Free-Carrier Grating due to the Optical Phonon Emission in InP n^+nn^+ Structures

V. Gružinskis, E. Starikov, P. Shiktorov,
Semiconductor Physics Institute, A. Goštauto 11, LT 01108 Vilnius, Lithuania
e-mail: viktor@pav.pfi.lt

The scattering by optical ponons takes a special place in hierarchy of scattering mechanisms in semiconductors. At low temperatures when the optical phonon energy $\hbar\omega_0$ considerably exceeds the carrier thermal energy the scattering by optical phonons is mainly accompanied by optical phonon emission. Due to the constant value of energy $\hbar\omega_0$ the optical phonon emission rate dependence on energy has a threshold. At such conditions the periodic motion of carrier ensemble in momentum space is possible. This motion can lead to the microwave power generation as it was shown for bulk InP theoretically and confirmed experimentally (see, e.g. [1] and references therein). Recently the modelling of electron transport in indium nitride based n^+nn^+ structures when optical phonon emission is dominating scattering mechanism shows the possibility of the cyclic real-space motion of carrier ensemble which leads to the formation of the free-carrier grating (FCG) in the n-region of the structure [2]. The aim of this report is to simulate the electron transport in InP n^+nn^+ structures in the conditions when FCG formation can be expected [2].

The calculations of electron transport in n^+nn^+ InP structures are performed by simultaneous solution of coupled Boltzmann and Poisson equations by Monte Carlo particle (MCP) technique [3]. The InP band and material parameters of a spherically symmetric nonparabolic conduction band are taken from [3]. The doping of simulated 0.02-5.00-0.02 μm n^+nn^+ InP structures is n = 10^{15} cm^{-3} and n^+ = 10^{17} cm^{-3}. All the calculations are made at 10 K and applied voltage U = 0.3 V to the structure with the n-region length L = 5 μm.

Figures from 1 to 4 demonstrate the FCG in real space due to periodic motion of electrons under low temperature optical phonon emission in n-region. A low energy electron injected from cathode contact is accelerated by field up to optical phonon energy and loose the energy and velocity after optical phonon emission. The process is repeated until the electron leaves the n-region through the anode contact. So the electron trajectory consists of flight and stop, where electron emits optical phonon, regions. The stop regions coinside with the concentration maxima. The number of stop regions is integer part of $eU/\hbar\omega_0$, where e is electron charge. The impedance $Z(f)$ of InP structure is calculated simulating by MCP technique the current response to periodic voltage. The frequency behaviour of the real and imaginary parts of impedance, ReZ and ImZ, respectively, is demonstrated in Fig. 5. For comparison, Fig. 5 also shows $Z(f) = [en\mu(f)/L + i2\pi f C_L]^{-1}$ obtained for the considered diode with the length L and geometrical capacitance C_L from small-signal mobility $\mu(f)$ calculated by MC simulation of bulk material subjected to the electric field equal to U/L in the n-region (i.e. without the grating).

In Fig. 6 the spectral density of current fluctuations (noise) in InP structure at a constant voltage U is shown. The noise peak at 0.345 THz frequency coincides with the high frequency edge of negative ReZ values (see Fig. 5).

REFERENCES

[1] L. Varani, J. C. Vaissiere, E. Starikov, P. Shiktorov, V. Gružinskis, L. Reggiani, and J. H. Zhao., *Monte Carlo Calculiations of THz Generation in Nitrides*, physica status solidi (a) **190**, 247 (2002).

[2] V. Gružinskis, P. Shiktorov, E. Starikov, L. Reggiani, L. Varani and J. C. Vaissiere., *Free-carrier grating and terahertz generation from InN n^+nn^+ structures under streaming plasma instability*, Semiconductor Science and Technology **19**, s173 (2004).

[3] V. Mitin, V. Gruzinskis, E. Starikov, and P. Shiktorov, *Submillimeter wave generation and noise in InP diodes*, Journal of Applied Physics **75**, 935 (1994).

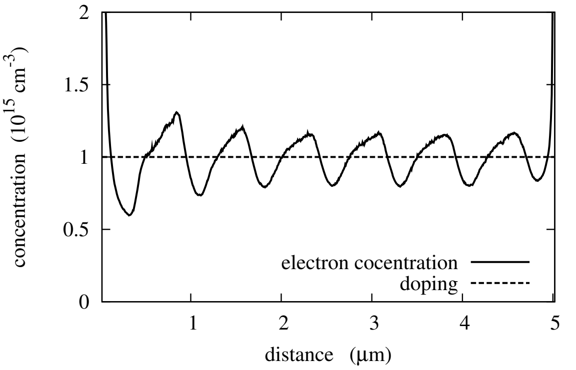

Fig. 1. Electron concentration profile in n-region of simulated InP n^+nn^+ structure.

