Narrow band noise in the SDW state of $(TMTSF)_2PF_6$

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Abstract

Narrow band noise has been studied in the SDW phase of $(TMTSF)_2PF_6$ in a magnetic field. Strong and weak periodic peaks are clearly observed. The spectrum largely changes with increasing current and depends on applied magnetic field. The fundamental frequency of the current oscillations comes from a sliding motion of the SDW condensate. The strong periodic peaks appear at the harmonic frequencies of this fundamental and move to lower frequency at large currents. This is interpreted in terms of the existence of the CDW collective excitation.

Key words: narrow band noise; SDW; CDW; phason

Recently, the coexistence of SDW with $2k_F$- and $4k_F$-CDWs was found between 4 and 12 K in the quarter-filled quasi-one-dimensional organic conductor $(TMTSF)_2PF_6$ by X-ray diffraction measurements [1,2], where k_F is the Fermi wavenumber. In this case the electron densities $\delta\rho_\pm$ with up (+) and down (−) spins are respectively written as

$$\delta\rho_\pm(x) \propto \pm\sin(2k_F x + \theta \pm \phi), \tag{1}$$

where the phase θ gives rise to the sliding motion of the SDW and ϕ represents the relative motion of the density wave with opposite spins followed by amplitude of the $2k_F$-CDW. In such a system, not only a sliding mode, i.e. a phason mode, but also a CDW mode originating from the fluctuations of ϕ are expected to be low-energy collective excitations [3]. As is well known, the phason mode plays a crucial role in new collective mechanism of the conductivity. The SDW condensate pinned by impurities and defects is depinned when a high electric field is applied. Consequently, the nonlinear conduction due to the phason is observed above a threshold electric field E_T. Moreover the narrow band noise (NBN) originating from the current oscillations with a fundamental frequency f given by

$$f = \frac{J_{SDW}}{e n_{SDW} \lambda_{pin}} \tag{2}$$

in principle appears, and it was actually observed in $(TMTSF)_2ClO_4$ [4] and $(TMTSF)_2PF_6$ [5]. Here J_{SDW} is the current density, n_{SDW} the number of condensed electron, and λ_{pin} the effective pinning length. Then it is expected that the low-energy CDW collective mode also contribute to the nonlinear conduction and the NBN in the SDW state, but this has not been observed yet. In this work, we measure the NBN in the SDW state of $(TMTSF)_2PF_6$ to study the collective excitations and the magnetic-field effect on them.

We measured the NBN spectra at 2 K by using a spectrum analyzer (Anritsu, model MS420B/K). The magnetic field H was applied along the b' direction.

Figures 1(a) shows the NBN spectra at $H = 0$ T. The NBN was detected when the electric current along the a axis is above about $10 \times I_T$, where the threshold current I_T corresponding to E_T was about 0.015 mA in both cases of 0 and 10 T. Strong and weak periodic sharp peaks were observed, and their frequencies strongly depend on current I.

In order to see the weak periodic peaks more clearly, we show two typical cases; one is when $I = 0.28$ mA and $H = 0$ T and the other when $I = 0.18$ mA and $H = 10$ T in Fig. 2(a). The fundamental frequency f of the NBN as a function of I is shown in Fig. 2(b),

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and it increased linearly with increasing I when I was small. From Eq. (2), we obtained that $\lambda_{\rm pin} = 18.0$ Å at 0 T and 13.0 Å at 10 T, which agree well with the wavelength of SDW, $\lambda_{\rm SDW} = 2a \sim 14.6$ Å. However, $\lambda_{\rm pin}$ depends on magnetic field H. The weak periodic peaks are, therefore, due to the phason of SDW.

On the other hand, the frequencies of the strong periodic peaks agree with the harmonics of f, i.e., the periodicity F is given as $\ell \times f$ where ℓ is an integer. The cases of Fig. 2(a) stand $F = 8 \times f$.

The sliding motion of the SDW coexisting with the CDW, described by Eq. (1), may produce the following current oscillations;

$$\sum_{\ell} A_{\ell}\{\sin \ell(2\pi f t + \theta + \phi) + \sin \ell(2\pi f t + \theta - \phi)\}$$
$$= \sum_{\ell} 2A_{\ell} \cos(\ell\phi) \sin \ell(2\pi f t + \theta). \qquad (3)$$

The intensity of the ℓth harmonics of the NBN is given as $\{2A_{\ell}\cos(\ell\phi)\}^2$ and has a maximum at $\ell\phi = m\pi$ (m =integer), if the coefficient A_{ℓ} is independent of ℓ. Recently Kagoshima *et al.* [2] reported that the static CDW disappeared below 3∼4 K, but the theoretical study [3] indicated that the CDW excitation with a low energy existed even at pure SDW state near the phase boundary of the coexistent state of SDW and CDW. We think that the observed strong periodic peaks are produced at $\ell\phi_0 \simeq m\pi$, where ϕ_0 is the amplitude of the CDW excitation.

