NOISE IN SPACE-CHARGE-LIMITED CURRENT IN A CdS-SINGLE CRYSTAL AT LOW INJECTION LEVEL

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Current noise spectra (25 Hz - 20 MHz) of a CdS-diode, working under space-charge-limited conditions, show trapping noise at low frequencies and slightly suppressed shot noise in the upper frequency range. Suppression is relatively small due to the effect of traps.

In recent years much attention has been given to the noise behaviour of space-charge-limited current (SCLC) in solids. In SCLC-diodes one can expect contributions of generation-recombination noise, shot noise and thermal noise.

Trapping transitions will introduce generation-recombination noise, as known from ordinary semiconductors and space-charge-limited current noise measurements [1,2].

The random injection and extraction of charge carriers at the contacts should give rise to shot noise. On the other hand, space charge will exert a suppression effect. Theoretical studies give almost the same formula for the suppression factor F [3,4]. Sergiescu [3] in addition, discussed the smoothing effect of traps on the suppression. Experimentally, however, the situation is not very clear as far as shot noise is concerned. Noise measurements of Anderson and Meltzer at 20 MHz [5] were interpreted as shot noise. The frequency dependence of the noise was not investigated. Rohde and Marz [2] found a plateau slightly below the shot noise level in the spectrum of CdS-crystals, under space-charge-limited current conditions in darkness. The dependecy on current of this plateau is not available from their paper, due to the trapping noise contribution.

Thermal noise is due to the carrier-lattice interaction, and can be demonstrated if the conductance is sufficiently high [6-8].

This paper gives experimental results of a

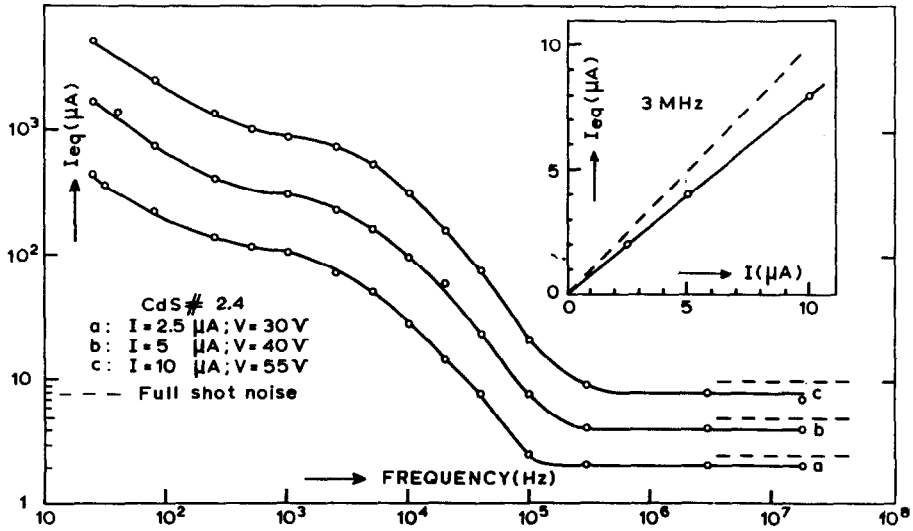

Fig. 1. Equivalent saturated diode current (I_{eq}) versus frequency at three currents (I) in the space-charge-limited current region of a CdS-single crystal. Insert: I_{eq} as a function of current at 3 MHz.

CdS-SCLC-diode with shallow trapping. A thin CdS-single crystal with dimensions $2\times2\times0.03$ mm^3 (Semi-Elements Inc., Saxonbourg, U.S.A.) was first compensated for sulphur vacancies by heating for five hours at 900°C in a sulphur atmosphere. The crystal was then provided with mercury-indium amalgam contacts on the large faces, the effective contact area being 1 mm^2. To obtain suitable electrical contacts, the device was afterwards heated for one hour at 200°C.

The current-voltage (I-V) characteristic (in darkness) showed a specific resistivity of $10^8\,\Omega m$ in the ohmic region and space-charge-limited current in the presence of shallow traps for $V > 0.5$ volt. Comparing with Child's law for space-charge-limited current in a trap-free insulator, the ratio θ of free to trapped electron charge could be obtained [9]. It turned out to be $\theta \approx 5\times10^{-5}$.

Noise measurements in the quadratic portion of the I-V characteristic are shown in the figure for three currents. The spectral density S_i of the short-circuited noise current, is plotted in terms of the equivalent saturated diode-current I_{eq}, according to $S_i = 2eI_{eq}$. The bumps in the spectra are characteristic for generation-recombination noise. The plateau levels at low frequencies are proprotional to the product $I\cdot V$, a result which can be understood theoretically [10] and which was found earlier [1].

The plateau level at high frequencies, however, varies proportionally to the current I, and is slightly below the full shot noise level, as shown specifically at 3 MHz in the insert of the figure. This noise contribution is therefore inpreted as suppressed shot noise. Since the electron transit time $\tau_0 \lesssim 2\times10^{-9}$ s, the noise is independent of frequency in this frequency and voltage range. From definition $I_{eq} = I\cdot F^2$ it follows that $F^2 = 0.8$. Available theories for the ideal trap-free case give $F \approx 2kT/eV \approx 10^{-3}$. So the smooting effect of traps is very clear from these experimental results. Moreover, the value of F, as found in this voltage range, seems in agreement with Sergiescu's formula [3],

$$F = [1 + eV\theta/kT]^{-1}$$

where k is Boltzmann's constant and T the temperature of the crystal (see also ref. 10). The qualitative agreement is corroborated by the fact, that the actual shot noise level was observed to decrease with increasing temperature, due to the rather strong increase of θ with T.

The absence of thermal noise in the measurements is easily explained. An estimation for the magnitude of this noise source, as derived from van der Ziel's formula [7], yields $I_{eq}(th) < 10^{-9}$ A, whereas in the low current limit ($I \to 0$) the ohmic resistance of the device corresponds to $I_{eq}(th) < 10^{-11}$ A.

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