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Simulation of Improved MODFET Characteristics under Backside Illumination

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Abstract: Simulation of the DC characteristics of depletion mode AlGaAs/GaAs Modulation Doped Field Effect Transistor (MODFET) under backside optical illumination 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 AlGaAs layer is considered transparent to illumination. The photoconductive effect which increases the two dimentional electron gas (2DEG) channel electron concentration alone is considered. These electrons generated in the GaAs layer is collected in 2DEG, which increases the source to drain current. The photo generated holes in GaAs layer drifts towards the semi-insulating substrate and is capacitively coupled into the grounded source. The I-V characteristics of MODFET under dark and illuminated conditions have been simulated and discussed.

Key words: MODFET, simulation, photoconductive effect, 2DEG

INTRODUCTION

A Special interest has been created in the study of optical effect in high speed devices due to their potentiality in fiber optical communication and optical integration. Although some investigators (Subha and Khan 1998; Mitra *et al*., 1998; Young *et al*., 1993; Romero *et al*., 1996) have carried out both experimental and analytical studies on the effect of illumination in GaAs MESFET and AlGaAs/GaAs MODFET which shows that there is significant effect of incident light on the electrical parameters of the devices, there is a lack of theoretical and experimental work describing the effect of back side illumination of MODFET. It is a very important micro wave device, since it presents extremely low noise performance at frequency up to several tens of GHZ. Also because it employ hetero structures using III-V semiconductors, it is very convenient for use in Microwave Monolithic Integrated Circuits (MMICS) or Optoelectronic Integrated Circuits (OEICS).

A detailed analysis considering all effects resulting from optical illumination of MODFET is a very complex task. However by making some assumption, a simplified analysis considering the relevant photo effects can be made (AdeSalles and Romero, 1991). In this study, a simplified analysis to account for the photoconductive 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) and without illumination (dark current) are simulated.

THEORY

Figure 1 shows the MODFET structure used for illumination, where source and drain electrodes are ohmic contacts and the gate electrode is a schottky-barrier junction. The band diagram of a typical depletion mode AlGaAs/GaAs MODFET under illumination with photon energy $E_{ph} = hc/\lambda$ as given in (AdeSalles and Romero, 1991) is considered. The major photoeffects arising in the illumination of AlGaAs/GaAs MODFET are band to band photon absorption in the GaAs and in the AlGaAs layer, generating hole-electron pairs in these regions.

When photons are absorbed only in the GaAs layer an increase in the electron concentration of the 2-DEG channel occurs (photoconductive effect). The relevant dimensions and material properties of the MODFET considered are presented in Table 1. The photoconductive effect is dominant when the incident photon energy $E_{ph} = hc/\lambda$ is equal to or greater than the GaAs band gap but smaller than the AlGaAs band gap ($E_{g1} \leq E_{ph} \leq Eg2$). Then the AlGaAs is transparent to the illumination and the dominant photo effect in the generation of hole electron pairs in the GaAs layer. Photo electrons generated in this layer will experience a vertical

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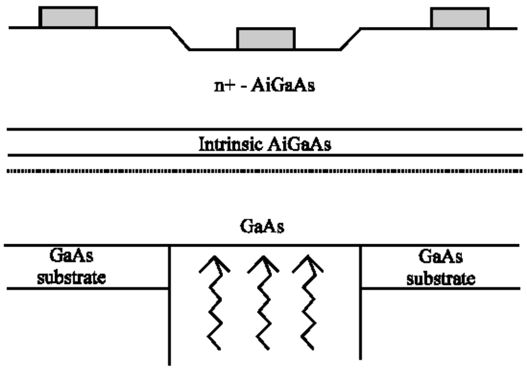

Fig. 1: AlGaAs/GaAs MODFET under backside optical Illumination

field associated with the band bending of the heterojunction and a horizontal field associated with the applied drain to source voltage. The electrons traveling in the vertical direction will be collected by 2 DEG layer. And all the photo electrons generated in the GaAs layer will contribute to increase in source to drain current.

