Program for designing maximum power IMPATT diode in the millimeter waves region

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Abstract:-. We present the results of a program for designing the internal structure of a maximum power IMPATT diode in the millimeter waves region. The simulation utilizes a non-linear model based on the diffusive semiconductor model with parameters depending on the applied electric field and the temperature. The results represents the graphic response of the internal dynamical state of the diode, such as the electric field distribution, carrier density and electrical current density. After knowing the internal state it is possible to calculate total external electric current, electrical power and the efficiency of power generation, finally we can determine the first harmonic model of the diode. Optimization algorithms of conjugate directions are used to establish the internal structure of the diode corresponding to the maximum power for a given frequency. The main results of design and simulation corresponds to the maximum power IMPATT diode generating 38GHz(≈ 8 mm) of power in silicon devices.

Key-Words: - Impatt Diode, Semiconductor Transport Simulation, Optimization based Design

1. Introduction

The power generation of an impatt diode depends on several factors such as temperature, quiescent point, the amplitude and spectrum of the information input signals, besides the load circuit. Our strategy of devices design, consist in optimize the characteristic parameters of the diode by simulation, followed by an adjust of results procedure, as shown in figure 1. Firstly is proposed some initial structure for the impatt diode and following an iterative procedure of simulation gives the optimal structure of performance.

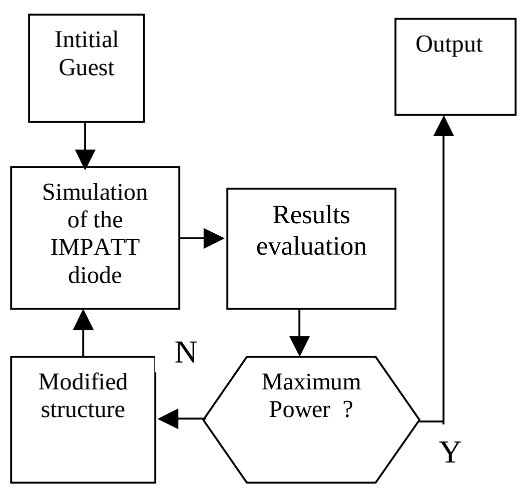


Figure 1 Strategy of optimization. The objective function of the simulation method is generated by the diode structure and it is evaluated by simulation.

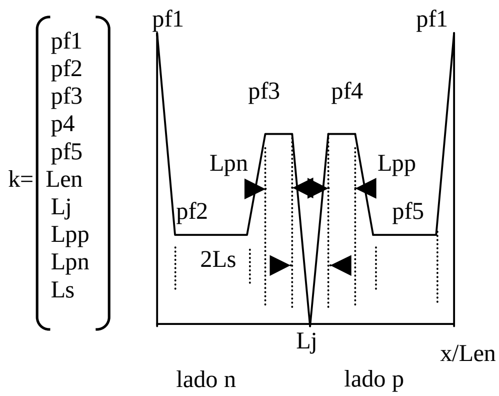


Figure 2 Vector parameters and doping structure of the Impatt diode.

2. Simulation and Optimization

To evaluate the performance of the impatt diode under a given internal structure, we implement the usual simulation algorithms as given in Ref.[1-4]. With them we calculate numerically the internal state along the active region (n+npp+) characterized by, the applied electric field (e), electrical potential (u), carriers concentration (n and p), and electrical current densities (jn and jp).

To find the optimal structure, corresponding to the maximum power performance, we utilize the conjugate directions algorithm having the advantage of no requiring of the gradient derivative methods.

The method is constructed under the following steps:

a) Two impatt diode structures are proposed k_A and k_B, to define the first search direction: $d_1 = (k_A,k_B)$.

b) Next a second search direction is proposed $d_2=(k_C,k_D)$, where $k_C=k_A+x_1$ and $k_D=k_B+x_1$, here x_1 is a constant vector. We get to set d_2 to be parallel to d_1.

c) Now, we have found two doping structures corresponding to the maximum power in each direction: X_M in d_1 direction and Y_M in d_2 direction.

d) Finally, the vector assignment $k_A=X_M$, $k_B=Y_M$ defines a new search directions. The we return to direction, that is orthogonal to both of the previous (c).

This iterative process ended when the required precision is obtained.

3. Input data and results

The frequency of operation and two search directions are given as inputs to the program. The first search direction $d_1=(k_A,k_B)$; in this direction we look for the influence of changes in the central doping area. The results are given by,

k_A = [1e+017, 3.3158e+016, 3.3158e+016, 3.3158e+016, 3.3158e+016, 0.939261, 0.621298, 0.0, 0.0, 0.05]$^{-1}$,

k_B = [1e+017, 3.3158e+016, 3.3158e+016, 3.3158e+016, 3.3158e+016, 0.939261, 0.621298, 0.1, 0.1, 0.05]$^{-1}$;

The second search direction $d_2=(k_C,k_D)$, is parallel to d_1, they are defined by,

k_C = [1e+017, 3.3158e+016, 3.3158e+016, 3.3158e+016, 3.3158e+016, 1.33926, 0.621298, 0, 0, 0.05]$^{-1}$;

k_D = [1e+017, 3.3158e+016, 5.30528e+016, 5.30528e+016, 3.3158e+016, 1.33926, 0.621298, 0.1, 0.1, 0.05]$^{-1}$.

