder and

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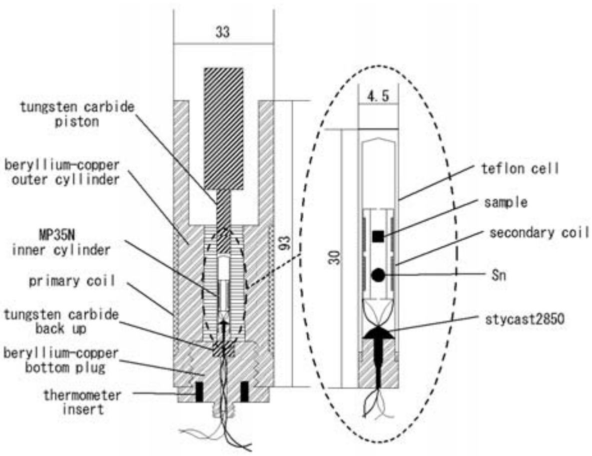

Fig. 1. Cross-sectional view of pressure cell combined with the AC susceptmeter. Unit of length is mm.

the Be-Cu outer shell. It is designed to be sustainable at high pressure up to 3.5GPa. In the present work, we coupled this pressure cell with a custom-made hydraulic ram and these were inserted to VTI in whole. Then the constant force was applied during the heat cycle. Fluorinert (FC70:FC77=1:1) was used as a pressure transmitter medium.

The present AC susceptmeter is based on the mutual inductance technique. The primary coil was wound of 0.20mm Cu wire on the Be-Cu outer shell. As for the secondary coil, we prepared a bobbin made from stycast1266. This can be inserted to the Teflon cell and has a cylindrical shape that enables the sample to be set inside it. Two balanced coils were wound of 0.050mm Cu wire on this bobbin with opposite turns each other. The number of the turns were 1100 for the primary coil and 170+170 for the secondary coil. The sample was always set as was at the center of one of the balanced coils. To measure the pressure at low temperature, the conventional superconductor such as Sn was set at the other side.

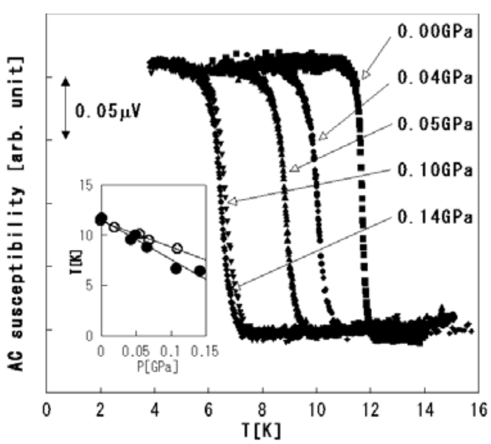

Fig. 2. The real part of AC susceptibility of κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br under several pressures. Inset shows the pressure dependance of T_c in the present work(closed circles) and the previous work[1](open circles).

To evaluate the present equipment, we performed the AC susceptibility measurement on a single crystal of the representative organic superconductor, κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. A size of the sample was $0.85\times0.85\times0.65$ mm^3. Figure 2 shows a systematic variation of the inductive transition by application of pressures. To the author's knowledge, it is the first observation of the diamagnetic transition of this compound under pressure. The driving AC field of 1.0G in amplitude and 31Hz in frequency was applied parallel to the conducting plane of this layered organics. We evaluated the standard deviation at the normal state above 12.5K and obtained the value of 0.0028 μV. This is far small compared with the shift due to the transition (0.21 μV). In this way, a satisfactory signal to noise ratio was obtained in the measurement of one small single crystal. As for the pressure dependence, the transition temperature defined at the mid point is plotted as a function of pressure in the inset with the previous data[1]. Two data show a fairly well agreement. A slight difference may be attributable to the cooling rate dependence of the transition temperature[5]. As other possibilities, it can be caused by the slight inhomogeneity of pressure at between the sample side and the manometer side or the ambiguity of the determination of the pressure. However, such problems are expected to fade away in further high pressure-range even if they exist.

In conclusion, we developed the AC susceptometer available under high pressure. We confirmed that it was satisfactory to measure the superconducitivity of a small organic crystal. After the performance test in further high pressure-range, this tool can be applied to other organics such as κ-(BEDT-TTF)$_4$Hg$_{2.89}$Br$_8$ and (TMTTF)$_2$X (X=PF$_6$, Br).

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