FEATURES OF CDWs IN NbS_3-II REVEALED BY SHAPIRO STEPS

S.G. Zybtsev[1], S.A. Nikonov[1], V.Ya. Pokrovskii[1], V.F. Nasretdinova[1], S.V. Zaitsev-Zotov[1], A. Maizlakh[1], Woei Wu Pai[2], N.Yu. Tabachkova[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], O.S. Volkova [10], A.N. Vasiliev [10], V.V. Pryadun [10], D. Starešinić[11], A.L. Vasiliev [12]

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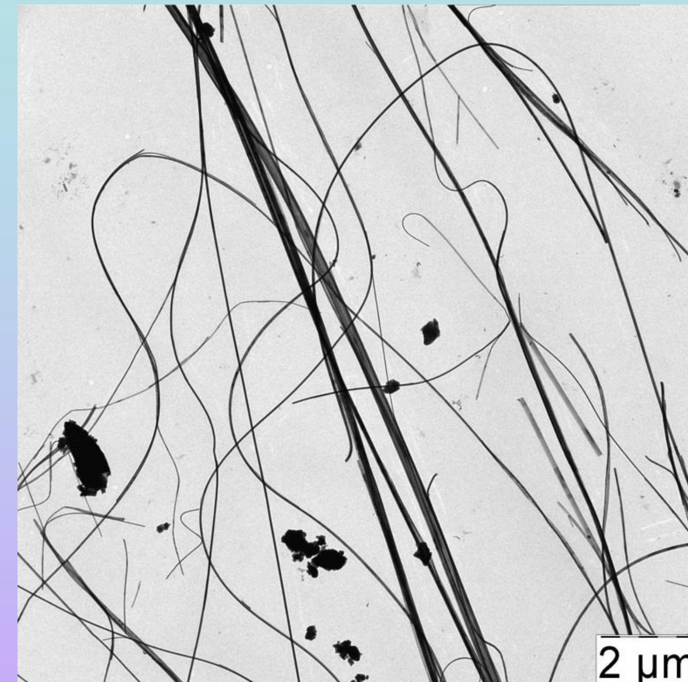
[11] *Institute of Physics, Bijenička cesta 46, HR-10000 Zagreb, Croatia*

[12] *National Research Centre "Kurchatov Institute"*

The samples were grown from the vapor phase by direct reaction of Nb and S in mole ratio 1:3 with a 10% excess of sulfur. The growth continued for two weeks in a quartz tube at T between 665 and 740 °C in a temperature gradient ~50 °C over the tube length (20 cm)

A 3μm-long bridge, an AFM image



Microphotos of NbS_3 in TEM

1. Introduction

a) NbS_3 I,II, …..?????.

b) Still more variety, if defects are considered. Stacking faults.

c) CDWs-1,2,3.

3. Shapiro steps (ShSs), what they give?

4. CDW-1: common features of CDWs, utmost characteristics. ShSs up to 20 GHz. Bessel-type oscillations. Synchronization of fluctuations near T_{P1}. Phase slippage.

5. CDW-0: high density, but low mobility. ***T* dependences of σ_∞??**

6. CDW-2: extremely low density and high mobility.

7. Discussion. What the 3 CDWs form from? The nature of CDW-2.

8. Announcement of a poster “CDWs UNDER STATIC AND DYNAMIC DEFORMATION OF WHISKERS ” /M.V. Nikitin/.

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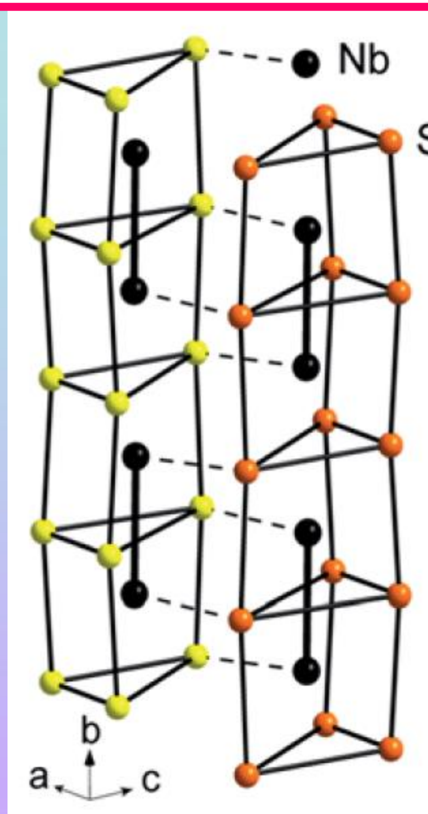
Structure and superstructure

But…We barely figured out phase II, as a family of new polymorphs were announced



a = 9.9 Å , b = 3.4 Å , *c* = 18.3 Å
- A combination of **4** units of phase I (without dimerization)

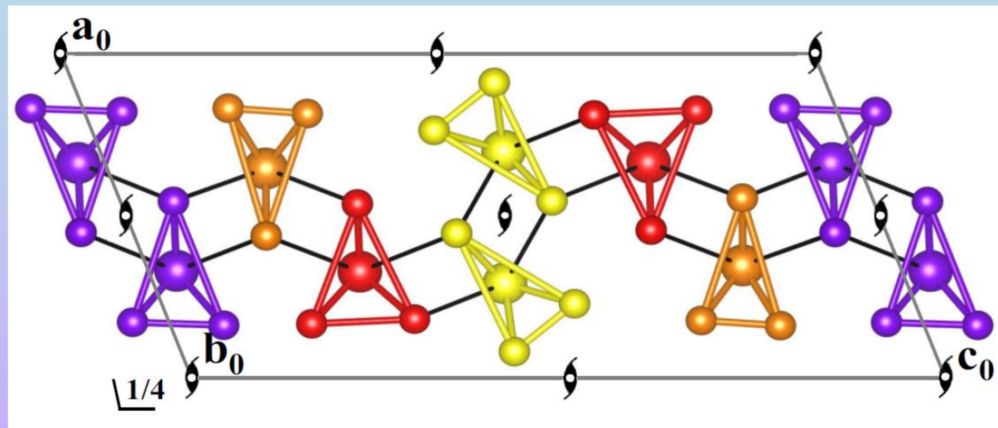


FIG. 1. The basic structure of NbS_3-II [$a_0 = 0.96509(8)$ nm, $b_0 = 0.33459(2)$ nm, $c_0 = 1.9850(1)$ nm, and $\beta_0 = 110.695(4)°$]. Large balls represent Nb and the small ones S atoms. There are four symmetry-related pairs of TP columns in the unit cell, three isosceles (Y, O, and P) and one almost equilateral (R). The two inter-column Nb-S bonds of the eight bonds forming the bi-capped trigonal prisms are shown in black. The symmetry elements of the space group $P2_1/m$ are added.

a = 4.963 Å, b = 2 × 3.365 Å, *c* = 9.144 Å

It was only an illusion of systematization

Following Mark Senn we were close to exclaim:
“Welcome to the ZOO!” + defects..

Matthew A. Bloodgood,[1] Pingrong Wei,[1] Ece Aytan,[2] Krassimir N. Bozhilov,[3] Alexander A. Balandin,[2] and Tina T. Salguero[1,a]

Pol ... es

Nb

Nb

CHEMISTRY OF MATERIALS

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Rich Polymorphism of Layered NbS_3

Sergio Conejeros, Bogdan Guster, Pere Alemany, Jean-Paul Pouget, and Enric Canadell*

Nb
(pr

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CONDENSED MATTER

Nb
(pr

“NbS_3-VI contains corrugated chains with paired Nb–Nb and uniform chains with unpaired, equidistant Nb centers.”

