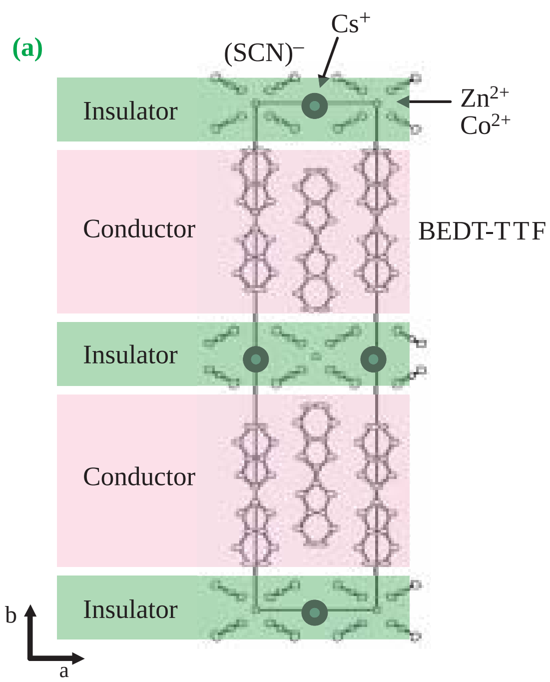
Organic Thyristor

Recently, "intrinsically inhomogeneous" states have attracted a keen interest in strongly correlated electron systems. A prime example is high-temperature superconductors, in which nano-size domains of the superconducting-gap and pseudo-gap phases coexist in the CuO_2 plane. Another example is perovskite manganites, in which percolation paths of the ferromagnetic metal phase in the charge-ordered insulator phase give rise to colossal magneto-resistance effects. These nano-scale inhomogeneities are driven by the interaction between coexisting/competing phases, not by imperfections of the crystal, hence the name "intrinsic inhomogeneity" [1].

We have discovered giant nonlinear conduction in the organic salt θ-(BEDT-TTF)$_2$CsM(SCN)$_4$ (M=Co and Zn), which is a brand new function in intrinsically inhomogeneous states [2,3]. This salt is a layered material composed of conducting BEDT-TTF layers and insulating CsM(SCN)$_4$ layers alternately stacked along the *b*-axis, as shown in Fig. 1(a). The Greek letter θ specifies a packing pattern of BEDT-TTF molecules in the conducting layer, representing a "triangular lattice". Because of charge frustration on the triangular lattice, two kinds of charge order compete at low temperatures [4]. They are eventually frozen as nano-size domains without long-range order, forming an intrinsically inhomogeneous charge-order phase.

Figure 1(b) shows the voltage-current (*V-I*) characteristics of the θ-salt. The current is applied along the *b*-axis direction (perpendicular to the conducting BEDT-TTF plane). The voltage is highly nonlinear with respect to current, and negative derivative resistance is clearly seen from 10^{-5} to 10^{-4} A. Since the voltage-current curve is essentially identical to that of a thyristor device, we call the θ-salt an organic thyristor.

A high-intensity X-ray from beamline **BL02B1** has revealed that the data in Fig. 1 stems from the melting of the charge order domains by an external current. Figure 2 shows the DC current dependence of the two diffuse peaks at $\mathbf{q}_1$=(2/3 *k* 1/3) and $\mathbf{q}_2$=(0 *k* 1/2) at 12 K, which correspond to competing charge order domains. Clearly, the $\mathbf{q}_2$ peak loses its intensity with increasing current, while the $\mathbf{q}_1$ peak remains nearly intact. This is a non-equilibrium thermodynamic phenomenon in which ordered phase domains are melted by an external steady flow. On a cold wintry



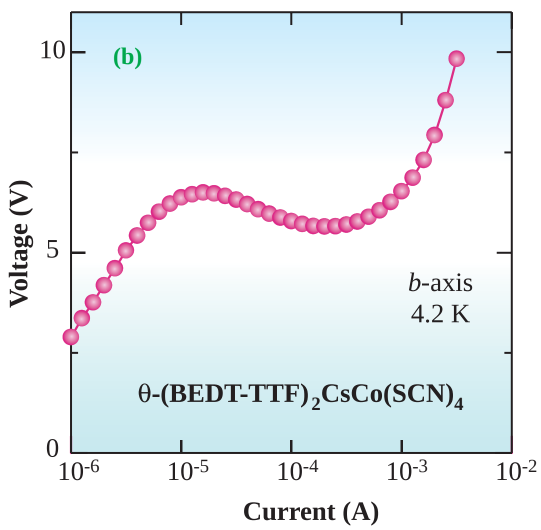


Fig. 1. **(a)** Crystal structure of θ-(BEDT-TTF)$_2$CsM(SCN)$_4$ (M=Co and Zn). **(b)** Voltage-current characteristics for M=Co at 4.2 K. The current was applied along the *b*-axis direction.

