Numerical Analysis of a DAR IMPATT Diode

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PROBLEM FORMULATION

The analysis of the $n^{+}pvnp^{+}$ avalanche diode structure (Fig. 1) has been realized on the basis of the nonlinear model. This type of the diode that was named as Double Avalanche Region (DAR) IMPATT diode includes two avalanche regions inside the diode. The phase delay which was produced by means of the two avalanche regions and the drift region v is sufficient to obtain the negative resistance for the wide frequency band. The drift-diffusion model which is used for the analysis of the internal diode structure describes all important physical phenomena of the semiconductor device. This model is based on the system of two continuity equations for the electrons and holes, the Poisson equation for the potential distribution and necessary boundary conditions as for continuity equations and for the Poisson equation [1]. The dependences of the ionization coefficients α_n, α_p on field and temperature have been approximated using the approach described in [2]. This physical model adequately describes processes in the IMPATT diode in a wide frequency band. However, numerical solution of this system of equations is very difficult due to existing of a sharp dependence of equation coefficients on electric field. The non-evident modified Crank-Nicholson numerical scheme was used to improve numerical stability. Computational efficiency and numerical algorithm accuracy are improved by applying the space and the time coordinates symmetric approximation.

DISCUSSION

The analysis showed that the active properties of the diode practically are not displayed for more or less significant width of the region v (Fig. 2). The negative diode admittance appears for three different frequency bands when the region v less than 0.4 μm (Fig. 3). However these characteristics are not optimal. The possible optimization of the diode internal structure for selected frequency band can improve the power characteristics.

The DAR diode internal structure optimization has been provided below for the second frequency band near 220 GHz. The optimization algorithm is combined by one kind of direct method and a gradient method. The cost function of the optimization process was selected as output power for frequency 220 GHz. It means that the energy characteristics for the first and the third frequency bands have been obtained as functions of a secondary interest without a special improvement.

The small signal characteristics of the optimized diode structure are shown in Fig. 4 for all possible frequency bands and three values of feeding current.

The characteristics obtained for 220 GHz under the large signal serve as the main result of the optimization process. The amplitude characteristics for this frequency and for three values of feeding current density are shown in Fig. 5.

The output power dependencies as a function of first harmonic amplitude U_1 for f = 220 GHz and for three values of feeding current are shown in Fig. 6.

CONCLUSION

The numerical scheme that has been developed for the analysis of the different types of IMPATT diodes is suitable for the DAR complex doping profile investigation. Some new features of the DAR diode were obtained by the analysis on the basis of nonlinear model. The diode structure optimization gives the possibility to increase the output power level for the high frequency bands.

ACKNOWLEDGEMENT

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REFERENCES

[1] A. Zemliak, S. Khotiaintsev, and C. Celaya, Complex nonlinear model for the pulsed-mode IMPATT diode. Instrumentation and Development, **3**, 8, 45 (1997).
[2] W.N. Grant, Electron and hole ionization rates in epitaxial silicon at high electric fields. Solid-State Electron, **16**, 1189 (1973).

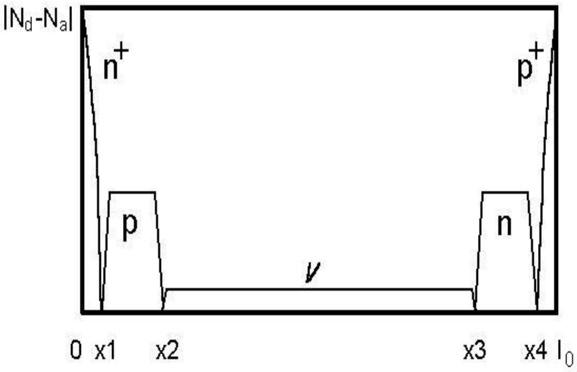

Fig. 1. Doping profile for DAR IMPATT diode.

