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Full Length Research Paper

Analytical model for I-V analysis of buried gate MESFET with modulation frequency characteristics

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The analysis of frequency-dependent characteristics of an ion-implanted buried-gate GaAs MESFET, with front side illumination has made achieving improved performance in I-V characteristics possible. When photo energy falls on the device, flow of charge carriers changes corresponding to the change in wave length and frequency of incident light. It has been observed that the channel conductance and I-V characteristic of buried gate increase. The data suggest that the magnitude of drain-to-source current increases, and as a result there are more uncovered ionic charges in the space charge region toward the drain-side of the gate. This analysis includes surface states and the ion implanted buried-gate process. The access charge density at the drain-side of the depletion induces opposite charges in the gate electrode. Consequently, it gives forward biasing to the Schottky barrier gate which increases with increasing values of Ids. As a result, the modulation of channel conductance and photo-voltage characteristics due to the buried-gate GaAs MESFET become highly effective. The results indicate very good performance of the device compared to other devices like MESFET under back illumination and MESFET with front illumination having surface gate.

Key words: AC model optically illuminated field-effect transistor (OPFET), GaAs OPFET, optically controlled metal–semiconductor–field-effect transistor (MESFET).

INTRODUCTION

High frequency metal semiconductor field effect transistors (MESFET's) will be highly suitable for optical communication and computing. Commercial applications include analog and digital circuits, which benefit from the superior noise and gain properties of these devices. To reduce the noise figure and to improve the gain properties of the device, standard values of frequencies are selected.

Previous various analyses have been conducted using GaAs MESFET under both AC and DC condition (Mistral et al., 1990). The effect of photo voltage at the Schottky junction active layer substrate junction has not been considered in that analysis. The ion implanted characteristics with modulated light was considered into the analysis of Pal et al. (1998), but in that work they did not consider the illumination under buried gate. They considered only surface state front illumination.

The sensitivity of the device depends on the absorption coefficient of light. There are different ways by which light may be absorbed within the material. The conventional way of illuminating the MESFET is the front illumination with transparent/ semitransparent or opaque gate (Shubha et al., 1999). However, for enhanced absorption in MESFET, de Salles (1983) has suggested two alternatives: 1) the device may be illuminated from the back where the fiber may be inserted partially or fully into the substrate of the device and 2) the buried gate MESFET with front illumination.

In this paper, we analyzed theoretically the effect of the modulated light on the characteristics of buried gate GaAs MESFET under front illumination (Singh et al., 1986). We consider the ion-implanted profile in the active region. The photo voltage drop takes place across the buried gate and substrate-active layer because fiber is inserted up to the substrate-active layer junction. The channel conductance and the V-I of the device have been calculated. Variations of drain saturation current Ids for radio frequency values of buried gate GaAs MESFET were calculated.

Present calculation shows that the modulated buried gate GaAs MESFET with front illumination represents better performance compared to the results of the conventional front illumination.

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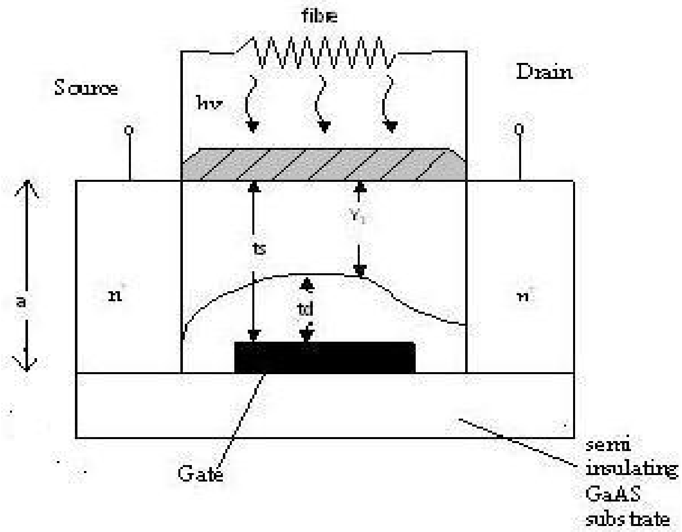

Figure 1. Schematic structure of MESFET.

THEORY

The cross-sectional view of MESFET is shown in Figure 1. The fundamental physical mechanism arising in optical Illumination of the MESFET is the production of free carriers within the semiconductor material. When light of photon energy is equal to or greater than the semiconductor material band gap energy is absorbed. The active region has a non-uniform doping profile represented by the Gaussian distribution. It consists of a neutral region followed by a depletion region due to Schottky junction of the buried gate. The photo absorption takes place in both neutral and depletion regions. The gate is assumed buried, so there is no or very little absorption in the substrate region.

