Chapter 4

TWO DIMENTIONAL MODELING OF MESFET UNDER ILLUMINATION

In the previous chapter the work is done using one dimensional Poisson’s equation. The work is extended in order to develop better understanding aspects of the submicronic device to be used as PD. The chapter starts with discussion on the existing theoretical models and their limitations which stimulate to propose the new physics based 2D model. The chapter is divided into four sections. Section 4.1 provides an accurate model of the device. The modeling is done using analytical approach and numerical technique approach. Section 4.2 discusses the results of the model developed. Section 4.3 verifies the results obtained for the model developed with the reference model. Section 4.4 concludes the chapter.

4.1 Theory

High speed detections at microwave frequencies require short channel optically controlled MESFETs. The research work deals MESFET with 0.25µm gate length. It is observed that for submicron devices 2D effects dominate the device operation. The accuracy of the model is governed by the device structure and the appropriate physical equations.

In a MESFET device the lateral field will be terminated by the edge side of the gate metal if the device has a long gate length, and the channel potential is slightly affected by the lateral field. However, this is not true for a short gate–length device because the lateral field is large. For a short gate–length MESFET, the channel potential cannot be entirely controlled by the gate bias and will be shifted by the penetration of the lateral field.

From this view point, there are two factors which may play important roles for the short–channel effect in a submicron MESFET:

1. First, the lateral field distribution at the sidewall of the gate edge,

2. Second, the efficiency of the gate metal in terminating the lateral field.

It is clear that a solution technique for the 2D Poisson’s equation satisfying suitable boundary conditions is required to model the short–channel effect. It is very difficult to find solution for the MESFET structure due to the complexity of the boundary conditions.
The models reported so far are [5, 19–24, 26, 30–60] either one dimensional (1D) considering gradual channel approximation for determining current–voltage characteristics of the device under illumination or 2D model considering 1D Poisson’s equation for determining the channel potential and electric field. The novelty of the work presented here is that it uses the 2D Poisson’s equation for determining the channel potential and electric field. The model also takes into consideration the extended depletion regions on the source and drain side for calculation of optical potential.

4.1.1 Device Modeling

The structure under consideration is a conventional GaAs MESFET with semi–transparent gate (fig. 1.1(b)). The schematic structure of the MESFET under consideration is shown in fig. 4.1. The simulated MESFET has a channel length of 0.25µm and active region thickness of 0.15µm. A semi–transparent gate can be made by reducing the thickness of the gold metal to 100Å.

![Schematic diagram of MESFET operated in the turn–on region for developing the 2D analytical solution](image)

Figure 4.1: Schematic diagram of MESFET operated in the turn–on region for developing the 2D analytical solution [Ref.33].

In the proposed model of 2D MESFET the investigations are done using basic 2D Poisson’s equation in the gate–depletion region with Schottky contact under illumination as in [33, 39, and 60].

\[
\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = \frac{-q}{\varepsilon} \left[ N_d(y) + K'e^{-\alpha y} \right] \tag{4.1a}
\]

\[
K' = \frac{P_{opt}(1 - R_m)(1 - R_s)\alpha \tau_L}{hv} \tag{4.1b}
\]

\(N_d(y)\) is the non–uniform doping density along y–direction and is given by eq. (3.2b).
The boundary conditions are taken from [39, 60]. The effect of illumination is included by replacing $V_{gs}$ by $(V_{gs} + V_{op})$.

\[
\psi(x, y)|_{y=0} = V_{gs} + V_{op} - \phi_{bi} \tag{4.2a}
\]

\[
\psi(x, y)|_{x=0} = \psi_{bi} \tag{4.2b}
\]

\[
\psi(x, y)|_{x=L} = \psi_{bi} + V_{ds} \tag{4.2c}
\]

\[
\psi(x, y)|_{y=a} = 0 \tag{4.2d}
\]

$V_{op}$ is calculated as in [39] considering the extension of depletion region on the drain side and the source side,

\[
V_{op} = \frac{n KT}{q} \ln \left[ \frac{q \alpha P_{opt}}{J_{sc} \hbar \nu_{bi}} \left( \int_{-\infty}^{L_{bi}} \int_{0}^{L_{bi}} \exp(-\alpha y) dy dx \right) \right] \tag{4.2e}
\]

where, $\nu$ is the frequency of incident radiation, $P_{opt}$ is the optical power density.