Nb

Impact of the chemical vapor transport agent on polymorphism in the quasi-1D NbS_3 system

Cite as: Appl. Phys. Lett. **120**, 173103 (2022); doi: 10.1063/5.0083997
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Published Online: 26 April 2022

View Online Export Citation

Matthew A. Bloodgood, Yassamin Ghafouri, Pingrong Wei, and Tina T. Salguero[a]

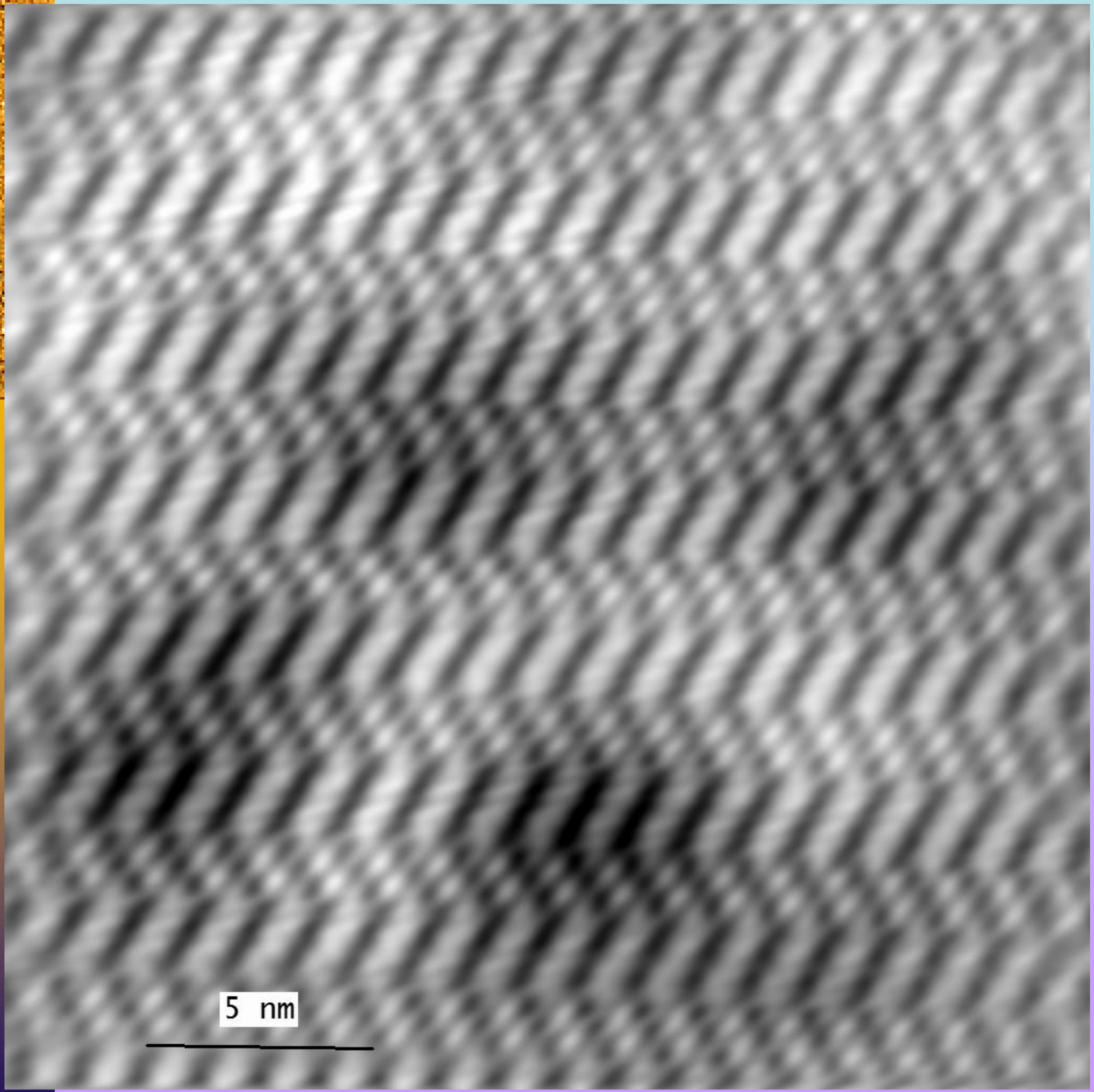
RT TEM rev ... n
NbS-II with
incommensur ... ved.

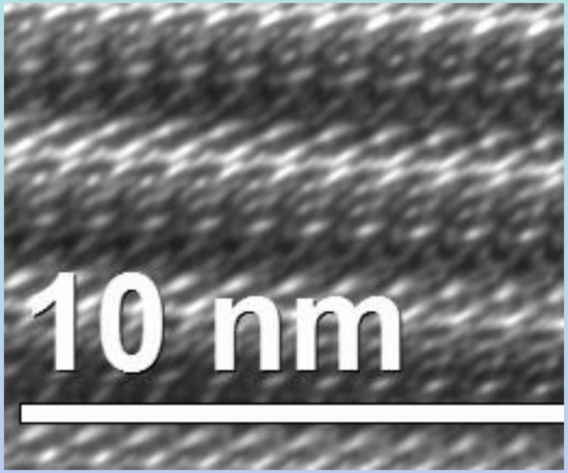
rk

Nb

rk

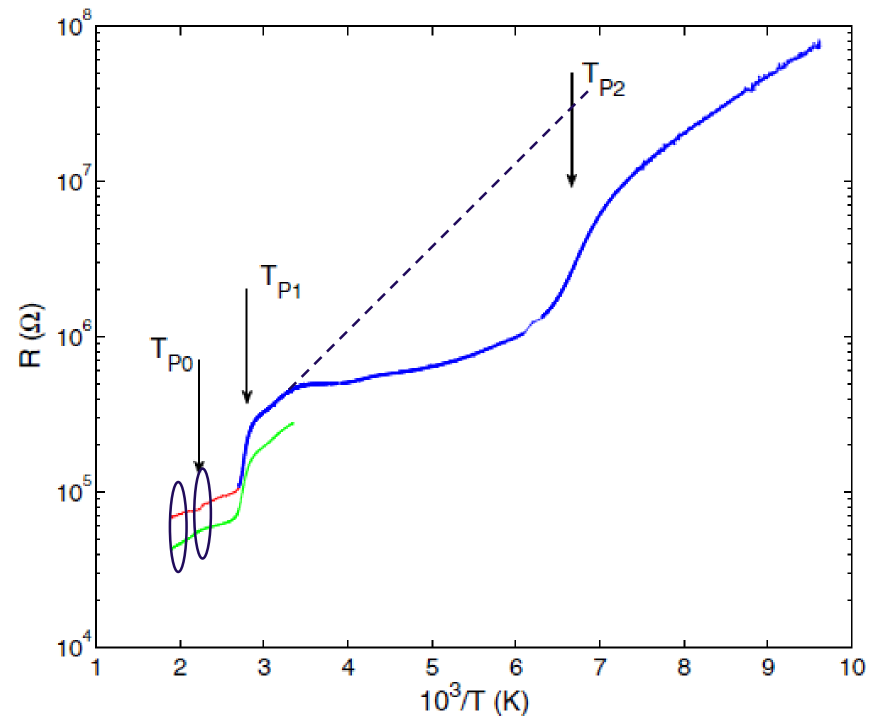
A recent TEM image in ac plane (⊥ to chains)

