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Two-Dimensional Electronic System in Conducting Langmuir-Blodgett Film of BEDO-TTF and Stearic Acid

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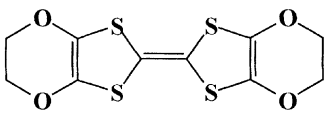
The bis-ethylenedioxy-tetrathiafulvalene (BEDO-TTF, BO) and stearic acid ($CH_3[CH_2]_{16}COOH$) molecules form a highly conducting Y-type Langmuir-Blodgett (LB) film with a specific charge transfer between BO and stearic acid. The $(BO)_2^+$ molecular layers, 20 Å thickness in each, alternate with stearic acid layers. At low temperature, weak carrier localization appears in the conduction properties. The transverse magnetoconductance shows that the coherent carrier diffusion occurs in two-dimension (2D). The temperature variation of the carrier phase relaxation distance indicates that the dephasing by quasi-elastic carrier-carrier scattering dominates in each $(BO)_2^+$ based conducting plane.

Keywords: Magnetoconductance, Weak localization, BEDO-TTF, Langmuir-Blodgett films, Stearic acid, Quantum interference

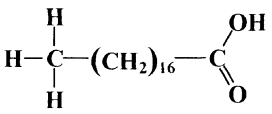
INTRODUCTION

The Langmuir-Blodgett (LB) film from the mixing BEDO-TTF (BO) and fatty acid molecules has successfully overcome the past-decade difficulties to obtain the high dc conductivity at a macroscopic scale [1-3]. The Y-type LB films of BO and stearic acid (SA) show the dc

conductivity at 300 K up to 100 Scm^{-1} [3] which is higher than that of the LB film of BO and behenic acid (BA) reported previously [1]. Therefore, the LB films of BO and SA have a merit of study on the carrier transport mechanism at low temperature. To prepare the present LB films of BO and SA, we followed the detail as described for the BO-BA LB films in ref. 1. The BO molecules form a monomolecular layer beneath the SA layer at the air-water interface. They form a molecular association assigned as $(BO)_2^+(RCOO\cdots HOOCR)^-$, where $R=CH_3(CH_2)_{16}$. The counteranion is supposed to come from SA [2,3]. The BO layer provides a metallic conductivity without percolation from the fatty acid clusters.



BEDO-TTF (BO)



Stearic acid (SA)

FIGURE 1 Molecules of BEDO-TTF and stearic acid

In this paper, we report the coherent charge transport and the inelastic scattering mechanism observed in the BO-SA LB film. Its high electrical conductivity and the results of the magnetotransport invite us to the study of conducting LB films to the mesoscopic physics.

EXPERIMENTAL

In the sample preparation, each chloroform solution of BO and SA was mixed with the 1:1 molar ratio before spreading on the water surface [4]. According to the vertical Y-type deposition with a surface pressure of 20 mN/m, the BO-SA layers are laid down on the sapphire substrate

with a stacking manner as BO-SA/SA-BO/BO-SA/···. The number of BO-SA layers is the number of depositions. The layer stacking periodicity is 58 Å from the x-ray diffraction [4]. The four-probe method was applied to measure the dc electrical conductivity. Four gold electrodes separated with 0.5-mm gaps were made by evaporation and chemical etching procedure prior to the deposition of the film. LB film was made on the present electrode-predeposited substrate.

RESULTS AND DISCUSSION

Figure 2 shows the film conductance G of the 21-layer LB film. The conductance G is defined as σd, where σ and d are the conductivity and film thickness, respectively. G shows a metallic character down to 120 K and initiates to decrease logarithmically with decreasing temperature.

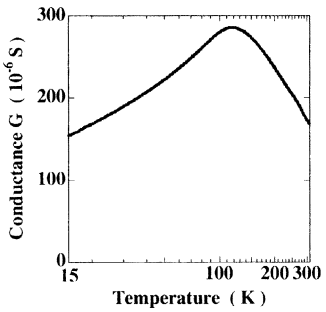


FIGURE 2 The film conductance G for 21-layer LB film of 1:1 mixture of BO and SA on sapphire substrate.

