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Numerical analysis of GaAs MESFETs OPFET

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Abstract
A Tow dimensional numerical model of channel potential for GaAs MESFET (Metal semiconductor field effect transistor) doped uniformly .the model takes into acount the effects in channel region considering both the photoconductive effect and photovoltaic effect at the gate schottky . the 2-D potential distribution function in the active layer of the divice is solved numerically under dark and illumination condition.
Keywords: *2-D modeling potential distribution, Photodetector, Photovoltage.*

1. Introduction

Later on ,the optically controlled MESFET was named on optical Field effect transistor OPFET. The photosensitivity of the MESFET has opened up the possibility of their use for a variety of optoelectronic application. At present the GaAs MESFET's under illumination plays an important role in communication technology For wide band multimedia and high speed application. An idea that has been widely investigated recently for performing optically controlled functions and it can be used to form an additional input port in photonic (MMIC) [1] and also drawn considerable attention potential application ion due to their potential of device.

As a number of research of theoretical and experimental works have been reported on optically controlled MESFET . A simple analytical model of an ion implanted GaAs MESFET is useful for computer aided design of divices and integrated circuits (IC's).To examine the optical controlled characteristics of GaAs Mesfet is necessary used model of optically gated Mesfet photodetector considering the short channel effect .This paper present the two-dimensional numerical simulation of MESFET using the Liebman iterative method in order to simulate 2D channel Potential and Elecric field equation.

2. Theoretical model

The 2-D Poisson's equation in the space charge region of the device in illuminated condition and Schottky contact [2,3]. Can be written as

$$\frac{d^2\psi(x,y)}{dx^2}+\frac{d^2\psi(x,y)}{dy^2}=-\frac{q}{\varepsilon}\left(N_d(x,y)-A\exp(-\alpha y)\right) \quad (1)$$

$$A=\frac{P_{opt}(1-R_s)(1-R_m)\alpha\tau_L}{h\gamma} \quad (2)$$

Where, $\psi(x,y)$ is 2-D Potential distribution $N_d(x,y)=N_d$ corresponds to the donor (uniform doping density) ,q (Electron charge), ε_s (Permittivity of the GaAs), (R_m, R_s) (are Reflection coefficient at the entrance and Reflection coefficient at the metal semiconductor contact), P_{opt} (Incident optical power density), α (Optical absorption coefficient of the semiconductor at the operating wavelength), h (Planck's constant), γ (Frequency of the incident radiation), τ_L (Mean lifetime of the minority carriers under illumination condition [4]).

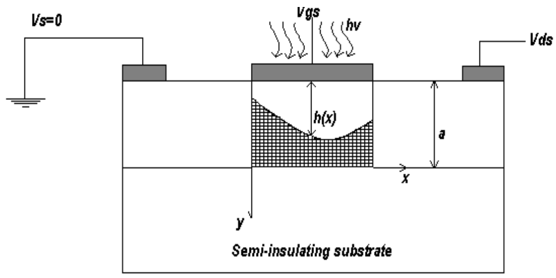

Fig.1 Schematic of MESFET under illumination

The boundary conditions as related to the Poisson's equation are taken from [3,5].

$$\begin{aligned}\psi(x,0)&=V_{gs}+V_{op}-\phi_{bi}\\ \psi(0,y)&=V_{bi}\\ \psi(L,y)&=V_{bi}+V_{ds}\\ \psi(x,a)&=0\end{aligned} \quad (3)$$

Where
Vgs Gate to source voltage
Vds Drain to source voltage
Vbi Built in volge between the channels to source junction
Øbi Built in voltage of the Schottky barrier gate.

Due to illumination, the device performance varies due to the photovoltage developed at the Schottky junction. This photovoltage is calculated using the following relation [7]

$$V_{op} = \frac{nKT}{q}\ln\left[\frac{q}{J_{SC}}\frac{\alpha P_{opt}}{h\gamma L}\left(\int_0^L\int_0^{h(x)}\exp(-\alpha y)dxdy\right)\right] \quad (4)$$

where $h(x)$ is the extension of the Schottky junction depletion region in the channel measured from the surface is given as

$$h(x) = \left[\frac{2\varepsilon}{qN_d}\left(\phi_B - \Delta + V(x) - V_{gs}\right)\right]^{\frac{1}{2}} \quad (5)$$

$h^{'}(x)$ is the is the extension of the Schottky junction depletion region in the channel measured from the surface under illumination is given by

$$h(x)^{'} = \left[\frac{2\varepsilon}{qN_d}\left(\phi_B - \Delta + V(x) - V_{gs} - V_{op}\right)\right]^{\frac{1}{2}} \quad (6)$$

