High field Hall effect in (DMET-TSeF)\textsubscript{2}AuCl\textsubscript{2}

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Abstract

The Hall effect of the quasi one-dimensional system (DMET-TSeF)\textsubscript{2}AuCl\textsubscript{2} is reported at high fields where the system is in the FISDW (Field Induced Spin Density Wave) state. The Hall voltage shows similar but different behavior to those observed in the famous TMTSF system. The Hall voltages step like behavior, but they are not clearly quantized. The voltage disappears above 18 T, and not the inverses of the FISDW boundary fields but the squares of them seem to show linear dependence to the phase indices n. The absolute values of the Hall voltages at the corresponding phase indices are about one tenth of the values observed in TMTSF system. Moving FISDW states have been proposed to understand the differences.

Keywords: Transport measurements, conductivity, Hall effect, magnetotransport, Organic superconductors

(DMET-TSeF)\textsubscript{2}AuCl\textsubscript{2} is one of the salts in (DMET-TSeF)\textsubscript{X} family which includes a variety of salts with remarkable physical properties [1]. It has been confirmed that this salt is not superconducting, but metallic at the lowest temperature measured (0.1K) and shows FISDW state at ambient pressure. The asymmetric DMET-TSeF molecule is related to the famous TMTSF, and actually a half of the molecule consists of the half of TMTSF, but another half consists of the half of BETS [2]. The QHE (Quantum Hall Effect) like phenomenon has been reported in TMTSF system[3], and many theoretical treatments have been given[4]. The evidence of Frohlich type conduction of FISDW has been experimentally observed at the high electric field condition [5]. But it seems that the complete understanding of the phenomenon is still on the way. We think that the study of the quasi one-dimensional system other than TMTSF system is helpful. We propose in this paper a possible moving FISDW state in (DMET-TSeF)\textsubscript{2}AuCl\textsubscript{2} even at low electric fields.

Short report on the Hall effect up to 15 T has been already given for the X=Au\textsubscript{1}, and X=AuCl, salts[6]. The result for the Au\textsubscript{1} salt has indicated a clear sign change near 13T. And the result for the AuCl\textsubscript{2} salt had been described to show a plateau-like behavior. Therefore higher field data have been waited for. Here we show the experimental data up to 27 T using hybrid magnet. The lowest temperature measured is liquid 4He temperature. The result is shown in Fig.1, where the transverse magnetoresistance(MR) is shown by the thick line and Hall field data have been obtained from 8 to 27 T (The data have been obtained by 180 degrees sample rotations in the field). The magnetoresistance shows a rapid increase above 18 T and grows monotonously to the maximum field (See the inset of Fig.1). Therefore it seems that the final FISDW transition boundary exists near 18 T. The maximum resistance is about 20 times larger than the value below the final transition at 18T. The Hall voltage becomes effectively 0 above the final transition (Fig.1 bottom), which is very similar to the behavior observed in (TMTSF)PF\textsubscript{6}[3] except the shape of the field dependence. If we assign phase indices following the TMTSF case, the inverse of the FISDW boundary field does not follow the linear dependence law to the phase index seen in TMTSF, but the square of the inverse field is proportional to the phase index n (Fig.2). The value of Hall field decreases rapidly than the TMTSF case at lower fields below 18 T. The ratio of the Hall resistance to the magnetoresistance is smaller than 1 which is contrary to the TMTSF case, and it is nearly one tenth of the corresponding TMTSF values.

![Fig.1 Hall field and magnetoresistance (MR) at 0.5 K.](image-url)
Fig. 2 The relation between phase indices and phase boundary fields.

