NOISE AND DIFFUSIVITY OF HOT ELECTRONS IN n-TYPE InSb
V. Bareikis, A. Galdikas, R. Miliūytė, J. Pozhela, Viktoravičius

To cite this version:

HAL Id: jpa-00221662
https://hal.archives-ouvertes.fr/jpa-00221662
Submitted on 1 Jan 1981

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
NOISE AND DIFFUSIVITY OF HOT ELECTRONS IN n-TYPE InSb

V. Bareikis, A. Galdikas, R. Miliušytė, J. Pozhela and V. Viktoravičius

Semiconductor Physics Institute, Lithuanian SSR, Academy of Sciences, Vilnius, USSR

Abstract. - The experimental results and Monte-Carlo calculations of hot electron noise are presented for n-InSb at 77 K and 10 K. The influence of inelastic optical as well as ionized impurity scattering on the noise characteristics is examined.

1. Introduction. - Thermal fluctuations of hot electrons in semiconductors have been studied by many workers /1,2/.

So far, the experimental and Monte-Carlo calculation results of hot carrier noise and closely related phenomenon diffusion have been mainly reported for Ge and Si. Only several publications are available for n-InSb /3-5/. In this semiconductor the inelastic scattering by polar optical phonons at low temperatures is rather effective and therefore the peculiarities of noise in microwave range due to this scattering is expected. In this note we present experimental results and Monte-Carlo calculations of hot electron noise in InSb at 77 K and 10 K.

2. Experimental and calculation techniques. - The noise along α direction is characterized by the spectral density of current fluctuations \( S_j(f)\) and the noise temperature \( T_{\text{noi}}\), which are related as

\[
S_j(f) = 4kT_{\text{noi}}\sigma_{\text{ac}}(f),
\]

where \( k \) is the Boltzmann constant, \( \sigma_{\text{ac}}(f) \) is the small signal a.c. conductivity at the frequency \( f \) in the presence of a steady high electric field \( E \). The \( T_{\text{noi}} \) was measured in microwave range (10 GHz) using a pulse (5 µs duration, 22 Hz repetition) technique described elsewhere /6/. In the parallel (II) direction \( \sigma_{\text{ac}} \)
is assumed to be equal to the differential conductivity, while for the transverse \((\perp)\) direction it was taken to be the same as the static conductivity. In the samples under the investigation the electron concentrations were \(n = 1,2 \cdot 10^{14} \text{ cm}^{-3}; 3 \cdot 10^{15} \text{ cm}^{-3}\) and mobilities \(\mu = 6 \cdot 10^{5} \text{ cm}^{2}/\text{V} \cdot \text{s}, 2 \cdot 10^{5} \text{ cm}^{2}/\text{V} \cdot \text{s}\) respectively. Simple rectangular strips as well as dumbbell shape samples were used. Typical sample dimensions are \(2.5 \times 0.3 \times 0.3 \text{ mm}^{3}\). An electric field was applied parallel to \(<110>\) direction. The spectral density of electron velocity fluctuations \(S_{V}(f,\alpha)\) and drift velocity was calculated by Monte-Carlo procedure described in /7/. \(S_{V}(f,\alpha)\) is simply related with \(S_{f}(f,\alpha) = e n \hat{S}_{f}(f,\alpha)\), where \(e\) is the electron charge.

The model used for calculations included only one isotropic and non-parabolic minimum of conduction band. Polar optical, acoustic and ionized impurity scattering was accounted. The deformation potential for acoustic phonon scattering was taken to be \(30 \text{ eV}\). The other parameters were the same as in /8/.

