Temperature hysteresis in dielectric and transport properties of charge density wave system o-TaS_3

D. Dominko[1], D. Starešinić[1], K. Biljaković[1], P. Lunkenheimer[2] and A. Loidl[2]

[1] *Institute of Physics, University of Zagreb, 10001 Zagreb, Croatia*
[2] *Experimental Physics V, University of Augsburg, 86135 Augsburg, Germany*

Abstract. We report on the temperature hysteresis observed in low frequency dielectric response and in nonlinear conductivity of charge density wave (CDW) system o-TaS_3. Between CDW transition temperature at 220 K and the glass transition temperature at 50 K both the amplitude and the relaxation time of the low frequency relaxational process are higher on heating than on cooling with similar temperature dependence as the well-known hysteresis in low field resistivity, but different hysteresis width. On the other hand, the hysteresis in the nonlinear conductivity can be seen only as the difference between the initial and subsequent I/V characteristics at given temperature implying field-induced relaxation from history dependent metastable states to stable, history independent state.

In many charge density wave (CDW) systems temperature (T) dependence of DC conductivity exhibits stable, rate independent hysteresis [1] below the CDW transition T down to several times smaller T. It is considered to be a consequence of different configurations on cooling and heating of CDW pinned by random impurities. As the low frequency dielectric spectroscopy and nonlinear conductivity measurements at low electric fields probe directly the properties of CDW metastable states, we have used these techniques to study one of the canonical CDW systems, o-TaS_3.

Frequency dependent dielectric response $\varepsilon(\nu)$ has been measured from RT down to about 20 K in the linear response regime using impedance analyzer Agilent 4294. Nonlinear conductivity $\sigma(E)$ has been measured in the same temperature (T) range in a 4 contact configuration using Keithley 220 current source and Keithley 2182 nanovoltmeter. The electric field (E) in the sample was varied from at least 10 times smaller than E_T up to few times E_T.

T dependence of Re ε on cooling and heating, presented in Figure 1 at selected ν, reveals huge, rate independent hysteresis. The ν dependence of Im ε at 100 K, given in the inset of Figure 1, shows that the hysteresis is a property of low ν relaxational process only (α process in [2]), and that both the amplitude and the mean relaxation time τ are higher on heating. T dependence of ν-independent resistivity ρ_{DC}, measured at low νs and of τ is presented in Figure 2. While the ν-independent conductivity, $\sigma_{DC} = 1/\rho_{DC}$, is lower on heating than on cooling, as typically observed, the ν-dependent part of the conductivity, $\varepsilon(\nu) = (\sigma(\nu) - \sigma_{DC})/(i \cdot 2\pi\nu)$, is higher on heating. Moreover, the hysteresis width, i.e. the ratio on heating and cooling, presented in the inset of Figure 2, is the same for ρ_{DC} and ε. As it has been shown that the amplitude of low-$\nu\varepsilon$ increases with the CDW phase corrugation [3] (therefore corrugation would be higher on heating), it might be that the hysteresis in ρ_{DC} is actually governed by the scattering of free carriers on corrugated phase (again higher on heating), and not by the free carrier concentration due to CDW wave vector changes [4].

As both $\varepsilon(\nu)$ and E_T are related to CDW pinning, we have expected to observe the thermal hysteresis in $\sigma(E)$ as well. $\sigma(E)$ curves on cooling and on heating at 90 K, presented in Figure 3, differ only for the first electric field (E) increase and merge at high E. Determination of threshold field E_T is only possible for second runs which give the same values for cooling and heating. The differences of $\sigma(E)$ in first and second run, $\Delta\sigma = \sigma_1(E)$-$\sigma_2(E)$, in Figure 4 which represent irreversible relaxation, have the same E dependence on both cooling and heating. Moreover, the fastest change of $\Delta\sigma$gccurs near E_T (inset

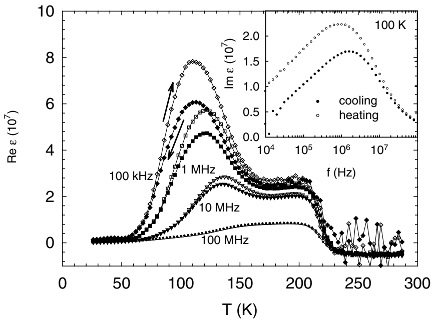

Figure 1. T dependence of Re ε on cooling and heating at selected ν. Inset: ν dependence of Im ε at 100 K.

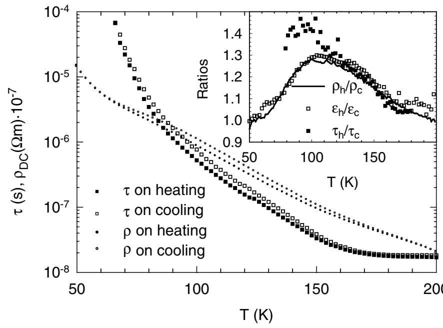

Figure 2. T dependence of τ and ρ_{DC} on cooling and heating. Inset: ratios of ρ_{DC}, Re ε and τu.

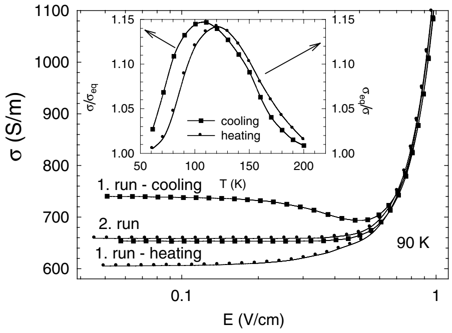

Figure 3. First and second run of σ(E) at 90 K on cooling and heating. Inset: ratios of initial and relaxed low E σ.

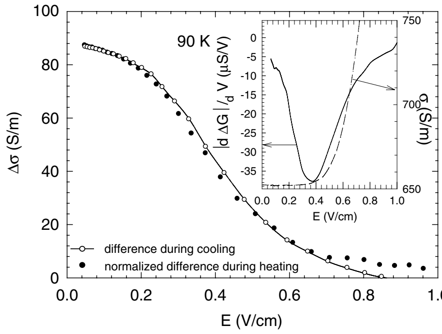

Figure 4. Δσ on cooling and heating (multiplied by −1.9 factor. Inset: Δσ change rate and σ(E) in second run.

of Figure 4), pointing to the same microscopic mechanism of σ relaxation and depinning. The relative change of σ(E→0) after first depinning (i.e. the amplitude of Δσ) is strongly T dependent and different for cooling and heating, as seen in the inset of Figure 3.

Thermal hysteresis is observed in low frequency dielectric response and low field nonlinear conductivity of CDW system o-TaS_3. It can be attributed to the low frequency relaxation process and corresponding low energy modes which can be relaxed already at low electric fields.

References

[1] Z. Z. Wang, N. P. Ong, Phys. Rev. B **34**, 5967 (1986) and references therein

[2] D. Starešinic K. Biljakovic, Brütting, K. Hosseini, P. Monceau, H. Berger, F. Levy, Phys. Rev. B **65**, 165109 (2002)

[3] P. B. Littlewood., Phys. Rev. B **33**, 6694 (1986)

[4] S. N. Artemenko, V. Y. Pokrovskii, S. V. Zaitsev-Zotov, JETP **83**, 590 (1996)