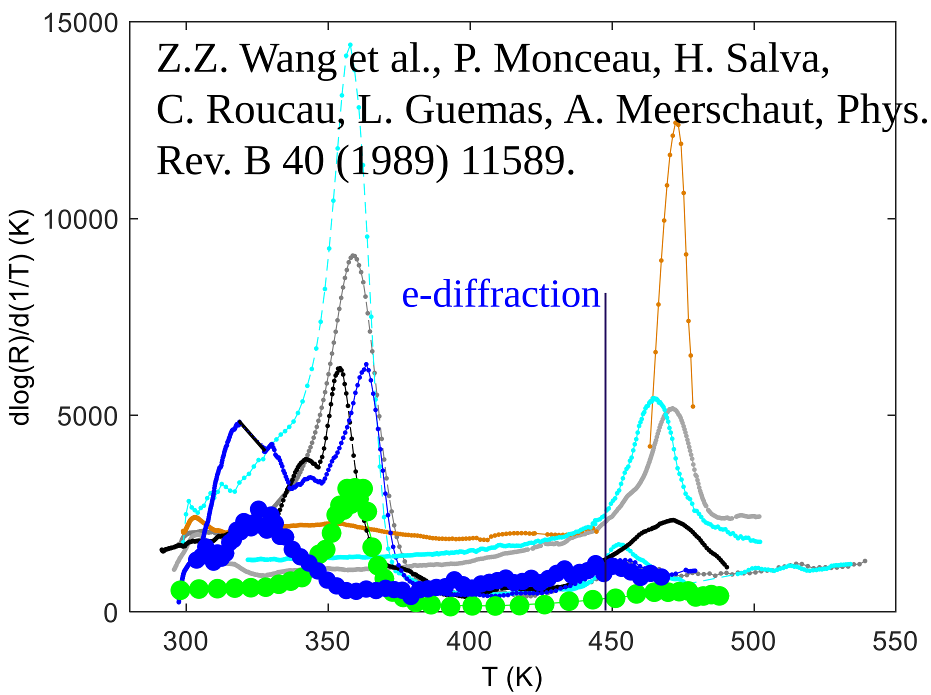




The basic properties of NbS_3-II

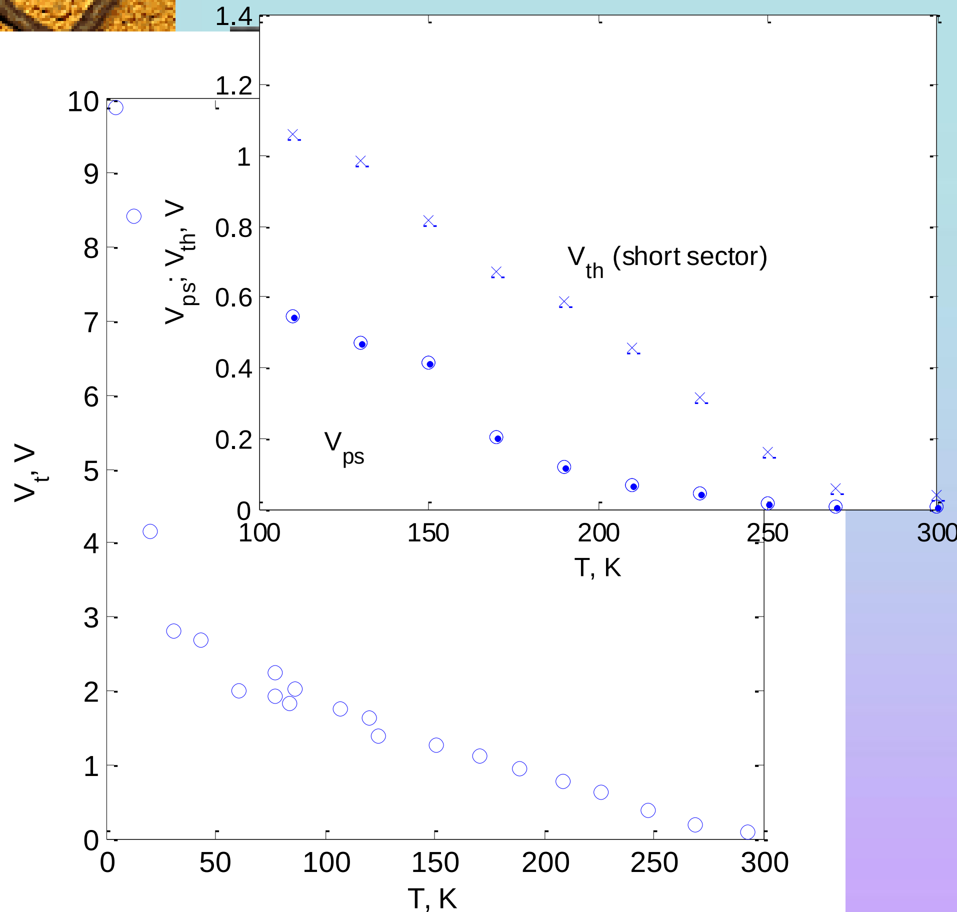
The **3** CDW transitions



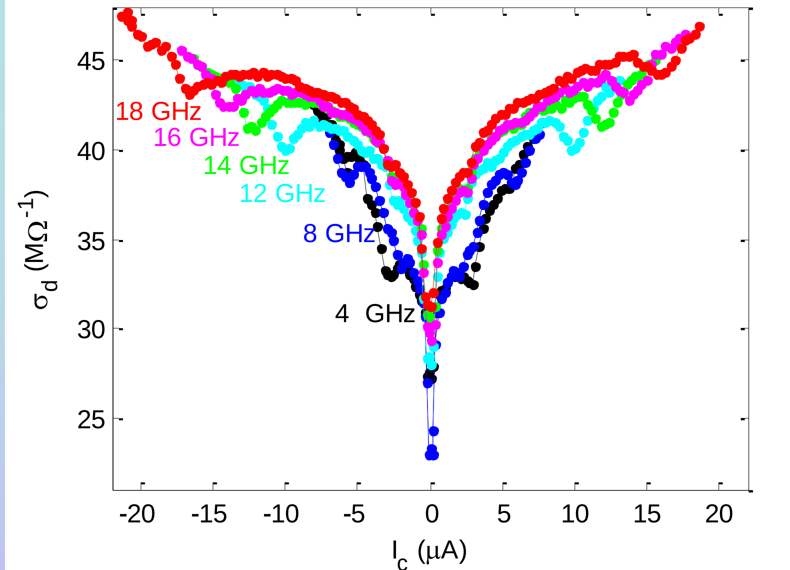


a for a low-Ohmic
igh-Ohmic).
T_{P2}=150K
obtained in an Ar flow

The basic properties of NbS_3-II
Two CDWs at room *T*. RT I-V curves



Zybtsev et al., 2018, http://lt38-conference.ru/



Differential conductivity vs. voltage under RF power up to 18 GHz. (1.6 μm×0.005 μm^2)

Differential conductivity vs. voltage at different strains ε. ε=0 (the bottom curve), ε~1% (the upper curve). *L*=24 μm.

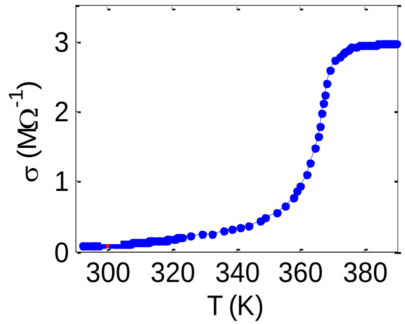
What is the profit from the Shapiro steps?

0) CDW velocity, its coherence

1) From j_{CDW}/f (= 18 A/MHz/cm^2 for NbS_3) one can find n:
$n = (j_{CDW}/f)/(e\lambda)$

2) From $\sigma(T)$ one can find $\delta\sigma$ and, thus, μ (just above T_P):

$\mu = \delta\sigma/en = \lambda\ \delta\sigma_s/(j_{CDW}/f)$,
or
$\mu = L\lambda(f/I_{CDW})\ \delta\sigma$.

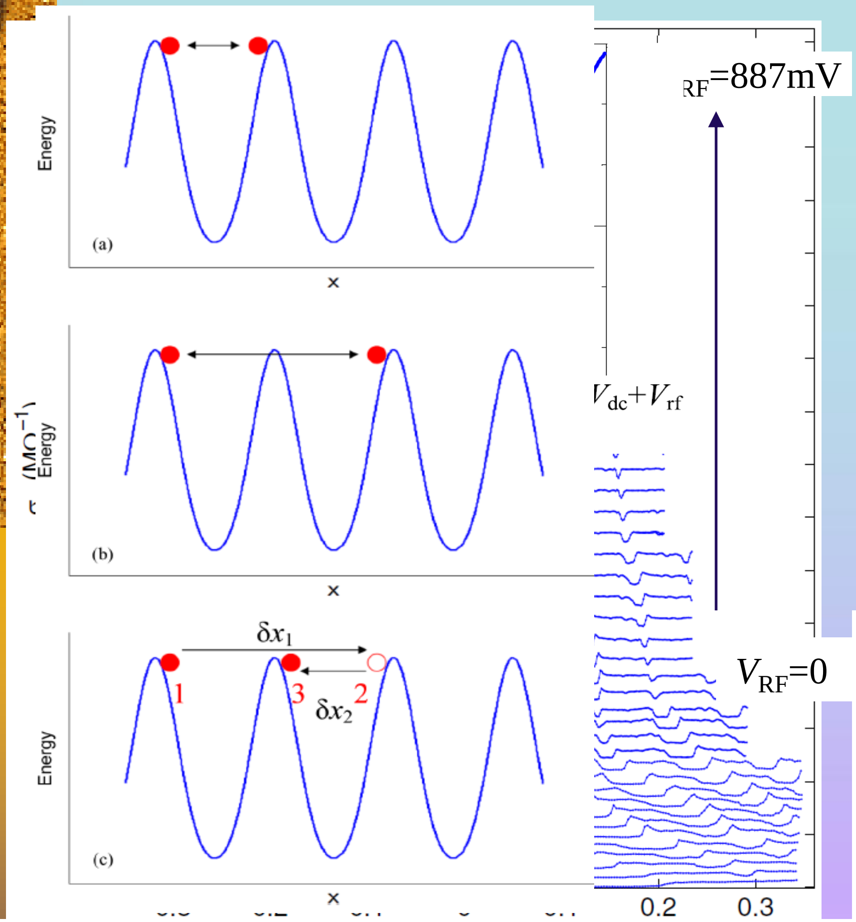


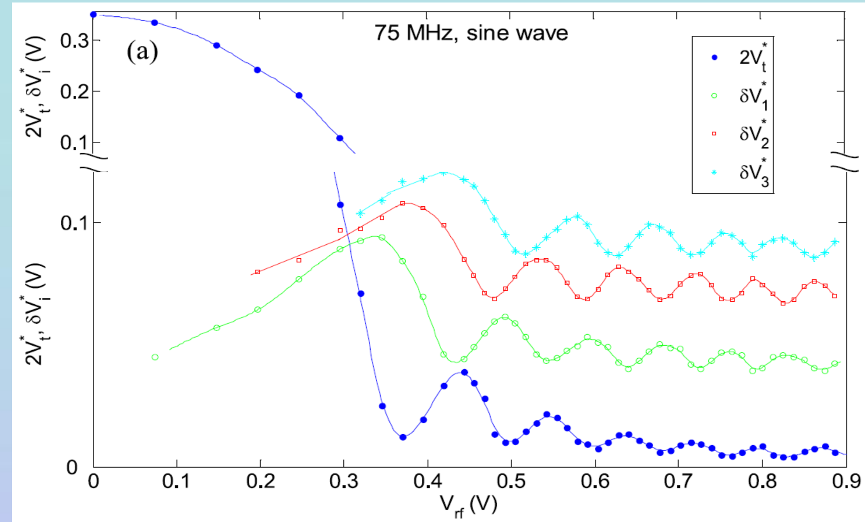
3) Also μ of a CDW !

