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Thermal Noise in $Hg_{0.795}Cd_{0.205}Te$ Detectors for Large Biasing Fields

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Abstract. Thermal noise in $Hg_{0.795}Cd_{0.205}Te$ detectors is estimated for large biasing fields at a lattice temperature of 77 K, by computing the correlation functions of the velocity fluctuations with the Monte Carlo technique. The noise temperature for current components transverse to the field is almost independent of the field, but that corresponding to the parallel component increases by a factor of about 1.3 at 50 V/cm and by a factor of 3.0 at 300 V/cm. The thermal noise voltage for a detector of 85 Ω resistance increases from 0.6 nV/Hz$^{1/2}$ at low biasing fields to about 3 nV/Hz$^{1/2}$ at a field of 300 V/cm. The noise power is also found to remain constant up to about 75 GHz, and it decreases thereafter by a factor of 0.25 for doubling of the frequency.

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Mercury-cadmium-telluride with the composition $Hg_{0.795}Cd_{0.205}Te$ is widely used for the construction of detectors of infrared signals[1]. It is advantageous to operate such devices with a large biasing voltage as the detection sensitivity increases with increase in the magnitude of the same [2]. But, the thermal noise which is a significant component of the total noise of the devices is also likely to increase and impair the detection sensitivity. No estimate of the thermal noise power for large fields is, however, available in the literature. The present authors reported earlier [3] a Monte Carlo method for the calculation of the frequency-dependent diffusion constant in semiconductors in the presence of a large steady electric field. In this method the auto-correlation function for the velocity fluctuations of the electrons is first computed, and the diffusion constant is calculated therefrom. Thermal noise power being proportional to the diffusion constant, the method gives also the former. It is also possible to obtain directly the full noise spectrum and estimate the noise power for any signal modulation frequency. The method has been used earlier to study the noise for indium antimonide [3]. In this paper, results are presented for $Hg_{0.795}Cd_{0.205}Te$. The method is briefly described in Sect. 1 and the results are discussed in Sect. 2.

1. The Method

The details of the method of computation of the diffusion constant and the noise current spectrum by the Monte Carlo simulation have been discussed in [3]. A brief description is, however, included here for the sake of completeness.

Let us consider a rectangular semiconductor sample of length L, cross sectional area A and electron concentration n. The spectral density of the noise current $S_{\Delta I}(\omega)$ in the sample is related to the frequency dependent diffusion constant $D(\omega)$ by the relation [4],

$$S_{\Delta I}(\omega)=(4e^2An/L)D(\omega), \tag{1}$$

where $-e$ is the electron charge. The diffusion constant is also given by

$$D(\omega)=\int_0^\infty C(s)\cos(\omega s)ds, \tag{2}$$

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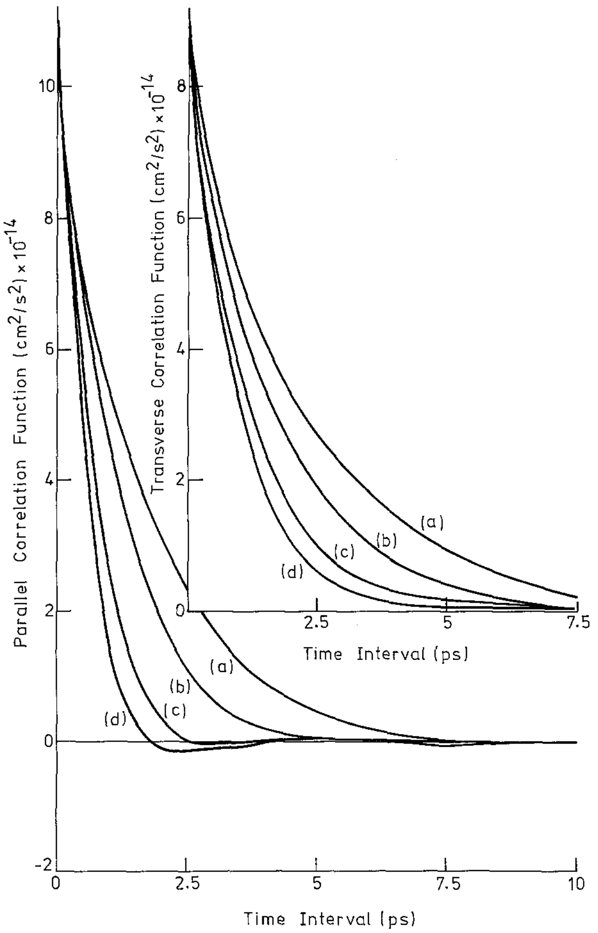