The Fermi Surface of the (DMET-TSeF)$_2$AuCl$_2$ is essentially the same as that of TMTSF [2]. We have confirmed that low temperature crystal structure is the same as room temperature one except thermal contraction by X-ray analysis [6], therefore the Fermi surface at low temperatures is quasi one-dimensional. And the low temperature structure analysis also confirmed that there is no superstructure at low temperatures. The low temperature quasi one-dimensional nature has been also confirmed by the magic angle resonance measurement [1]. Therefore, we can compare present results with those of the (TMTSF)$_2$PF$_6$ salt. As long as the Fermi surface is concerned, we could expect the same QHE like behavior in (DMET-TSeF)$_2$AuCl$_2$. We have tried many times to measure the Hall field in this system at lower fields than 15 T, but it was unsuccessful. We observed essentially no Hall field especially below 10 T, though we could observe magnetoresistance anomaly in the transverse magnetoresistance measurement. This has been a puzzle for us, because we could not imagine the origin of the physical difference. Therefore, our first assumption was that we are still measuring at FISDW phases with high index numbers. But, the present measurement revealed that the field which is supposed to be the last transition field (18 T) is nearly the same as that of (TMTSF)$_2$PF$_6$. We consider this field to be the last transition, because the transition is very sharp and the Hall field abruptly becomes 0. As noted above the Hall field in our case is never quantized and its field dependence is very similar to the shape of the magnetoresistance. The result of ref. 5 suggests that the Hall field is affected by the sliding motion of FISDW. Therefore we should consider the possibility first, as long as we consider the standard theory right.

Two different kinds of theories exist on the sliding effect of the FISDW. A.Virosztek and K.Maki have calculated the conductivity tensors considering the sliding motion of FISDW including only a single gap, and discussed the absence of the quantum Hall term and the absence of the electric field dependence in $\sigma_\parallel$ and $\sigma_\perp$ but field dependent $\sigma_n$ [7]. V.Yakovenko has reviewed the theoretical results which favors the quantum Hall effect together with the effect of sliding FISDW. In the case of QHE, the Hall conductivity per one layer is quantized, where $\sigma_n=2ne^2/h$ [4]. Such a behavior has been confirmed in (TMTSF)$_2$PF$_6$ and (TMTSF)$_2$ReO$_4$ [3,8]. If we consider our result from this view point, the result which shows zero Hall field at high fields is in favor of this view though the shape of the Hall field is not QHE-like. The low model of Virosztek-Maki cannot explain such an abrupt disappearance of Hall effect [7]. One of the most accepted models in accord with the QHE and standard theory is the quantized nesting model[9]. The theory predicts that the phase boundary obeys roughly to the $H_n=H_f/(n+\gamma)$ law, where $H_f$ is related to the size of the carrier pocket and $\gamma$ is nearly 3 for TMTSF. The law was experimentally confirmed in PF$_6$ and ReO$_4$ (Actually the quantized nesting model suggests this rule only for the n=2 states.) But this law should be revised in DMET-TSeF case. As noted before we found that $(H_n)^2$ is inversely proportional to the number n, and it seems that this dependence cannot be obtained by a simple application of the quantized nesting model. This model also fails to explain the values of Hall field for n=0.

At present we do not have a sufficient explanation to fulfill all the experimental result which we obtained. Therefore we next consult to the experimental results so far reported. T.Osada has found that $\rho_x$ increases by applying high electric field, though there is no effect on $\rho_y$ [10] (This result cannot be explained by Virosztek-Maki theory [7]). On the other hand, L.Balic has found that a similar enhancement of $\rho_x$ in PF$_6$ salt and a decrease of $\rho_y$. If the FISDW in DMET-TSeF system can move easily with low pinning, the $\rho_x$ would increase (though the mechanism is not clear) and $\rho_y$ will decrease. Therefore the situation in our case can be reproduced by the moving FISDW model where FISDW moves at low electric fields. As the magnetic field of the phase boundary is not affected by the FISDW movement [5], we should find out other origin to explain the result for the phase boundary. We do not have a direct justification on the moving FISDW model, but we have some indications of the related result. There is a salt which shows SDW transition at ambient pressure in the DMET-TSeF family. This is (DMET-TSeF)$_2$AuBr$_2$ [2]. We found the difference of the conductivity depending on the measuring current in this system at the lowest temperature measured. We have also tested the nonlinear effect on the same salt but obtained no clear threshold behavior by the moving SDW. Though it may indicate higher pinning field, but another possibility is the very low pinning potential. Another related qualitative feature is the apparent difference of the FISDW oscillation depending on the current direction. The oscillation is clearer when the current is along the perpendicular direction to the one-dimensional chain. It reminds us of the difference of the sliding motion depending on the current direction. These points should be confirmed by more precise measurements.

References