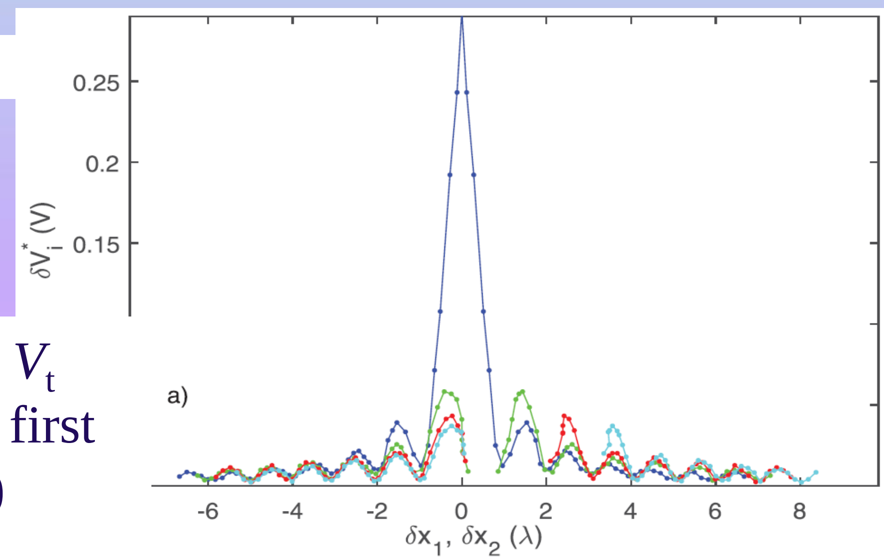
For orthorhombic TaS_3 with $\delta\sigma_s \approx 2.5\cdot10^3$ $(\Omega\text{cm})^{-1}$, j_{CDW}/f =38 A/cm^2/MHz and λ =13 Å, μ=8.5 cm^2/Vs, in agreement with Hall mobility at 300 K.
For $K_{0.3}MoO_3$ for the 21 μm-length sample $I_{CDW}/f = 1.6\times10^{-12}$ A/Hz and $\delta\sigma = 3.4\times10^{-3}\ \Omega^{-1}$. With λ=30Å we get μ=1.31 cm^2/Vs. For T=158 K the Hall mobility 1.18 cm^2/Vs can be found.

ShSs of CDW-1 – common features of CDWs.

Oscillations of ShS's magnitudes.



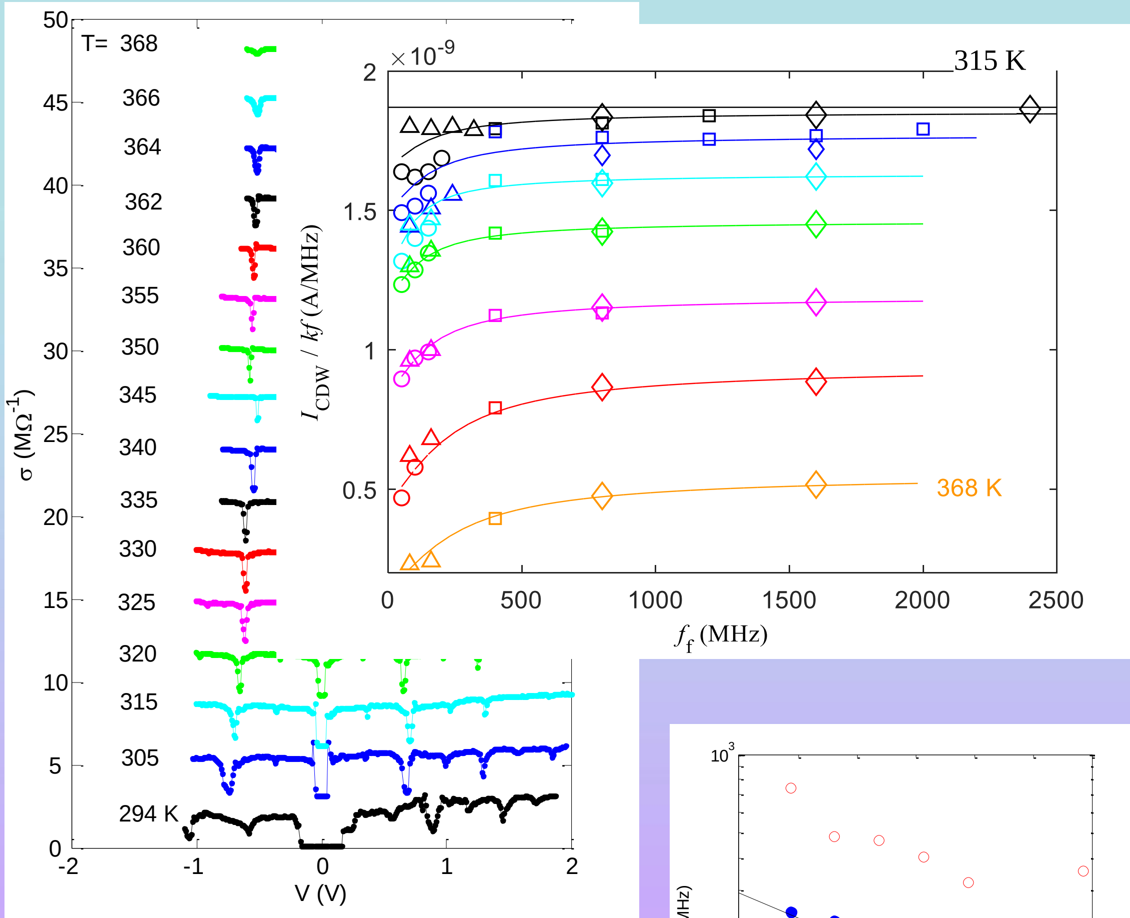




Illustrations of the effects of rf voltage on V_t (a), (b) and δV_1 (c). (a) corresponds to the first minimum of V_t , (b) to the second, and (c) corresponds to the first minimum of δV_1.

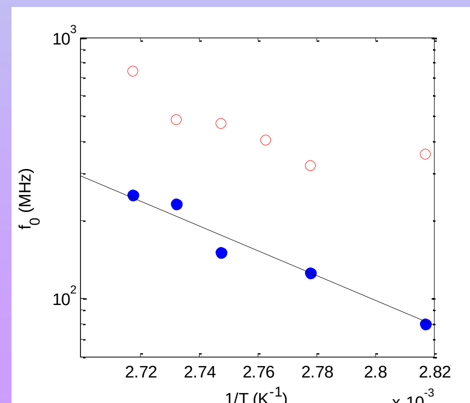
ShSs of CDW-1 – common features of CDWs.

ShS's at $T \rightarrow T_P$.



A set of $\sigma_d(V)$ curves at different T under irradiation at f=800 MHz for a NbS_3 sample. T_{P1}=367 K.

