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Non-linear conduction in a quasi one-dimensional conductor at low temperatures

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Abstract. The current-voltage characteristics of a quasi one-dimensional organic system having asymmetric donor molecule like Qn-$(TCNQ)_2$ pellet with stoichiometry 1:2 grown from acetonitrile as a solvent have been studied at $T = 69$ K. The characteristic curves show a pronounced deviation from ohmicity beyond a certain value of current. For higher values of currents a negative differential resistance region is observed.

Keywords. Non-ohmic conduction; charge transfer complex; quasi one dimensional conductor; negative differential resistance.

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1. Introduction

Charge transfer complexes grown with TCNQ (tetra-cyanoquinodimethane) as an acceptor are found to have probably the least resistivity at room temperature (Melby *et al* 1962). Qn-$(TCNQ)_2$ {quinolinium-$(TCNQ)_2$} pellet has a room temperature resistivity of about 0·47 Ω cm and is found to exhibit semiconducting behaviour in the temperature range studied (10 K to 300 K). The current-voltage ($I - V$) characteristics of Qn-$(TCNQ)_2$ have been studied at 69 K which show a marked deviation from ohmicity. The non-ohmic behaviour is explained on the basis of power law consistent with space charge limited currents. For the higher currents a negative differential resistance region is observed.

2. Experimental

Qn-$(TCNQ)_2$ has been prepared by the method due to Williams *et al* (1985), with acetonitrile as the solvent medium. The complex is synthesized in powder form and then pressed in pellet form. It has been characterized by using spectroscopic, X-ray diffraction and microanalysis techniques. All low temperature measurements have been carried out by four-probe arrangements in a closed-cycle liquid He cryostat. Electrical connections are provided to the sample using silver paste and the current is used as a driving source. The voltage across the two points on the sample is monitored as a function of current.

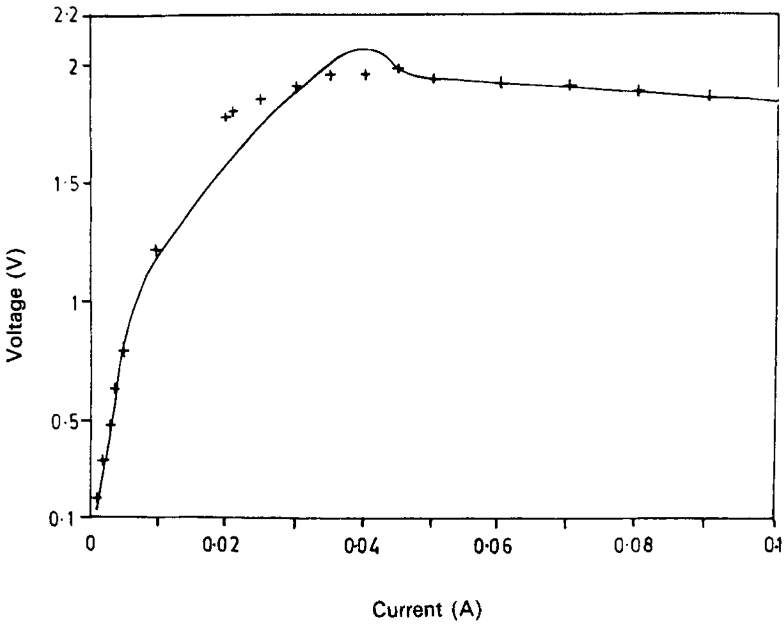

Figure 1. Current vs voltage characteristics of Qn-$(TCNQ)_2$ at 69 K (+ experimental; – theoretical).

3. Results

Figure 1 shows the $I-V$ characteristics at $T = 69$ K. At very low currents the characteristic is almost linear (ohmic). Pronounced non-linearity is observed beyond a threshold current $I_T = 5$ mA. In this region experimental results obtained can be fitted to the equation

$$V = C I^K \tag{1}$$

where C and K are constants which are calculated using least square fitting method. The values of C and K are found to be 7·95 and 0·412 respectively. Thus there is a transition from ohmic to power law region at I_T. The power law region continues up to a current $I_m = 45$ mA beyond which a region with negative differential resistance is obtained. In this region experimental results obtained can be fitted to the equation

$$V = C_1 I^{-K_1} \tag{2}$$

where C_1 and K_1 are constants which are calculated using least square fitting method. The values of C_1 and K_1 are found to be 1·58 and 0·068 respectively.

4. Discussion

A deviation from ohmic behaviour at high driving field has been reported in a number of compounds such as TTF–TCNQ (Gunning and Hegger 1978), Qn$(TCNQ)_2$ single crystal (Mihaly *et al* 1979), $NbSe_3$ and TaS_3 (Fleming and Grimes 1979). However the behaviour found in the above studies is quite different from that observed in

$Qn(TCNQ)_2$ pellet studied in this paper. The $I - V$ characteristic of our system shows that at some current I_m voltage attains a maximum value V_m known as the turnover voltage. Beyond this point as the current increases, the voltage decreases and the system shows a negative differential resistance. The values of V_m and I_m for our system are 1·97 V and 45 mA respectively. This behaviour is not observed in the other systems mentioned above. The overall behaviour can be explained qualitatively as follows.

We note that the slope of the curve at low field is constant and transition from ohmic to power law region appears at I_T, where the life time and transit time of electron are the same. Assuming the model given by Lampert and Rose, for a solid with uniform distribution of traps (here Qn^{++} ions), during power law region the Fermi level shifts with injection of electrons in the form of space charge. This causes conduction electron density to increase as some high power law. At higher currents differential negative resistance region is observed above the field of the order of 9·85 V cm^{-1} where double injection takes place. At high fields where holes are able to make transit, recombination centres are less significant than injected carriers in determining space charge and current flow. Life time of hole becomes effectively larger and space charge is partially relaxed. This results in differential negative resistance region.

5. Conclusion

Detailed experiment on the $I - V$ characteristics of an organic quasi one-dimensional conductor $Qn(TCNQ)_2$ at a particular low temperature has clearly demonstrated pronounced non-linear conduction. The non-linear conduction is explained on the basis of power law consistent with space charge limited currents. For the higher values of currents, a negative differential resistance region is observed which is explained on the basis of Lampert and Rose model of double injection, following another power law.

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References

Fleming R M and Grimes C C 1979 *Phys. Rev. Lett.* **42** 1423
Gunning W J and Hegger A J 1978 *Solid State Commun.* **27** 843
Lampert M A and Rose A 1961 *Phys. Rev.* **121** 26
Melby L R, Harder R J, Herter W R, Mahler W and Benson R E 1962 *J. Am. Chem. Soc.* **84** 3374
Mihaly G, Janosty A, Ferro J and Gruner G 1979 *Phys. Stat. Solidi.* **B94** 287
Williams J M, Hau H W, Thomas J E, Mark A B, Peter C W and Arthur J S 1985 *Prog. Inorg. Chem.* **35** 80