$n'$ is the ideality factor.

### 4.1.2 Current Modeling

The 1D current model calculates the current using gradual channel approximation, constant mobility and considers the current saturation to occur at pinch–off. But for short channel devices due to high field existing in the device constant mobility model cannot be considered because here the current saturates due to velocity saturation before pinch–off as discussed in section 2.1 and therefore, 2D model is required.

In order to obtain accurate model, some reasonable approximations are made. The first approximation is that the current flow in the $y$–direction can be neglected, which is valid for modern devices with channel thickness smaller than the channel length. The second approximation is that the variation of electron mobility vs. the $y$ position can be neglected for simplicity. The other approximations used are abrupt depletion edge and the quasi–neutral condition in the channel region. Based on these approximations, the drain current can be expressed as in [39],

\[
I_{ds} = q \int_{-\infty}^{L_{bi}} \int_{0}^{L_{bi}} Q_n(V) \mu_n(E) dV \tag{4.3}
\]

The mobility model is developed as in [39]. The field dependent mobility is given by:
\[ \mu_n(E_x) = \mu + \frac{2(-2\mu E_x + 3v_x)}{E_x^2} E_x + \frac{3(\mu E_x - 2v_x)}{E_x^3} E_x^2 \]  \hspace{1cm} (4.4) 

where, \( E_c \) is the critical field, 
\( E_x \) is the field along x–direction, 
\( Q_n(V) \) is the charge in the neutral channel region.

\[ Q_n(V) = q \int_{y_{c(x)}}^{a} N(y)dy + qH(y) \]  \hspace{1cm} (4.5b) 

\[ H(y) = K' \int_{0}^{a} \exp(-\alpha y)dy \]  \hspace{1cm} (4.5c) 

where, \( Y_{dd}(x) \) is the variation of depletion depth under the gate and is calculated using eq. (3.17a) for dark condition and eq. (3.17b) for illuminated condition.

Substituting eq. (4.4) into eq. (4.3) we get the following relation for the current:

\[ I_{dd} = \frac{Z \mu}{L_g} \int_{0}^{v_g} Q_n(V)dy + \frac{Z}{L_g^2} \frac{2(-2\mu E_x + 3v_x)}{E_x^2} \left[ \int_{0}^{v_g} \sqrt{Q_n(V)}dV \right]^2 + M(V) \]  \hspace{1cm} (4.6a) 

\[ M(V) = \frac{Z}{L_g^2} \frac{3(\mu E_x - 2v_x)}{E_x^3} \left[ \int_{0}^{v_g} Q_n(V) \frac{1}{3} dV \right]^3 \]  \hspace{1cm} (4.6b) 

### 4.1.3 Channel Potential

To find the channel potential and field the 2D basic Poisson’s equation is solved using analytical approach and numerical technique approach.

#### 4.1.3.1 Analytical Approach

The channel potential is approximated using Green’s function as in [33].

\[ \psi(x, y) \approx \psi_{id}(x, y) + A_i \sinh \frac{\sinh k_i(L_g - x)}{\sinh(k_iL_g)} + A_i' \frac{\sinh(k_i x)}{\sinh(k_i L_g)} \]  \hspace{1cm} (4.7a) 

where, \( k_i = \pi/2a \)  \hspace{1cm} (4.7b) 

\[ \psi_{id}(x, y) = \int_{0}^{y} qN_d(y') \frac{1}{\varepsilon} dy' + \int_{y}^{a} qN_d(y') \frac{1}{\varepsilon} dy' \]  \hspace{1cm} (4.7c)
\[ A^i_p = V_p \left[ a_j + b_j \left( \frac{V_{bi} - V_{gs} - V_j}{V_p} - c_j \right)^{1/2} \right] \]  \hspace{1cm} (4.7d)

\[ A^d_p = V_p \left[ a_2 + b_2 \left( \frac{V_{ds} + V_{bi} - V_{gs} - V_j}{V_p} - c_2 \right)^{1/2} \right] \]  \hspace{1cm} (4.7e)