3.1. Doping structure of maximum power to 38 GHz

The operating conditions proposed by the design program are 26.5 DC Volts and an alternating signal to 60% of the DC Voltage. It is found that the expected external DC current density is 28.6 kA/cm^2.

The power corresponding to the first harmonic generated by the diode at 38 GHz is expected to be 132.885 kw/cm^2 with efficiency greater than 17%.

The proposed internal structure of the impatt diode to generate maximum power at 38GHz, is characterized by the following set of parameters founded by the program,

$$k=\begin{pmatrix} pf1 \\ pf2 \\ pf3 \\ p4 \\ pf5 \\ Len \\ Lj/Len \\ Lpp/Len \\ Lpn \\ Ls \end{pmatrix} = \begin{pmatrix} 1.00 \\ 0.33158 \\ 0.446694 \\ 0.446694 \\ 0.33158 \\ 0.939261 \\ 0.621298 \\ 0.0578612 \\ 0.0578612 \\ 0.05 \end{pmatrix}$$

In Figure 5 we have: 1) Waveform of the external current 2) The addition of the DC and the first harmonic currents 3) Only the first harmonic current. It is observed a delay of 112^o (-4.29 rad= 1.99 rad=114^o).

Figure 6 shows the evolution of the internal state of the impatt diode in four instants inside a period of AC current. The electric is field scaled by a factor of 10^7. Takes its maximum value (5 $*10^5$ Volts/cm) at t=T/4, this value is very close to that founded in Ref. [5]. The carrier densities(cm^{-3}), scaled by a factor of $2.52*10^{17}$, are quite at t=0, starts to growth in number at t= T/4, and take their maximum values at t = T/2. The current densities of carriers (A/cm^2), are scaled by a factor of $4.0*10^5$, they take a vanishing value at t=0 and a maximum at t = T/2.

3.2. Convergence analysis

To know the precision of our results as a function of the points number in space and time, M and N respectively we make an analysis of convergence.

This analysis consists in two steps. In the first one the simulation is worked within the AC signals as shown in Fig. 5(a), have a variation less than 5%. The second analysis indicates that the breakdown voltage for the diode is 30.7 DC Volts, with a current density of 5 kA/cm^2.

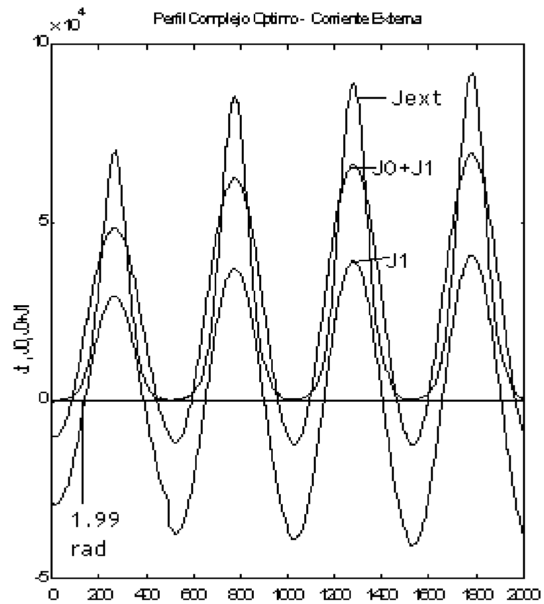


Figure 5. Current densities for the IMPATT diode with maximum power of a 38 GHz. We have, the conduction current, the addition of the direct current and the first harmonic.

4. Conclusions

The results of the simulation in designing an IMPATT diode at maximum power are presented. The optimal parameters are given through an optimization procedure about the internal structure of the diode. It is expected that this program becomes an useful tool for the design of silicon devices to generate power in the millimeter region, in particular to improve the IMPATT diode design.

