Bolometric response of charge-density waves

R. Gaal, A. Beleznyay, G. Mihaly

► To cite this version:

R. Gaal, A. Beleznyay, G. Mihaly. Bolometric response of charge-density waves. Journal de Physique IV Proceedings, 1993, 03 (C2), pp.C2-361-C2-364. 10.1051/jp4:1993272 . jpa-00251355

HAL Id: jpa-00251355

<https://hal.science/jpa-00251355>

Submitted on 1 Jan 1993

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Bolometric response of charge-density waves

R. GAAL, A. BELEZNAY and G. MIHALY

Research Institute for Solid State Physics, P.O. Box 49, 1525 Budapest, Hungary

Abstract

The large dielectric constant associated with charge-density waves has been used to find low level bolometric signal in $K_{0.3}MoO_3$. We have investigated the frequency dependence of the minimal detectable power at various temperatures. Due to the broad distribution of the dielectric relaxation times the parameters of the bolometric response can be optimized over a wide frequency range of the detection.

The dielectric constant of $K_{0.3}MoO_3$ is strongly temperature dependent in the frequency and temperature range where internal CDW deformations dominate the polarization. Below about $T \approx 60$ K the low frequency dielectric constant drops exponentially with decreasing temperature. The activation energy is close to the single particle gap (1). In the present work we used this feature to detect minor changes in the temperature of the sample generated by irradiation with infrared light.

We applied a double lock-in technique to measure the bolometric response. The electric circuit of the experiment is shown on Fig. 1. The infrared beam was chopped at a 50% duty cycle with a period of ω_T . The resulting periodic modulation of the sample temperature was detected in the following way: the first lock-in measured the dielectric constant of the sample at a frequency ω , while the second one detected the analog output of the first lock-in ($\omega \gg \omega_T$). The second lock-in was triggered from the light chopper in order to measure the change in the dielectric constant caused by the irradiation. The chopping frequency was varied between 20-100 Hz, while the frequency applied in the capacitance measurement was $500 \text{ Hz} < \omega < 120 \text{ kHz}$.

Fig. 1. The electrical circuit used in the experiments.

In the above arrangement the responsivity of the capacitive bolometer, i. e. the change of the voltage signal (ΔV) due to the variation of the incident power (ΔW), is given by the following expression:

$$r = \frac{\Delta V}{\Delta W} = \frac{U_0 \omega C R}{G_T \sqrt{1 + \omega_T^2 \tau_T^2}} \frac{T^*}{T^2} \quad (1)$$

Here U_0 is the amplitude of the driving voltage, C is the capacitance of the bolometric sensor, R is the value of the reference resistor used to detect the current ($R \ll 1/\omega C$) and G_T is the heat conductance between the crystal and the environment. The thermal time constant of the crystal is $\tau_T = C_T/G_T$, where C_T is its heat capacitance. Deriving the above relation we assumed a temperature dependence in the form of $\varepsilon(T) \sim \exp \{-T^*/T\}$.

In our experiments the theoretical value of the sensitivity is determined by the Johnson noise of the sample. Neglecting other possible noise sources (e.g. current noise, $1/f$ noise etc.) the theoretical limit for the minimal detectable power is

$$W_{\min}^2 = r^2 4kT \operatorname{Re}(Z) \Delta f = 4k \frac{G_T (1 + \omega_T^2 \tau_T^2)}{(U_0 \omega C R)^2} \frac{T^5}{T^*} \Delta f \quad (2)$$

where, Z is the impedance of the sample. The responsivity goes linearly with ωC while the noise is inversely proportional to ωC . It is important to notice that in case of our CDW sensor the capacitance, C , is also frequency dependent down to extremely low frequencies. As discussed below this unusual frequency dependence allows a broad range of frequencies for bolometric detection.

Figure 2 shows the temperature dependence of $\varepsilon(\omega)$ measured at various frequencies in $K_{0.3}MoO_3$. Though the accuracy of a capacitance measurement decreases as the frequency is lowered, from the point of temperature detection this is compensated by the increase in the slope, $\delta\varepsilon(\omega, T)/\delta T$. The goal of the experiments was to explore the optimal frequency and temperature range for bolometric detection.

Fig. 2. Temperature dependence of the dielectric constant at various frequencies.

Fig. 3. Time dependence of the Joule and radiation heating.

In order to characterize the system first we determined the thermal parameters C_T , G_T and τ_T . The sample was heated up by application of an electric pulse and the temperature rise was detected by measuring the time dependence of the current. From the curve, shown on Fig. 3, we deduced the above parameters with a method similar to that described elsewhere (2). In order to calibrate the incident light power we performed a similar experiment with infrared irradiation: the time dependence of the analog output of the lock-in measuring the dielectric constant was recorded after turning on the light. The result is also shown on Fig. 3. (In both cases the temperature scale has been calibrated by changing the set point of the temperature controller.) Comparing the temperature change in the two cases we were able to determine the light power at the sample position. In the experiments discussed below we applied a power of $W = 5 \mu\text{W}$.

The thermal parameters C_T , G_T and τ_T , as well as the geometrical factor determining the capacitance strongly depend on the actual size of the sample. The dimensions of the crystal studied in the present work were $0.29 \times 1.0 \times 1.14 \text{ mm}^3$ with the conducting chains in the shortest direction. We have not investigated the effect of the sample geometry on the signal and the noise of the bolometer. Note also that the S/N ratio increases with the square of the driving voltage. In spite of this we performed the experiments at low level ($U_0 = 25 \text{ mV}$ and $R = 500 \Omega$) in order to ensure the same electronic noise level both for the signal and noise measurement.

The results are summarized on Figs. 4 and 5 for experiments carried out with chopping fre-

Fig.4. Temperature dependence of the bolometric signal and noise detected at various frequencies.

quency of $\omega_T = 40$ Hz. (Since the thermal time constant is about 1 s, for frequencies above 10 Hz both the signal and the noise are simply proportional to the modulation period. No other significant dependency on ω_T has been observed.) In all experiments the noise and the signal have been determined using the same bandwidth of 0.3 Hz. Figure 4 demonstrates that the optimal operation is around $T = 35$ K, where the current modulation due to the periodic change of the sample temperature has a maximum for most frequencies applied for the detection of sample capacitance. In the same temperature interval the noise level approaches the theoretical limit. On Fig. 5 the frequency dependence of the signal and noise are shown. We found that the S/N ratio does not change significantly from $\omega = 5$ kHz to 80 kHz, and this offers a broad range for the light chopping frequency, as well.

Fig. 5. Frequency dependence of the signal and the noise measured at $T = 35$ K.

The noise level achieved experimentally shows that we were able to detect a temperature variation of $\Delta T = 10 \mu\text{K}$ corresponding to a beam power resolution of 10^{-8} W. The minimal detectable power can be considerably lowered by choosing better sample geometry, larger driving voltage, etc. In this work our aim was just to demonstrate a new principle for bolometric detection. We showed that the huge dielectric constant of CDW materials allows their application for this purpose and we have mapped up the characteristic features of the frequency and temperature dependencies.

This work was supported by the Hungarian Scientific Research Foundation under Grant No. 2944 and 7277.

References

1. Kriza G., Kim Y., Beleznay A. and Mihaly G., Solid State Commun. **79** (1991) 811.
2. Gaal R., Donovan S., Sorlei Zs. and Mihaly G., Phys. Rev. Lett. **69** (1992) 1244.