\[ a_i = \frac{\beta A^d_i + \eta(W_i)}{\alpha V_p} \cdot \frac{64}{\pi^3 \alpha_i^2} \]  \hspace{1cm} (4.7f)

\[ b_i = \frac{8}{\pi \alpha_i} \]  \hspace{1cm} (4.7g)

\[ c_i = \frac{2a_i}{\pi} \cdot \frac{64}{\pi^4 \alpha_i^2} \]  \hspace{1cm} (4.7h)

\[ a_2 = \frac{\beta A^i_2 + \eta(W_d)}{\alpha V_p} \cdot \frac{64}{\pi^3 \alpha_i^2} \]  \hspace{1cm} (4.7i)

\[ c_2 = \frac{2a_2}{\pi} \cdot \frac{64}{\pi^4 \alpha_i^2} \]  \hspace{1cm} (4.7j)

\[ a_j = \frac{\pi}{2} \coth(k_i L_g) + \frac{1.4}{\pi} \]  \hspace{1cm} (4.7k)

\[ \beta = \frac{\pi}{2} \frac{1}{\sinh(k_i L_g)} \]  \hspace{1cm} (4.7l)

\[ V_j = \sum_{m=0}^{\infty} \frac{2B_m}{(2m-1)\pi} \]  \hspace{1cm} (4.7m)

\[ W_i = \left[ \frac{2\epsilon}{qN_{d0}^i} \left( V_{bi} - V_{gs} - V_i - \frac{2}{\pi} A^i_j \right) \right]^{1/2} \]  \hspace{1cm} (4.7n)

\[ W_d = \left[ \frac{2\epsilon}{qN_{d0}^d} \left( V_{ds} + V_{bi} - V_{gs} - V_i - \frac{2}{\pi} A^d_j \right) \right]^{1/2} \]  \hspace{1cm} (4.7o)

\[ N_{d,n} = \frac{1}{a} \int_{a}^{b} N_d(y) \cos(k_n y) dy \]  \hspace{1cm} (4.7p)
\[ k_n = \frac{n\pi}{a} \quad (4.7q) \]

\[ B_m = \frac{2}{a} \int_0^a \sin(k_m y) \left[ \int_0^y \frac{qN_d(y')}{\varepsilon} y' dy' + \int_y^a \frac{qN_d(y')}{\varepsilon} dy' \right] dy \quad (4.7r) \]

\[ k_m = \frac{(m - 1/2)\pi}{a} \quad (4.7s) \]

\[ \eta = a \sum_{n=1}^\infty T_{ln} \left( \sum_{m=1}^{\infty} k_n B_m T_{m,n} \right) \frac{qN_d}{k_n \varepsilon} \quad (4.7t) \]

\[ T_{mn} = \frac{2}{a} \int_0^a \sin(k_m y) \cos(k_n y) dy \quad (4.7u) \]

n and m are integers.

Flowchart for this approach is included in Appendix–A.

4.1.3.2 Numerical Technique Approach

Since the analytical modeling is very tedious and complicated the same equations are solved using the numerical techniques which reduce the complexity and are easier to implement. Monte Carlo finite difference method is used to solve the basic model eq. (4.1a) (2D Poisson’s second order differential equation) [61, 68].

In Monte Carlo finite difference the channel voltage profile is obtained by dividing the channel region into several meshes as shown in fig. 4.2.

![Figure 4.2: Mesh modeling of the channel region](image-url)
The potential \( \psi(x, y) \) at subsequent mesh points towards the drain end separated by \( 'mx' \) in longitudinal direction and \( 'my' \) in the transverse direction is calculated using Gaussian/Liebman iterative process and appropriate boundary conditions until the drain end of the gate is reached. Thereafter the field at these points is calculated under various conditions. These parameters will help to find the current in the device.