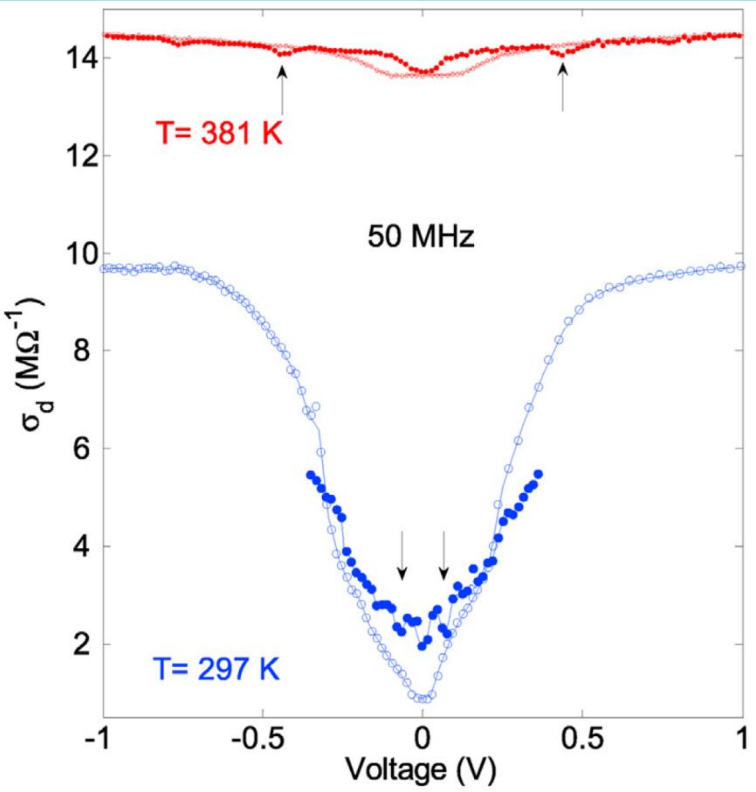
I_{CDW}/fk vs f_f, at selected temperatures. k is the harmonic. ○– f=50 MHz, △ – f=80 MHz, □ – f=400 MHz, ◊ – f=800 MHz. The broken lines approximate the dependencies as A+B **arctan(f/f_0).**

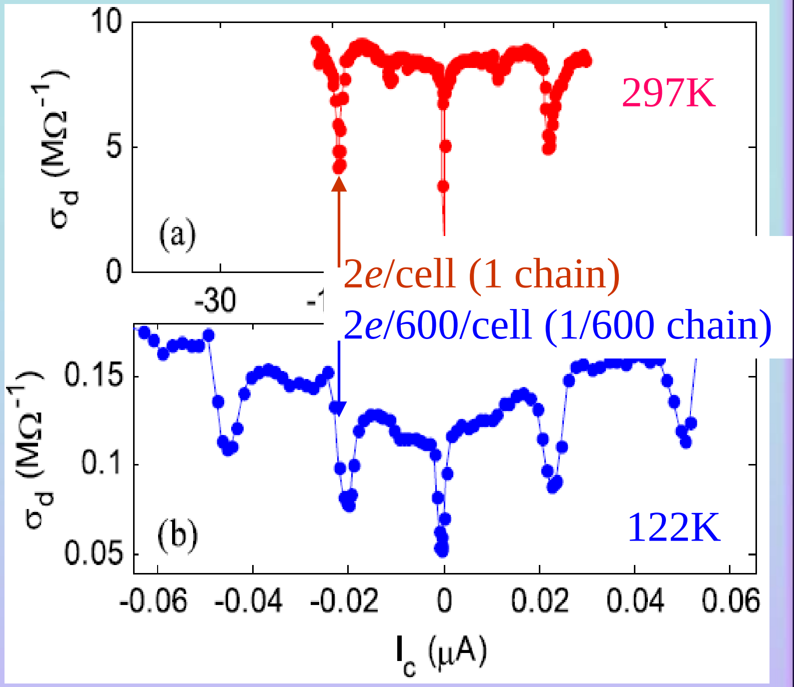


Temperature dependence of f_0 determined from the arc tan approximation (closed circles) and visually. The slope corresponds to W=11000 K.

We synchronized CDW fluctuations and found their characteristic time vs. *T* !

Sliding of CDW-0 and CDW-2.
Confronting CDWs at the same samples.





The closed signs correspond to measurements under f = 50 MHz, the open signs – without irradiation.
297K: CDW-1 is sliding.
381K: CDW-0 is sliding.
17 μm × 0.013 μm^2.

σ_d vs I_{CDW} under RF 400 MHz
(a) 297K: CDW-1 is sliding. (18 A/MHz/cm^2) and
(b) 122 K: CDW-2 is sliding.
170 μm x 0.2 μm^2

Densities and mobilities of CDW-0,1,2.

For CDWs 0,1,2: $n_0:n_1:n_2$ ~ (1.5-2.5) : 1 : (1/3-1/1000) (chains / unit cell)

Quasiparticles' μ : $\mu_0:\mu_1:\mu_2$ = 0.05 : 0.6 : 3 (in cm^2/Vs)

And μ of CDWs ??

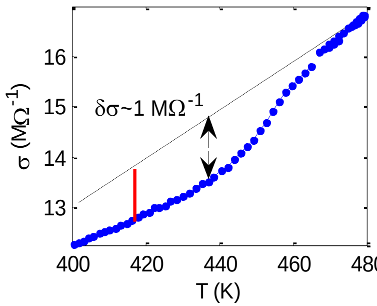
Spatial order ... waves

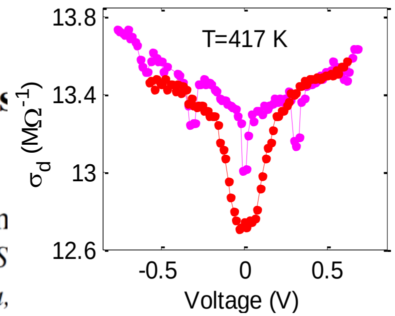
CDW-0:

M. A. van Midden,[1] H. J. F ... C. Ben

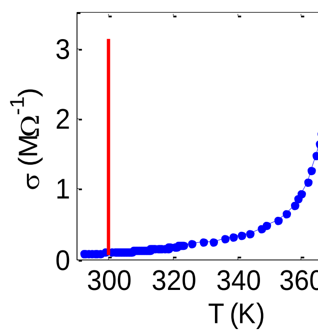
[1]Jožef Stefa ... bljana, S

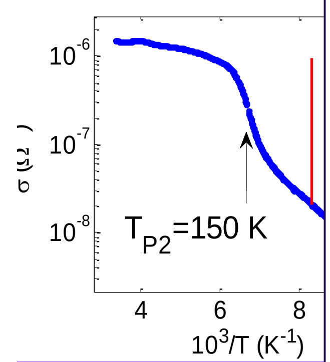
[2]Department of Physics ... a Scotia,





CDW-1:





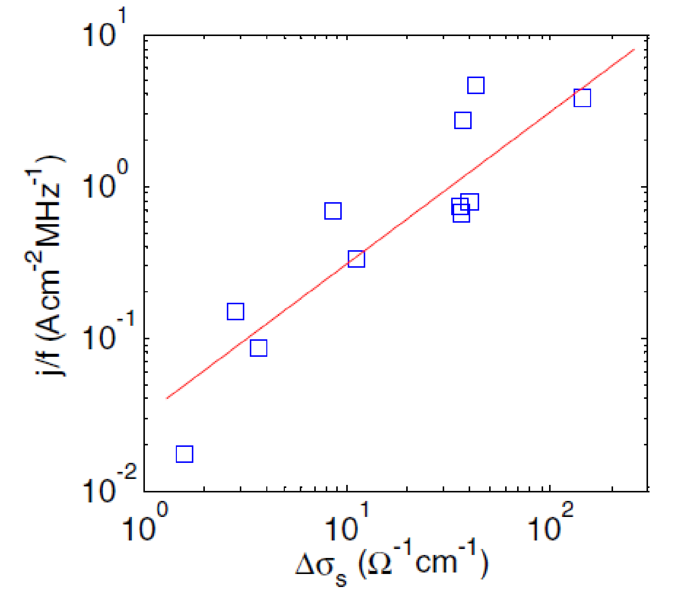


FIG. 15. The "fundamental ratio" j_c/f_f of the LT CDW vs the specific conductivity drop at T_{P2}. The straight line represents a linear approximation of the data.