The excess carriers generated per unit volume in the semiconductor due to the absorption of incident optical power density is given by

$$\Delta n = \frac{1}{H_m}\int_0^{H_m} G_{op}(x,y)\tau_L dy \quad (7)$$

Where Hm is the maximum width of the depletion layer

$$H_m = \left[\frac{4\varepsilon\ln(\frac{N_a}{n_i})}{q\beta N_a}\right]^{\frac{1}{2}} \quad (8)$$

τ_L is the minority carrier life time given by

$$\tau_L = \left(\frac{n_i}{ni + \Delta n}\right)\tau \quad (9)$$

and $G_{OP}(x,y)$ is the excess generation rate at any point y in the semiconductor and is given by

$$G_{op}(x,y) = A\int_0^L\int_0^a \exp(-\alpha y)dxdy \quad (10)$$

3. I-V Characteristics

The drain current Ids has been calculated by numerically integrating the charge in the channel region given by

$$I_{ds} = \mu_n \frac{Z}{L}\int_0^{V_{ds}} \varphi_n(V)\,dV \quad (11)$$

The charge is calculated using the relation (1)

$$\varphi_n(v) = q\int_{h(x)}^{a} N_d(y)dy + qA\int_0^a \exp(-\alpha y)dy \quad (12)$$

Where µn is the mobility of electrons, and $\varphi_n(V)$ is the charge in the neutral channel region per unit area at a point x where the channel voltage $V(x)$ is given by [6], $h(x)$ is function of the channel voltage $V(x)$.

3.1. Mobility model

The field dependent mobility of the charge carriers in the channe lis given by

$$\mu_n(E_x, E_y) = \frac{\mu_0(E_y)}{\left[1 + (\frac{E}{E_c})^2\right]^{\frac{1}{2}}} \quad (13)$$

3.2 Electric field

The electric fields along the x and y directions can be calculated as

$$\mathrm{E}_x = \frac{(\psi_{i+1,j} - \psi_{i-1,j})}{2L/Nx}$$
$$\mathrm{E}_y = \frac{(\psi_{i,j+1} - \psi_{i,j-1})}{2L/Ny} \quad (14)$$

Where Nx and Ny are the separation of the grid line along the x and y directions. Where E is the field electric given by

$$E = \sqrt{E_x^{\ 2} + E_y^{\ 2}} \quad (15)$$

These equations are used to calculate the field dependent mobility and drain current equation.

3. RESULTS AND DISCUSSIONS

Computations have been carried out for GaAs MESFET at 300K under Dark and illuminated conditions The gate metallisation has been assumed to be thin enough to allow 90% of the incident radiation to pass through.

The basic 2D Poisson's equation (1) is solved using 2D Poisson equation (1) is solved by finite iterative method (Liebmann iterative method) to determine the potential distribution at every grid point in conductor channel whith applied the approprite condition .

The voltage profile in the channel is divided into large number of elementary strips.

The parameters used in the calculation are shown inTable1

Table1. Simulation table parameters

Parameter	**Values**
Channel depth, a	0.22µm
Channel length, L	1.2 µm
Channel width, Z	0.4 µm
Absorption coefficient α	25 µm
Minority carrier life time,τ_L	106 /m
Intrinsic carrier concentration,ni	10-8s
Incident optical power, Popt	0.85 v
Reflection coefficient at entrance,Rm	0.2,0.5W/m2
Reflection coefficient at metal contact, Rs	10% of Pop
Position of Fermi level below the conduction band,Δ	0.02 eV
Built-in voltage of Schottky gate, Φbi	0.85 v