Fig. 1. Correlation functions for the fluctuations in the transverse and parallel components of velocity for fields of *a* 50 V/cm, *b* 100 V/cm, *c* 200 V/cm, and *d* 300 V/cm

where the correlation function

$$C(s) = \mathscr{L}t_{T\to\infty}\left(\frac{1}{T}\right)\int_0^T \Delta v(t)\cdot\Delta v(t+s)dt \tag{3}$$

and $\Delta v(t)$ is the velocity fluctuation.

The velocity fluctuations are calculated by simulating the electron trajectories by the Monte Carlo method. For HgCdTe, we are required to consider deformation potential acoustic phonon scattering, alloy scattering and two modes of polar optic phonon scattering. The scattering by acoustic phonons was calculated by using the formula given in [5]. In the case of polar optic phonon scattering [5] the factor $(K_\infty^{-1} - K_0^{-1})$ was, however, replaced by SK_0^{-2}. The constant S represents the mode strength for one of the modes of the two modes of optic phonons. The alloy scattering probability λ_{alloy} was calculated by [6, 7],

$$\lambda_{\text{alloy}} = \frac{2\sqrt{2}e^{1/2}m^{*3/2}x(1-x)(\Delta U)^2}{\pi\hbar^4 N_A} \cdot\left[\gamma^{1/2}(E)\cdot\frac{(1+\alpha E)^2+\frac{1}{3}(\alpha E)^2}{1+2\alpha E}\right], \tag{4}$$

where $\gamma(E) = E(1+\alpha E)$, E being the energy of a carrier, and α the non-parabolicity parameter. ΔU: alloy scattering potential and $N_A = 8/a^3$, a being the lattice constant.

The instants of scattering, the energy and components of the wave vector after the collision were calculated with the usual Monte Carlo technique and stored. The integral of (3) was then evaluated by using analytic expressions to compute the velocity in between two

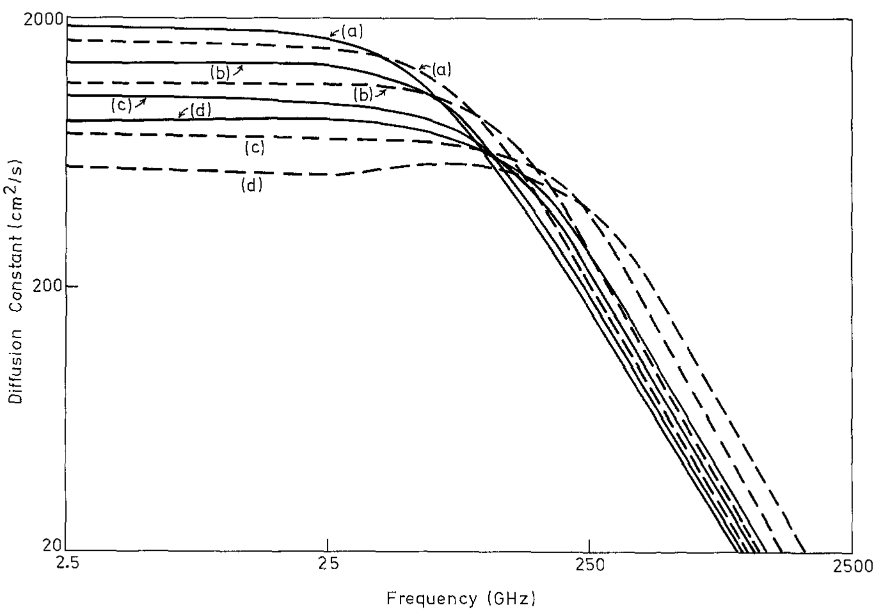

Fig. 2. Diffusion constants $D_t(\omega)$ and $D_p(\omega)$ for fields of *a* 50 V/cm, *b* 100 V/cm, *c* 200 V/cm, and *d* 300 V/cm. Solid line: $D_p(\omega)$, Dotted line: $D_t(\omega)$