3. Results and discussion. - Experimental and calculated noise temperature as well as spectral density of current fluctuations vs electric field are plotted in Figs. 1, 2 and 3. All the curves except \(A\) in Fig. 2 (the noise temperature at \(10 \text{ K}\)) are obtained for dumbbell shape samples. At \(77 \text{ K}\) the results for both types of samples are identical. At both temperatures for \(n = 1,2 \cdot 10^{14} \text{ cm}^{-3}\) experimental and theoretical \(T_{n\parallel}\) for comparatively high \(E\) are found to be higher than \(T_{n\perp}\), however \(S_{f}(f,\parallel) < S_{f}(f,\perp)\). These results agree with the main
conclusions of the fluctuation theory for quasielastic scattering mechanisms /1/ as well as with the data obtained by Monte-Carlo method for noise temperature in InSb at 77 K /4/. As far as agreement of our calculated and experimental data is concerned at 77 K the best fit is obtained when the acoustic phonon deformation potential is assumed to be 30 eV. At 10 K this agreement for dumbbell shape samples is worse as compared to that at 77 K. The main reasons are supposed to be the experimental errors (15% for $T_n$ and 25% for $S_j^{(f)}$), heating of the lattice, neglect of electron-electron and piezoelectric scattering in the adopted model. For the rod-like shape samples at 10 K a considerably higher value of $T_{nn}$ was observed. This is attributed to the electron transit through the potential barrier at the contact. At 10 K and low electric fields, however experimentally and theoretically is obtained that $S_j^{(f)\parallel} > S_j^{(f)\perp}$ (Fig. 3b). Consequently, the sign of anisotropy of $S_j^{(f)\alpha}$ is opposite to that observed at high electric fields as well as at 77 K.

The existence of such anisotropy for inelastic scattering by optical phonons was predicted theoretically in /9/. The Monte-Carlo calculations in the case when the ionized impurity scattering is neglected show that this effect in InSb at 10 K is significant (Fig. 4).

$S_j^{(f)\parallel}$ has a maximum at the frequency equal to the reciprocal time necessary to accelerate the electron from energy $\epsilon = 0$ to the energy of optical phonon (Fig. 4a). The resonant character of $S_j^{(f)\parallel}$...
Fig. 4: Monte-Carlo calculations at 10 K of $S_V(f,\omega)$ (a) and autocorrelation function $\Phi(\tau,\omega)$ (b). $n_i = 0$.

corresponds to the oscillations of autocorrelation function of velocity $\Phi(\tau,\omega)$ vs time $\tau$ (Fig. 4b). At higher temperatures and electric fields the maximum is reduced due to the increase of electron gas randomization (Fig. 4a and 5).

Ionized impurity scattering also causes the randomization. Therefore the maximum is reduced when this type of scattering is accounted (Fig. 6).

Fig. 5: Monte-Carlo calculations of $S_V(f,\omega)$ at 77 K; $n_i = 0$.

Fig. 6: Monte-Carlo calculations of $S_V(f,\omega)$ at 10 K; $n_i = 1.2 \cdot 10^{14}$ cm$^{-3}$.
Ionized impurity scattering effects considerably the value of the noise temperature and its anisotropy too. The experiment and calculations show that in n-InSb with \( n_i = 3 \times 10^{15} \text{ cm}^{-3} \) at 77 K \( T_{\text{nff}} \) (Fig. 7) is decreased as compared to that for \( n_i = 1.2 \times 10^{14} \text{ cm}^{-3} \). Besides, the calculations show that the degree of doping has an influence on the sign of \( T_n \) anisotropy in low field region (compare Figs. 1 to 7).

![Graph showing experimental and calculated \( T_{\text{nff}} \) values.](image)

Fig. 7: Experimental and calculated \( T_{\text{nff}} \).

Finally, it should be mentioned that for low electron densities \( (n \approx 10^{14} \text{ cm}^{-3}) \) \( S_j(f_{\text{x}}) \) is simply related with the diffusion coefficient \( D_\alpha \): \( S_j(f_{\text{x}}) = 4e^2nD_\alpha /1/ \).


1. The high frequency (10 GHz) hot electron noise in n-InSb is measured.
2. The influence of the streaming motion of electrons on the hot electron noise is observed.
3. Ionized impurity scattering significantly effects on the value of electron noise temperature and its anisotropy.