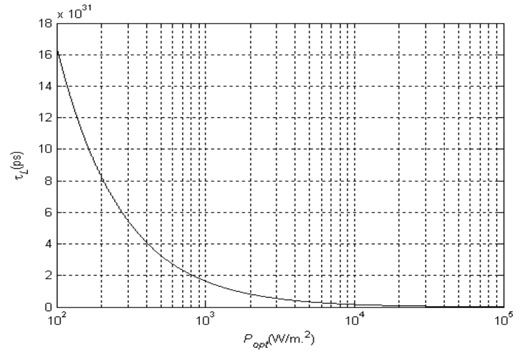

Fig.2. The variation of P_{opt} versus the minority carrier life time,τ_L

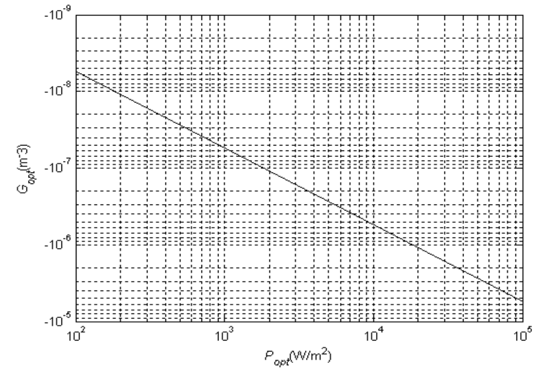

Fig.3. The variation of Incident optical power density P_{opt} versus photovoltage G_{opt}

Fig. 3 shows the increase of photvoltage Gopt with an increase in the incident optical power density ,Popt due to the reduction in lifetime of the carrier in the presence of illumination presented in Fig.2, which limits the excess photogeneration under intense illumination.

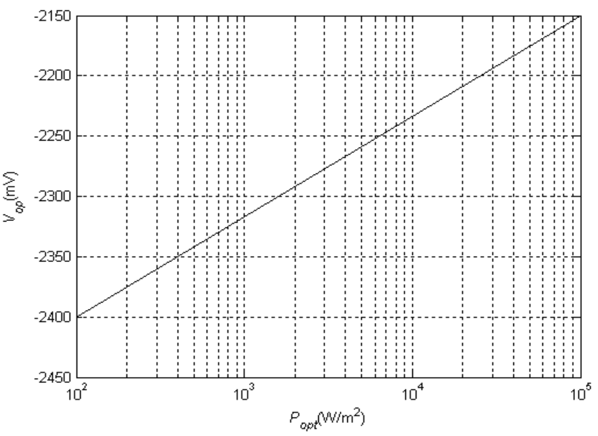

Fig4 shows the variation of the photo voltage V_{op} developed at the Schottky contact with the optical power density P_{opt}.

The Surface recombination has not been taken into account. The photo voltage developed at the Schottky junction increases with the incident optical power density P_{opt}.

The drain to source current Idsop can be written considering its continuity equation as

$$I_{dsop} = \left(\frac{Z\mu_n}{L} \right) \varphi_n(v) E \qquad (16)$$

Where μ_n is the field dependent mobility of carriers, E is the electric field at point (x,y) due to the field E_x and E_y.

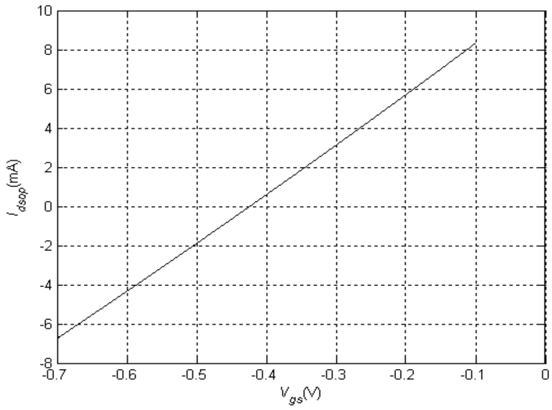

Fig 5 shows the variation drain to source curent Idsop with the Vgs under illumination.

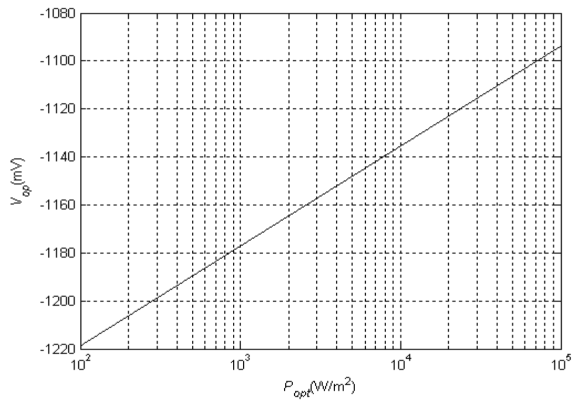

Fig. 6. Variation of the photovoltage Vop across the Schottky barrier with the incident optical power densityPopt.

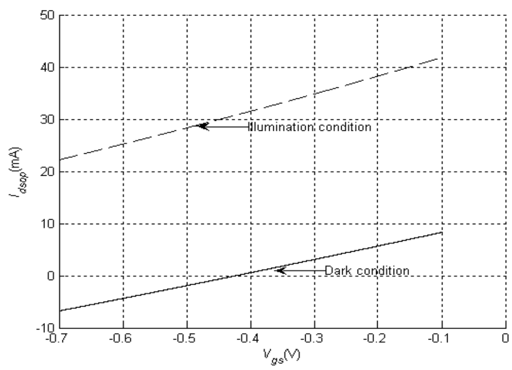

Fig.7. shows the variation drain to source curent Idsop with the Vgs under illumination and dark condition.