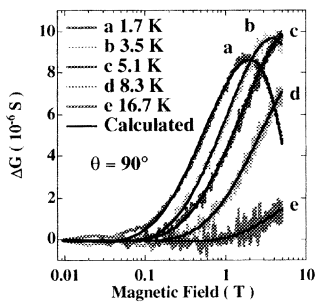


FIGURE 3 Transverse magnetoconductance ΔG for the 25-layer LB film of 1:1 mixture of BO and SA .

In Fig. 3 we show the transverse magnetoconductance ΔG using the definition ΔG = G(B,T) - G(0,T) at several temperatures when the magnetic field is applied normal to the film plane (θ = 90°). The

data was taken on the 25-layer LB film. A positive ΔG is enhanced with decreasing temperature as shown in Fig. 3. The observed logarithmic decrease in zero-field G and positive ΔG are a common feature in the weakly localized two-dimensional (2D) electronic system [5].

Below 40 K, the weak localization becomes dominant. The elastic scattering loops leading to a weak localization presumably lie in 2D planes organized by an array $(BO)_2^+$ molecules. Externally applied magnetic field disrupts both the coherent back-scattering and the constructive quantum interference [5]. It suppresses the weak localization and results in positive ΔG under low magnetic field i.e., negative magnetoresistance. The ΔG is interpreted by using the two-component model [6] which describes two independent terms in conductance, namely the classical contribution and the other one associated with the 2D weak carrier localization in the intra-layer. They show up in the magnetoconductance in the form [4-6]:

$$\Delta G = A_1 \frac{e^2}{2\pi^2\hbar}\left[\ln\left(\frac{B}{B_i}\right) + \psi\left(\frac{1}{2} + B_i / B\right)\right] - A_2 B^{\alpha}$$

where $B_i = \hbar/4eD\tau_{in}$, A_1, A_2, α denote parameters used in the fitting procedure of the magnetoconductance data. $D = v_F^2\tau/2$ and v_F are diffusion constant and the Fermi velocity, respectively. ψ is digamma function. τ is carrier elastic scattering time, and τ_{in} is the inelastic scattering time. In the classical part strongly depends on the electronic structure and disorder. In practice, we used the fixed vale of $\alpha = 0.9$ and then calculated the other parameters. The accuracy for the value α was 0.9(1) in the final refinement, which indicates that the classical part obeys the linear magnetoresistance due to inhomogeneous electron density distribution in the 2D electronic system [7]. Figure 3 gives the

calculated solid curve fitted for experimental magnetoconductance. All numerical values are summarized in Table 1.

TABLE 1 Parameters found in the fitting procedure of the magnetoconductance

T (K)	A_1	B_i (T)	A_2	$(D\tau_{in})^{1/2}$ (Å)
1.7	0.82	0.049	5.51×10^{-6}	580
3.5	0.86	0.087	4.76×10^{-6}	443
5.1	0.70	0.115	1.67×10^{-6}	383
8.3	0.63	0.205	0.93×10^{-6}	285
16.7	0.33	0.475	0.40×10^{-6}	186

The relevant scale size $(D\tau_{in})^{1/2}$ over which quantum interference is onset increases up to 580 Å, so that the weak localization becomes progressively evident at the mesoscopic scale. The factor A_1 in Table 1 grows rapidly and becomes close to 1 with decreasing temperature. According to the perturbative scaling theory for the 2D electronic system with in-plane anisotropy, the value A_1 may become less than 1 [8]. The temperature variation of B_i gives a measure of phase coherence time $\tau_{in} = aT^{-p}$. a = 0.026 and p = 1 from Table 1. The value p = 1 has been reported in a metallic phase of Si/SiGe quantum wells [8] and expected for dephasing by quasielastic electron-electron scattering [8].

CONCLUSION

The LB film of BO and SA provides a well defined layered stacking and exhibits high conductivity at 300 K. The film magnetoconductance together with ln(T) dependence of the zero-field film conductance were interpreted in terms of the weakly localized 2D electronic system

formed in the BO layers. This result indicates that the electronic transport is essentially in a coherent transport regime at the mesoscopic scale, influenced by the effect of weak random potential possibly produced by a small disorder inside the 2D molecular stacks of BO. The carrier transport across the SA layers inbetween BO layers is the next step focus to clarify the phase correlation/coherence between the conducting BO layers in the present LB film.

Acknowledgments

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