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Terahertz Self-Induced Oscillations in the Injection *p–n* Junction with Fixed Reverse Bias

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Abstract—The results of numerical solutions of the complete equations of the diffusion-drift model (DDM) of Ge, Si and GaAs reverse-biased abrupt *p–n* junctions with injection of the constant-intensity electron flow into the *p*–region have been presented. The excitation mechanism of *p–n* junctions was examined and the factors affecting the frequency and amplitude of self-induced oscillations were established. The spectra of power and electron efficiency have been also presented. Abrupt Ge, Si and GaAs *p–n* junctions were shown to generate oscillations over the entire microwave range, while the second harmonic frequency could reach the terahertz (THz) range.

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In recent years the ever growing attention has been drawn to the THz range of the electromagnetic spectrum occupying the position between the microwave and infrared (IR) ranges. This is determined by the properties of THz waves. They can be applied, e.g., in medicine, control systems for radiographing of objects and detection of explosives, and in telecommunications sector. However, the creation of THz oscillators is confronted with difficulties of generating and detecting these waves.

Impact avalanche and transit-time (IMPATT) diode is one of the semiconductor oscillators, the frequency of which approaches the THz range [1]. As is known, the IMPATT diode operates in the forced-oscillation regime that is determined by the limiting value of avalanche current. In this case for exciting the IMPATT diode oscillations a high frequency component should be added to the dc voltage [2]. We have shown that in the regime without the avalanche current limitation the reverse-biased *p–n* junctions with injection of the constant-intensity electron flow produce oscillations at the dc voltage [3, 4]. The spectral content of self-induced oscillations of the avalanche current in these self-excited oscillators has not been studied in detail yet.

The purpose of this study is a detailed investigation of the self-oscillation mode in abrupt Ge, Si and GaAs *p–n* junctions with fixed reverse bias and injection of the constant-intensity electron flow into the *p*–region of the junction and the assessment of possibilities of creating the millimeter (MM) and submillimeter (SubMM) wave self-excited oscillators based on these junctions. To this end, the finite-difference methods for solving the DDM equations were used [5–8].

PROBLEM STATEMENT

Figure 1 presents a diagram of the idealized abrupt reverse-biased *p–n* junction with the injection of constant-intensity electron flow J_{in} into the multiplication layer of *p–n* junction. Where $U < 0$ is the *p–n* junction voltage; point x_1 is the boundary of *p*–region; point $x_2 = 0$ is taken as the origin of coordinates and represents an interface of the uniformly doped *p*– and *n*–regions of *p–n* junction; x_3 is the boundary of *n*–region; $w_p(t)$ and $w_n(t)$ are the coordinates of the depletion region of *p–n* junction that are time-dependent in the self-oscillation mode. The calculation of the static electric field and the avalanche breakdown voltage was performed in accordance with the procedure from paper [8].

The initial system of DDM equations providing an adequate description of the impact ionization in *p–n* junction has the following form [2, 9, 10]:

$$\frac{\partial E(x,t)}{\partial x} = \frac{q}{\varepsilon\varepsilon_0}[N(x) - n(x,t) + p(x,t)],$$