NONLINEAR BEHAVIOR OF CDW CONDUCTORS AT MICROWAVE FREQUENCIES

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Abstract

Results of phase-resolved microwave harmonic mixing (PREHM) experiments on $(TaSe_4)_2I$ are compared with various theoretical models. Additional experiments show that contact contributions to the mixing signal are negligible.

Introduction

Although several classical models [1-4] as well as a quantum mechanical model [5] have been proposed for an explanation the mechanism of CDW transport is still controversial. To elucidate this problem we have studied in the past the non-ohmic behavior of trichalcogenides [6,7,8] at microwave frequencies using the method of phase-resolved microwave harmonic mixing (PREHM) [9] which is described elsewhere in this volume [10]. In this paper we report results on $(TaSe_4)_2I$ samples whose relevant material parameters were known. Therefore the comparison of the experimental results with the theories can be done for the first time without the use of any fit parameter.

Results and discussion

Fig. 1 shows the dependence of the $\cos(2\phi)$-dependent contribution U_2 of the measured mixing signal U_{mix} on the amplitude E_ω of the fundamental frequency ω for a constant ratio $E_\omega/E_{2\omega}$ corresponding to a E_ω^3 law for ω = 9.5775 GHz and 19.0 GHz. This dependence is predicted by all the models [3,4,5] except by the overdamped oscillator model [2]. This latter model which treats the CDW as a rigid entity predicts regions of E_ω where U_2 vanishes alternatingly with regions where U_2 increases strongly with an E_ω^{10} law to some value where it starts to decrease again just as steeply [8]. A calculation of U_2 based on the Bardeen model [5] yields values which are in excellent agreement with the experimental values without the use of any fit parameter in the investigated temperature range from 210 K up to 260 K [11]. In contrast Matsukawa's perturbational analysis of the Fukuyama-Lee-Rice model [1] gives values of U_2 which are by a factor of 3×10^3 higher than the experimental results [11]. As indicated in Fig.1 the ω^{-3} law predicted by the tunneling model [5] and by most of the classical models [3,4]

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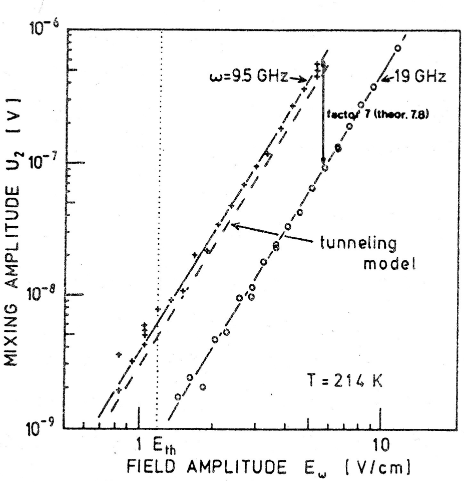
is obeyed, too, within an accuracy of 10%. To rule out the possibility of U_2 consisting of the superposition of the CDW response and of a contribution arising from eventually rectifying sample contacts exposed to microwave fringe fields outside the waveguide, we made two measurements on one and the same $NbSe_3$ sample for different positions of the sample inside the waveguide. The upper curve in Fig. 2 was obtained with the sample centered in the waveguide and the two contacts outside. A second measurement was made with the sample shifted in the waveguide so that one of the contacts was centered in the guide. These data are represented by the second curve which is by up to a factor of 10 below the first one and also is very noisy. Therefore we conclude that the contribution of the contact to U_2 is negligibly small. In contrast to CDW conductors where U_2 shows an $E_\omega{}^3$ behavior followed by a gradual deviation from this law at very high power levels [6,7,8] in a microwave diode there is an abrupt kink from an $E_\omega{}^3$ law to an $E_\omega{}^{2.46}$ law at relatively low microwave powers . Furthermore there is a $\cos(4\phi)$-dependent contribution to U_{mix} which reaches 20% of the value of U_2. The existence of U_4 is theoretically expected for an asymmetric I–V characteristic [8] and has never been seen in the case of a CDW conductor where instead a $\cos(6\phi)$-dependent contribution becomes important for $E_\omega \approx 200$ V/cm as expected from theory [9].



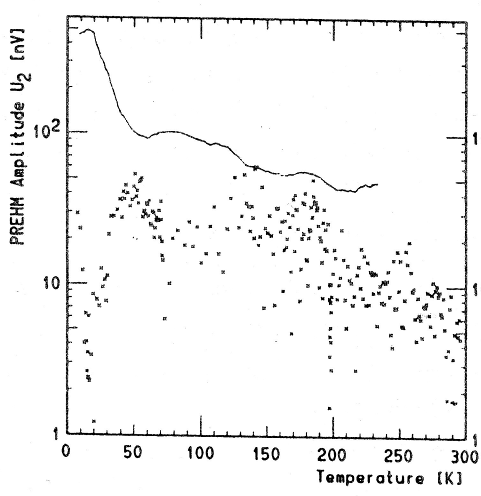


Fig.1: PREHM amplitude U_2 in $(TaSe_4)_2I$ vs. microwave field strength E_ω for $E_\omega/E_{2\omega}=2$ at 214 K. The vertical dotted line corresponds to $E_\omega + E_{2\omega} = E_{th}$, the dashed line to the Bardeen-model [5]. Full lines represent an E_ω^3 law.

Fig.2: PREHM amplitude U_2 in $NbSe_3$ vs. temperature with the sample centered in the waveguide (full curve) and with the contact centered in the waveguide (x).

Conclusion

PREHM experiments yield results which are in excellent quantitative agreement with the Bardeen model [5] but with some classical calculations [3,4] at best only in qualitative agreement. Contact contributions to the mixing signal are shown to be negligibly small.

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