# An Overview of the analysis of two dimensional back illuminated GaAs MESFET

Prof. Lochan Jolly*, Ms. Sonia Thalavoor**

*(A.P- Department of Electronics & Telecommunication, TCET, Mumbai
Email: lochan.jolly@thakureducation.org)
** (M.E student - Department of Electronics & Telecommunication, TCET, Mumbai
Email: soniathalavoor@gmail.com)

**ABSTRACT**

**This paper presents an analysis of two dimensional MESFET under back illumination. The purpose of this paper is to study certain aspects of device fabrication and material properties of ion implanted MESFET. It is observed that when the gate length becomes shorter than about 2µm, 2D effects dominates the device operation. Therefore for accuracy while modeling MESFET under illumination both the device structure and appropriate physical 2D equations governing device behavior are taken into consideration.**

*Keywords* **– MESFET, OPFET, Photovoltage, Photoabsorption, Schottky**

## 1. INTRODUCTION

Increasing demand for high speed circuits in digital logic and microwave devices for example, in real time signal processing, continuous voice recognition and satellite broadcasting has stimulated interest in GaAs [7]. The emerging GaAs technology requires the development of an accurate and efficient device model of GaAs metal- semiconductor field effect transistor (MESFET). MESFET being an optically sensitive element can be considered as a dual gate device under optically illuminated field effect transistor (OPFET) in which the first gate which is the real gate is electrical and the second gate which is the virtual gate is optical. A number of studies have illustrated that both the dc and microwave characteristics of a GaAs MESFET can be modified by coupling a portion of the optical power radiated by an external source (in our case it is the fiber which is inserted into the substrate) into the channel of the device. The excess electron-hole pair generation due to the optical radiation in the channel is utilized to modify the device characteristics. Since these excess electron-hole pairs can be controlled by the radiated power level of the external optical source, the radiated power level has direct control on the device characteristics [1]. With the increasing use of optical transmissions in different systems, development of an efficient device structure with improved coupling efficiency between optical and microwave energies have become very important. For optimum optical/microwave interaction, optical absorption in the active region of the device must be improved [2].

## 2. NEED OF TWO DIMENSIONAL ANALYSIS

GaAs MESFET's with gate length values in the range of 0.2-0.5 µm show high drain to source current and large transconductance values at the microwave frequency. The 1D Poisson's equation will fail to provide potential distribution of such MESFET's with channel length in the above mentioned range since the electrical characteristics of these scaled down devices are known to be greatly influenced by 2D potential distribution and high electric field effects [1]. Therefore we can solve the Poisson's equation to obtain the channel potential of MESFET devices which can be utilized for further modeling of electrical characteristics of devices.

## 3. EFFECT OF ILLUMINATION

The mechanism of operation of GaAs MESFET in the presence of optical illumination is explained on the basis of photoconductive effect and photovoltaic effect. **Photoconductive effect :** It is the phenomenon in which the photons in the incident light is absorbed which results in increase in the generation of free charge carriers which in turns increases the electrical conductivity of the device. The fundamental physical mechanism behind optical illumination is the absorption of photons in the valence band of the material thereby creating electrons and holes. The photogenerated electrons contribute to the drain-source current when a drain-source voltage is applied and the holes develop a photovoltage at the schottky junction and p-n junction of the device resulting in the modulation of the channel conductance [2]. **Photovoltaic effect:** It is the mechanism by which a voltage is developed when the material is exposed to incident light. **Back illumination** is the type of illumination in which light enters the device through the substrate.

## 4. WHY MESFET PHOTODETECTOR

MESFET's have been known for its applications in optical communication as detector devices. An important class of photodetectors involves the use of Schottky barrier produced between a metal and a lightly doped semiconductor. The key advantage of Schottky barrier devices is that being a majority carrier device, it does not suffer from speed delays arising from minority carrier lifetime issues [6]. MESFET has drawn considerable attention in recent years as a good contender in VLSI technology because of the following device characteristics:

i) enhanced radiation hardness
ii) immunity to hot carrier aging
iii) scaling well
iv) less mobility degradation [6].

