НАНОФИЗИКА И НАНОЭЛЕКТРОНИКА

Труды XXI Международного симпозиума

13–16 марта 2017 г., Нижний Новгород

Том 2

Секция 3

Нижний Новгород
Издательство Нижегородского госуниверситета им. Н.И. Лобачевского
2017

The unusual charge-density wave in the monoclinic phase of NbS_3

S.G. Zybtsev[1], V.Ya. Pokrovskii[1*], V.F. Nasretdinova[1], S.V. Zaitsev-Zotov[1], V.V. Pavlovskiy[1], Woei Wu Pai[2§], M.-W. Chu[2], Y.G. Lin[3], E. Zupanič[4], H.J.P. van Midden[4], S. Šturm[4], E. Tchernychova[5], A. Prodan[4], J.C. Bennett[6], I.R. Mukhamedshin[7], O.V. Chernysheva[8], A.P. Menushenkov[8], A.N. Titov[9]

1 Kotel'nikov Institute of Radioengineering and Electronics of RAS, Mokhovaya 11-7, Moscow, 125009

2 Center for condensed matter sciences, National Taiwan University, Taipei, Taiwan, 106

3 National synchrotron research center, Hsinchu, Taiwan 300

4 Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

5 Department of Materials Chemistry, National Institute of Chemistry, Hajdrihova 19, SI-1000 Ljubljana, Slovenia

6 Department of Physics, Acadia University, Wolfville, Nova Scotia, Canada B0P 1X0

7 Institute of Physics, Kazan Federal University, Kazan, 420008

8 National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute), Kashirskoe sh. 31, Moscow, 115409

9 Ural Federal University, Mira 19, 620002, Yekaterinburg

* pok@cplire.ru, § wpai@ntu.edu.tw

We are reporting on the charge-density wave (CDW-2) forming in NbS_3, phase II, at the temperature T_{P2}=150 K. The transition is found only in the sulfur deficient samples. The CDW-2 is clearly detected in the resistance and in the collective transport measurements, but does not show any lattice distortions at T_{P2} in the diffraction studies. However, features near T_{P2} are clearly detected in the temperature dependences of the ^{93}Nb NMR relaxation time and in XANES (X-ray absorption near-edge spectroscopy) spectra measured at S and Nb peaks. Anomalous photoresponse of CDW-2 is also reported. Among others, the concept of excitonic dielectric is considered as the origin of CDW-2.

Introduction

The monoclinic phase of NbS_3, known also as phase II, shows two coexisting charge-density waves (CDWs) at room temperature, T. The corresponding lattice distortions are characterized by the wave-vectors $\boldsymbol{q_1}$ = (0.5, 0.298, 0) and $\boldsymbol{q_0}$ = (0.5, 0.352, 0) [1]. The $\boldsymbol{q_1}$-CDW (CDW-1) emerges at T_{P1}=340-370 K and shows the features typical of the collective electronic transport. Evidence for the $\boldsymbol{q_0}$-CDW (CDW-0) transport has been also shown recently, T_{P0} has been tentatively estimated as 620-650 K [2].

Here we are reporting on the unusual features of the CDW forming at T_{P2}=150 K (CDW-2).

The results and discussion

The appearance of CDW-2 and its collective transport are clearly detected in the transport studies. The T dependence of conductivity, σ, shows a distinct feature at T_{P2}; the voltage, V, dependences of σ below T_{P2} show a drop at the threshold value, V_t [2]. However, no lattice distortions at T_{P2} have been detected in the diffraction structural studies (TEM and powder X-ray). Nevertheless, features near T_{P2} have been clearly detected in the temperature dependences i) of the nuclear transverse magnetization relaxation time measured at the central ^{93}Nb NMR line and ii) of XANES (X-ray absorption near edge structure) spectra measured at two S and one Nb peak [2].

Under RF irradiation sliding CDW-2 shows Shapiro steps, – a typical feature of CDW transport. The RF interference shows that the charge density carried by CDW-2 per one wavelength can be from 3 to 1000 times lower than that of CDW-1. This is too low for a usual CDW formed though the Peierls transition. The charge density scales with the sample specific conductivity, σ_s, above T_{P2}. The composition studies of NbS_3 samples have shown that CDW-2 is observed only in S deficient samples, which show relatively high σ_s. Therefore, CDW-2 is concluded to be a condensate of electrons donated by S vacancies [2]. This is the first known case of doping-induced electrons condensation into a collective state.

One of the surprising features of CDW-2 is the variation of the σ(T) curves with the change of σ_s (for T>T_{P2}). The value of T_{P2} does not depend on σ_s, and changes in σ_s within 1.5 orders of magnitude result only in vertical shift of the $\sigma_s(T)$ curve in the logarithmic scale. Thus, the transition at T_{P2} is not directly coupled with the concentration of the electrons induced by doping [2].

