

Electron Mobility in CdS at High Electric Fields*

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The Hall mobility of electrons in CdS platelets has been measured at 230°K as a function of the electric field using stationary cathode-adjacent high-field domains in the range of negative differential conductivity. The electron mobility is observed to be field-independent up to 30 kV/cm. Above 30 kV/cm it decreases linearly with the field from its low-field value of about 620 cm²/V sec, to about 300 cm²/V sec at 70 kV/cm, indicating scattering of hot electrons with optical phonons.

THE knowledge of electron mobility at high field strength in CdS is of great interest for hot-electron studies. Several attempts have been made to determine the drift velocity¹ at high fields or to measure the high-field Hall mobility² using a pulse technique.

However, at fields above 10 kV/cm characteristic field inhomogeneities occur, which interfere with the usual methods of measuring mobilities. Such field inhomogeneities have been observed in CdS in ranges of negative differential conductivity caused by field-enhanced recombination³ (field quenching) or acousto-electric interaction,⁴ depending on experimental conditions. Pulse techniques to prevent the formation of high-field domains need sufficiently short pulses to give reliable results. Pulses of 10 to 40 μsec duration as used in Ref. 2 are not short enough to guarantee a homogeneous field distribution, and therefore render questionable the results reported earlier.

A recently developed method of stationary high-field domain analysis⁵ provides a new tool which can also be used to measure the mobility of majority carriers at high fields. Within a high-field domain the electric field is, to a good approximation, constant and can be easily determined from the change in domain width l with applied voltage V [neglecting the width of the space-charge region between high-field (E_{II}) and low-field (E_I) region] by $E_{II}l + E_I(L-l) = V$ (L is the distance between the electrodes). With properly doped CdS crystal platelets and under certain boundary conditions⁶⁻⁸ it is possible to observe high-field domains in a range of negative differential conductivity which remain stationary adjacent to the cathode.

If Hall electrodes of the same material as the cathode and deposited in the same evaporation process and lie within a high-field domain, it is expected that the presence of these narrow Hall electrodes does not seriously alter the field in the high-field domain. Direct observations of the field distribution using the Franz-Keldysh effect⁹ confirm this. A measurement of the Hall effect in such an arrangement does not suffer lack of knowledge of the actual field and therefore should provide more reliable results on high-field electron mobility than earlier measurements.

With an electrode arrangement as given in Fig. 1, the dc Hall voltage was measured in five CdS:Al, Ag crystal platelets with slightly different doping,¹⁰ cleaved in air ambient, and having evaporated Au electrodes. All measurements were done at 230°K with the electric field parallel to the c axis. The maximum magnetic field used was 12 kG. The Hall effect was measured for applied voltages for which the stationary high-field domain extended well beyond the Hall probes ($l > 3 \times 10^{-2}$ cm, as observed by the Franz-Feldysh effect) in order to obtain the high-field values of the mobility. After reversing the applied voltage, the Hall electrodes now being the low-field part of the crystal, the low-field values of the Hall mobility were checked.

Figure 2 gives the average values of the Hall mobility measured with magnetic field in both polarities as a function of the electric field. The different field values in the high-field domain were obtained for the different crystals since it was not possible to change the bound-

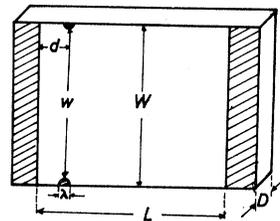


FIG. 1. Schematic of CdS crystal with current and Hall electrodes. $L \approx 5 \times 10^{-2}$ cm, $W \approx 2.5 \times 10^{-2}$ cm, $w \approx 2 \times 10^{-2}$ cm, $D \approx 5 \times 10^{-3}$ cm, $d \approx 1.5 \times 10^{-2}$ cm, $l \approx 4 \times 10^{-3}$ cm.

⁹ W. Franz, *Z. Naturforsch.* **13a**, 484 (1958); I. V. Keldysh, *Zh. Eksperim. i Teor. Fiz.* **34**, 1138 (1958) [English transl.: *Soviet Phys.—JETP* **6**, 788 (1958)].

