Non-linear Conductivity in the Spin-Density Wave Phase of $(TMTSF\text{-}d_{12})_2ClO_4$

K. Nomura [a,1], T. Terazaki [a], A. Hoshikawa [a], N. Matsunaga [a], M. Watanabe [b], S. Nakatsuji [b], J. Yamada [b]

[a] *Division of Physics, Hokkaido University, Sapporo 060-0810, Japan*

[b] *Department of Material Science, Himeji Institute of Technology, Kamigohri 678-1201, Japan*

Abstract

In the SDW phase of $(TMTSF\text{-}d_{12})_2ClO_4$ induced by the rapid cooling, the non-linear electric conductivity with a threshold field E_T was observed, associated with the sliding motion of SDW. The monotonous increase of E_T against the temperature is explained with the strong pinning. The sharp drop of excess conductivity below $0.3T_{SDW}$ and the temperature independent I-V characteristic suggest the quantum origin for the SDW sliding.

Key words: spin-density wave; sliding; organic conductor; non-linear conductivity

The sliding motion of the spin-density wave (SDW) is observed in the SDW phase with an incommensurate wave vector of the organic quasi-one dimensional conductor $(TMTSF)_2X$. This collective SDW mode has been confirmed in the non-linear conductivity, narrow band noise etc. [1] [2]. The sliding motion of SDW is well explained in the classical pinning model similarly to the case of the charge density wave (CDW). It has been also proposed that the SDW phase in $(TMTSF)_2X$ is divided into two sub-phases. In the low temperature sub-phase, the dynamics of SDW shows temperature independent characteristic behavior [3] and attracts much interest in connection with the quantum origin for the SDW sliding. We investigated the mechanism of SDW sliding in $(TMTSF)_2ClO_4$ with controlling the two-dimensional character of electron band by changing the cooling rate at the anion ordering temperature [4]. Here we present the results of conductivity measurement in $(TMTSF\text{-}d_{12})_2ClO_4$, which has larger two-dimensionality than $(TMTSF)_2ClO_4$, and discuss the mechanism of SDW sliding through the chemical pressure.

The single crystals of $(TMTSF\text{-}d_{12})_2ClO_4$ were synthesized by the standard electro-chemical method from deuterated TMTSF molecules. The electrical conductivity was measured in the four-wire configuration by the pulse current to avoid the self-heating. The temperature was controlled with use of the helium-3 cryostat down to 0.5 K.

We confirmed the anion ordering at $T_{AO} = 27$ K from the bend of temperature dependent resistivity curve. This value is slightly larger than that in $(TMTSF)_2ClO_4$. The SDW phase is induced in $(TMTSF\text{-}d_{12})_2ClO_4$ by the rapid cooling through T_{AO} as $(TMTSF)_2ClO_4$ and the SDW transition temperature T_{SDW} increases with increasing cooling rate. However, T_{SDW} for a fixed cooling rate is slightly smaller in $(TMTSF\text{-}d_{12})_2ClO_4$ than $(TMTSF)_2ClO_4$. These results are understood with the chemical pressure due to the substitution of deuteron for proton [5]; i.e. the two-dimensional character of electron band is larger in $(TMTSF\text{-}d_{12})_2ClO_4$ than $(TMTSF)_2ClO_4$.

The non-linear conductivity is observed with a clear threshold electric field E_T in each SDW phase. Figure 1 shows the temperature dependence of E_T for several SDW transition temperatures. For each T_{SDW}, E_T

1 Corresponding author. E-mail: knmr@phys.sci.hokudai.ac.jp

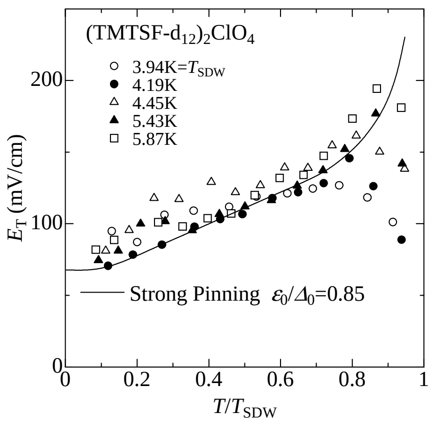

Fig. 1. Temperature dependence of the threshold electric field E_{T} for several SDW transition temperatures. The solid line represents the theoretical fit with the strong pinning.