The device is suitable for application in microwave monolithic integrated circuits (MMIC) and Optoelectronic Integrated circuits (OEIC) due to their integrated circuit compatibility. Most devices are required for high speed operation, and therefore an n-channel is used because electrons have a much greater mobility than holes that would be present in a p-channel.

## 5. WHY GaAs MESFET

GaAs MESFET's can be used as photodetector due to its higher carrier mobility and its potentiality [4]. GaAs being a direct band gap semiconductor, it is highly suitable for optoelectronic applications and makes possible a monolithic integration of ultra high speed submicron transistors together with laser or LEDs on the same chip for use in optical communication. These devices have better radiation hardness since the direct band gap results in high electron-hole recombination rates. Both discrete components and integrated circuits which are made in GaAs are faster than those made in silicon because its low-field electron mobility is larger than that of silicon, and GaAs has a lower saturation field than silicon. GaAs has an energy gap that is four orders of magnitude larger than Si. This allows GaAs to be made semi-insulating (with a bulk resistivity on the order of 10^9 ohms). The readily available semi-insulating GaAs substrates reduces interconnect parasitic capacitance provides a natural way for isolating devices making device isolation simple [7]. The low field at which electron drift velocity saturates in GaAs as compared to Si allows the high saturation velocity to be reached at lower voltages than for Si as shown in Fig.1[7]. GaAs has the ability to emit light which is useful for making lasers, light-emitting diodes, and microwave emitters used in cellular phones. (It is a direct band gap material) Its 5 to 6 times higher electron mobility than Si can be exploited for higher speeds [7]. Its ability to work at higher temperatures and better radiation resistance [7]. GaAs is a compound material which makes its processing and synthesis more complicated than Si [7].

