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Ballistic Generators of Terahertz Current Oscillations with p-Quantum Well Bases

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Oscillations of space charge limited currents in short doped p-quantum well bases of ballistic diodes as a result of a negative effective mass region in the quantized hole dispersion relation are considered. Details of contact design (contact shape and Fermi-energy of injected ballistic holes) strongly affect the generation regime. This regime has a maximum voltage range for flat contacts and for an optimal Fermi-energy that would provide a quasineutral region in the diode base.

If we consider a one-dimensional space charge limited ballistic current problem in diodes with bulk bases [1], the problem formulation includes a set of base material parameters (base length, l, base doping, $N_{\rm b}$, dielectric constant and dispersion relation of current carriers), and boundary conditions for the distribution function of ballistic carriers and electrostatic potential at *dissipative contact/ballistic base* junctions. The distribution function of carriers entering into the base from the p^+-contacts is usually assumed to be the equilibrium Fermi distribution with a Fermi-energy μ. The value of μ influences the considered current to a small extent, resulting only in a space charge redistribution near the contacts. This is due to a short screening length in the doped semiconductor bases.

Turning to the bases in the form of thin current-conducting channels with 2D-electron or 2D-hole gas makes this problem more complicated. The Poisson problem becomes two-dimensional and requires additional data concerning the surroundings. As a result, a detailed contact structure strongly affects the space charge limited currents. Therefore the bypassing capacitance of the structure becomes responsible for the nonstationary processes in the conducting channel. This influence is much stronger than for the bulk bases because of weak screening by the 2D gas [2].

Here we consider a flat capacitor with equipotential plates – cathode and anode, which are connected by current-conducting channels. These channels form a spatially periodic system with a period a. The system consists of a ballistic p-QW base with two p^+-contact tips of the length b. The equilibrium Fermi distribution of the holes entering into the base from the p^+-contacts specifies the distribution function of the ballistic holes in the p-QW base. The geometry of the diode defines the self-consistent potential $V(x)$ in the base. The additional parameter that describes the geometry of the considered structure is the length b of these contact tips. Depending on the correlation between a, b, and l we can consider the following cases: (i) massive or bulk contacts ($b = 0$); (ii) flat or knife-shaped contacts ($b \gg l$); (iii) solitary channels ($a \gg l$), and others.

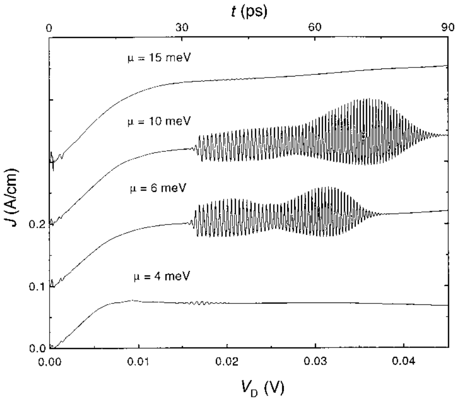

Fig. 1. Current–voltage characteristics with oscillation regimes for the set of samples with different Fermi-energies: $l = 0.1$ μm, $b = 0.01$ μm, $a = 0.4$ μm, $N_b = 1 \times 10^{11}$ cm^{-2}, and the well width is 11 nm

Quantized holes in the p-QW have a ground state dispersion relation, $\epsilon(k)$, that contains a negative effective mass (NEM) region. The NEM region position depends on the p-QW material, the well width, and the matrix material. In a recent series of papers (see [1,3] and references therein) we demonstrated that the existence of a NEM region in $\epsilon(k)$ did not allow the ballistic carriers (which moved across the channel biased with applied voltage V_D) to establish a stable stationary distribution of carrier concentration and electrostatic potential corresponding to a steady current. At a fixed applied voltage V_D a quasistationary oscillating current appeared instead. In most cases, numerical simulations indicate that the spectrum of these current oscillations is characterized by a main frequency which is in terahertz range for submicrometer bases. The effect of the Fermi-energy value and the length of contact tips on the generation regime for p^+pp^+-diodes with p-GaAs QW bases is investigated in this work. Very short ballistic diode bases, $l = 0.1$ μm, considered here, guarantee that a ballistic transport condition is valid at low temperatures as long as the energy of the ballistic holes is smaller than the LO-phonon energy, $\hbar\omega_o = 36$ meV. The oscillation frequency is 1 to 1.5 THz depending on the applied voltage and the Fermi-energy.

