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

Akio Kurita a,*, Masashi Miyashita a, Hiromi Taniguchi a, Kazuhiko Satoh a, Masafumi Tamura b, Reizo Kato b, Masato Hedo c, Yoshiya Uwatoko c

a Department of Physics, Saitama University, Saitama 338-8570, Japan
b Riken, Wako, Saitama 351-0198, Japan
c The Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan

Abstract

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

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Superconductivity of organic conductors is well known to be sensitive to pressure. The transition temperature of the ambient-pressure organic superconductors have large (negative) pressure coefficient and, with increasing pressure, immediately vanish 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 0.1–0.2 GPa). 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 2 GPa [2]. In addition, there is an exceptional case that the superconductivity disappears at above 2 GPa, as seen in a \( \kappa \)-(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, become to be unmeasurable. Indeed we encountered this phenomenon in some of the resistivity measurements of \( \kappa \)-(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 2 GPa. In the present work, we show the structure and the performance of our high-sensitivity AC susceptometer available under high pressure. In addition, the test result for the representative organic superconductor is presented.
Fig. 1 shows cross-sectional view of pressure cell combined with AC susceptometer. Unit of length is mm.

The present AC susceptometer is based on the mutual inductance technique. The primary coil is wound of 0.20 mm Cu wire on the Be–Cu outer shell. As for the secondary coil, we prepared a bobbin made from styecast1266. 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 are wound of 0.050 mm 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 is always set at the center of one of the balanced coils. To measure the pressure at low temperature, the conventional superconductor such as Sn is set at the other side.

To evaluate the present equipment, we performed the AC susceptibility measurement on a single crystal of the representative organic superconductor, $\kappa$-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br. A size of the sample is $0.85 \times 0.85 \times 0.65$ mm$^3$. Fig. 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 1.0 G in amplitude and 31 Hz in frequency is applied parallel to the conducting plane of this layered organics. The pressure dependance of 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 is satisfactory to measure the superconductivity of a small organic crystal. After the performance test in further high pressure-range, this tool can be applied to other organics such as $\kappa$-(BEDT-TTF)$_2$Hg$_{2.89}$Br$_8$ and (TMTTF)$_2$X (X = PF$_6$, Br).

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