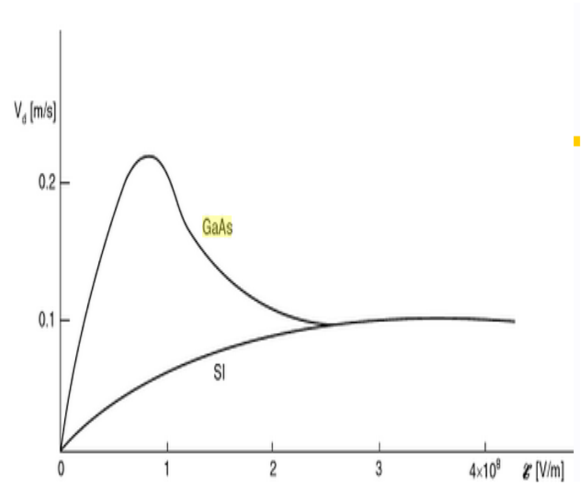


**Fig.1 electron velocity as afunction of electric field in GaAs & Si**

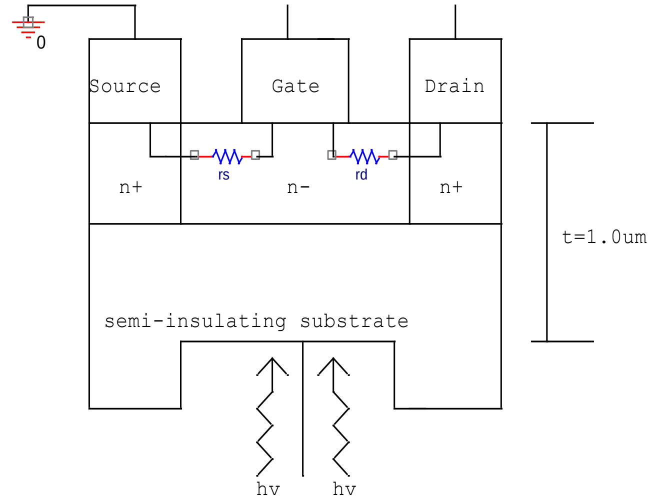


**fig.2 fiber partially inserted into the fiber**

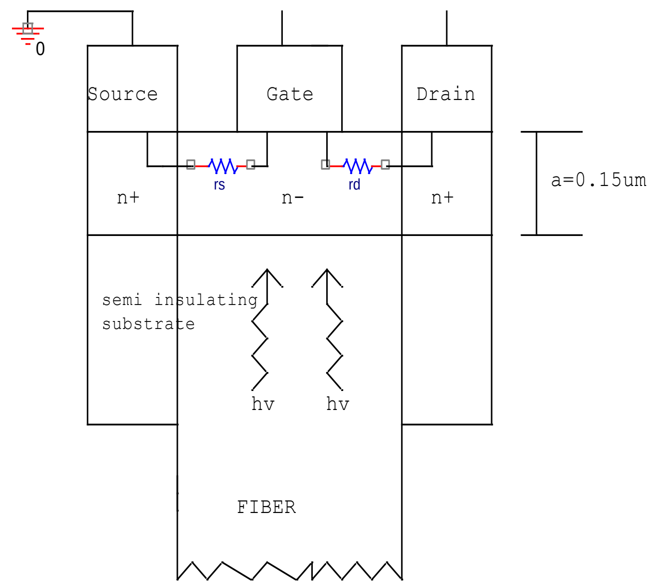


**fig.3 fiber inserted upto the active layer**

## 5. DEVICE STRUCTURE

The device consists of a non-uniformly doped semi-insulating GaAs substrate followed by an epitaxially grown ion-implanted active layer of n-type doping. This is similar to the conventional MESFET except the former uses the semitransparent metal gate which facilitates the absorption of optical radiation illuminated on the gate [4]. The gate electrode is deposited directly on the semiconductor and forms a Schottky barrier contact with the conducting channel underneath, between the source and drain ohmic contacts.

The gate bias modulates the depletion region under the gate and, thus, modulates the effective width of the neutral channel and thus the current flow between source and drain. [2]. This work will consider non-uniformly doped ion-implanted n-channel MESFET. The schematic structure of the ion-implanted GaAs MESFET with back illumination is as shown in Fig.1 and Fig.2 for the two cases. In Fig.1, the fiber is inserted partially into the substrate so that the absorption takes place in both substrate and active region. In Fig.2, the fiber is inserted upto the junction of the substrate and the active layer where photoabsorption takes place in the active region only.

## 6. DEVICE MECHANISM

The drain-source current flows along the x-direction and the illumination is incident through the fiber along the y-direction of the device. When the device is illuminated, the photons of the illumination are absorbed and electron hole pairs are generated in the semi insulating substrate region, the active layer-substrate depletion region, the channel region and the schottky junction depletion region. The optically generated electrons move towards the channel and contribute to the drain-source current when a drain-source voltage is applied while the holes move in the opposite direction. Due to the electrons crossing the junction, a photovoltage is developed. This voltage being forward biased reduces the depletion width of both the junctions. For the first case where the substrate effect is included, an external photovoltage $V_{op1}$ is developed across the schottky junction and an internal photovoltage $V_{op2}$ is developed across the substrate-active layer junction[2] . For the second case where no substrate effect is involved the only photovoltage developed is the external photovoltage across the schottky junction.

The ion- implanted profile is represented by the Gaussian distribution as shown in Fig.4

$$N(y) = \frac{Q}{\sigma\sqrt{2\pi}} \exp\left[-\left(\frac{y-R_p}{\sigma\sqrt{2}}\right)^2\right] \quad \text{..........} (1)$$

where Q is the ion implanted dose, σ is the straggle parameter and $R_p$ is the projected range.

