Collaborative workshop „Charge density waves: small scales and ultrashort time"
Vukovar, Croatia, 28 – 31 October 2010.

Size effects on the CDW pinning in the blue bronze $K_{0.30}MoO_3$

J. Dumas[1] and J. Marcus

Institut Néel, CNRS, BP166, 38042 Grenoble cedex 9, France

[1]phone: 33 4 76 88 74 60, email : jean.f.dumas@grenoble.cnrs.fr

The blue bronzes $K_{0.30}MoO_3$ show a Peierls transition at 180 K towards an incommensurate semiconducting charge density wave (CDW) ground state. The crystal structure consists of clusters of ten MoO_6 octahedra arranged in chains along the [010] direction, the high conductivity b-axis of the monoclinic unit cell. The chains are bonded in sheets along the [102] direction and separated by the alkaline ions, so that the crystals can be easily cleaved along the (-201) plane.

The CDW properties depend on the size of the system when crystal dimensions are comparable to the CDW correlation lengths. While systematic studies for pure and doped $NbSe_3$ and TaS_3 are well documented [1,2] no such detailed studies in $K_{0.30}MoO_3$ were performed up to now mainly because crystals grow three dimensionally reaching comparatively a large volume. In an effort to provide insight into the depinning process, we have investigated needle-like samples and compared with bulk crystals. We present the results of a study of size effects (thickness t and width w) on the threshold field E_t measured at $30\ K < T < 140\ K$ on bulk crystals and $77\ K < T < 160\ K$ on needles and nonlinear conductivity. E_t for needles is found to be much larger than in bulk crystals and temperature independent. The nonlinear conductivity of needles shows a non monotonous behaviour as a function of temperature.

Experimental results and discussion

The typical dimensions of the crystals were: 4 x 2 x 0.2 mm^3 corresponding to the b axis, [102] and [-201] directions respectively. For needle-like samples obtained after repeated cleavages, the dimensions were L = 2 mm, width $0.05\ mm < w < 2.5\ mm$, thickness $0.04\ mm < t < 0.2\ mm$. Measurements were performed with the standard four-probe configuration. A well defined threshold field E_t for the onset of CDW sliding is observed, $E_t = 1$ V/cm at 78 K. This threshold is approximately ten times larger than that observed on bulk samples [3].

Figure 1 shows E_t as a function of the width w of the samples for a given thickness $t = 90\ \mu m$: E_t is found to increase rapidly when w < 0.2 mm: E_t (78 K) = 100 mV/cm for w = 2.5 mm and E_t reaches 2.5 V/cm for w = 0.05 mm. We found no obvious correlations between E_t and the thickness in the explored range. Our results are corroborated by previous results at 77 K: $E_t = 2$ V/cm for a sample with w = 0.1 mm and t = 1 μm [4]; $E_t = 320$ mV/cm for w = 0.5 mm and t = 0.2 μm [5].

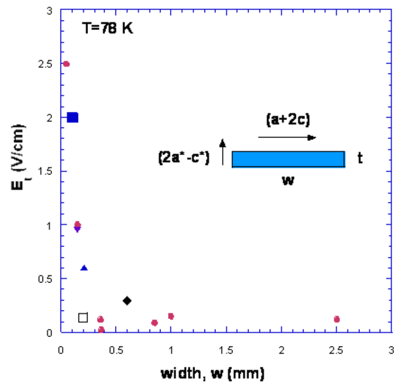

Figure 1. Threshold field at T = 78 K as a function of the width of the samples. (♦) from ref. [5].

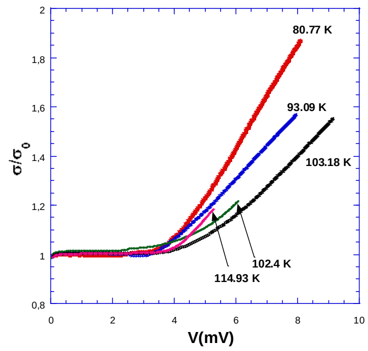

Figure 2 (a). Nonlinear conductivity normalized to the Ohmic conductivity at different temperatures vs dc voltage.

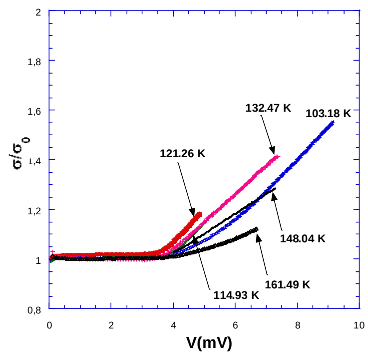

Figure 2 (b). Same as in Fig. 2(a) for different temperatures.

Figures 2 (a,b) show the nonlinear conductivity $\sigma = I/V$ normalized to the Ohmic conductivity $\sigma 0$ plotted as a function of dc voltage at different temperature for a needle-like sample. It can be seen that the threshold voltage for the onset of nonlinearity is nearly temperature independent and that the nonlinear conductivity at given voltages is not a monotonous function of the temperature.

The temperature dependence of the threshold field normalized to its value at 78 K is compared in Figure 3 for bulk and needle samples. While E_t is strongly temperature dependent in bulk samples [3], in needle-like samples E_t, measured only above 78 K, remains nearly temperature independent.