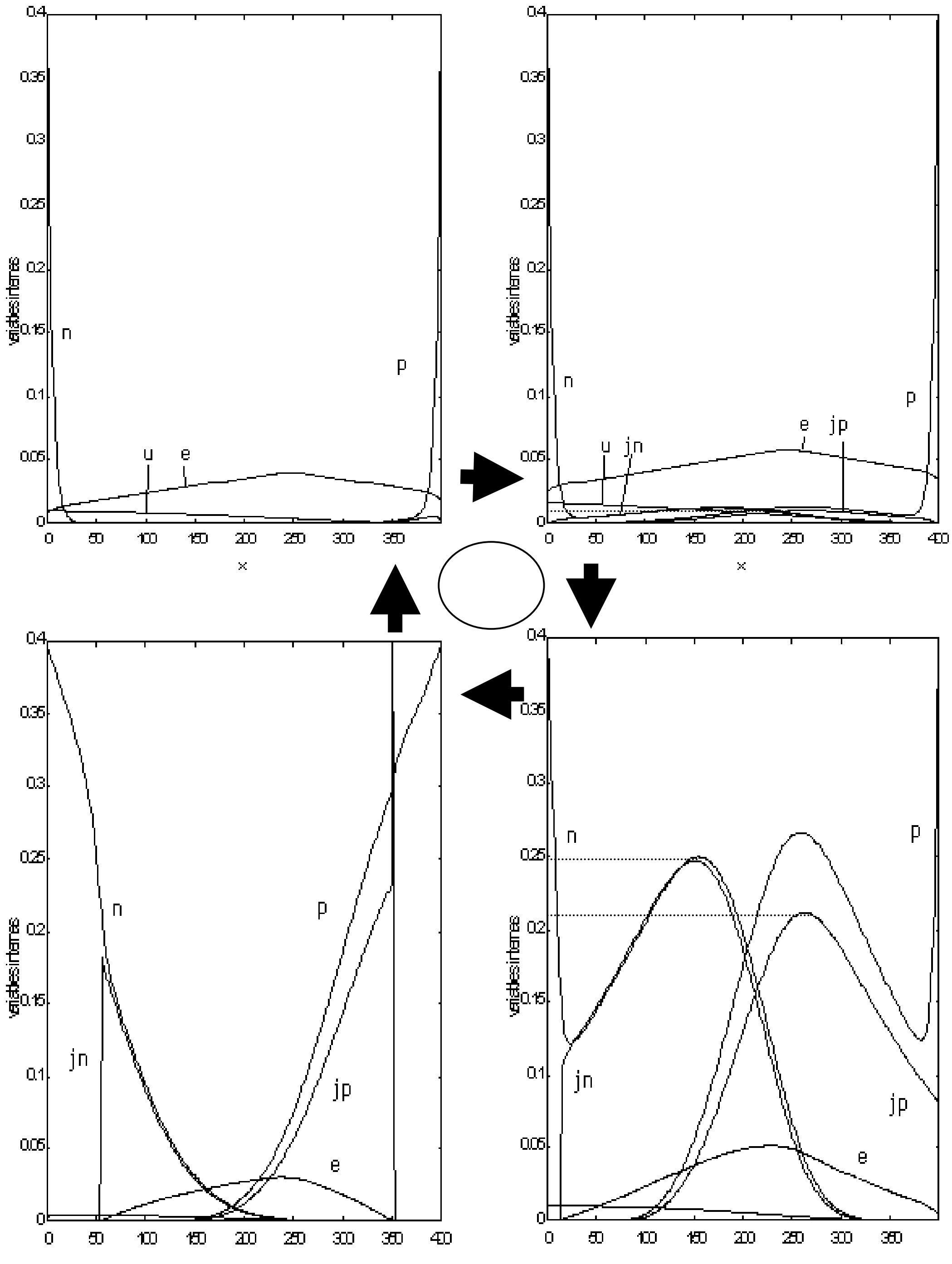
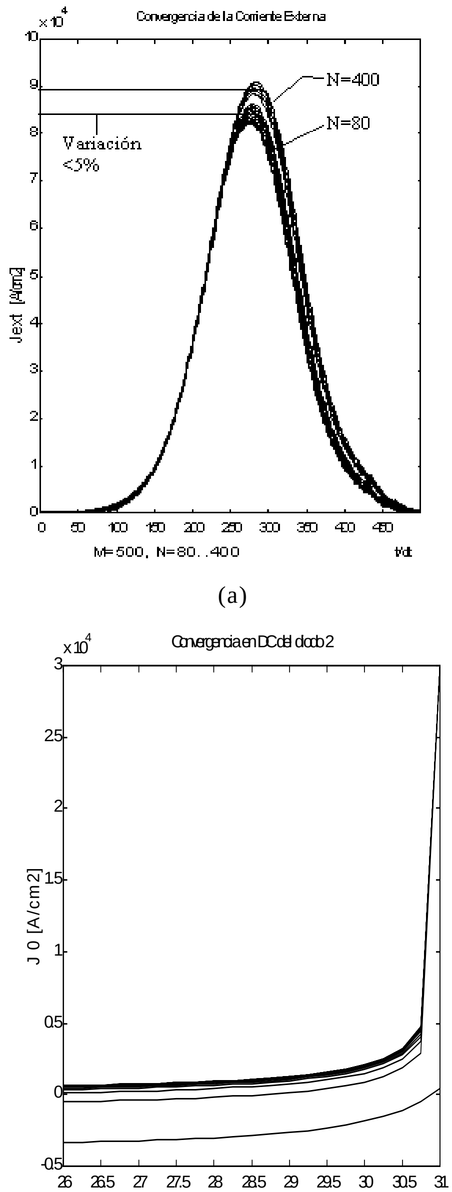


Figura 6. Evolution of the Internal State of the optimal structure of the diode



(a)

(b)

Figure 6. The period of the AC current signal divided in M segments, running from 0 to M-1. The size of the active region of the diode (Len) is divided in N segments. A period of the external current corresponds to the characteristic curve of DC Current-Voltage.

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