### A. Gaussian Iterative Process:

The channel potential at any mesh point of a rectangular grid in the \( x-y \) plane with sides \( \Delta x=mx \) and \( \Delta y=my \) can be calculated using the following Gaussian relation if the boundary conditions are provided.

\[
\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = f(x, y) \tag{4.8a}
\]

\[
f(x, y) = \frac{q}{\varepsilon} \left[ N(y) + H(y) \right] mxmy \tag{4.8b}
\]

where, \( u(x,y) \) is the channel potential at different grid points, \( f(x,y) \) is the function of \( x \) and \( y \).

\[
u(i,j) = \frac{1}{4} \left( u(i-1, j) + u(i-1, j+1) + u(i, j-1) + u(i, j+1) + f(x, y) \right) \tag{4.9}
\]

![Figure 4.3: Rectangular grid showing Gaussian iteration process](image-url)
**B. Liebman Iterative Process**

The channel potential at any mesh point of a rectangular grid in the \(x-y\) plane with sides \(\Delta x=m_x\) and \(\Delta y=m_y\) can also be calculated using the Liebman relation if boundary conditions are provided.

The channel potential can be calculated using eq. (4.10).

\[
u(i, j) = \frac{1}{4} \left( u(i-1, j-1) + u(i-1, j+1) + u(i+1, j-1) + u(i+1, j+1) + f(x, y) m_x m_y \right)
\]  

(4.10)

**Figure 4.4:** Rectangular grid showing Liebman iteration process

**C. Calculation of Potential at all Mesh Points**

To find the initial values of channel potential \((u)\) for given boundary values \((b)\), at the interior mesh points (9×9 matrix), first diagonal five point method is used. Using diagonal five points formula \(u_{3,3}, u_{2,4}, u_{4,4}, u_{4,2}\) and \(u_{2,2}\) are computed in order mentioned as:

\[
u_{3,3} = \frac{1}{4} \left( b_{1,5} + b_{3,1} + b_{3,3} + b_{1,1} \right)
\]  

(4.11a)

\[
u_{2,4} = \frac{1}{4} \left( b_{1,5} + u_{3,3} + b_{3,3} + b_{1,3} \right)
\]  

(4.11b)

\[
u_{4,4} = \frac{1}{4} \left( b_{1,5} + b_{5,3} + b_{5,5} + u_{3,3} \right)
\]  

(4.11c)
\[
\begin{align*}
\bar{u}_{4,2} &= \frac{1}{4}(u_{3,3} + b_{3,1} + b_{3,1} + b_{3,3}) \\
\bar{u}_{2,2} &= \frac{1}{4}(b_{1,3} + b_{3,1} + u_{3,3} + b_{1,1})
\end{align*}
\] (4.11d)

The values at the remaining interior points i.e. \(u_{2,3}, u_{3,4}, u_{4,3}\) and \(u_{3,2}\) are computed by standard five point formula.

\[
\begin{align*}
\bar{u}_{2,3} &= \frac{1}{4}(b_{1,3} + u_{3,3} + u_{2,4} + u_{2,2}) \\
\bar{u}_{3,4} &= \frac{1}{4}(u_{2,4} + u_{4,4} + b_{3,3} + b_{3,3}) \\
\bar{u}_{4,3} &= \frac{1}{4}(u_{3,3} + b_{3,3} + u_{4,4} + u_{4,2}) \\
\bar{u}_{3,2} &= \frac{1}{4}(u_{2,2} + u_{3,2} + u_{3,3} + u_{3,1})
\end{align*}
\] (4.11f-g-h-i)

Having found all the nine values, \(u_{i,j}\) at the remaining points are calculated by using Liebman and Gaussian in tandem. Their accuracy is improved by optimization. Flowchart for this approach is included in Appendix–B.

### 4.1.4 Electric Field Model

The electric field along \(x\) and \(y\) direction can be obtained by solving eq. (4.12a) and eq. (4.12b) [64, 68]

\[
\begin{align*}
E_x &= \frac{\psi(i+1, j) - \psi(i-1, j)}{2mx} \\
E_y &= \frac{\psi(i, j+1) - \psi(i, j-1)}{2my}
\end{align*}
\] (4.12a-b)

These equations are utilized for estimating the field dependent mobility and the drain current characteristics equation.

### 4.1.5 Velocity Model

The velocity–field characteristics of electrons in GaAs are assumed, as in [18].

\[
\nu(E) = \frac{\mu E + \nu_v(E/E_c)^4}{1 + (E/E_c)^4}
\] (4.13a)
\[ E = \sqrt{E_x^2 + E_y^2} \]  

(4.13b)

where, \( E \) is the resultant applied field, 
\( E_x \) is the electric field in the \( x \)-direction, 
\( E_y \) is the electric field in the \( y \)-direction.