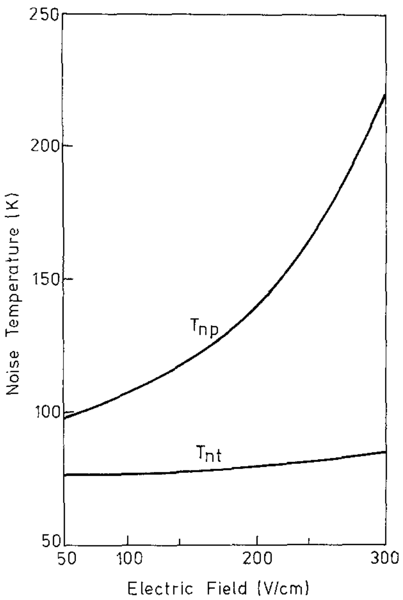

Fig. 3. Noise temperatures T_{nt} and T_{np} versus biasing field

where T_{np} and T_{nt} are the noise temperature, corresponding to noise currents parallel and perpendicular to the biasing field; μ_c and μ_d are, respectively, the chord and the differential mobility; k_B is the Boltzmann constant.

For a detector the noise voltage is of interest, and for the current biased mode it is given by [9]

$$V_{NF} = (4k_B T_{np} R_F)^{1/2} (\Delta f)^{1/2}, \tag{7}$$

where V_{NF} is the noise voltage for a biasing field F, R_F is the ac resistance of the detector for the same field, and Δf is the bandwidth of the detector.

Noting that

$$R_F = L(en\mu_d A)^{-1} \tag{8}$$

and using (5) we get

$$\frac{V_{NF}}{V_{NO}} = \frac{\mu_0}{\mu_d}\left(\frac{D_p(0)}{D_0}\right)^{1/2} \tag{9}$$

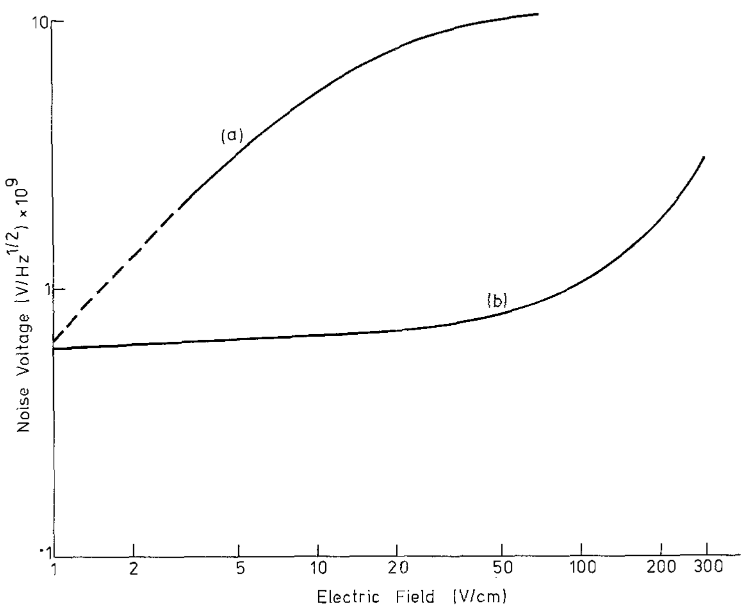

Fig. 4. Noise voltage versus biasing field for a detector of 85 Ω resistance. *a* Experiment, *b* calculated thermal voltage

scattering events. The constants $D_p(\omega)$ and $D_t(\omega)$ for diffusion parallel and transverse to the steady electric field were computed by using (2). The noise current may be obtained from the values of the diffusion constants by using (1). However, noise is often discussed in terms of the equivalent noise temperature. These are defined for the two components of noise current by [8]

$$T_{np} = eD_p(0)(\mu_d k_B)^{-1} \tag{5}$$

and

$$T_{nt} = eD_t(0)(\mu_c k_B)^{-1}, \tag{6}$$

where μ_0 and D_0 are, respectively, the low-field mobility and the diffusion constant, and [9]

$$V_{NO} = (4k_B T_L R_0)^{1/2} \quad \text{per} \quad Hz^{1/2}, \tag{10}$$

T_L and R_0 being the lattice temperature and the low-field detector resistance, respectively.