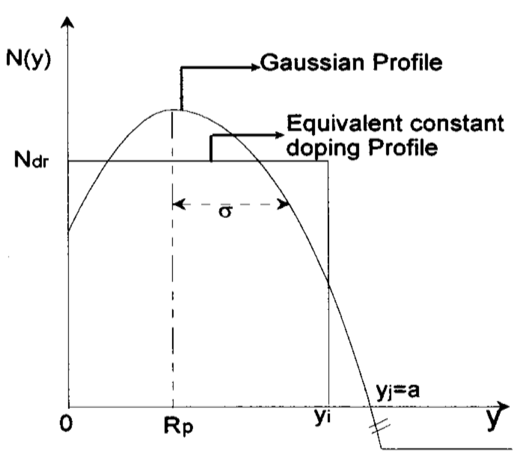


**fig.4 Gaussian profile**

## 7. PHOTOVOLATGES

The photovoltage is developed due to the flow of holes across the junctions. The transport mechanism of carriers in the depletion region is due to drift and recombination. The number of photogenerated electrons and holes are obtained by solving the 2D continuity equation.

The volume generation rate of carriers is assumed to vary exponentially with distance and it is given as

$$G = \alpha\phi e^{-\alpha(t-y)} \quad \text{.............} (2)$$

Under back illumination, carrier generation is maximum at the substrate end at y=t and y=0 refers to the surface of the device where the generation is minimum.

The external photovoltage $V_{op1}$ across the schottky junction is calculated using the relation [2]

$$V_{op1} = \frac{kT}{q}\ln\left(\frac{qv_y p(0)}{J_{s1}}\right) \quad \text{............} (3)$$

where $J_{s1}$ is the reverse saturation current density across the schottky junction and p(0) is the number of holes crossing the junction at y=0.

The internal photovoltage $V_{op2}$ across the channel substrate junction is obtained using the relation

$$V_{op2} = \frac{kT}{q}\ln\left(\frac{qv_y p(a)}{J_{s2}}\right) \quad \text{............} (4)$$

where $J_{s2}$ is the saturation current density for the p-n junction and the surface recombination is zero for $V_{op2}$.

## 8. DEVICE SPECIFICATIONS

**Table-1**

| Para-meter | Description | Values considere d |
|---|---|---|
| L | Gate length o | 0.5 μm |
| A | Active layer | 0.15 μm |
| Z | Width of device | 20 μm |
| $\tau_p$ | Recombination lifetime of hole | 7.7 psec |
| $\tau_s$ | Recombination lifetime of an electron | 7.7 p sec |
| $\nu_p$ | Drift velocity of hole | $1.3x10^5$ m/ sec |

| | | |
|---|---|---|
| $\nu_s$ | Drift velocity of an electron | $1.3 \times 10^5$ m/ sec |
| $\eta_{int}$ | Internal quantum efficiency | 1.0 |
| A | Optical absorption co-efficient | $1.0 \times 10^4$ /m |
| $J_s$ | Reverse saturation current density for the metal-GaAs Schottky junction | 0.255 $A/m^2$ |
| $N_D$ | Uniform doping concentration | $1.0 \times 10^{14}$ $/cm^3$ |
| $\mu_n$ | Mobility of electron in GaAs | 0.25 $m^2/V\text{-}sec$ |

## 9. RESULTS

Using the above device dimensions the device was created using Sentaurus device simulator and the created device is as shown in Fig.5 and the created device with doping and meshing is as shown in Fig.6. For semi insulating GaAs substrate, carbon was used to dope GaAs to make it semi- insulating and Si was used to create n type active channel and n+ drain and source regions with different doping concentrations.

