NONLINEAR BEHAVIOR OF CDW CONDUCTORS
AT MICROWAVE FREQUENCIES

A. Philipp, W. Mayr, and K. Seeger
Institut für Festkörperphysik der Universität Wien, and
Ludwig Boltzmann Inst. für Festkörperphysik, Kopernikusg. 15, A-1060 Wien, Austria

Abstract

Results of phase-resolved microwave harmonic mixing (PREHM) experiments on (TaSe₄)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 (TaSe₄)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(2φ)-dependent contribution \(U_2\) of the measured mixing signal \(U_{\text{mix}}\) on the amplitude \(E_\omega\) of the fundamental frequency \(\omega\) for a constant ratio \(E_\omega/E_{2\omega}\) corresponding to a \(E_\omega^3\) law for \(\omega = 9.5775\) 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 \(E_\omega\) where \(U_2\) vanishes alternatingly with regions where \(U_2\) increases strongly with an \(E_\omega^{40}\) 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 \(3 \times 10^3\) higher than the experimental results [11]. As indicated in Fig.1 the \(\omega^{-3}\) law predicted by the tunneling model [5] and by most of the classical models [3,4]

(received October 31, 1989)
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 $E_\omega^2$ 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](image1.png)

**Fig.1:** PREHM amplitude $U_2$ in (TaSe$_4$)$_2$I vs. microwave field strength $E_\omega$ 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 $E_\omega^3$ law.

![Fig.2](image2.png)

**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

PREHGM 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.

Acknowledgements

Work supported by the Fonds zur Förderung der wissenschaftlichen Forschung in Österreich, grants nos. P5359 and P7014. We gratefully acknowledge the donation of (TaSe$_4$)$_2$I samples by G. Grüner, University of California, Los Angeles, USA and of microwave diodes by Alpha Ind., USA.

References

8 K. Seeger, Synthetic Metals 15 (1986) 361
10 A. Philipp, W. Mayr, “Microwave experiments on YBa$_2$Cu$_3$O$_{9-y}$“, this volume
11 A. Philipp, Z. Physic B-Condensed Matter 75 (1989) 31