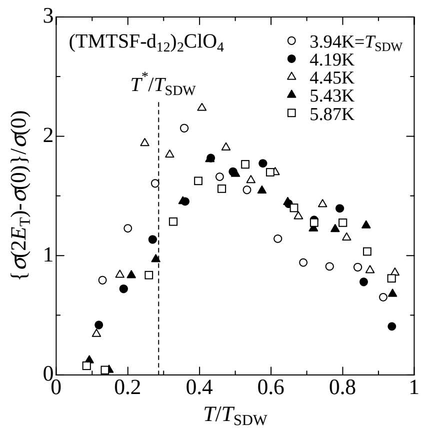

Fig. 2. Temperature dependence of the normalized excess conductivity for several SDW transition temperatures.

shows gradual increase with increasing temperature. This temperature dependence in the reduced temperature scale is almost unchanged irrespective of T_{SDW} in contrast with the case of $(\mathrm{TMTSF})_2\mathrm{ClO}_4$, where the temperature dependence becomes steeper with increasing T_{SDW}. As shown in Fig. 1, the temperature dependence of E_{T} for $T_{\mathrm{SDW}} = 4.19K$ is well fitted by the theoretical curve for the strong pinning with the imperfect nesting parameter $\epsilon_0/\Delta_0 = 0.85$. The starting material of TMTSF-d_{12} molecule contains a small amount of TMTSF. Accordingly, TMTSF molecule distributed in $(\mathrm{TMTSF\text{-}d}_{12})_2\mathrm{ClO}_4$ crystal plays the impurity pinning center in contrast with the case of $(\mathrm{TMTSF})_2\mathrm{ClO}_4$, where the disordered array of anions gives the weak pinning [4]. The absolute value of E_{T} around 100 mV/cm is several times larger than that in $(\mathrm{TMTSF})_2\mathrm{ClO}_4$. This fact is consistent with the picture described above.

Figure 2 shows the temperature dependence of excess conductivity $\{\sigma(E_{\mathrm{T}}) - \sigma(0)\}/\sigma(0)$ for several SDW transition temperatures. In the figure, the position of the sub-phase transition temperature T^* ($\simeq 0.3T_{\mathrm{SDW}}$) is indicated by the broken line. The excess conductivity increases gradually with decreasing temperature from T_{SDW} and shows a sharp drop below T^*. This behavior is similar to that in $(\mathrm{TMTSF})_2\mathrm{ClO}_4$. Figure 3 shows the I-V characteristic for $T_{\mathrm{SDW}} = 5.43K$. In the low temperature range below T^*, the temperature independent increase of current against the electric field, which is described as $j = j_0 \exp(-E_0/E)$, is observed, similarly to other $(\mathrm{TMTSF})_2\mathrm{X}$ salts [3] [4]. The essentially same behavior is observed irrespective of the value of T_{SDW}, although the value of E_0 shows a slight increase with increasing T_{SDW}. These properties are common in the SDW phase of $(\mathrm{TMTSF})_2\mathrm{X}$ in spite of the difference of detailed pinning mechanism. It is suggested that the SDW with discommensuration structure [4] gives the temperature independent conductivity increase from the quantum origin in the low temperature sub-phase.

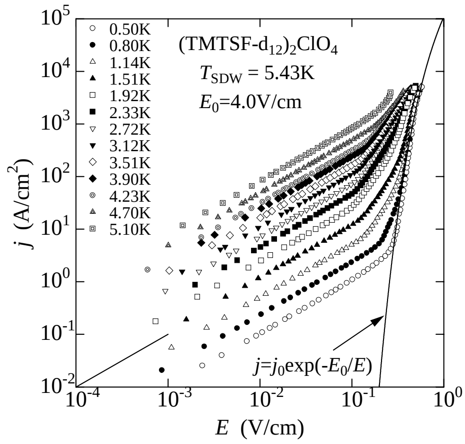

Fig. 3. $I - V$ characteristic for $T_{\mathrm{SDW}} = 5.43K$. The solid curve represents the functional form of $j = j_0 \exp(-E_0/E)$.

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