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 nGaAs layer, obtained by ion implanting Si into semi-insulating substrate.

\[ N_d(y) = N_s + (N_p - N_s)F(y) \]  
(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,

\[ F(y) = c_e \left[ a_e + \frac{2b_e \beta}{\sqrt{2} \sigma} \left( y - R_p \right)^2 - 2b_e \right] \times \exp \left[ \frac{a_e \beta}{2 \sigma^2} \left( y - R_p \right)^2 \right] \]  
(2)

where
\[ a_e = 1.7857142 \text{ , } b_e = 0.6460835 \text{ , } c_e = 0.28\sqrt{\pi} \text{ and } \beta \]

\[ \begin{cases} +1 & \text{for } y > R_p \\ -1 & \text{for } y < R_p \end{cases} \]
The net doping concentration \( N_D(y) \) in the active channel region under illuminated condition can be given as [7]

\[
N_D(y) = N_d(y) + G(y)\tau_n - \frac{R\tau_p}{a}
\]  

(3)

where \( N_d(y) \) represents the doping profile defined by (1). \( R \) is the surface recombination rate, \( \alpha \) is the absorption coefficient of GaAs material, \( \tau_n \) and \( \tau_p \) are the lifetime of electrons and holes, respectively and \( G(y) \) is the photogeneration rate given as [8].

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

\[
\frac{\partial^2 \phi(x,y)}{\partial x^2} + \frac{\partial^2 \phi(x,y)}{\partial y^2} = qN_D(y)/\varepsilon_s
\]

(4)

\( \varepsilon_s \) 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].

\[
\phi(x,0) = V_{bi} - V_{gs} - V_{op}
\]

(5)

\[
\phi(0,y) = V_{bi}
\]

(6)

\[
\phi(L,y) = V_{bi} + V_{ds}
\]

(7)

\[
\frac{\partial \phi(x,y)}{\partial y} \bigg|_{y=h_1} = 0
\]

(8)

where \( V_{bi} \) is the Schottky barrier built in potential, \( V_{gs} \) is the gate-source voltage, \( V_{op} \) is the photovoltage developed across Schottky metal gate, \( V_{ds} \) is the drain-source voltage and \( h_1 \) 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(\( E_x \)) as

\[
E(x) = \sum_{n=1}^{\infty} \frac{3\pi}{2a} A_n \cosh(k_n(L-x)) + \frac{3\pi}{2a} B_1 \cosh(k_1 x)
\]

(9)

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

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

\[
\tau = \int_0^{L_s} \frac{dx}{v(x)} \left( \frac{L - L_s}{v_s} \right)
\]

(10)
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

4. REFERENCES