¹⁰ For doping, CdS platelets were heated in an atmosphere of H₂S and N₂ for 3 h in direct contact with CdS powder containing 50–200 ppm Ag and Al supplied as nitrates.

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⁵ K. W. Böer and P. Voss, *Phys. Rev.* **171**, 899 (1968).

⁶ K. H. Kröll, *Solid State Commun.* (to be published).

⁷ K. W. Böer, G. Döhler, G. Dussel, and P. Voss, *Phys. Rev.* **169**, 700 (1968).

⁸ K. W. Böer and P. Voss, *Phys. Status Solidi* **28**, 355 (1968); **30**, 316 (1968).

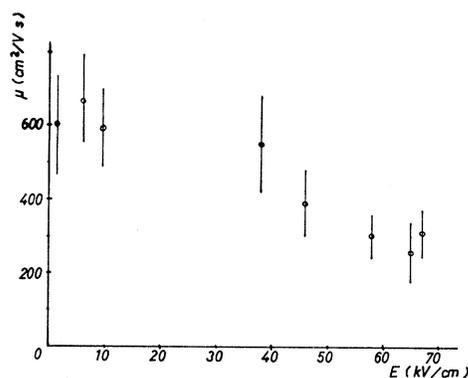


FIG. 2. Hall mobility as a function of the electric field.

ary condition and thereby obtain different field values for the high-field domain in the same crystal as was done, for example, in Ref. 7. However, the fact that the low-field value of the mobility, μ (230°K) = 620 cm²/V sec, of all crystals used agrees well with the value attributed to phonon scattering and obtained by several

other investigators,¹¹ and the similar trend of $\mu(E)$ at higher fields indicates that the slightly different doping has no significant effect on the Hall mobility for all investigated crystals in the entire measured range.

Therefore, before better results for one and the same CdS crystal are available it seems legitimate to assume the values of μ as given in Fig. 2 to describe the field-dependent mobility $\mu(E)$ for not-too-heavily doped CdS platelets. Up to about 30 kV/cm the mobility seems to remain field-independent; then the mobility decreases approximately in proportion to E^{-1} . This behavior is in agreement with the theory of hot-electron scattering with optical phonons.

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X-Ray Determination of the Electron Momentum Density in Diamond, Graphite, and Carbon Black

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The Compton profile has been measured with the x-ray scattering vector along five selected crystallographic directions in diamond, in polycrystalline diamond, in carbon black, and with the x-ray scattering vector along three selected directions in pyrolytic graphite. The electron momentum densities in both diamond and graphite are more extended in momentum space than a superposition of Hartree-Fock $1s^22s2p^3$ free-atom momentum densities, with the diamond momentum density more extended than the graphite. The momentum densities of carbon black and graphite are similar, as expected from an earlier x-ray diffraction investigation of their crystal structures. The small anisotropies found in the diamond momentum density can be qualitatively explained by assuming that some momentum density at high momentum values in momentum space has been transferred from the $\langle 211 \rangle$ directions to the $\langle 100 \rangle$ directions. The small anisotropy measured in graphite is in marked contrast to the large anisotropy found in positron-annihilation measurements. In addition, the momentum density of graphite deduced from positron annihilation is less extended in momentum space than that deduced from the x-ray measurements. As suggested by Berko, these results give insight into the positron wave function and its perturbation of the annihilated electron. In diamond, the momentum densities deduced from positron annihilation and the Compton profile are similar.

INTRODUCTION

SOME exploratory work in determining the ground-state electron momentum density from the x-ray Compton profile has been reported for Li, Be, B, LiF, Na, Mg, and Al.¹ In the experiments reported here on

diamond, graphite, and carbon black, an effort has been made to decrease the statistical uncertainty in order to detect differences between diamond and graphite as well as the anisotropy in each. In previous work at lower resolution Cooper and Leake² did not report any such

¹ Walter C. Phillips and R. J. Weiss, *Phys. Rev.* **171**, 790 (1968).

² Malcolm Cooper and J. A. Leake, *Phil. Mag.* **15**, 1201 (1967).