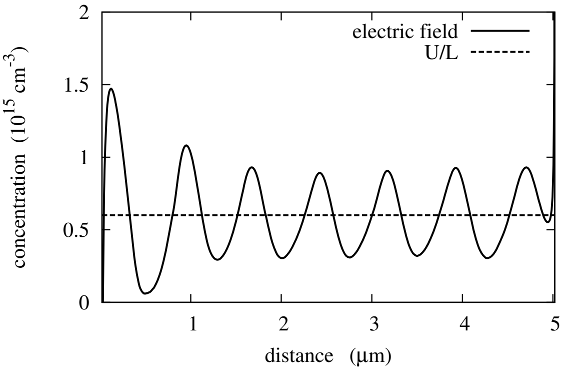

Fig. 2. Electric field profile in n-region of simulated InP n^+nn^+ structure.

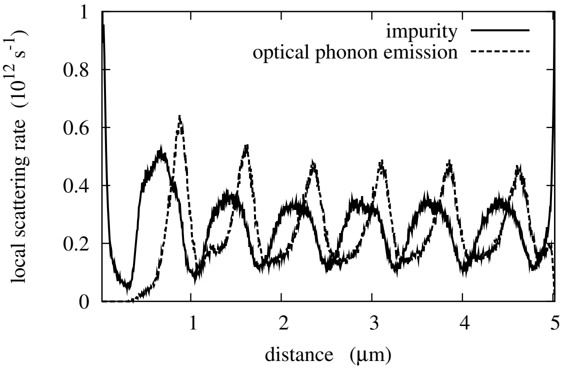

Fig. 3. Impurity and optical phonon emission local scattering rate profiles in n-region of simulated InP n^+nn^+ structure.

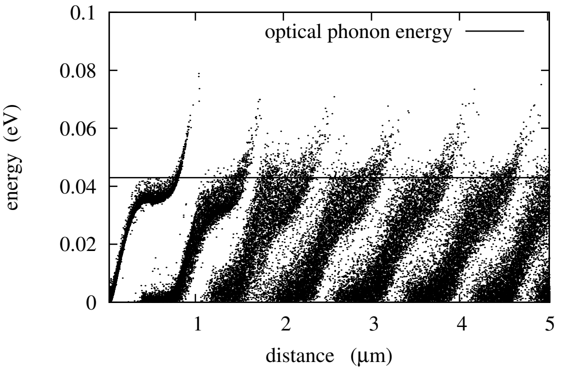

Fig. 4. Positions of simulated particles in energy - coordinate plane in n-region of InP n^+nn^+ structure.

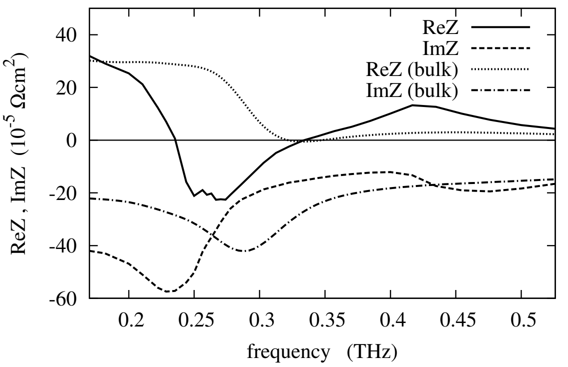

Fig. 5. Impedance real ReZ and imaginary ImZ part spectra of simulated InP n^+nn^+ structure. For comparison MC results for bulk InP are presented.

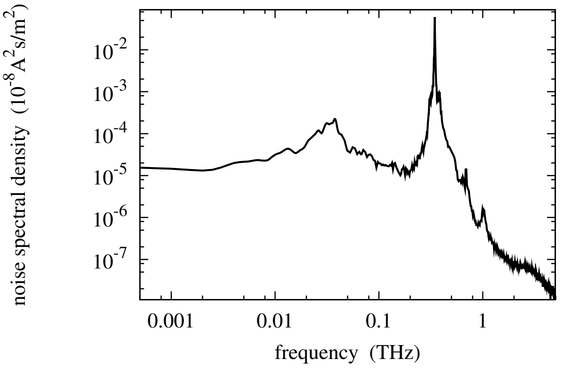

Fig. 6. Spectral density of current fluctuations (noise) in simulated InP n^+nn^+ structure at applied constant voltage.