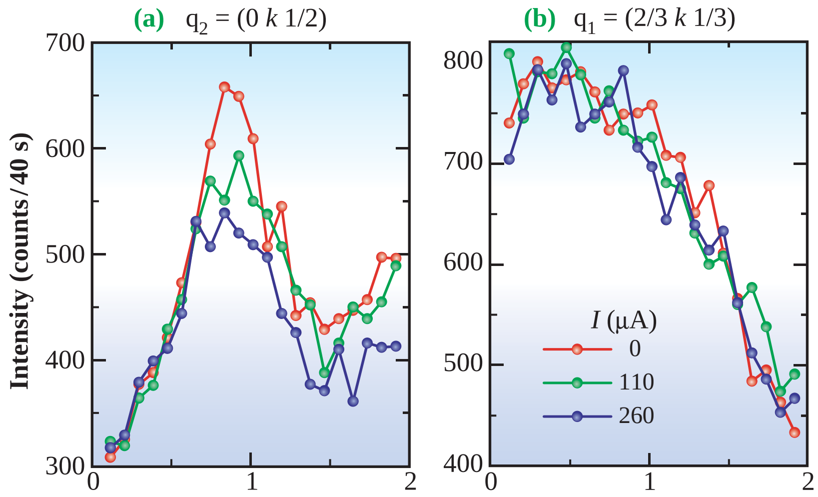


Fig. 2. Diffuse peaks for competing charge ordered domains for various external currents. **(a)** $\mathbf{q}_2 = (0\ k\ 1/2)$ and **(b)** $\mathbf{q}_1 = (2/3\ k\ 1/3)$. Only the $\mathbf{q}_2$ peak loses its intensity with increasing current.

day, we often see ice on a pond and water flowing in a river. The present result is a manifestation of such phenomena in a sea of conduction electrons.

Since a thyristor is an essential component in an inverter (DC-to-AC converter), the organic thyristor is expected to work as a "nature-made" inverter. In fact, we have succeeded in observing DC-to-AC conversion in this organic salt. We measured the ac voltage component across a standard resistor connected to the sample in series for various DC bias voltages at 4.2 K. As shown in Figs. 3(a) and 3(b), the nonlinear resistance shows an abrupt jump between 6.2 and 6.5 V, at which a large AC signal of 40 Hz suddenly appears. The observed oscillation is nearly sinusoidal, as shown in the fast Fourier transform (FFT) spectra in Fig. 3(c). The results shown here suggest a new way to design electronic devices using intrinsically inhomogeneous states.

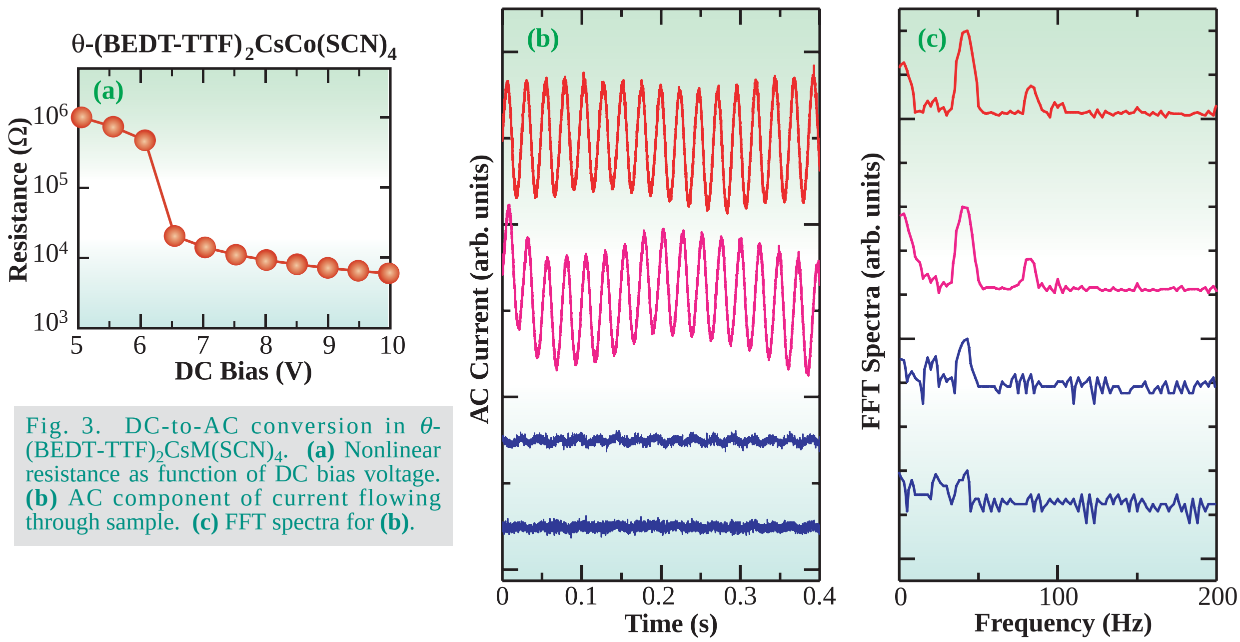


Fig. 3. DC-to-AC conversion in θ-(BEDT-TTF)$_2$CsM(SCN)$_4$. **(a)** Nonlinear resistance as function of DC bias voltage. **(b)** AC component of current flowing through sample. **(c)** FFT spectra for **(b)**.

Ichiro Terasaki

Department of Applied Physics, Waseda University

E-mail: terra@waseda.jp

References

[1] J. Burgy *et al.*: Phys. Rev. Lett. **87** (2001) 277202.
[2] K. Inagaki *et al.*: J. Phys. Soc. Jpn. **73** (2004) 3364.
[3] *F. Sawano, I. Terasaki, H. Mori, T. Mori, M. Watanabe, N. Ikeda, Y. Nogami and Y. Noda: Nature* ***437*** *(2005) 522.*
[4] M. Watanabe *et al.*: J. Phys. Soc. Jpn. **68** (1999) 2654.