Transit-Time model for short-gate length ion-implanted GaAs OPFETs

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ABSTRACT
This paper presents transit time model for short gate –length ion-implanted GaAs OPFET. The finite transit-time that carriers take to traverse the channel from source to drain is calculated considering the effect of onset of velocity saturation.

Keywords
Component; transit-time; Gaussian-like doping profile; saturation velocity.

1. INTRODUCTION
GaAs MESFET is a significant microwave device used in Microwave monolithic integrated circuits (MMICs) [1-2]. Since microwave characteristics can be governed very well by illuminating the Schottky metal gate of the GaAs MESFET device hence optically controlled GaAs MESFET (GaAs OPFET) are in high demand for use in Microwave circuits and systems [3-4]. Under microwave operation, two factors generally limit the frequency response of a GaAs MESFET: the transit time and the RC time constant. In view of the fact that the transit-time can also cause a serious delay in drain-source current through the channel therefore it is essential to model this for proper realization of underlying device physics of GaAs OPFET. Transit time is the result of finite time required by carriers to travel from source to drain. Normally, transit- time of an electron under the gate of a MESFET is estimated by taking the ratio of the gate length to the saturated velocity of the electron.

In transient operation, high electric fields are generated due to the temporary formation of large positive potential within the channel. This field is high enough to induce saturated velocity, so it is important to have the accurate transit-time modeling. In the present analysis transit-time modeling of short gate-length ion-implanted GaAs OPFET has been done. The doping profile due to ion-implantation has been assumed as Gaussian-Like doping profile [5] since it closely resembles Gaussian doping profile produced due to ion-implantation. The transit-time has been obtained using two-dimensional potential distribution in the channel region.

2. MODEL FORMULATION
The schematic structure of the optically controlled GaAs MESFET device considered for modeling is shown in Fig.1. where a and L are active layer thickness and gate length respectively. The optical radiations are allowed to fall upon the gate metal made up of Indium Tin Oxide (ITO) along vertical y-direction. The substrate of the device is assumed as undoped high pure LEC semi-insulating GaAs material. The active channel region of the device is an n-GaAs layer, obtained by ion implanting Si into semi-insulating substrate.

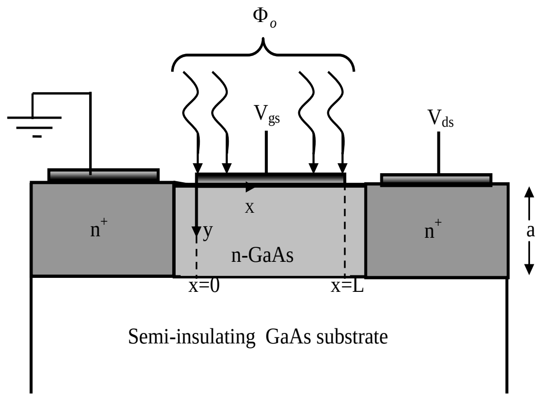

Fig. 1. Schematic of GaAs OPFET used for the modeling. a is the thickness of active channel region , L is the length of the Schottky metal gate and Φ_o is the incident flux density

The approximate doping distribution in the channel can be given as [6]

$$N_d(y) = N_s + (N_p - N_s)F(y) \quad (1)$$

where N_p is peak ion concentration, N_s is the substrate doping concentration and $F(y)$ is an approximate analytic form of Gaussian function [5] given as,

$$F(y) \approx c_c\left[\left\{a_c + \frac{2b_c\beta}{\sqrt{2}\,\sigma}\left(y - R_p\right)\right\}^2 - 2b_c\right]\times \exp\left[-\left\{\frac{a_c\beta}{\sqrt{2}\sigma}\left(y - R_p\right) + \frac{b_c}{2\sigma^2}\left(y - R_p\right)^2\right\}\right] \quad (2)$$

where

$a_c = 1.7857142$, $b_c = 0.6460835$, $c_c = 0.28\sqrt{\pi}$ and

$$\beta = \begin{cases} +1 & \text{for } y > R_p \\ -1 & \text{for } y < R_p \end{cases}$$

The net doping concentration $N_D(y)$ in the active channel region under illuminated condition can be given as as [7]

$$N_D(y) = N_d(y) + G(y)\tau_n - \frac{R\tau_p}{a} \quad (3)$$

where $N_d(y)$ represents the doping profile defined by (1). R is the surface recombination rate, α is the absorption coefficient of GaAs material , τ_n and τ_p are the life time of electrons and holes, respectively and $G(y)$ is the photo-generation rate given as [8].

The Poisson equation for the partially depleted channel region under the Schottky metal gate of the device can given as [9]

$$\partial^2\phi(x,y)/\partial x^2 + \partial^2\phi(x,y)/\partial y^2 = qN_D(y)/\varepsilon_s \quad (4)$$

ε_s is the dielectric permittivity of GaAs semiconductor, q is electron charge.

