ENHANCED OPTICAL CHARACTERISTICS OF MODFET UNDER BACKSIDE ILLUMINATION

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Abstract

An enhanced optical response of the depletion mode AlGaAs / GaAs MODFET under backside optical illumination with DC light is presented. A device structure with fiber inserted into the substrate up to the GaAs layer is considered for direct illumination into the GaAs layer. The photoconductive effect in the GaAs layer which increases the 2DEG channel electron concentration and the photovoltaic effect which forward bias the AlGaAs – gate junction are considered. In addition the reflection effect of the contact metals which also increases the 2DEG channel electron concentration is also considered. The electrons generated in the GaAs layer and AlGaAs layer are collected in 2DEG, there by increasing the source to drain current and the photo generated holes are drift towards the semi insulating substrate and are capacitively coupled in to the grounded source. The I-V characteristics, transconductance, photovoltage and transfer characteristics have been evaluated and discussed . The I-V characteristics is compared with available experimental data at a particular gate source voltage with and without illumination showing good agreement .

Key words: MODFET, photovoltage, internal reflection, transconductance.

I.INTRODUCTION

The effect of optical illumination on Modulation Doped Field Effect Transistors (MODFET) have been investigated by researchers and excellent photo sensitivities have been measured [1]-[3]. When an optical signal is injected in to MODFET device ,the signal is first detected and then internally amplified by the transistor. This makes the MODFET an excellent photo detector for the recovery of an intensity modulated optical signal. Since the front side illumination of MODFET limits the sensitivity and quantum efficiency[4] by the shadowing effect of the contact metals, it is desired to control MODFET device optically with backside illumination. Still it is difficult to achieve high quantum efficiency with backside illumination because the semiconductor substrate also absorbs the incident light, causing the optical signal to be completely attenuated before reaching the active layer. One approach for eliminating the attenuation effect due to substrate with backside illumination is epitaxial lift of (ELO) process[5]. Another method which we used in this paper is to insert an optical fiber in the substrate region.Here the fiber touches the active layer for direct illumination of the device from its backside by eliminating the attenuation effect of the substrate. Also, the optical response of the device is improved by the internal reflection effect [6],[7] of the contact metals.

A detailed analysis considering all effects resulting from optical illumination of MODFET is a very complex task. However, by making some assumptions , a simplified analysis considering the relevant photo effects can be made[8].In this paper ,a simplified analysis to account for the photoconductive effect , the photo voltaic effect and reflection effect is described and from this, the change in the DC performance with back side illumination is estimated. The current voltage characteristics of the device (MODFET) with illumination (photocurrent),improved illumination (reflection effect) and without illumination (dark current) are calculated and the overall characteristics of the device under illumination is presented.

II.THEORY AND V-I CHARACTERISTICS

Fig.1 shows the MODFET structure used for illumination. The band diagram of a typical depletion mode AlGaAs/GaAs MODFET under illumination with photon energy E_{ph}= hc/λ as presented in [8] is considered . When photons are absorbed only in the GaAs layer, an increase in the electron concentration of the 2-DEG channel occurs (photoconductive effect).When photons are absorbed in AlGaAs layer also then, the photovoltaic effect is dominant. The relevant dimensions and material properties of the MODFET considered are presented in Table 1.

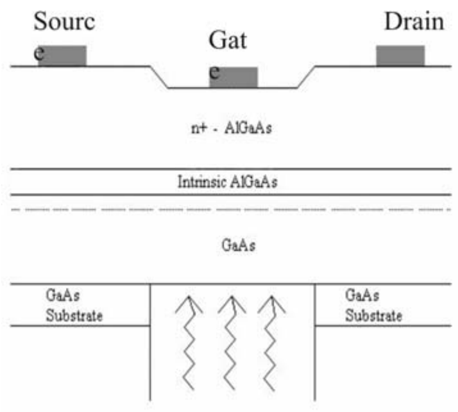

Fig 1. AlGaAs/GaAs MODFET Under Backside Optical Illumination.