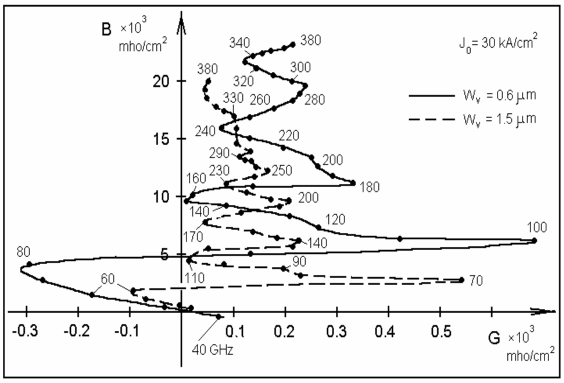

Fig. 2. Complex small signal DAR diode admittance (conductance $-G$ versus susceptance B) for different frequencies and two values of drift layer widths W_v.

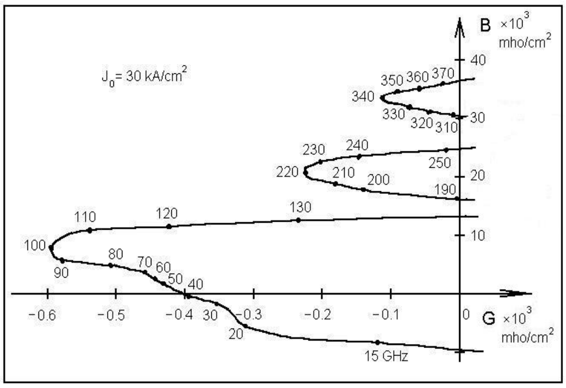

Fig. 3. Complex small signal DAR diode admittance (conductance $-G$ versus susceptance B) for different frequencies and $W_v = 0.32\ \mu$m.

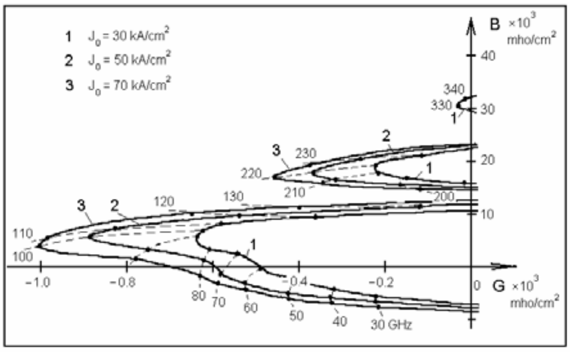

Fig. 4. Complex small signal DAR diode admittance optimized for second frequency band for different value of feeding current density.

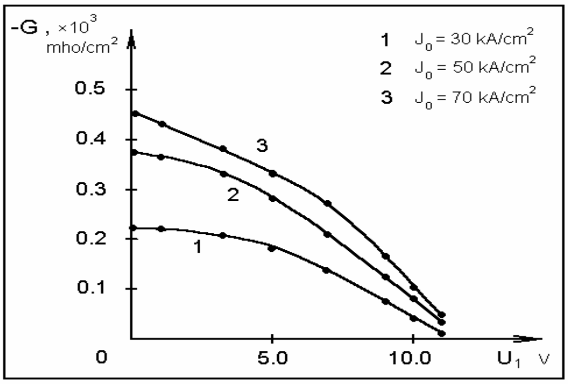

Fig. 5. Conductance G dependency as functions of first harmonic amplitude U_1 for f = 220 GHz and for three values of feeding current density.

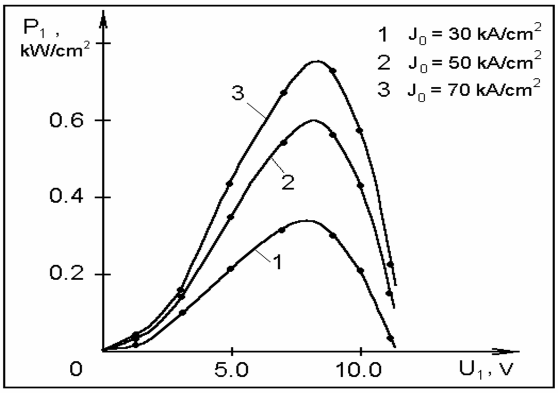

Fig. 6. Output generated power P dependency as functions of first harmonic amplitude U_1 for f = 220 GHz and for three values of feeding current density.