The electron-hole pairs are generated in both neutral and depletion regions. The electrons move from source to drain in the channel region when a drain-source voltage with various frequencies is applied. The holes move toward the substrate. In the neutral region the photo generated electrons move by the process of diffusion and recombination (both bulk and surface).In the depletion region the transport of carriers is due to drift and bulk recombination only. Under illumination the photo generated electrons and holes in the neutral and depletion regions are obtained by solving the dc continuity equations.

For electrons;

$$\frac{1}{q}\frac{dJ_n}{dy} + G_n - U_n = 0 \qquad (1)$$

For holes;

$$-\frac{1}{q}\frac{dJ_P}{dy} + G_P - U_P = 0 \qquad (2)$$

In the above equations, G_P and G_n are the generation rate per unit volume ($m^{-3}s^{-1}$), U_P and Un are the recombination rates, $Un = \frac{n}{\tau_{\alpha n}}$ and $G_n = \Phi \alpha e^{-\alpha y}$

and J_n and J_p are the electron and hole current densities, respectively defined by,

$$J_n = qv_y + qD_n \frac{dJ_n}{dy} \qquad (1a)$$

and

$$J_p = qv_y + qD_p \frac{dJ_p}{dy} \qquad (2a)$$

The above equation includes drift and diffusion terms.

Current due to depletion region

Applying the continuity equation of first order differential equation in the depletion region is given by

$$\frac{dn_1}{dy} + \frac{n_1}{v_y \tau_{\alpha n}} = -\Phi e^{-\frac{\alpha y}{v_y}} \qquad (3)$$

The number of carriers generated in this region per unit volume is obtained by solving (3). From physical conditions, we assume the coefficient of the exponentially increasing function to be zero. The photo generated electrons in the gate depletion region is obtained as

$$I_{dep} = \frac{q\mu Z}{L}\int_{0}^{V_D}\int_{y_1}^{t_s} n_{1d_y} d_v \qquad (4)$$

The photo generated holes in the gate depletion region is obtained as

$$\frac{dp_1}{dy} - \frac{p_1}{v_Y \tau_{\alpha n}} = -\Phi \alpha e^{-\frac{\alpha y}{v_y}} \qquad (5)$$

Current due to generation in the neutral region

The channel being neutral, there is no field within this region in the absence of any drain-source voltage, so and the transport of carriers will be only due to diffusion and recombination;

$$\frac{d^2 n_2}{dy^2} = \frac{n_2}{Dn\tau_{\alpha n}} - \frac{\Phi}{Dn} e^{-\frac{\alpha y}{v_y}} + \frac{Rs\tau_{\alpha n}}{\alpha L_{\alpha n}^2} \qquad (6)$$

Rs is the surface recombination rate. Rs is calculated using the relation:

$$R_s = \frac{N_T k_n k_p (n_s p_s - n_t p_t)}{k_n(n_s + n_t) + k_P(p_s + p_t)}$$

Table 1. Parameter values.

Device parameter	Symbol	Value
Photon absorption coefficient	α	1.0×10^6 m^{-1}
Carrier velocity in y-direction	v_y	1.2×10^5 m/s
Equivalent constant doping profile	N_{dr}	0.658×10^{23} m^{-3}
Straggle parameter	σ	0.383×10^{-6} m
Permittivity	ε	1.04×10^{-10} f/m
Total effective thickness of active layer	t_s	0.1 µm
Projected range	Rp	0.861×10^{-7} m
Schottky barrier height	Φ_B	0.9 eV
Trap density	N_t	1.0×10^{15} m^{-2}
Channel width	Z	100×10^{-6} m
Channel length	L	3×10^{-6} m
Electron mobility	μ_n	0.85 m^2/v.s
Hole mobility	μ_p	0.04 m^2/v.s
Active layer thickness	a	0.25 µm

Where

$$n_s = \alpha\Phi\tau_n$$

$$p_s = \alpha\Phi\tau_p$$

Table 1 shows the various data's like device parameter, symbols and values to apply for the current equation. According to the variation of data's the current voltage characteristics and channel conductance are varied.

The optical flex density being assumed to be modulated by the signal frequency, with small signal as

$$\Phi = \Phi_0 + \Phi_1 e^{j\omega t}$$

$$n = n_0 + n_1 e^{j\omega t}$$

$$p = p_0 + p_1 e^{j\omega t}$$

$$G = G_0 + G_1 e^{j\omega t}$$

Where "zero" indicates the dc value and "one" " indicates the ac value.