The NBN spectra largely changed at $I_1 \leq I \leq I_2$, denoted by the shaded regions in Figs. 1(b) and 2(b); the strong periodic peaks broadened and the weak periodic peaks smeared. This region strongly depends on H. Above I_2 the former become sharp and the latter are distinctly observed again, but the fundamental frequency f deviates largely from Eq. (2). Moreover the periodicity F of the strong periodic peaks and the multiple ℓ quickly decrease with increasing I, which suggests that the amplitude ϕ_0 of the CDW excitation rapidly increases when I is large. These facts lead that the CDW excitation also plays an important role in carrying the nonlinear current at large currents.

In conclusion the present study shows clearly the existence of the CDW collective excitation in the SDW state of $(TMTSF)_2PF_6$.

References

[1] J.P. Pouget and S. Ravy, Synth. Met. **85** (1997) 1523.

[2] S. Kagoshima *et al.*, Solid State Commun. **110** (1999) 479.

[3] Y. Tomio *et al.*, J. Phys. Soc. Jpn. **70** (2001) 2884.

[4] K. Nomura *et al.*, Solid State Commun. **72** (1989) 1123.

[5] N. Hino *et al.*, Synth. Met. **40** (1991) 275.

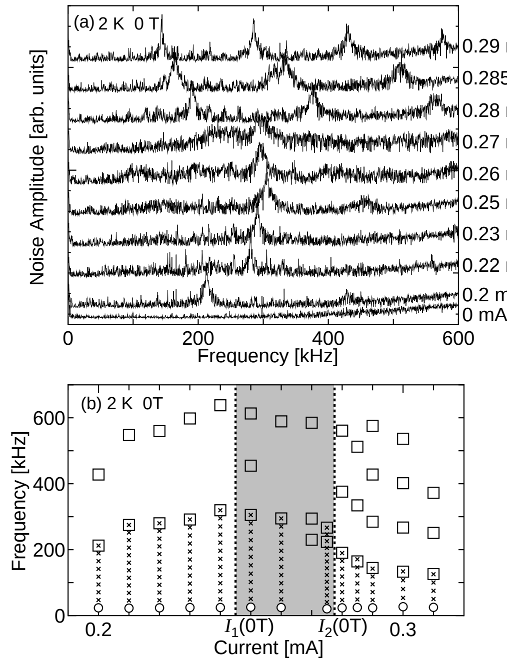

Fig. 1. (a) NBN spectra at $H = 0$ T and (b) the frequencies of the strong periodic peaks as a function of I. The fundamental frequency f (○) of the weak periodic peaks and the harmonics (×) are also shown in order to read the multiple ℓ.

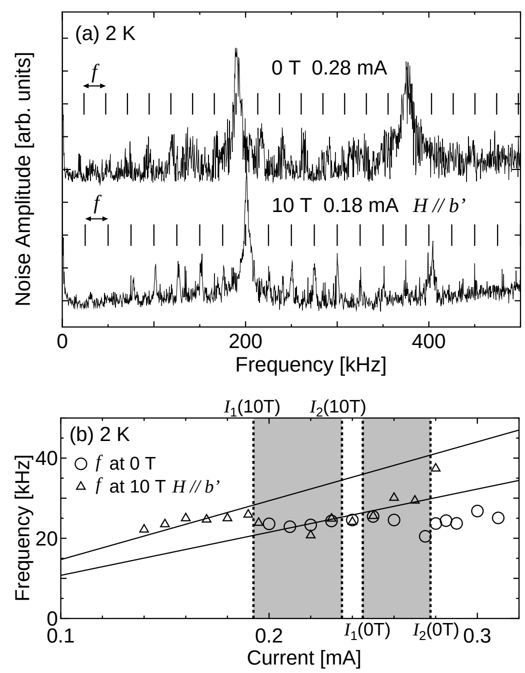

Fig. 2. (a) NBN spectra when $I = 0.28$ mA and H =0 T and when $I = 0.18$ mA and H =10 T, and (b) the fundamental frequency f as a function of I. The solid lines denote Eq. (2) at $H = 0$ and 10 T.