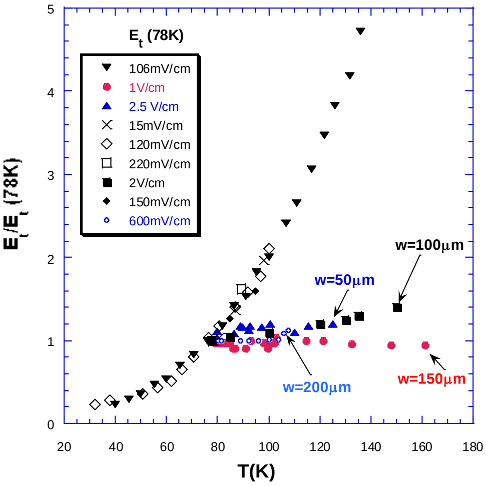

Figure 3. Threshold field as a fuction of temperature normalized to the threshold at 78 K for bulk samples and needles.

Figure 4 shows the normalized nonlinear conductivity σ/σ_0 as a function of temperature for different values of the dc voltage above threshold. σ/σ_0 decreases monotonously when the temperature increase from 80 K to ~100 K then shows a rapid rise in the temperature interval 100 K - 130 K and finally decreases as T approaches 180 K.

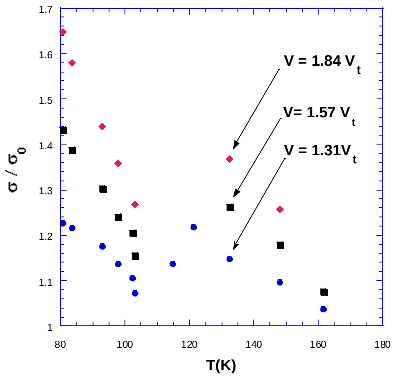

Figure 4. Normalized conductivity vs temperature for different values of the dc voltage.

In the weak pinning 3D Fukuyama-Lee-Rice model with no confinement of CDW, E_t is independent of w and t. In the 2D confinement case $E_t = 1/t$ and in the 1D case $E_t = (w{\cdot}t)^{-2/3}$ when the CDW is confined both in width and thickness [6].

In the context of CDW dislocations model, for surface pinning, $E_t \sim K_{\perp}/t$ where $K_{\perp}$ is the CDW elastic constant in the transverse direction [7].

In $K_{0.3}MoO_3$ the phase coherence lengths are strongly anisotropic. Since the thickness of the samples was always larger than the coherence length in the transverse direction, no thickness dependence is expected. The strong dependence of E_t upon the width w when the CDW is confined in the width direction reflects important in-plane couplings of MoO_6 octahedra and a large lateral phase coherence length. In $K_{0.3}MoO_3$, w plays the role of t.

While E_t increases rapidly with temperature in bulk samples, E_t in needles is temperature independent. A new mechanism is involved possibly related to the nucleation of CDW dislocations.

CDW damping by normal carriers is expected to give a monotonous variation of σ/σ_0 with temperature. In our needle samples, the nonlinear conductivity is non monotonous. Therefore, other processes are involved to explain the increase of σ/σ_0 between 100 K - 130 K. We suggest that a change with temperature in the mobility or structure of CDW dislocations generated through the crystal under the effect of the electric field may occur near 100 K which in turn induces a change in σ/σ_0 [8].

Edge dislocations would be dominant above ~ 100 K while screw dislocations would be dominant below ~ 100 K. Since the screening becomes more important as the temperature increases, it may obviate the cost in Coulomb energy for edge dislocations. Screw dislocations have smaller energies than edge dislocations and they do not involve dilatation or compression along the b axis which produce an excess or charge default expensive in Coulomb energy.

In summary, we have shown that in needle samples of blue bronzes the threshold field is approximately one order of magnitude larger than in bulk crystals, temperature independent and varies strongly with the width of the sample. In addition, the nonlinear conductivity shows a maximum near 130 K.

References

[1] J. McCarten, D.A. DiCarlo, M.P. Maher, T.L. Adelman, R.E. Thorne, Phys. Rev. B **46**, 4456 (1992).
[2] S.V. Zaitsev-Zotov, Physics Uspekhi **47**, 533 (2004).
[3] G. Mihaly, P. Beauchêne, J. Dumas, J. mMrcus, C. Schlenker, Phys. Rev. B **37**, 1047 (1988).
[4] W. Xue-Mei, Z. Dian-Lin, Solid State Commun. **91**, 283 (1994).
[5] M.F. Hundley, A. Zettl, Phys. Rev. B **39**, 3026 (1989).
[6] E. Slot, H. S. J. van der Zant, K. O'Neil, R. E. Thorne, Phys. Rev. B **69**, 073105 (2004).
[7] J. Dumas, D. Feinberg, Europhys. Lett. **2**, 555 (1986); D. Feinberg, J. Friedel, J. Physique **49**, 485 (1988).
[8] S.N. Artemenko, F. Gleisberg, W. Wonneberger, J. Physique IV, **9**, Pr100-101 (1999).