The curent Idsop increase with increase of the applied sourse to gate voltage and we observe the excess of Idsop in illumination condition than the dark condition.

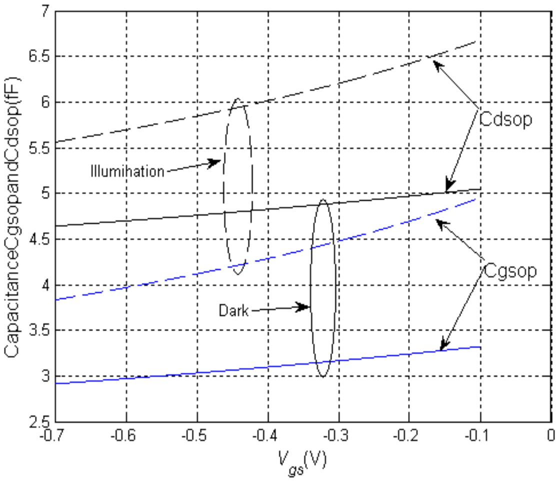

Fig.8 shows the variation of the gate to source capacitance Cgsop and Cdsop with the Vgs for different illumination (Popt1=0W/m2, Popt2=1E5W/m2).

It shows that the capacitance increases slightly with the increase in illumination.

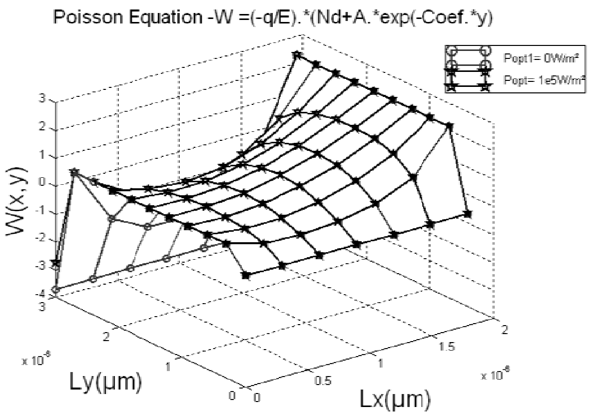

Fig.9 shows the variation of channel potential with Lx andLy for different illumination(Popt1=0W/m²,Popt2=1E5W/²).

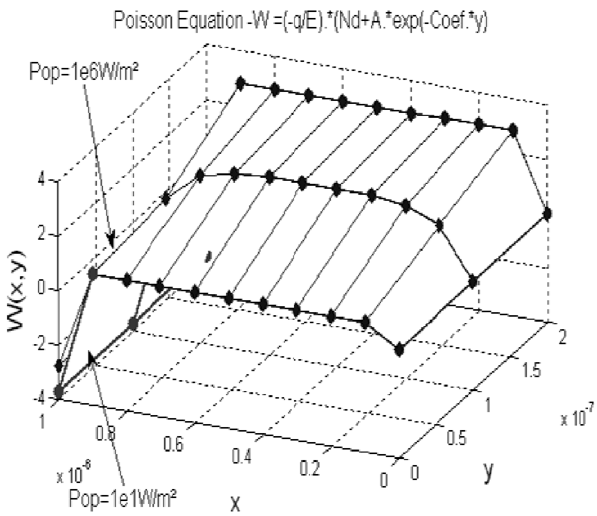

Fig.10 shows the variation of channel potential with Lx andLy for different illumination(Popt1=1E6W/m²,Popt2=1E 1W/m²).

It clearly shows that the channel potential increases towards the drain side. This is because the biasing is applied at the drain

The Fig.9 and Fig10 shows the two dimensional potential profile in the channel under dark and illumination conditions.

4. Conclusion

The 2D Poisson's equation is solved numerically for GaAsMESFET photodetector with uniform doping profile. The device characteristics and parameter have been calculated under the dark and illumination conditions. The effect of various internal device parameters such as electric filed, mobility of the carriers in the presence of illumination, potential distribution of the carriers have also been studied extensively through numerical simulation. The drain current and transfer characteristics of the GaAs MESFET photodetector has also been calculated. The present work is limited to modeling and simulation of uniformly doped two dimensional GaAs MESFET photodetectors.

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