ESRF

**Experiment title:**
Phase slip and current conversion in the sliding CDW-mode of $NbSe_3$

**Experiment number:**
HS-194

**Beamline:**
ID10 / BL9

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24

**Local contact(s) :**
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## Report:

A characteristic property of charge-density-wave materials (CDW) [l] is the non-linear conductivity when applying an electric field $E$ exceeding a threshold field $E_T$ due to the sliding of the unpinned CDW through the crystal. Thus the quasi-particle current in the electrodes has to be converted to CDW current in the crystal by adding and removing of CDW wave fronts via phase slip processes. This leads to a compression of the CDW near one contact and stretching near the other resulting in a macroscopic spatial variation of the CDW wave vector, i.e. a shift of the CDW satellite position.
The experiment was carried out to follow in detail the variation of the CDW periodicity with high ***momentum*** resolution as well as high spatial resolution, the latter achieved by reducing the beam spot size to $100\mu m$ width, for some measurements even down to $30\mu m$. The measurements were performed on the CDW-compound $NbSe_3$ at a temperature of 90 K on the upper CDW satellite peaks ($T_{P1}$ = 145 K) having a modulation wave vector of (0, $q_1$, 0), $q_1$ = 0.241. The ribbon-shaped sample of cross section 10 x $2\mu m^2$ was mounted on a sapphire substrate. Low-ohmic contacts were prepared by evaporation of thin gold layers leaving a sample length of 4.lmm between the contacts.
Generally, it is observed that the sliding CDW re-pins in a remnantly deformed state after switching off the electric field $E > E_T$. In our earlier measurements [2] the CDW was reset by heating the sample above $T_{P1}$ and cooling it back for further measurements. This time-consuming procedure included the problem of recovering the sample position with respect to the incident beam with sufficiently high precision. To cope with the remnant deformation in a time-saving way, in this experiment we applied a “depolarisation“ technique to reset the re-pinned CDW to its original undeformed state. This technique, similar to a technique applied earlier by [3], allows to keep the sample at low temperature thus avoiding the problems related to a heating-retooling cycle.
The comparably low threshold current of the studied sample offered the possibility to carry out measurements with applied direct current without any measurable effect of ohmic heating. This allowed for the first time to collect data on the complete CDW deformation by ***direct current*** (dc) and to compare

it with data taken with an applied pulsed *current* (PC), where the CDW can relax between pulses. The figures below show the "double"-shift data $2\Delta k = k(I = +4.6mA) - k(I = -4.6mA)$ $(I = 4.6mA = 2.1 \cdot I_T)$ between a contact and the center of the sample: Fig.a) presents the data $2\Delta k$ for applied direct current, Figb) those for applied unipolar pulsed current (I00Hz, pulse length loo/~) with the same current pulse-amplitude. Similar for both data sets, in the central section of the sample the "double"-shift follows an about linear variation with position $y$ along the sample. When approaching closer than about 0.5mm to the contact the satellite shift becomes increasingly non-linear with position y with a maximum at about 1OOpm away from the contact boundary. Within these last 100pm from the contact one observes for both dc and pc a longitudinal splitting in k of the satellite with one part generally returning to a zero shift at the contact boundary and staying at zero within the contact. A second part stays at about the maximum satellite shift observable even within the contact. This satellite splitting suggests an inhomogeneous contact quality across the sample width leaving parts of the CDW pinned while neighbouring CDW are already sliding. However, this interpretation cannot explain, why the split profiles are mostly found when applying a current $I < 0$, and that for some satellite profiles one part does not return to zero shift, but shifts beyond zero as for the opposite current polarity.
When comparing the data sets for dc with that for pc one observes an about equal shift in the center section with its linear dependence $2\Delta k(y)$, but an increasing difference in shift in the section with non-linear behaviour starting at about 0.5mm from the contact up to the contact boundary. At the maximum of the satellite shift one finds $2\Delta k_{dc} \approx 2 \, . \, 2\Delta k_{pc}$. This difference between dc- and pc-data suggests a relaxation of the unpinned CDW during the pauses between the pulses (about 10ms) with a strong spatial dependence of the relaxation time scales: very close to the contact the relaxation times are shortest, increasing with distance from the contact and becoming finally significantly longer than the pauses between current pulses when reaching the section of linear dependence $2\Delta k(y)$. This spatial dependence of CDW relaxation behaviour is in good qualitative agreement with results by Adelman et al.[4] obtained from spatially resolved electrical measurements and simulations.

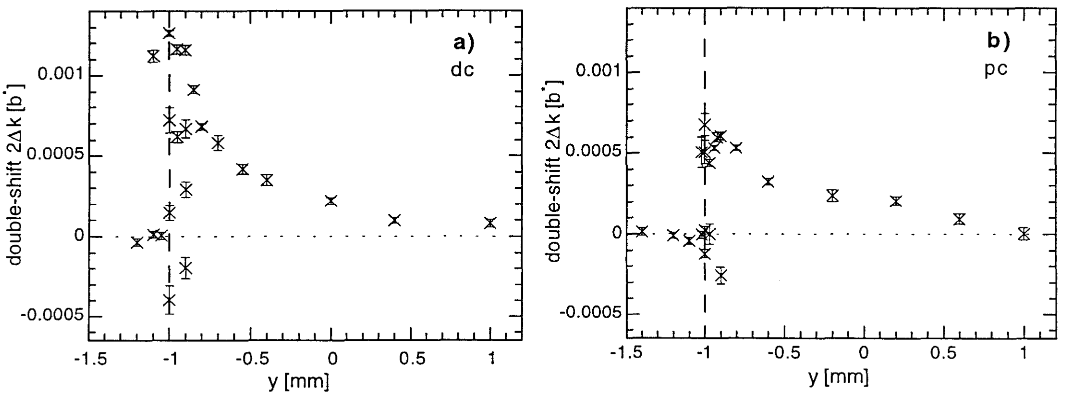


Fig.: "double"–shift $2\Delta k$ of the high temperature CDW satellite at (0, 1.241, 0) at $T$ =90 K for applied currents of $I = \pm 4.6mA = \pm 2.1 \cdot I_T$. a) For direct current (dc), b) for pulsed current (pc). The dashed line represent the contact boundary.

References :

[l] For a recent review on CDW *see: Physics and Chemistry of Low-Dimensional Inorganic Conductors*, NATO AS1 Series B, vol.354. Eds.: C.Schlenker, J.Dumas, M.Greenblatt, S.van Smaalen. Plenum Press, 1996.

[2] P.Monceau, H.Requardt, R.Currat, F.Ya Nad', J.E.Lorenzo and Ch.Vettier. ESRF Annual Report 1995/1996.

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[4] T.L.Adelman, M.C.de Lind van Wijngaarden, S.V.Zaitsev-Zotov, D.DiCarlo and R.E.Thorne. Phys.Rev. B 53 (1996) 1833.