Article

Axionic charge-density wave in the Weyl semimetal $(TaSe_4)_2I$

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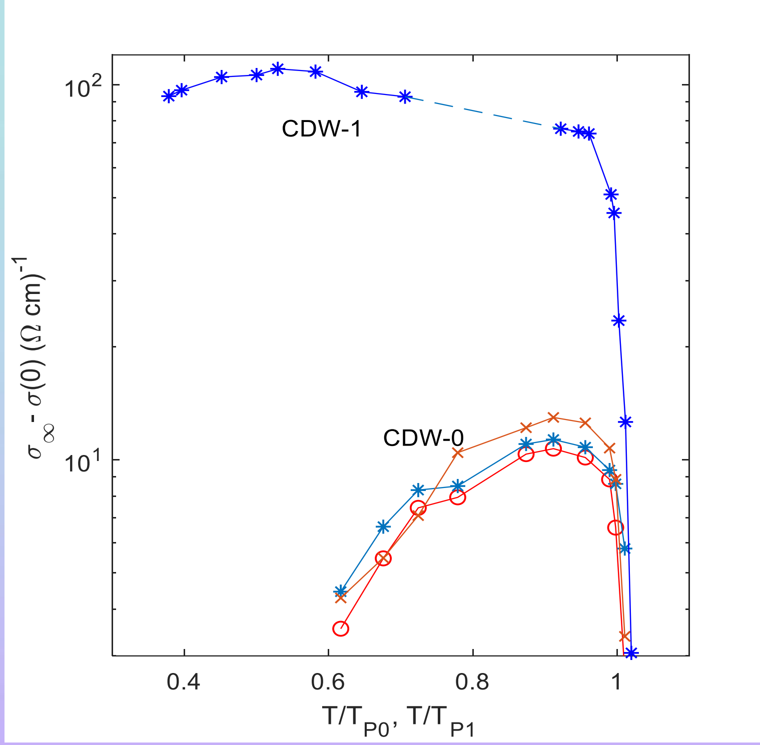
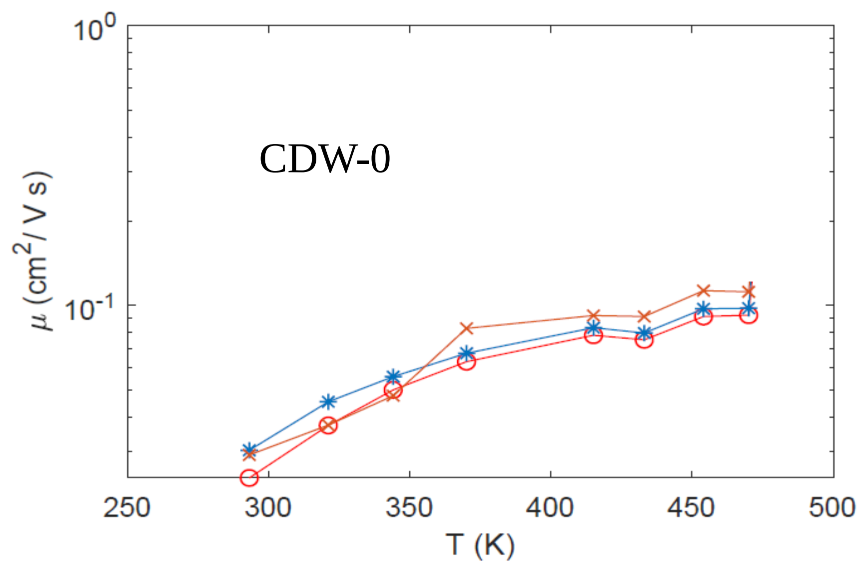
J. Gooth[1*], B. Bradlyn[2], S. Honnali[1], C. Schindler[1], N. Kumar[1], J. Noky[1], Y. Qi[1], C. Shekhar[1], Y. Sun[1], Z. Wang[3,4], B. A. Bernevig[5,6,7] & C. Felser[1]

An axion insulator is a correlated topological phase, which is predicted to arise from the formation of a charge-density wave in a Weyl semimetal[1,2]—that is, a material in which electrons behave as massless chiral fermions. The accompanying sliding mode in the charge-density-wave phase—the phason—is an axion[3,4] and is expected to cause anomalous magnetoelectric transport effects. However, this axionic charge-density wave has not yet been experimentally detected. Here we report the observation of a large positive contribution to the magnetoconductance in the sliding mode of the charge-density-wave Weyl semimetal $(TaSe_4)_2I$ for collinear electric and magnetic fields. The positive contribution to the magnetoconductance originates from the anomalous axionic contribution of the chiral anomaly to the phason current, and is locked to the parallel alignment of the electric and magnetic fields. By rotating the magnetic field, we show that the angular dependence of the magnetoconductance is consistent with the anomalous transport of an axionic charge-density wave. Our results show that it is possible to find experimental evidence for axions in strongly correlated topological condensed matter systems, which have so far been elusive in any other context.

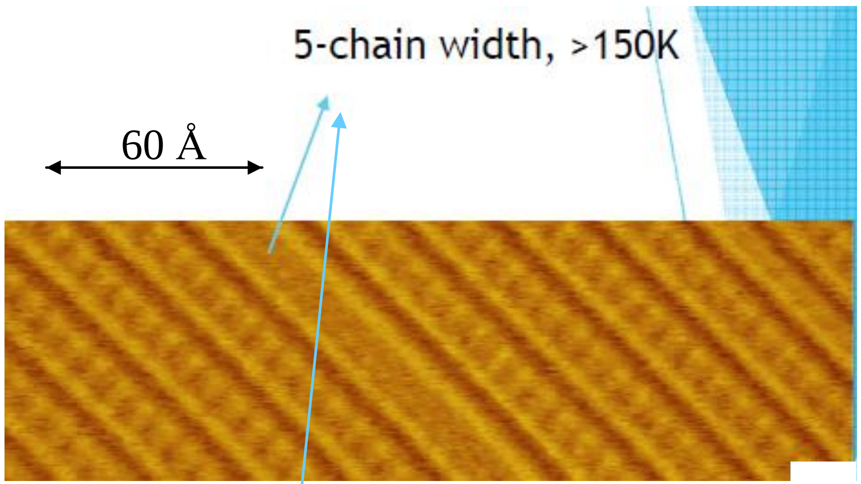
A still stronger assumption: $\sigma_\infty(T)$ follows $\sigma_{qp}(T)$??
And $\mu_{CDW}(T)$ follows $\mu_{qp}(T)$??
On the origin of CDW-0,1: what is condensing therein?



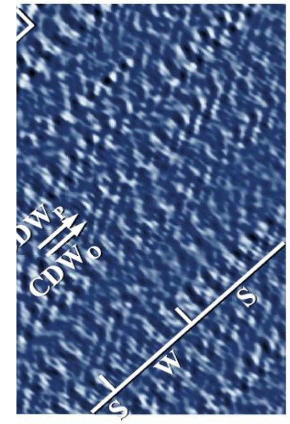


Hopping CDW ??

On the origin of CDW-2: stacking faults?

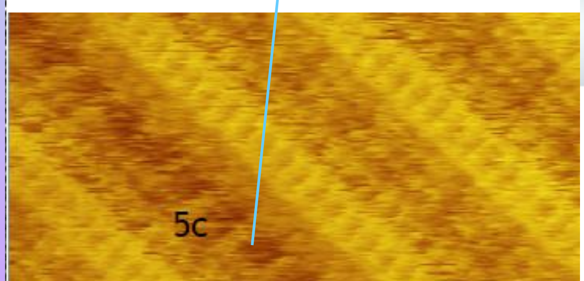


An STM image in the *bc* plain. *T*=160 K, **above** T_{P2}.
CDW- 0 and CDW-1 are seen. The stacking fault is without CDW

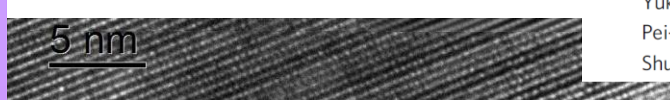


ʋith resolved surface S columns
ɪns, as well as strongly (S) and
esponding IFFT, obtained with
modulation along and between
= 140 K.

ı NbS_3-II



The same at *T*=140 K, **below** *T*
superstructure with 2*b* (or 2.2*b*

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ARTICLE

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https://doi.org/10.1038/s41467-021-26105-1 OPEN

Robust charge-density wave strengthened by electron correlations in monolayer $1T\text{-}TaSe_2$ and $1T\text{-}NbSe_2$

Yuki Nakata[1], Katsuaki Sugawara[1,2,3], Ashish Chainani[4], Hirofumi Oka[3], Changhua Bao[5], Shaohua Zhou[5], Pei-Yu Chuang[4], Cheng-Maw Cheng[4], Tappei Kawakami[1], Yasuaki Saruta[1], Tomoteru Fukumura[6], Shuyun Zhou[5,7], Takashi Takahashi[1,2,3] & Takafumi Sato[1,2,3]✉

The conclusions.