Above equation, when solved with following boundary condition yields potential distribution in the channel region [9].

$$\phi(x,0) = V_{bi} - V_{gs} - V_{op} \quad (5)$$

$$\phi(0,y) = V_{bi} \quad (6)$$

$$\phi(L,y) = V_{bi} + V_{ds} \quad (7)$$

$$\left.\frac{\partial\phi(x,y)}{\partial y}\right|_{y=h_x} = 0 \quad (8)$$

where V_{bi} is the Schottky barrier built in potential, V_{gs} is the gat-source voltage, V_{op} is the photovoltage developed across Schottky metal gate, V_{ds} is the drain-source voltage and h_x depletion region height same as [9].

When the Eq.(4) is solved using above boundary conditions then the two-dimensional potential distribution is obtained as in [9]. Differentiating the potential distribution obtained in [9] with respect to "x" we can obtained the transverse electric field(E) as

$$E(x) = \sum_{n=1}^{\infty} \frac{\sinh(k_1 y)}{\sinh(k_1 y)}\left[-\frac{3\pi}{2a}A_1\cosh(k_1(L-x)) + \frac{3\pi}{2a}B_1\cosh(k_1 x)\right] \quad (9)$$

where A_1 and B_1 are the values of coefficients of two dimensional potential distribution and k_1 is same as [9].

The transit-time (τ) can be computed if the carrier velocity in the channel is known. The transit-time can be given as [10]

$$\tau = \int_0^{L_s} \frac{dx}{v(x)} + \frac{(L - L_S)}{v_S} \quad (10)$$

where v_S is the bulk saturation velocity[11] and L_S is the length of the saturation region given as[12]

$$L_S = 2.06K_d\left(\frac{\varepsilon_S(V_{ds} - V_{sat})}{q\sqrt{n_{cr}N_D(y)}}\right)^{1/2} \quad (11)$$

where K_d is a domain parameter ($K_d \approx 1$ for the devices with self aligned gate) , n_{cr} is the characteristic doping density of GaAs (typically $3\times10^{21}/m^3$) and V_{sat} is the saturation voltage same as [13].

$v(x)$ can be given as

$$v(x) = \mu_o E(x) \quad (12)$$

where μ_o is the low field carrier mobility[11] and $E(x)$ is the transverse electric field given by Eq.(9).

3. RESULTS AND DISCUSSIONS

This section presents some results for the computed transit-time of the short-gate-length ion-implanted GaAs OPFET. The values of different parameters used for the computation are:

$a = 0.2\mu$m , $R_p = 0.1\mu$m , $V_{bi} = 1.02$V , $T_m = 0.9$,

$L = 0.3\mu m$, $\sigma = 0.02$µm , $\alpha = 10^6/$m , $\lambda = 0.87$µm ,

$\tau_n = 10^{-6}$s , $\tau_p = 10^{-8}$s $N_p = 5\times10^{23}$m^{-3} and

$N_s = 1\times10^{21}$m^{-3} , $P_{in} = 0.1mW$.

Fig.(3) shows the variation of transit-time with gate-length for different drain-source voltages. It can be observed that as the gate-length increases transit-time increases. It may be due to the fact that the distance between source and drain terminal increases with the increase in gate-length and carriers traversing the channel takes more time to reach drain terminal from the source terminal. It can also be observed from Fig.(3) that transit time is more the smaller value of drain bias. At small value of V_{ds} the carriers traverse the distance between source and drain with small velocity so transit time is large. As the drain-source voltage V_{ds} increases the carrier velocity reaches saturation velocity v_S and transit-time is reduced. In Fig.(4) variation of transit-time with gate length is shown for different gate-source voltages. It can be seen that for gate-source voltages near pinch off, transit time is very large and recedes as the gate-source junction is shifted toward less negative values.

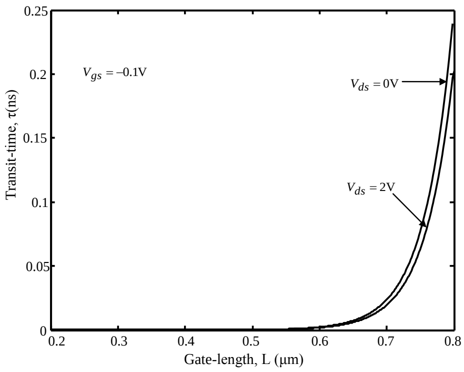

Fig. 2. Variation of transit-time with gate-length for different drain-source voltages

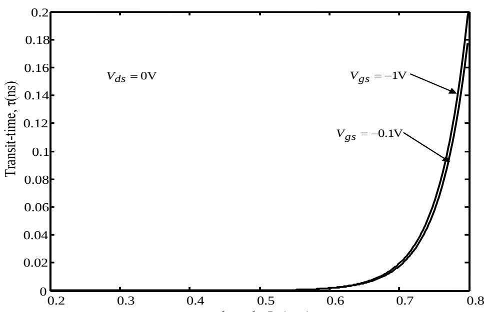

Fig. 3. Variation of transit-time with gate-length for different gate-source voltages

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