We have also observed indications of the purely electronic nature of the CDW-2, while the lattice distortion, if any, plays a secondary role. In contrast to CDW-1, both T_{P2} value and the I-V curves of CDW-2 show very low sensitivity to the uniaxial strain, ε, of the samples [2]: $d\log(T_{P2})/d\varepsilon \sim 0.1 d\log(T_{P1})/d\varepsilon \sim 1.5$, which is a very low value for a CDW, while the non-linear conductivity does not show any regular changes for ε in the range 0 – 1%. The critical slowing-down of fluctuations revealed by NMR near T_{P2} is also in accord with the electronic nature of the distortion: the relaxation of the transverse magnetization can be stimulated by fluctuations of both magnetic and electric fields, and its freezing can reveal not only a lattice but also an electronic ordering. This would explain, why no lattice distortion is observed at T_{P2} with diffraction methods.

Another anomalous feature of NbS_3 is the effect of infra-red (IR) irradiation on the CDW-2 transport [3]. Earlier the impact of light on the CDW transport has been reported for $K_{0.3}MoO_3$ [4] and *o*-TaS_3 [5]. In both cases the threshold field, E_t, for the CDW depinning grows under optical irradiation. The effect was explained in terms of the CDW rigidity: the optically excited electrons are supposed to decrease the CDW elastic modulus and increase E_t.

To study photoconductivity in NbS_3 we used IR LED with the frequency corresponding to $h\nu$=1.2 eV, which is above the known energy gap, 0.43 eV [6]. In case of CDW-1 the V_t value is found to increase with the power of irradiation, W, like in [4,5]. The V_t variation was too small to establish the dependence of V_t *vs*. W.

In contrast, CDW-2 shows a *decrease* of V_t vs. W; $\delta V_t \propto W^{1/2}$ (Fig. 1). For the maximum W values δV_t is of the order of V_t at W=0, while $V_t(W)$ is non-linear even for the lowest values of W, when $\delta V_t << V_t(0)$. Presumably, changes of the CDW-2 rigidity [4,5] result in a linear $V_t(W)$ dependence for small W. Thus, the behavior of CDW-2 under the irradiation indicates its specific interaction with the pristine lattice.

The increase of the linear conductivity under the IR irradiation also follows the $W^{1/2}$ dependence [3].

To explain the origin of CDW-2 we considered the mechanisms of Wigner crystallization and Keldysh-Kopaev transition (formation of excitonic dielectric) [2]. These orderings are primarily of electronic nature.

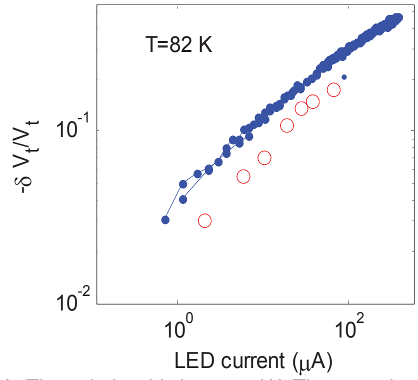

Fig. 1. The relative V_t drop vs. W. The sample dimensions are 45μm×0.014 μm^2. 100 μA corresponds to ~1 mW/cm^2. 'o'– data taken from the I-V curves matching. '•' – from σ(W) at fixed V.

The concept of excitonic dielectric is more favorable, because it explains the low sensitivity of T_{P2} on the concentration of electrons condensed into CDW-2. In the limiting case of zero concentration of the donated electrons the transition persists: the CDW-2 is formed by coupling of equal numbers of electrons and holes, as is suggested for the "classical" Keldysh-Kopaev transition. Alternatively, the CDW-2 can emerge at stacking faults in NbS_3. This hypothesis seems to be supported by the first STM studies of this compound.

RFBR (Grants 16-02-01095, 17-02-01343, 14-02-92015) and Slovenia-Russia project ARRS-MS-BI-RU-JR-Prijava/2016/51 are acknowledged.

References

1. P. Monceau // Adv. in Physics, V. 61, 325 (2012).
2. S.G. Zybtsev, V.Ya. Pokrovskii, V.F. Nasretdinova et al. // Phys. Rev. B, V. 95, 035110 (2017)
3. S.G. Zybtsev, V.Ya. Pokrovskii, V.F. Nasretdinova et al. //International research school "Electronic States and Phases Induced by Electric or Optical Impacts" IMPACT 2016, Cargese, France, "Program and abstracts",PII-10, p. 160
4. N. Ogawa et al. // Phys. Rev. Lett. V. 87 256401 (2001)
5. S.V. Zaitsev-Zotov, V.F. Nasretdinova, and V.E. Minakova // Physica B V. 460, 174 (2014)
6. V.F. Nasretdinova et al. // Nonequilibrium Phenomena in Complex Matter: new observations and new theories, Ambrož, Krvavec, Slovenia, 13-16 December 2015, BOOK OF ABSTRACTS, p. 46.