The photo generated holes drifting towards the semi insulating substrate will be capacitively coupled in the grounded source. An estimation of the increase in the electron concentration n_{sph} in the 2DEG channel due to illumination in GaAs layer alone can be made as follows.

The photo electron density generated in the GaAs layer when $\alpha_1 d_1 << 1$ and assuming that the quantum efficiency is unity is expressed as Sze (1981) and Simons (1987).

$$\Delta n = \frac{\tau_n P_{opt}}{d_1 E_{ph}} \cdot (1\text{-}e^{-\alpha_1 d_1}) \tag{1}$$

Where, P_{opt} is the incident optical power density, E_{ph} is the incident photon energy, α_1 the GaAs optical absorption coefficient and d_1 is the thickness of the GaAs layer. τ_n is the electron life time.

Then the electron concentration n_{sph} in the 2-DEG due to illumination alone can be estimated from (1) as

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

CURRENT VOLTAGE CHARACTERISTICS

The current voltage relation of MODFET under backside illumination and without illumination for simulation in the linear and saturation regions are presented as follows. Assuming the saturated drift velocity of the photo electrons as ν_s. The drain to source photo current I_{dsph} in the linear region can be estimated from

$$I_{dsph} = Zqn_{sph}\nu_s(1 - e^{(V_D\mu - VD_D^2/V_S L)}) \tag{3}$$

And the drain to source photo current I_{dsph} in the saturation region can be estimated from

$$I_{dsph} = Zqn_{sph}\nu_s \tag{4}$$

And the overall drain to source current under back side illumination considering only GaAs is

$$I_{dsi} = I_{ds} + I_{dsph} \tag{5}$$

where, I_{ds} is the drain to source current without illumination. The drain to source current I_{ds} without illumination is also divided in to current in the linear region and current in the saturation region.It is calculated as follows.

Let us consider the charge in the 2-DEG from Kwangmeanpark and Kwack (1986) as:

$$Q_S = \frac{\varepsilon_1}{d}(V_g - V_{OFF} - V(x)) \tag{6}$$

where, V(x) is the channel voltage under the gate. For linear region simulation, the current density equation, average einstien relation and mobility degradation effect are considered. We get:

$$I = \frac{W\mu_0\varepsilon_1(V_g - V_{OFF} - V(x))\left(\frac{dv}{dx}\right)}{d\left(1 + \frac{1}{E_S}\frac{dv}{dx}\right)} \tag{7}$$

Using the boundary condition $V(x = 0) = R_s I$ and $V(x = L) = V_D\text{-}R_D I = V_D\text{-}R_s I$ and when $R_D = Rs$, the integration of Eq. (7) gives the I-V characteristics in the linear region as

$$I = \frac{E_S L}{4R_S}\left(C - \sqrt{C^2 - \frac{8AR_S\left(BV_D - \frac{V_D^2}{2}\right)}{E_S L}}\right) \tag{8}$$

where:

$$C = \frac{V_D}{E_S L} + 2ABR_S - AR_S V_D + 1 \tag{9}$$

$$A = \frac{W\mu_0\varepsilon_1}{dL} \tag{10}$$

$$B = \left(V_g - V_{OFF} + \frac{kT}{q}\right) \tag{11}$$

The saturation current characteristics is simulated by solving the poisson equation

$$\frac{\partial^2 V}{\partial x^2} = \left(\frac{1}{\varepsilon_2}\right)\left(\frac{J}{v_s}\right) \tag{12}$$

