DEVELOPMENT OF THE HIGH FIELD MAGNETO-OPTICAL MEASUREMENT SYSTEM WITH A ROTATIONAL CAVITY FOR THE STUDY OF ORGANIC CONDUCTORS

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We have developed a new magneto-optical measurement system with a rotational cavity. It consists of a millimeter vector network analyzer and a 15T solenoid type superconducting magnet and it can go down to 1.5 K. The rotational cavity can be used in the transmission configuration and the rotation can be performed up to almost 360 degrees in 1 degree precision. We will show the magneto-optical measurement results of $\beta''$-(BEDT-TTF)(TCNQ) using our new system. We observe the quasi-two-dimensional periodic orbit resonance (POR) in $\beta''$-(BEDT-TTF)(TCNQ). The Fermi surfaces of this system will be discussed.

Keywords: $\beta''$-(BEDT-TTF)(TCNQ); magneto-optical measurement; periodic orbit resonance; a rotational cavity.

1. Introduction

In order to understand the physical properties of low dimensional organic conductors, the study of their Fermi surface (FS) topology is very important. For the study of quasi-two dimensional organic conductors, it is well known that de Haas-van Alphen (dHvA) and Shubnikov-de Haas (SdH) measurements are the powerful
means to study them but these measurements are not effective for the study of quasi-one dimensional organic conductors. In case of quasi-one dimensional organic conductors, angular dependent magnetoresistance oscillation (ADMRO) measurements is a powerful mean to study the Fermi surface. However, recent magneto-optical measurements using a cavity perturbation technique show that the studies of periodic orbit resonances (POR) are powerful means to study the Fermi surface of both quasi- two-dimensional (q2D) and quasi-one-dimensional (q1D) organic conductors$^{1-5}$. The 2D POR is different from the conventional cyclotron resonance (CR), and the condition to observe either 2D POR or CR is discussed$^4$. In order to obtain such information from the POR results, a precise angular dependence measurement of POR is required. Therefore, we developed a rotational cavity for the millimeter vector network analyzer (MVNA) at High Field Laboratory for Superconducting Materials, Institute for Material Research, Tohoku University. In this paper, our new rotational cavity system will be shown, and the result of the precise angular dependence measurements of POR in $\beta^\prime\prime$-(BEDT-TTF)(TCNQ) obtained by using our rotational cavity system will be discussed.

2. Experimental Method

The experiments have been performed using a millimeter vector network analyzer (MVNA) and a 14 T solenoid type super conducting magnet at the High Field Laboratory for Super Conducting Materials, Institute for Materials Research, Tohoku University. Original system is equipped with a fixed cylindrical cavity, which can be used at V- and W-bands with cavity perturbation techniques, and can go down to 0.5 K$^6$. However, as a precise angular dependence measurement is important for the study of Fermi surface, we developed a new rotational cylindrical cavity with the diameter of 7 mm and the height of 6 mm, whose size is the same with the fixed cylindrical cavity, as shown in Fig. 1. The cylindrical axis is perpendicular to the axis of the solenoid superconducting magnet. The cylindrical cavity and the coupling plate, which are made of oxygen-free copper, rotate together, and they are connected to the wave guides through the 1 mm diameter coupling holes. A rotating mechanism consists of a worm drive and a gear wheel around the cavity, which are shown in the photo of Fig. 1. The worm which turns the wheel is driven by a rod from the top of the insert, and the cavity rotates 10 degrees when the worm is rotated 360 degrees. The rotational cavity shows $Q$-factors of 22500 and 16700 for around 58 GHz and 72 GHz, respectively, at 4.2 K without the sample. The cavity shows almost the constant $Q$-values during the rotation. The temperature of the rotational cavity can go down to 1.6 K. The sample is mounted at the top of the polyethylene pillar ($\sim$2 mm), and the pillar is mounted at the center of end plate of the cylindrical cavity. Due to the $TE_{011}$ resonant cavity mode, the oscillatory magnetic field is always applied to the sample.

$\beta^\prime\prime$-(BEDT-TTF)(TCNQ) has a plate like shape with the dimension of $0.7\times0.4\times0.1$ mm$^3$. The fundamental frequency and the $Q$ factor of the cavity are 58
GHz and 3000~5000, respectively. The magnetic field was rotated in the \( b^*c \)-plane with the angle \( \theta \) and in the \( b^*a \)-plane with \( \phi \), where \( \theta \) and \( \phi \) are measured from the \( b^* \) and \( c \)-axes, respectively.

3. Results and Discussions

\( \beta^"-(BEDT-TTF)(TCNQ) \) is the novel organic conductor\(^7\). ADMRO and SdH measurements at low temperature (below 20 K) have been performed for this salt, and these results suggest the existence of q1D Fermi surface generated by BEDT-TTF layer (1D direction is the \( a \)-axis) and several small q2D Fermi surface pockets which correspond to few \% of the first Brillouin zone\(^8\). However, ADMRO dips do not satisfy the conventional conditions of q1D ADMRO. Therefore, the Fermi surface topology is not completely clear, and we have performed the magnetooptical measurements of \( \beta^"-(BEDT-TTF)(TCNQ) \).

If the q1D Fermi surface, which is predicted by ADMRO, exists, q1D POR’s should be observed. The expected \( \theta \) dependence at \( \phi=0^\circ \) is shown in Fig. 2(a). However, Fig. 2(b) shows the observed experimental results and they are completely different from Fig. 2(a). The \( \theta \) dependence shown in Fig. 2(b) is the typical behavior of q2D POR. We should also suggest that the obtained effective masses of carriers are 1.8\( m_e \) and 2.6\( m_e \), which are consistent with SdH results\(^8\). Therefore, this fact suggests that the Fermi surface of this system at low temperature consists of q2D Fermi surface only, and it is not consistent with the previous ADMRO result\(^8\). For the reason of this disagreement, we would like to point out that the anisotropy of q2D FS should be considered. And we think that the q1D-like behavior of ADMRO may be caused by the anisotropy of the q2D FS.
Fig. 2. (a) The expected $\theta$ dependence of $\nu/B_{res}$ assuming the q1D Fermi surface, which is predicted by ADMRO results. $(m, n)$ is the Fourier components of the FS corrugations$^5$. (b) The observed $\theta$ dependence of $\nu/B_{res}$ at 1.6 K. Solid diamonds and open circles show the data observed at 57.8 GHz and 71.9 GHz, respectively.

4. Conclusions
We have developed the new rotational cavity system equipped with MVNA and performed magneto-optical measurements for novel organic conductor $\beta^\infty$-(BEDT-TTF)(TCNQ). The results clearly show the effectiveness of observing POR to gain information of the Fermi surface of these systems at low temperature.

Acknowledgements
The authors would like to acknowledge Dr. S. Uji and Prof. K. Kishigi for valuable discussions. This work was partly supported by a Grant-in-Aid for Scientific Research (B) (No. 16340106) from the Ministry of Education, Culture, Sports, Science and Technology of Japan. This work was performed at the High Field Laboratory for Super Conducting Materials, Institute for Materials Research, Tohoku University.

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