11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Monte Carlo Simulation of 2D TASER

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INTRODUCTION

To develop THz-frequency range micro- and nano-structures the modern strategy widely uses 2D carrier transport in real space, where the third dimension is quantizied (see, e.g. [1] and references therein). From one hand, this allows to avoid strong impurity scattering since carriers move in practically undoped 2D channels. From another hand, the transition from a 3D to a 2D transport leads to sharper behaviors of the phonon emission probability at the optical threshold energy and of carrier transfer to upper valleys. Both these reasons can lead to a considerable extension of the lattice temperature and frequency ranges where THz radiation generation related with transit-time effects in momentum space or intervalley transfer is possible. To investigate various quantum wells (QW) a general model of electron transport, which allows a quick comparison among different materials, QW widths d, etc. is of great importance.

The aim of this communication is to present such a model that is based on Monte Carlo (MC) simulations of 2D electron transport and noise at low lattice temperatures and to investigate the so-called optical-phonon-assisted transit-time resonance (OPTTR) of electrons favorable for THz radiation generation [2,3].

MODEL

The model includes the deformation acoustic and polar optical phonon emission (POPE) scatterings in deep QW as described in [4]. Fig. 1 shows the energy dependence of the corresponding scattering rates for 2D-GaN QW of $d = 5nm$ in comparison with those of 3D-GaN. By choosing the angle ϕ after POPE through a random number r the dependence of $\phi(P)$ on the corresponding probability $P = r$ is presented in Fig. 2.

RESULTS

The spectral density of velocity fluctuations, $S_{vv}(\nu)$, and the real part of the differential mobility, $Re[\mu(\nu)]$, calculated by the MC method [2] for the 2D-GaN QW are shown in Figs. 3 and 4, respectively. In the frequency regions, where $Re[\mu(\nu)] < 0$ the amplification and generation of the radiation are possible. By comparing Figs. 3 and 4, we conclude that near these regions there also appear spikes in $S_{vv}(\nu)$, which should be considered as precursors of the generation. The frequency regions for THz generation in 2D-GaN and 2D-InP 5 nm QW are displayed in Figs. 5 and 6, respectively, and compared with the 3D case. Results show a considerable extension of the frequency region for TASER (Terahertz-Amplification-by-the-Stimulated-Emission-of-Radiation) when going from 3D to 2D.

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ISBN 3-901578-16-1

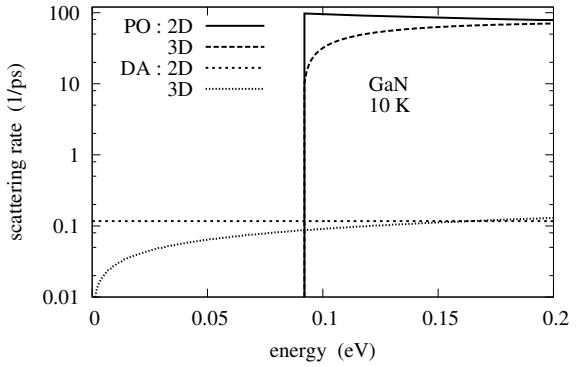

Fig. 1. Scattering rates for polar-optical phonon emission (PO) and deformation acoustic (DA) scatterings in bulk GaN (3D) and 5 nm GaN superlattice (2D)

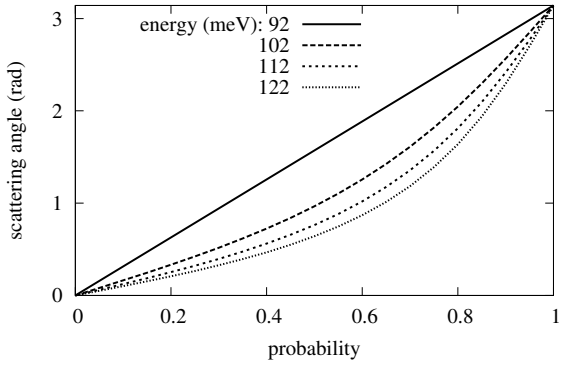

Fig. 2. Dependence of scattering angle for POPE on probability $0 < P < 1$ for different electron energy

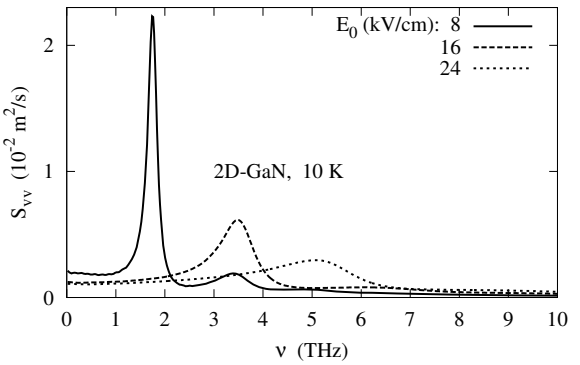

Fig. 3. Spectral density of velocity fluctuations calculated by MC method for 2D-GaN at different values of the applied constant field E_0

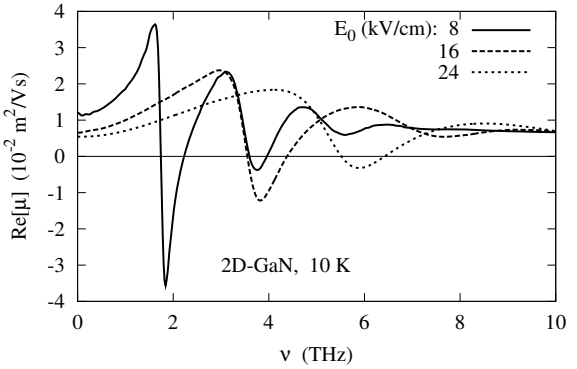

Fig. 4. Frequency dependence of real part of differential mobility calculated by MC method for 2D-GaN

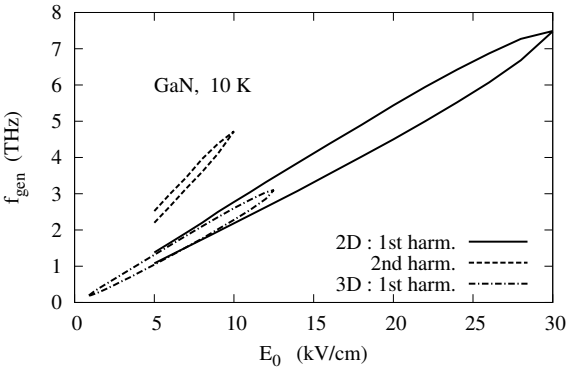

Fig. 5. Contour plot of the dynamic negative differential mobility in the $E - f$ plane for 2D-GaN. For comparison dot-dashed line reports MC results of bulk GaN.

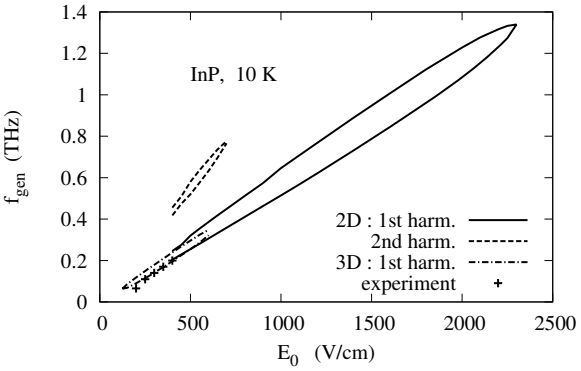

Fig. 6. Contour plot of the dynamic negative differential mobility in the $E - f$ plane for 2D-InP. For comparison dot-dashed line reports MC results of bulk InP and symbols show experimental data [5].