Solving Eq. (12) by considering the boundary condition $V(x = 0) = V_{DS}\text{-}R_D I_S = V_{DS}\text{-}R_S I_S$ and $V(x = L) = V_D\text{-}R_D I_S = V_D\text{-}R_S I_S$, when $R_D = Rs$ we get the equation

$$V_D = V_{DS} + \frac{I_S}{2Wd_0\varepsilon_2 v_s}(\Delta L)^2 - E_S\Delta L \tag{13}$$

using the relation$(I_S/I_{DS}) = (L/L\text{-}\Delta L)$, the I-V characteristics in the saturation region is obtained as

$$I_S = \frac{B' - \sqrt{B' - 4A'(I_{DS}^2 A' - E_S L I_{DS})}}{2A'} \tag{14}$$

where

$$A' = \frac{L^2}{2Wd_0\varepsilon_2 v_S} \tag{15}$$

$$B' = V_{DS} - V_D - I_{DS}A' - E_S L \tag{16}$$

The total drain to source current under illumination is simulated by using the Eq. 3, 4, 8 and 14.

RESULTS AND DISCUSSION

An analytical simulation have been carried out for an AlGaAs/GaAs MODFET considering the optical effect. The dimensions and other basic parameters used for calculation are given in Table 1.

Table 1: Parameter Values used for calculation

Symbol	Name	Value
Z	Gate width	100 μm, 145 μm
L	Gate length	1 μm
N_D	Donar concentration	$1.0\times10^{18}/m^3$
N_A	Acceptor concentration	$3.0\times10^{20}/m^3$
vs	Saturated velocity	2×10^7cm/s
ε_1	Permittivity of GaAs	13.2 ε_0 F/cm
ε_2	Permittivity of AlGaAs	12.1 ε_0 F/cm
ε_0	Permittivity of vaccum	8.854×10^{-12}F/m
μ	Low field mobility	6800 cm^2/vs
h	Plancks constant	6.6×10^{-34} J-s
q	Electron charge	1.6×10^{-19}C
d_s	Spacer thickness	60 A°
d_d	Active layer thickness	525 A°
d^1	Width of the well	80 A°

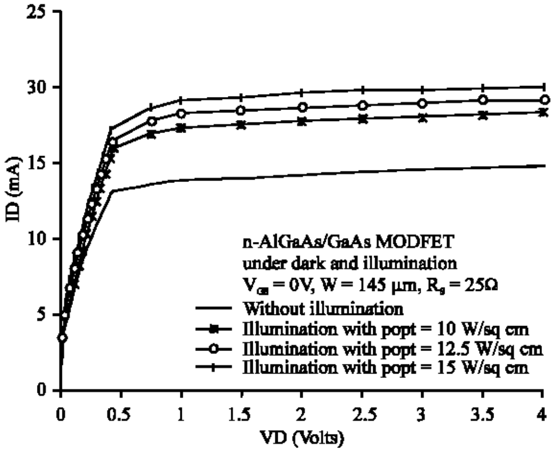

Fig. 2: I-V Characteristics of MODFET due to photoexitation of carriers in GaAs layer with V_{GS} = 0V, Z = 145 μm, R_S = 25 Ω

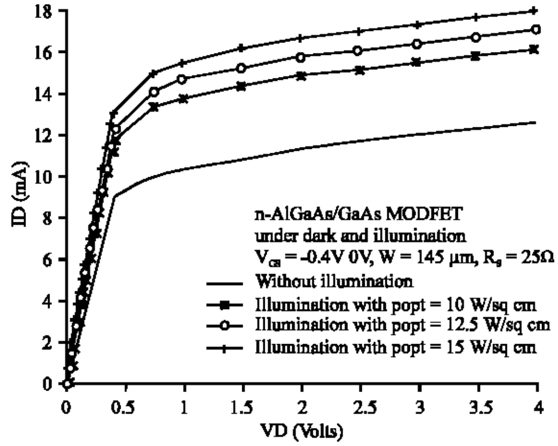

Fig. 3: I-V Characteristics of MODFET due to photoexitation of carriers in GaAs layer with V_{GS} = -0.4 V, Z = 145 μm, R_S = 25 Ω