2. Results and Discussions

The values of the physical parameters used in the calculations were taken from [7]. These are given below: Effective mass ratio (at 0 K) = 0.007, energy-band gap E_g(at 0 K) = 0.076 eV, band-gap temperature coefficient $(dE_g/dT)\ E_g^{-1} = 4.61 \times 10^{-3}$ eV/K, elastic constant $C_l = 6.97 \times 10^{10}$ N/m^2, static dielectric constant $K_0 = 17.3$, high-frequency dielectric constant $K_\infty = 12.6$, acoustic-phonon deformation potential constant $E_l = 9.5$ eV, polar-optic phonon temperature (for mode 1 : 198 K, for mode 2 : 227 K), optic-phonon mode strength S (for mode 1 : 4.13, for mode 2 : 0.5), alloy scattering potential $\Delta U = 1.33$ eV, $N_A = 2.96 \times 10^{28}$ m^{-3}.

Results were computed for four values of the electric fields of 50, 100, 200, and 300 V/cm.

The auto-correlation functions are plotted in Fig. 1. The functions are of the same shape as for InSb [3]. The transverse coefficient $C_t(s)$ falls almost exponentially with s while the parallel coefficient $C_p(s)$ decreases sharply, becomes negative and becomes zero for large values of s.

The diffusion constants are presented in Fig. 2. Both the constants remain approximately constant up to about 75 GHz, and decreases thereafter. The noise may therefore be considered to be white up to the millimeter wave modulation frequencies. It decreases above 75 GHz almost linearly on a log-log scale, the rate of fall being 0.25 for doubling of the frequency.

The calculated values of the drift velocity for the fields of 50, 100, 200, and 300 V/cm are, respectively, 1.33×10^7, 2.08×10^7, 2.92×10^7 and 3.39×10^7 cm/s. These are in good agreement with those given in [7]. The chord mobility was calculated from these values of drift velocity. However, the differential mobilities could only be calculated approximately by obtaining a plot of the drift velocity against the field and estimating the slope of this curve. The noise temperatures obtained from the values of the diffusion constants and the mobilities are given in Fig. 3. It is observed that the temperature for the transverse noise currents increases by only 10%. But, the temperature for noise currents parallel to the field increases from the lattice temperature by a factor of about 1.3 at 50 V/cm and by about 3 at 300 V/cm.

Noise voltage was also calculated using (9) and (10) for a detector resistance of 85 Ω, for which measured values of noise voltage are reported in [9]. The values are presented in Fig. 4. It is seen that the noise voltage increases from a low-field value of 0.6 nV/Hz$^{1/2}$ to a value of 0.9 nV/Hz$^{1/2}$ at 70 V/cm and 3 nV/Hz$^{1/2}$ at 300 V/cm. The measured values of noise voltage are also presented for comparison. We may conclude from Fig. 4 that although the thermal noise is the major component of the total noise at low-fields, it becomes less and less significant as the biasing field is increased. At a field of 70 V/cm for which the detector sensitivity as well as the noise voltage saturates [9], the thermal noise (0.9 nV/Hz$^{1/2}$) is only 8% of the total noise voltage of 11 nV/Hz$^{1/2}$.

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References

1. R.J. Keyes (ed.): *Optical and Infrared Detectors*, 2nd ed., Topics Appl. Phys. **19** (Springer, Berlin, Heidelberg, New York 1980)
2. E. Igras, J. Piotrowski, T. Piotrowski: Infrared Phys. **19**, 143 (1979)
3. M. Deb Roy, B.R. Nag: Appl. Phys. A**26**, 131 (1981)
4. K.M. van Vliet: Solid State Electron. **13**, 649 (1970); J. Math. Phys. **12**, 1998 (1971)
5. W. Fawcett, A.D. Boardman, S. Swain: J. Phys. Chem. Solids. **31**, 1963 (1970)
6. D. Chattopadhyay: Private communication
7. D. Chattopadhyay: Phys. Lett. **81**A, 241 (1981)
8. M. Deb Roy, B.R. Nag: Int. J. Electron. **48**, 443 (1980)
9. M.A. Kinch, S.R. Borrello, A. Simmons: Infrared Phys. **17**, 127 (1977)