Assuming that only negative trap centers are present and that the traps close to the surface

Therefore

$R_s \approx N_t k_p p_s$ and $D_n = \frac{KT}{q}\mu_n$

$$\frac{1}{\tau_{\omega p}} = \frac{1}{\tau_p} + j\omega$$

$$\frac{1}{\tau_{\omega n}} = \frac{1}{\tau_n} + j\omega$$

$\tau_{\omega p}, \tau_{\omega n}$ are the lifetime of holes and electrons under ac condition

If $\frac{1}{\tau_{\omega p}} \geq \omega$, is independent of ω

The corresponding charge density is obtained as

$$Qact = q\int_0^{y_{11}} n_2\, dy \quad (7)$$

$$Y_1 = t_s - \frac{2\varepsilon}{qNdr}\left[\Phi_B - \Delta + V(x) - V_{GS}\right]^{\frac{1}{2}} \quad (8)$$

Where, Y_1 is the distance from the surface to edge of the gate depletion region in the channel under dark region.

$$I_{act} = \frac{q\mu Z}{L}\int_0^{y_1}\int_0^{V_D} n_2 d_y d_v \quad (9)$$

Current due to ion-implantation

The semi-insulating substrate is p-type doped and has uniform doping profile, which is represented by

$$N(y) = \frac{Q}{\sigma\sqrt{\pi}}\exp\left[-\left[\frac{Y - Rp}{\sigma\sqrt{2}}\right]^2\right] - N_{sd} + N_{de} \quad (10)$$

Where Q, Rp and σ are the implanted dose per unit area, projected range and straggle parameter in length respectively.

The corresponding channel charge due to ion- implantation is obtained as

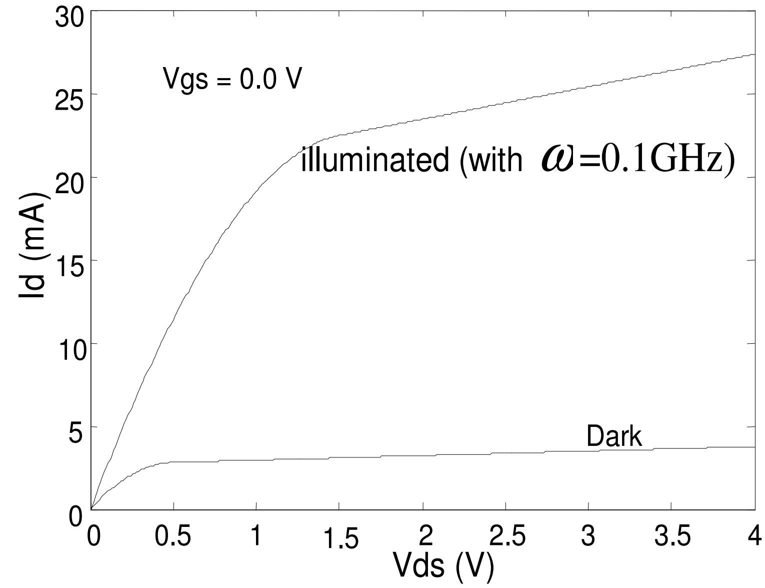

Figure 2. Modulated drain-source current versus drain-source voltage under dark and illuminated condition for buried gate structure MESFET at zero gate-source voltage.

$$Q_{ion} = q\int_{0}^{Y_{11}} N(y)dy$$

N(y) is being given by (10); it is obtained as

$$Q_{ion} = q\{\frac{Q}{2}\left[erf\frac{Y_{11}-Rp}{\sigma\sqrt{2}}\right]-\frac{Q}{2}\left[\frac{-Rp}{\sigma\sqrt{2}}\right]-N_{sd}Y_{11}+N_{de}Y_{11}\} \quad (11)$$

$$y_{11} = t_s - \frac{2\varepsilon}{qNdr}(\Phi_B - \Delta + V_{gs} - V_{op})^{\frac{1}{2}}$$

Where Y_{11} is the distance from the surface to the modified edge of the gate depletion region due to photo voltage developed across the Schottky junction of the buried gate.
The channel current due to ion-implantation is obtained using the relation,

$$I_{ion} = \frac{\mu Z}{L}\int_{0}^{V_D} Qiondv \quad (12)$$

Where
V_D is the channel voltage.

The number of holes crossing the Schottky junction at ($y=t_s$) is calculated. The photo voltage is obtained using the relation,

$$V_{op} = \frac{KT}{q}\ln\left(\frac{v_y qp_{1(y=t_s)}}{J_S}\right) \quad (13)$$

Channel current and drain current

The modulated channel current is contributed by the carriers from ion implantation and optical generation in the channel and depletion regions. The total channel current is the summation of ion implantation and current in the active and depletion regions.

$$I_{ch}=I_{ion}+I_{dep}+I_{act} \quad (14)$$

The drain current is expressed as

$$Ids = Isat(1+\lambda V_i)\tanh(\eta V_i) \quad (15)$$

RESULTS AND DISCUSSION

Figure 2 shows the plot of modulated I-V characteristics under dark and illumination ($\Phi = 10^{16} / m^2s$). It is observed that the modulated drain source verses drain source voltage for lambda is equal to 0.1. This increases V-I characteristic linearly. The drain-source current is more in the condition of buried gate MESFET with optical fiber inserted up to the active layer-substrate junction with front illumination. It is also observed that under illumination, drain-source current tends to saturate at higher values of drain-source voltage.

