Gunn Effect in n-InP MOSFET at Positive Gate Bias and Impact Ionization Conditions

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INTRODUCTION

In modern FET/HEMT structures the Gunn-effect is not usually considered as one of the mechanisms able to realize high-frequency (near terahertz (THz)) oscillations of the current. Physically, the effect is caused by the suppression effect of the remote Coulomb interaction which takes place in the gated region of the conducting channel. In the present work we propose a way to overcome this limitation by using the impact ionization effect. It is shown by Monte Carlo simulation that the impact ionization in MOSFET structures allows us to get near THz oscillations.

MODEL

For simulation we have used a MOSFET structure based on 50-700-50 nm n^+nn^+ InP channel of width equal to 200 nm. The 500 nm long gate is centered in the n-region at a distance of 50 nm from the channel. The doping is $n = 5\times10^{16}$cm^{-3} and n^+ = 4×10^{18}cm^{-3}. The simulations were performed by simultaneous solution of coupled Boltzmann and pseudo-2D Poisson [1] equations. The bipolar InP model consists of three conduction (Γ-L-X) valleys [2] and two valence (heavy hole and spin-orbit split-off) bands [3]. Also the model includes the impact ionization calculated using Keldysh formula [4], carrier lifetimes (10 ns for electrons and 2 ns for holes) and Auger recombination with the same coefficient 10^{-28}cm^{-6}s^{-1} for electrons and holes. The lattice temperature in all cases is 300 K.

RESULTS

In Fig. 1 the drain currents (J$_d$) as functions of drain bias (U$_d$) at different gate voltages (U$_g$) up to avalanche breakdown are presented. The breakdown potential of the device decreases with increasing U$_g$ and at U$_g$ $>$ 3 V starts to increase. The 200 GHz J$_d$ Gunn oscillations at U$_g$ = 3 V arise when U$_d$ $>$ 1.6 V and the oscillation amplitude is increasing with U$_d$ increased (see Fig. 2). The J_d-U$_g$ relations at different U$_d$ values are shown in Fig. 3. The J$_d$(U$_g$) hump is associated with the Gunn effect at impact ionization conditions in the range 2 V $< U_g <$ 5 V. The Fig. 4 shows the J$_d$ time dependencies inside (U$_g$ = 3 V) and outside (U$_g$ = 1.5 and 6 V) the hump. No J$_d$ oscillations outside the hump are evident. In Fig. 5 the J$_d$ and impact ionization intensity dependencies on U$_g$ are demonstrated. The hump similar to J$_d$(U$_g$) one is formed on impact ionization curve. At U$_g$ $>$ 6 V impact ionization becomes negligible and J$_d$(U$_g$) coincides with the one calculated without impact ionization (see Fig. 5). The impact ionization decrease at U$_g$ $>$ 5 V is associated with electric field redistribution at given U$_d$ which leads to lower electron energy values at drain contact (see Fig. 6). Finally, Gunn effect is most efficient at positive gate voltages. The hump on J_d-U$_g$ relation at given U$_d$ can indicate the range of Gunn oscillations in the device.

ACKNOWLEDGMENT

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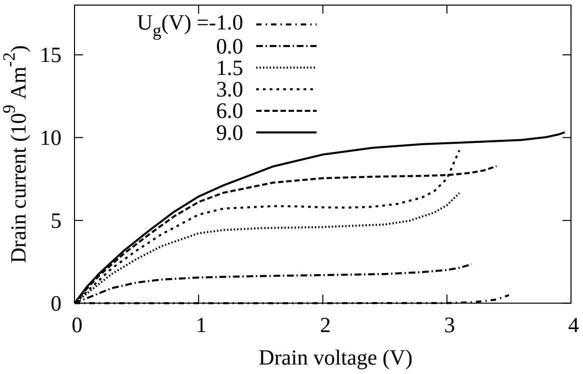

Fig. 1. Drain currents as functions of drain bias at different gate voltages U_g.