1. NbS_3 crystallizes in a number of polytypes, and phase II is reproducible with certain reservations.
2. NbS_3-II shows 3 CDWs, which can slide.
3. CDW-1 reveals common features of sliding CDWs:
-ShSs up to 20 GHz.
-The oscillations of ShS magnitudes are periodic in CDW travel in t=1/(2f).
-ShSs are observed up to T_{P1}. Time of fluctuations can be found.
4. ShSs allow estimation of charge density of a CDW. Knowing $\delta\sigma$ at T_P one can estimate the mobilities of a CDW and *its* quasiparticles.
5. For all the 3 CDWs $\sigma(E \to \infty) \approx \sigma_{qp}$.
6. For CDW 2,1,0: $n_2:n_1:n_0 \sim$ (1/3-1/1000) : 1 : 2,
$\mu_2:\mu_1:\mu_0 =$ 3 : 0.6: 0.05 (in cm^2/Vs).

7. CDW-2 is seen on the low-Ohmic, S deficient, samples. It is likely, that CDW-2 are 2D formations on the stacking faults.
8. CDW-0 seems to form from hopping holes. Also hopping?

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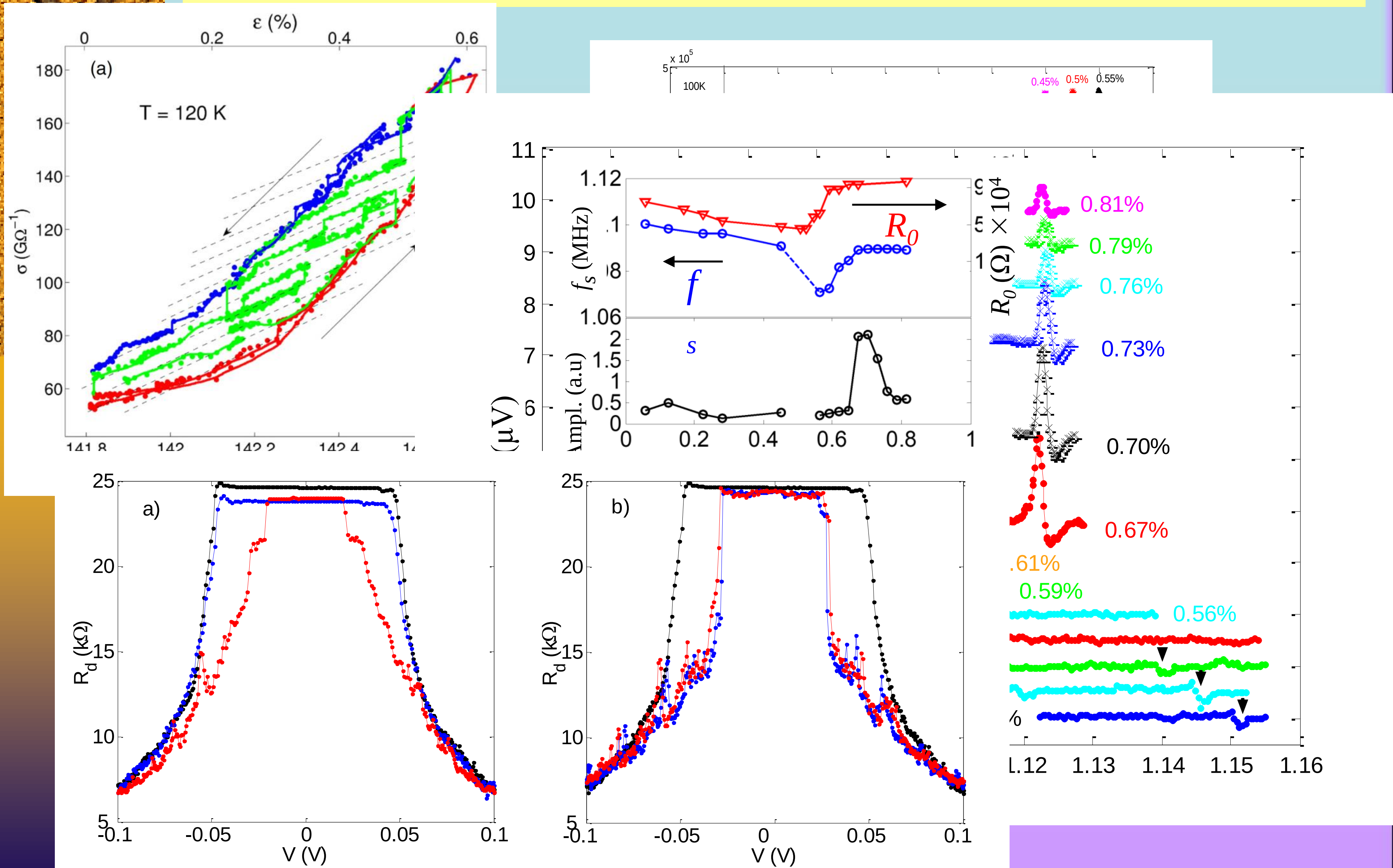
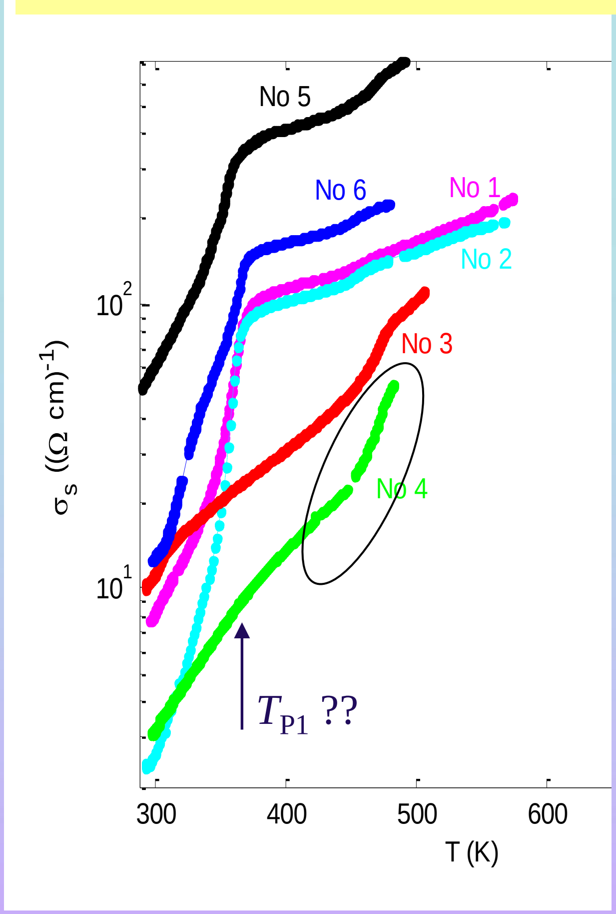
+ “hidden” questions:
- high-*E* limit of CDW conductions
- distribution of CDW between chains

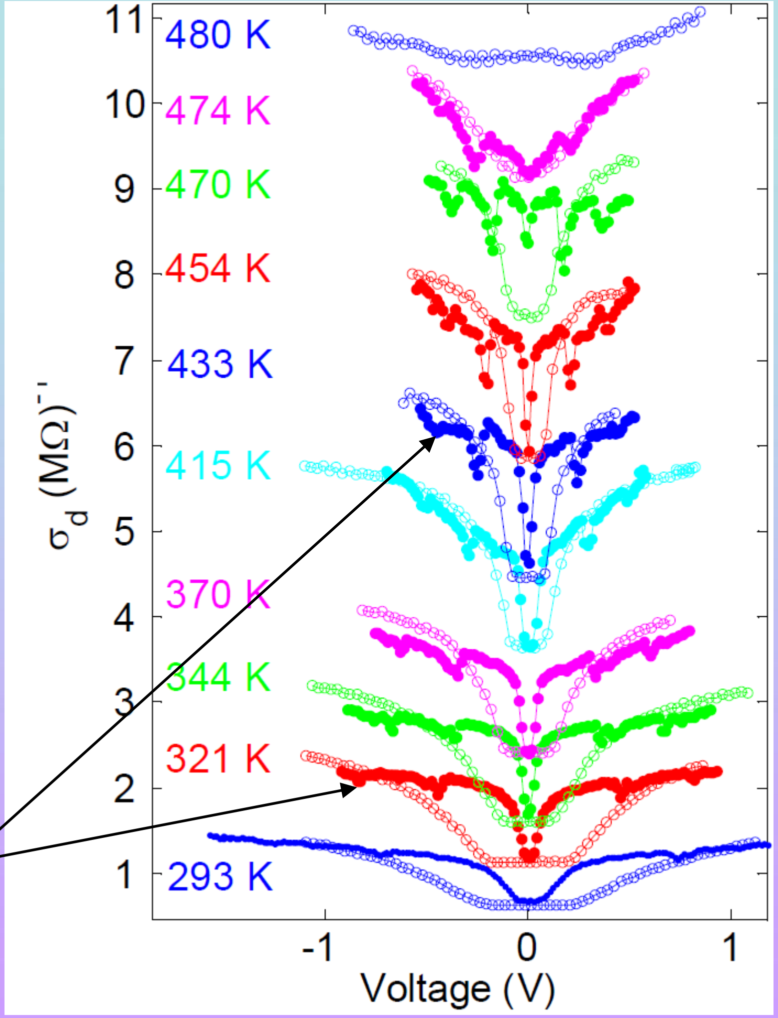
Announcement of a poster “CDWs UNDER STATIC AND DYNAMIC DEFORMATION OF WHISKERS ” /M.V. Nikitin/.