Figure 3 shows modulated drain source current verses drain source voltage for λ=0.025 and it reaches saturation after threshold level.

Figure 4 shows modulated drain source current verses various flux densities for various drain source voltage. It produces high accuracy with low device size.

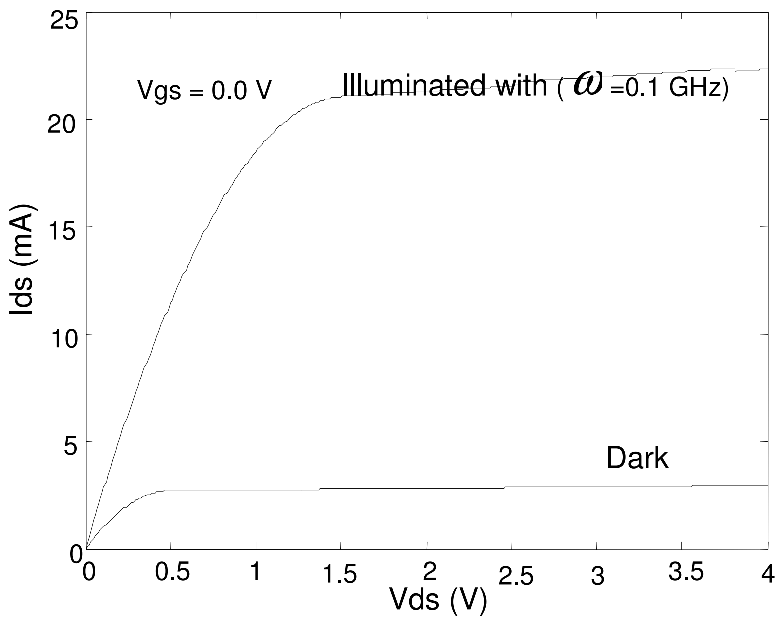

Figure 3. Modulated drain source current verses drain source voltage for λ= 0.025.

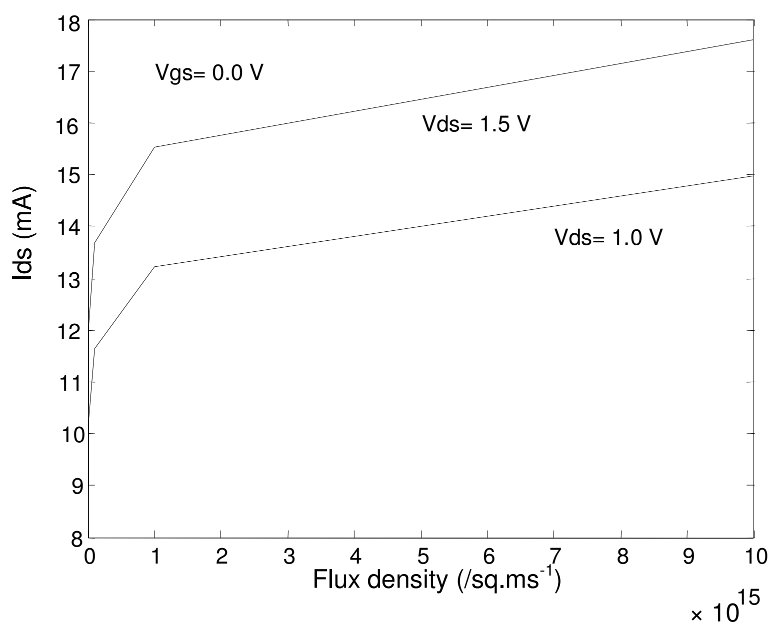

Figure 4. Modulated drain source current verses flux densities for various drain source voltage.

Conclusion

A theoretical model for the modulated I-V characteristics of buried-gate GaAs metal semiconductor field-effect transistors has been developed. The ac analysis of the buried gate GaAs MESFET with ion-implanted profile under front illumination has been carried out. It has been observed that the modulated channel conductance and V-I characteristics increase. The data suggest that the magnitude of drain-to-source current increases, and as a result there are more uncovered ionic charges in the space charge region toward the drain-side of the gate. It produces high accuracy with low device size. The present OPFET, with buried gate and fiber inserted up to the substrate-active layer junction appeared to be the most sensitive to optical illumination because the optical absorption is more prominent in the neutral region that in the depletion region. The device thus may be useful in optical communication and computer.

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