The oscillation regime substantially depends on μ (Fig. 1). This dependence is nonmonotonous. The oscillations are suppressed for small and large values of μ reaching their optimum at $\mu = 10$ meV. With the increase of μ the voltage range of the oscillation regime is shifted to larger voltages. When the concentration of injected holes becomes too large because of the high Fermi-energy, larger voltages are required to establish the concentration distributions that lead to the current oscillations, or this regime is not settled at all. On the other hand, too small an amount of Fermi-energy results in the early concentration depletion in the diode base that prevents the formation of the quasi-neutral region with NEM holes. These effects of the concentration accumulation and depletion are clearly seen in Fig. 2, where the concentration distributions in the base are presented for two stable branches of the current–voltage characteristic. Concentration distributions for $\mu = 10$ meV clearly display the existence of a quasineutral region for a stable low-voltage branch, and this value of μ can be chosen as optimal. Certainly, the optimum value of μ depends on base doping and length: for the structure with $N_b = 2 \times 10^{10}$ cm^{-2} and $l = 0.5$ μm it is equal to 6 meV.

A detailed picture of the oscillation is presented in the form of snapshots of the concentration and potential distributions recorded during one period of current oscillations

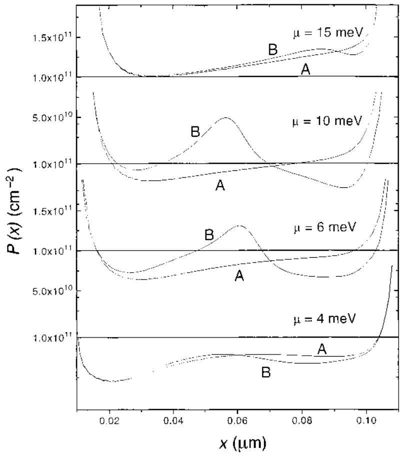

Fig. 2

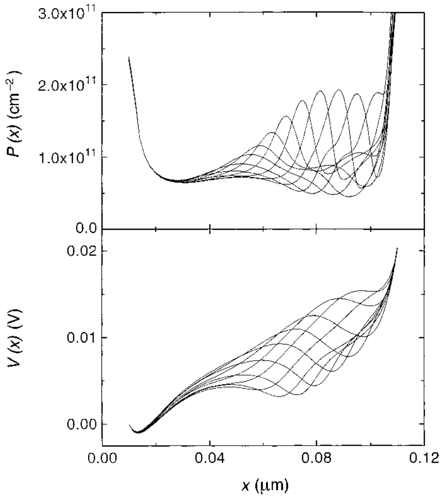

Fig. 3

Fig. 2. Stable hole concentration distributions, $P(x)$, before (curve A) and after (curve B) the oscillation regimes for the samples from Fig. 1

Fig. 3. Snapshots of the concentration $P(x)$ and potential $V(x)$ distributions recorded during one period of the current oscillations, $\mu = 6$ meV

(Fig. 3). It is seen that the concentration and potential waves do not spread into the anode, but decay in the anode depletion region. Consequently, the NEM plasma is in the right part of the base, where the unstable quasineutral region containing the NEM carriers should be.

Naturally, the design of the p^+-anode and cathode affects the electric field distribution around the p^+–p-junctions and regulates the number of the holes injected in the base and their distribution $P(x)$. The absence of concentration and field oscillations near the electrodes means that outer (that is bypassing) displacement currents dominate here. Therefore, we have to expect that the current oscillation regime depends on the shape of the p^+-contacts. We examine this influence in the framework of our model by varying the length of the contact tips, b. Embedding of small, knife-shaped contact tips facilitates the oscillation condition. This effect occurs for small b only and is saturated with the enlarging of b (for example, saturation occurs for $b > 0.05$ μm in the base with $l = 1$ μm). The fact that the oscillation regime substantially depends on the tip length indicates its sensitivity to the details of the design.

We also analyze the influence of the outer resistance on the oscillation regime in the ballistic diode. In agreement with general examination, the oscillation regime is affected by the outer resistance strongly if it is of the order of the inner resistance of the diode in the corresponding voltage range.

References

[1] N.Z. Vagidov, Z.S. Gribnikov, and A.N. Korshak, Semiconductors **31**, 150 (1997).
[2] N.Z. Vagidov, Z.S. Gribnikov, and A.N. Korshak, Semiconductors **29**, 286 (1995).
[3] Z.S. Gribnikov, A.N. Korshak, and N.Z. Vagidov, J. Appl. Phys. **80**, 5799 (1996).