The most recent effects observed

NbS_3-II without T_{P1} ?!





Solid circles – f=10 MHz

Examples of the correlation between σ_{CDW} ($E \to \infty$) and σ_{qp}. TaS_3 – o and m

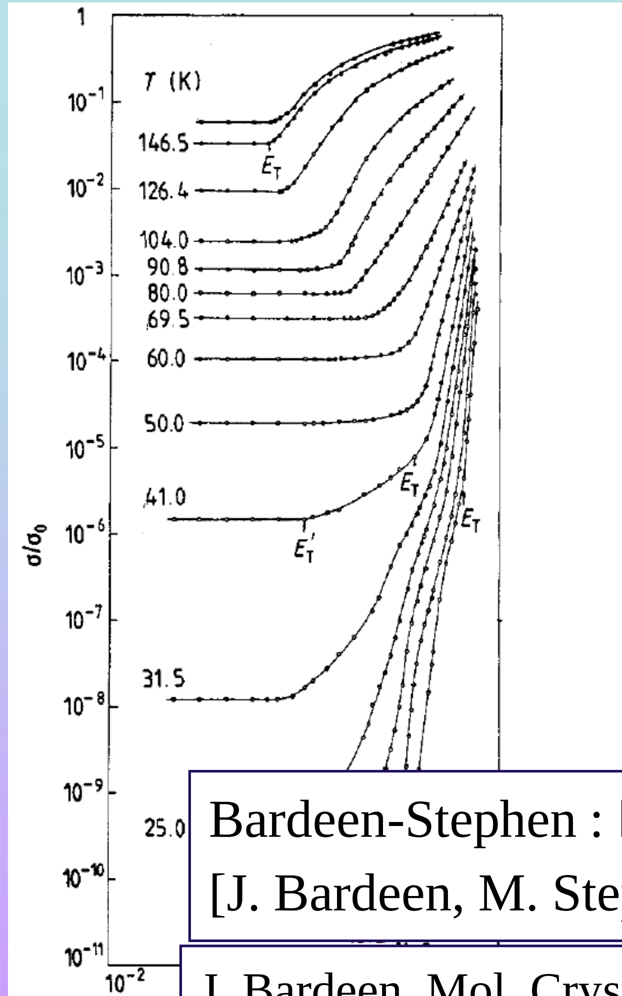
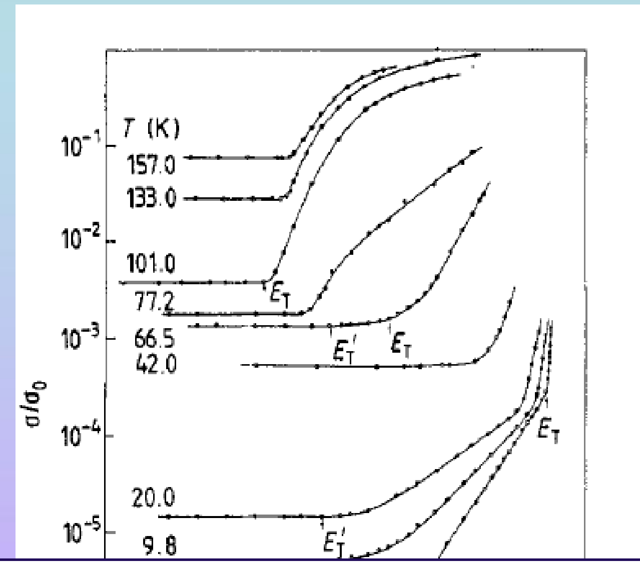


Figure 3. Dep…
to its room-te…
electric field…
peratures are indicated on the curves.

Normalized to σ(300 K) σ(*E*) curves at different *T* for m- (left) and o-TaS3 (right) (из [Itkis et al., J.Phys.Cond. Mat. 2 (1990) 8327]).



peratures are indicated on the curves.

Bardeen-Stephen : $R \sim R_0 \zeta^2 n_f$

[J. Bardeen, M. Stephen. Phys. Rev. **136**, A1485 (1964).].

J. Bardeen, Mol. Cryst. Liq. Cryst. 81 (1982) 1.

L.P. Gorkov and N.N. Dolgov, Zh. Eksp. Teor. Fiz. 77 (1979) 396 [Sov. Phys. JETP 50 (1979) 203].

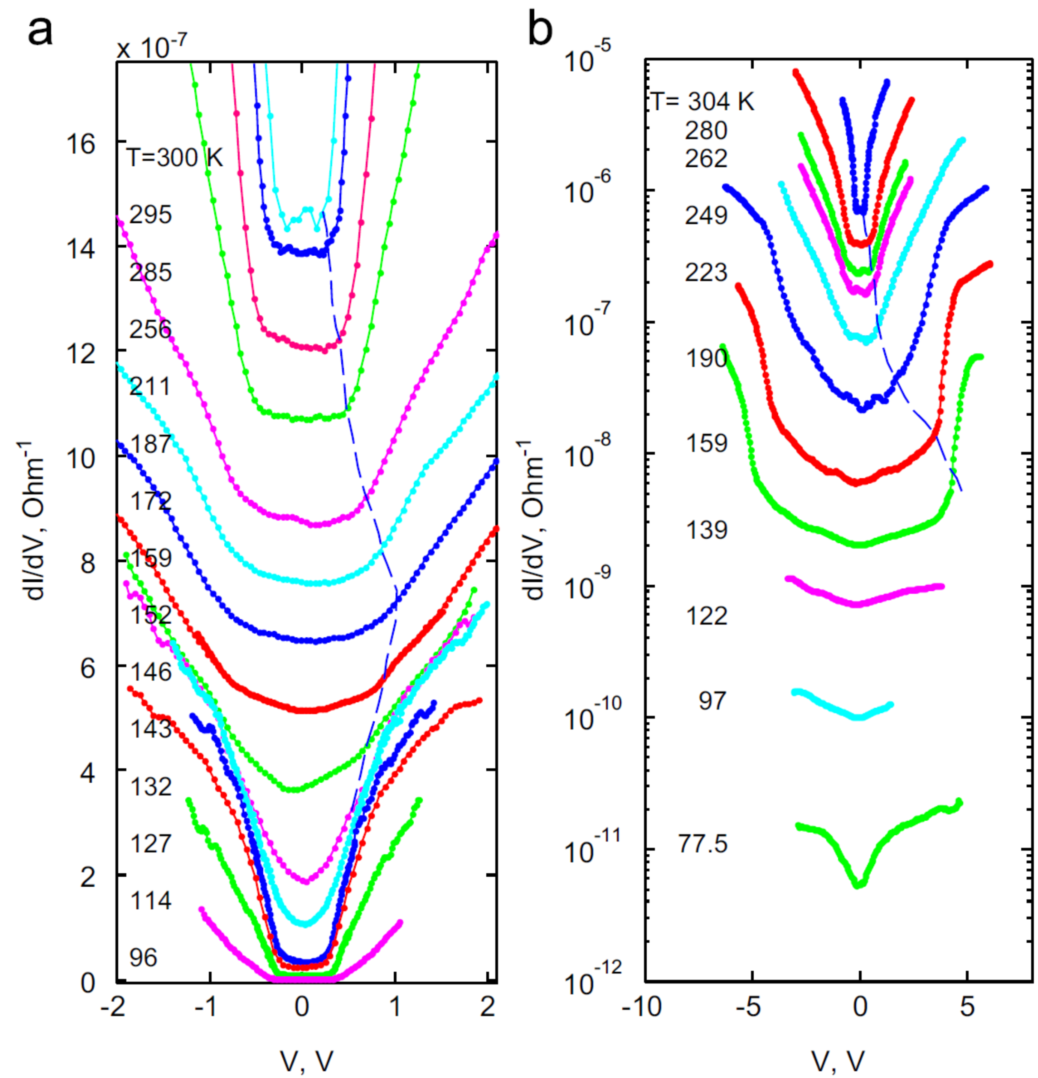


Fig. 3. Differential conductivity vs. voltage at different T for a low-ohmic (a) and a high-ohmic (b) samples.