If the incident photon energy E_{ph} is equal to or greater than the AlGaAs band gap($E_{Ph} \geqslant E_{g2}$) then, the optical absorption and generation of free hole –electron pairs may occur in both AlGaAs and GaAs layers. The generation of free hole electron pairs in the GaAs layer due to photo effect is called as the photoconductive effect. The generation of hole electron pairs in the AlGaAs layer due to photo effect is called as the photovoltaic effect.Since the polarity of photo voltage is the same as forward biasing the gate junction ,the drain to source current will increase with the increase of the photo voltage developed. In addition the photons reaching the contact metals are reflected internally and in turn it generates additional free electrons and holes in the device. The different effects leads to the increase in drain sourse current are explained as follows:

A. Photoconductive Effect:

Photo electrons generated in the GaAs layer will be collected by 2DEG layer and will contribute to increase the source to drain current. The photo generated holes drifting towards the semi insulating substrate will be capacitively coupled to the grounded source An estimation of the increase in the electron concentration n_{sph} in the 2DEG channel due to illumination in GaAs layer is estimated as [9][10]

$$n_{sph} = \Delta n d_1 = \frac{3\tau_n P_{opt}}{2E_{ph}} \cdot \left(1 - e^{-\alpha_1 d_1}\right) \quad (1)$$

where P_{opt} is the incident optical power density, E_{ph} is the incident photon energy ,α_1 is the GaAs optical absorption coefficient and d_1 is the thickness of the GaAs layer. τ_n is the electron life time. Equation (1) includes the electron concentration due to the internal reflection also.

The drain to source photo current I_{dsph} in the linear region due to photoconductive effect can be estimated from

$$I_{dsph} = Zqn_{sph}v_s\left(1 - e^{-(V_D\mu - V_D^2/V_S L)}\right) \quad (2)$$

where v_s is saturated drift velocity .The drain to source photo current I_{dsph} in the saturation region due to photoconductive effect can be estimated from

$$I_{dsph} = Zqn_{sph}v_S \quad (3)$$

And the overall drain to source current due to photoconductive effect, photovoltaic effect and internal reflection effect under back side illumination is

$$I_{dsi} = I_{ds} + I_{dsph} \quad (4)$$

where I_{ds} is the sum of dark current and the drain to source current due to photovoltaic effect.

B. Photovoltaic Effect:

The drain to source current due to photovoltaic effect is calculated as follows.

The photogenerated hole concentration Δp can be made using the expression[10].

$$P = \frac{3\tau_p P_{opt}}{2d_2 E_{ph}} \cdot \left(1 - e^{-\alpha_2 d_2}\right) \quad (5)$$

where P_{opt} is the incident optical power density, E_{ph} is the incident photon energy ,α_1 the GaAs optical absorption coefficient , d_1 is the thickness of the GaAs layer and τ_p is the hole life time. Then the photovoltage V_{ph} generated in the gate depletion region can be obtained by

$$V_{ph} = 0.0259 \ln\left(\frac{p + \Delta p}{p}\right) \quad (6)$$

where $p = \frac{n_i^2}{n}$ is the equilibrium hole concentration, n_i is the intrinsic carrier concentration, $n=N_D$ is the donor impurity density of AlGaAs .The net voltage at the gate under illumination is a super position of the gate bias V_{GS}

and photovoltage V_{ph} , given by

$$V_{GST} = V_{GS} - V_{ph} \quad (7)$$

Therefore the I-V characteristics can be estimated from the expressions for the MODFET without illuminationin in which V_{GS} is replaced by V_{GST}.The I-V characteristics of the device due to photovoltaic effect is calculated as follows:

Let us consider the charge in the 2-DEG from[11] as

$$Q_S = \frac{\varepsilon_1}{d}\left(V_{GS} - V_{OFF} - V(x)\right) \quad (8)$$

From the current density equation ,average Einstein relation ,Mobility degradation effect and by using the boundary condition V(x=0)=R_sI & V(x=L)=V_D-R_DI=V_D-R_sI when R_D =Rs, the I-V characteristics in the linear region is calculated as

$$I = \frac{E_S L}{4R_S}\left(Z - \sqrt{Z^2 - \frac{8XR_S\left(YV_D - \frac{V_D{}^2}{2}\right)}{E_S L}}\right) \quad (9)$$

where

$$Z = \frac{V_D}{E_S L} + 2XYR_S - XR_S V_D + 1 \quad (10)$$

$$X = \frac{W\mu_0\varepsilon_1}{dL} \quad (11)$$

and $$Y = \left(V_g - V_{OFF} + \frac{kT}{q}\right) \quad (12)$$

The saturation current characteristics is obtained by solving the Poisson equation

$$\frac{\partial^2 V}{\partial x^2} = \left(\frac{1}{\varepsilon_2}\right)\left(\frac{J}{v_S}\right) \quad (13)$$

Solving eqn(13) by considering the boundary condition V(x=0)=V_{DS}-$R_D I_S$= V_{DS}-$R_S I_S$ and V(x=L)=V_D-$R_D I_S$= V_D-$R_S I_S$ where R_D =Rs, we get the I-V characteristics in the saturation region as

$$I_S = \frac{Y' - \sqrt{Y' - 4X'(I_{DS}{}^2 X' + E_S L I_{DS})}}{2X'} \quad (14)$$

where $$X' = \frac{L^2}{2Wd_0\varepsilon_2 v_s} \quad (15)$$

and $$Y' = V_{DS} - V_D - I_{DS}X' - E_S L \quad (16)$$

The total drain to source current under back side illumination with an energy $E_{ph} \geqslant E_{g2}$, is obtained by using (2),(3),(9)& (14).