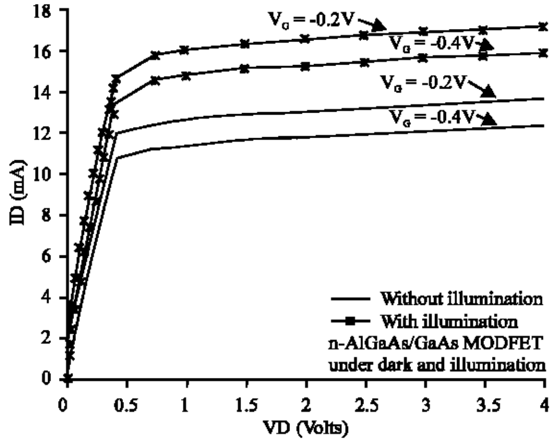

Fig. 4: I-V Characteristics of MODFET due to photoexitation of carriers in GaAs layer with different gate voltages

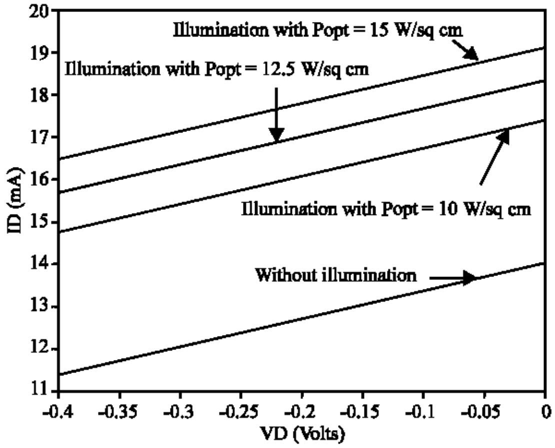

Fig. 5: Transfer Characteristics of MODFET due to Illumination and with out illumination

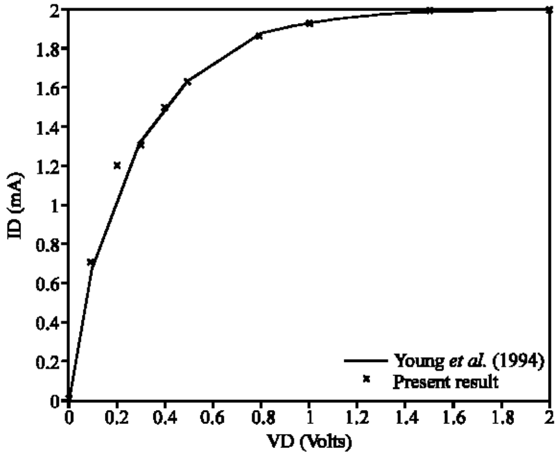

Fig. 6: Comparision of the I-V characteristics under dark condition at V_G = -0.668V

Figure 2 shows the simulated I-V characteristics of n-AlGaAs/GaAs MODFET both under backside optical illumination and without illumination for a gate voltage of V_G = 0V. Figure 3 shows the simulated I-V characteristics of n-AlGaAs/GaAs MODFET both under backside optical illumination and without illumination for a gate voltage of V_G = -0.4V. Figure 4 shows the simulated I-V characteristics of n-AlGaAs/GaAs MODFET under backside optical illumination for different gate voltages. 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. It can be concluded from the the plots, the effect of backside illumination leads to improved absorption and increases the drain current considerably. Figure 5 represents the transfer characteristics of MODFET under both optical illumination and dark condition. Figure 6 shows the comparision of I-V characteristics of our result with the published data under dark condition. A good agreement is observed between our calculated results with those given in Young *et al.* (1994).

CONCLUSIONS

The effect of illumination on the backside of AlGaAs/GaAs MODFET has been simulated. The offset voltage has been calculated with the effect of illumination. The I-V characteristics under dark condition and under different illumination power density have been simulated and discussed. The effect of backside illumination leads to improved absorption and increases the drain current considerably. The transfer characteristics of the device is also simulated. The I-V characteristics have been compared with the available experimental data (Young *et al.*, 1994), showing a good agreement.

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