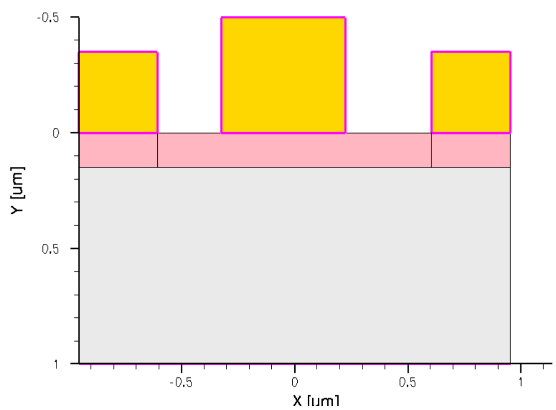


**fig.5 device with gate length 0.5µm**

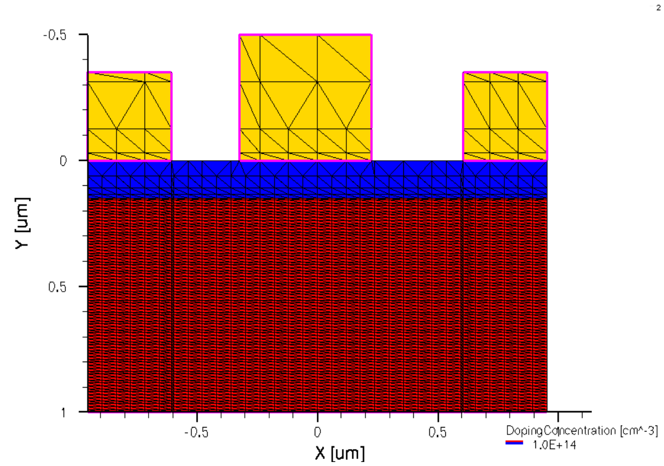


**fig.6 doped and meshed device**

## CONCLUSION

A new model for the OPFET frequency dependent characteristics have been outlined under back llumination with and without substrate effect. The significant feature of this new analytical model is the higher drain-source current of the device due to improved absorption. Internal photovoltaic effect is found to be more significant than the external photovoltage. The back illuminated GaAs model will be developed by taking into consideration both the cases where i) Fiber is inserted partially into the substrate and ii) Fiber is inserted up to the active layer.

OPFET model with back illumination is considered as a useful method for the design of optical transducer, detector and preamplifier and radio frequency optical switch in communication and computers.

## ACKNOWLEDGEMENTS

An acknowledgement to IIT, Bombay for allowing to simulate the device using Sentaurus device simulator at IIT, Bombay.

## REFERENCES

**Journal Papers:**

[1] Shweta Tripati, S. Jit, "A Two-Dimensional Analytical Model for the Potential Distribution and Threshold Voltage of Short Channel Ion-Implanted GaAs MESFETs under Dark and Illuminated Conditions," *Journal of Semiconductor Technology and Science*, *Vol.11 No.1*, March, 2011

[2] Nandita Saha Roy and B.B. Pal, OPFET Characteristics with Improved absorption under back illumination," *Journal of Lightwave Technology Vol. 18, No.4*, April 2000.

[3] Nandita Saha Roy, B.B Pal, R.U Khan, "Frequency Dependent Characteristics of an Ion- Implanted GaAs MESFET with Opaque Gate under Illumination," *Journal of Lightwave Technology*, *Vol.18, No.2*, February 2000.

[4] Dr. B.K. Mishra, Lochan Jolly and Kalawati Patil, "Two Dimensional Modeling of Nonuniformly Doped MESFET under Illumination," *International journal of VLSI design & Communication Systems*, *Vol.1, No.2,* June2010.

[5] Dr. B.K. Mishra, Lochan Jolly and Kalawati Patil, " Back Illumination-A technique to enhance the performance of GaAs MESFET," *2nd International Conference and Workshop on Emerging Trends and Technology*, 2011.

[6] K. Balasubadra, T. Thangam, V.Rajamani, K.Sankaranarayan, "Three dimensional numerical modeling and simulation of a uniformly doped GaAs MESFET photodetector," Journal of Optoelectronics and Advanced Materials, Vol.10, No.10, October 2008.

**Thesis:**

[7] Kim Wah Tan, *GaAs materials and fabrication* , McGill University, 1983.

[8] Ping Chen,Yuba R Shresta, hui Shen,*The fabrication and characterization of GaAs n – MESFET*, University of Cincinnati,March 2003