The transconductance of the MODFET device considered is obtained by

$$g_m = \left[\frac{dI_{DS}}{d_{VG}}\right]_{V_{DS}=consant} \quad (17)$$

C. Internal reflection effect

The quantity of optical power reaching the top surface of the sample due to backside illumination is given by equation [12]

$$P(a) = P_{inc}e^{-\alpha a} \quad (18)$$

where α is the absorption coefficient of GaAs, 'a' is the thickness of the sample and P_{inc} is the incident optical power density. It is considered that a portion of the light reaching the top surface is leaving the top surface of the sample through the gaps of source-gate and gate-drain metallizations. Remaining optical power is assumed to be reflected by the metals of source,gate and drain.

III. RESULTS AND DISCUSSION

Numerical calculations have been carried out for an n-AlGaAs/GaAs MODFET, considering the optical effect.The dimensions and other basic parameters used in the calculation are given in Table-1 as referred to our earlier publication.

Table1: Parameter Values used for Calculation

Sym bol	Name	Value
Z	Gate width	145μm
L	Gate length	1μm
N_D	Donar concentration	$1.0 \times 10^{18}/m^3$
N_A	Acceptor concentration	$3.0 \times 10^{20}/m^3$
vs	Saturated velocity	2×10^7cm/s
ε_1	Permittivity of GaAs	$13.2\ \varepsilon_0$
ε_2	Permittivity of AlGaAs	$12.1\ \varepsilon_0$
ε_0	Permittivity of vaccum	8.854×10^{-12}F/m
μ	Low field mobility	6800cm²/vs
h	Plancks constant	6.6×10^{-34}
q	Electron charge	1.6×10^{-19}
d_s	Spacer thickness	60 A°
d_d	Active layer thickness	525A°
d^1	Width of the well	80A°

Fig 2. & Fig 3. show the I-V characteristics of n-AlGaAs/GaAs MODFET under backside optical illumination for a gate voltage of V_G=0V. It shows the characteristics of the device with and without reflection effect. We have significant increase in the current with a higher pinch off, as radiation optical power density increases. This shows the sensitivity of the device to radiation and also the amplifying and switching capability of the device with respect to incident optical power density.

Fig 4. shows the transconductance of the device as a function of gate voltage with different effects at an optical power density

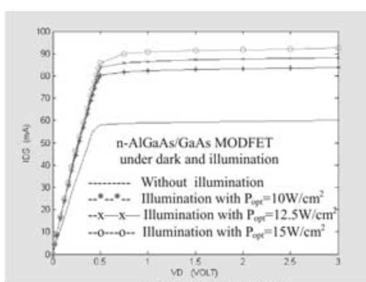

Fig 2. Drain source current versus drain voltage under optical illumination considering reflection effect with different optical power levels at a gate voltage of V_G=0V.

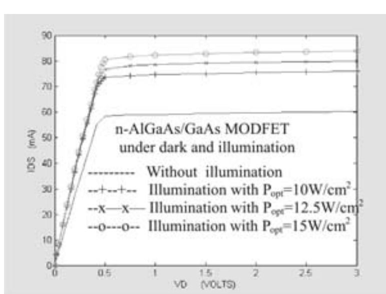

Fig 3. Drain source current versus drain voltage under backside optical illumination without considering reflection effect for different optical power levels at a gate voltage of V_G=0V.

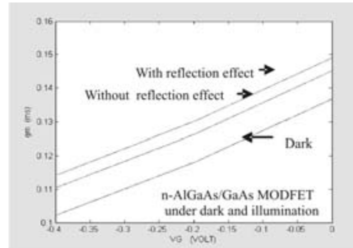

Fig 4. Transconductance versus gate voltage under dark and illumination with different effects.