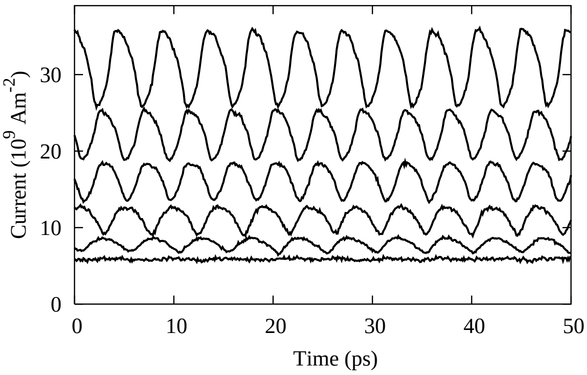

Fig. 2. Drain currents as functions of time at different drain biases. From bottom to top: U_d = 1.6, 1.8, 2.0, 2.4, 2.8 and 3.1 V. To avoid the overlap the curves are shifted by 0, 2, 5.5, 10.5, 16, $22 \times 10^9\mathrm{Am}^{-2}$. Gate bias U_g = 3 V.

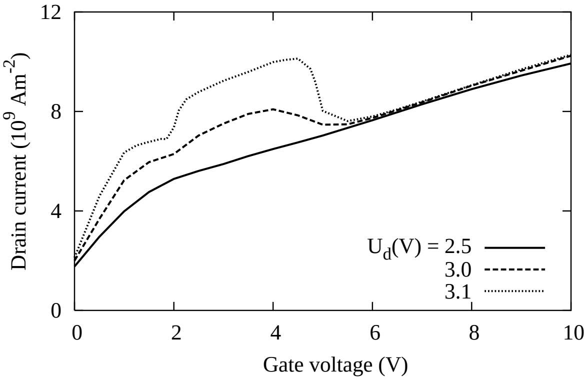

Fig. 3. Drain currents as functions of gate bias at different drain voltages U_d.

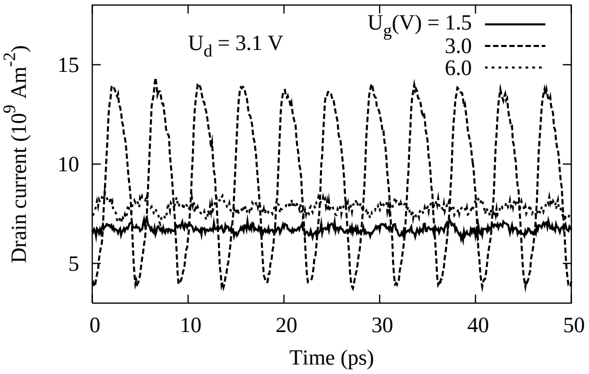

Fig. 4. Drain currents as functions of time at different gate biases and U_d = 3.1 V

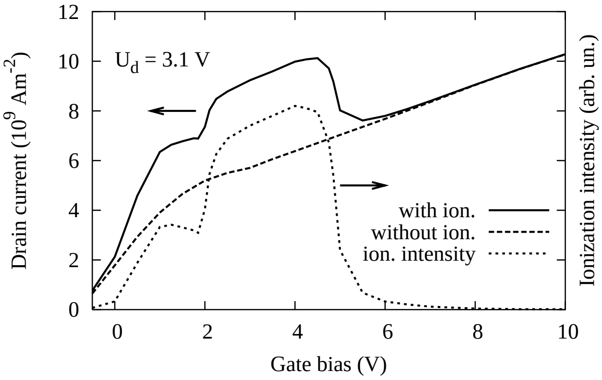

Fig. 5. Drain currents and impact ionization intensity as functions of gate bias with and without impact ionization. U_d = 3.1 V

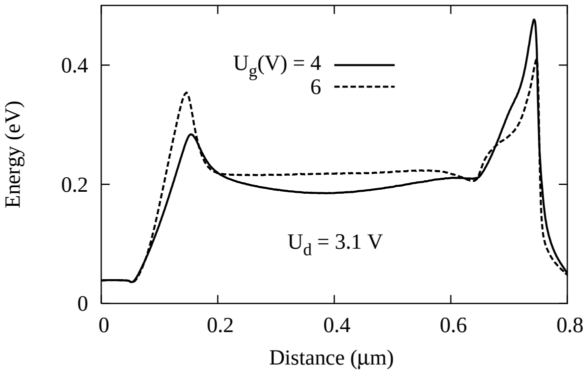

Fig. 6. Energy profile in n-InP MOSFET channel at different gate biases. U_g = 4 and 6 V, U_d = 3.1 V.