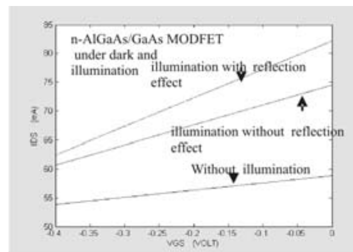

Fig 5. Transfer characteristics under illumination with and without reflection effect

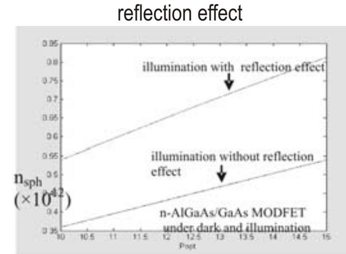

Fig 6. Electron concentration versus optical power density due to illumination

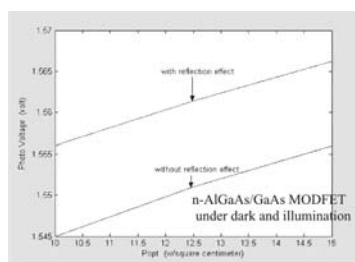

Fig 7. Photovoltage versus optical power density with and without reflection effect.

of P_{opt}=10W indicating a significant enhancement in the maximum cutoff frequency of the device due to illumination. Fig 5. represents the transfer characteristics of MODFET under both optical illumination and dark condition.Fig 6. shows the plot of electron concentration versus radiation optical power density due to illumination alone.It shows that electron concentration increases with the increase in the illumination power level and also it increases due to the internal reflection effect. Fig 7. shows the plot of Photovoltage versus optical power density with different effects . It can be concluded from the plots for the I-V characteristics is that the illumination of the device from its backside and the effect of internal reflection by the metals of source ,drain and gate have considerably improved the optical absorption and increase the drain current. A good agreement is observed between our calculated results and with available experimental data under dark condition.

IV.CONCLUSION

The effect of backside optical illumination on the characteristics of n-AlGaAs/GaAs MODFET with and without internal reflection effect has been carried out . The I-V characteristics with and without different illumination levels, trans conductance, photovoltage and transfer characteristics have been calculated ,plotted and discussed. The I-V characteristics has been compared with available experimental data under dark condition showing good agreement.

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REFERENCES

[1] Subha,B.B.Pal,R.U.Khan, 1998. “Optically controlled Ion- Implanted GaAs MESFET characteristics with opaque Gate”, IEEE Trans. on ED,Vol.45,No.1,pp78-84.

[2] H.Mitra,B.Bpal,S.Singh and R.U.Khan, 1998. “Optical Effect in InAlAs/AnGaAs/InP MODFET ”, 1. IEEE Trans. on ED,Vol.45,No.1,pp68-77.

[3] Paul.G.Young,Samuel A.Alterovitz,R.A.Meena and ED.Smith, 1993. “RF Properties of Epitaxial Lift off HEMT Devices”, IEEE Trans. on ED,Vol.40,No.11,pp1905-1909.

[4] Murilo A.Romero,MAG.Martinez and Peter R.Herezfeld, 1996. “An Analytical Model for the Photodetection Mechanism in High Electron Mobility Transistors”, IEEE Trans. on MTT,Vol.44,No.12,pp2279-2287.

[5] Paul.G.Young, Rainee N.Simons, S.A.Alterovitz, R.R.Romanofsky and E.D.Smith, 1994. “RF Control of Epitaxial lift off PHEMT's under Backside illumination”, IEEE Trans. Of Quantum Electronics,Vol.30,No.8,pp1782-1786.

[6] H.S.Lee and S.M.Sze , 1970. “Silicon Pin photo detector using internal reflection Method”, IEEE Trans. on ED,Vol.ED-A,pp342.

[7] J.Muller, 1978. “Thin Silicon Film Pin Photodiodes with internal reflection”, IEEE Trans. on ED,Vol.ED-25,pp247.

[8] Alvero AdeSalles and Murilo A.Romero, 1991. 1991. “AlGaAs/GaAs HEMT's under optical illumination”, IEEE Trans. on MTT,Vol.39,No.12,pp2011-2017.

[9] S.M.Sze, 1981. “Physics of Semiconductor Devices”,2nd ed.,NewYork:Wiley.

[10] R.N.Simons, 1987. “Microwave Performance of an optically controlled AlGaAs/GaAs High Electron Mobility Transistor and GaAs MESFET ” , IEEE Trans. on MTT,,Vol.MTT-35,pp1444-1455.

[11] Kwangmeanpark and Kae Dal Kwack, 1986. “A Model for the current- Voltage Characteristics of MODFET's”, IEEE Trans. on ED,Vol.ED-33,No.5,pp673-676.

[12] Pallab Bhattacharya, 1995. “Semiconductor Optoelectronic Devices”New Delhi,PHI.

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