### 4.1.6 Gate to Source Capacitance (\( C_{gs} \)) Model

The gate to source capacitance can also be calculated using the following relation under dark and illuminated conditions [60] by calculating the charges under different illuminated condition as in chapter 5.

\[
C_{gs} = \frac{dQ_d}{dV_{gs}} \left|_{V_{gs}=\text{constant}} \right| = \frac{Q_d(i+1) - Q_d(i-1)}{V_{gs}(i+1) - V_{gs}(i-1)}
\]

(4.14)

where, \( Q_d \) is the charge in the depletion region.

### 4.2 Results and Discussions

Computations and simulations are carried out for GaAs MESFET at 300° K for different illuminations (optical power densities: \( P_{opt1}=0\,\text{W/m}^2 \), \( P_{opt2}=0.2\,\text{W/m}^2 \), \( P_{opt3}=0.5\,\text{W/m}^2 \)) using 2D model developed above. The gate metallization is assumed to be thin enough to allow 90% of the incident radiation to pass through.

![Figure 4.5: Variation of photo–voltage \( V_{op} \) across the Schottky barrier](image)

Figure 4.5: Variation of photo–voltage \( V_{op} \) across the Schottky barrier
Table 4.1: Comparison of optical potential for simulated model and reference model [36]

<table>
<thead>
<tr>
<th>$P_{opt}$ (W/m$^2$)</th>
<th>Simulated model $V_{op}$ (mV)</th>
<th>Reference model $V_{op}$ (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>92.8</td>
<td>92</td>
</tr>
<tr>
<td>3</td>
<td>91.26</td>
<td>89</td>
</tr>
<tr>
<td>4</td>
<td>88.59</td>
<td>84.5</td>
</tr>
<tr>
<td>5</td>
<td>84.68</td>
<td>78.5</td>
</tr>
</tbody>
</table>

Fig. 4.5 shows comparison of variations in the photo–voltage developed at the Schottky contact with the optical power density for the opaque and semi–transparent gate. The photo–voltage developed at the Schottky junction increases with the incident optical power density $P_{opt}$, and finally saturates at higher values of optical power density. This saturation at higher values of optical density is due to reduction in the lifetime of the carriers in the presence of illumination, which limits the excess photo generation under the intense illumination. As clear from the plot the optical potential developed across the gate increases for the semi–transparent gate. The optical effects become more prominent in semi–transparent metal gate as it facilitates transmission of optical radiation incident on the gate.

Table 4.1 shows that the comparison of the photo–voltage developed using the simulated model with the reference model for same dimensions, biasing and illuminations. The tabulated results show that the model gives a good estimate of the optical potential developed in the semi–transparent gate device under illumination.

The results obtained for the channel potential and current characteristics using the analytical and numerical technique are discussed in section 4.2.1 and 4.2.2 respectively.

**4.2.1 Analytical Method**

Fig. 4.6 shows the variation of channel potential with normalized length. It clearly shows that central potential distribution increases with decreasing gate length. The result is in agreement with the reported result in [33].

Swing of channel potential (SCP) (minimum to maximum) for different channel lengths is listed in table 4.2 and result is in agreement with the model presented in [33].

Fig. 4.7 shows the variation of channel potential with normalized length. The curve shows that with increase in $V_{ds}$, the channel potential increases at the drain and the curve shifts upwards on the drain side and there is no change in channel potential at the source side. The result is in agreement with the reported result in [33].
Figure 4.6: Channel potential vs. normalized distance for various $L_g$

Figure 4.7: Channel potential vs. normalized distance for various $V_{ds}$
Figure 4.8: Channel potential vs. normalized distance for various illuminations

Figure 4.9: Current–voltage ($I_{ds}$–$V_{ds}$) for the simulated 2D model for various $V_{gs}$
Figure 4.10: Current–voltage ($I_{ds}$–$V_{ds}$) for the simulated 2D model under various illuminations at $V_{gs}=-0.75V$

Table 4.2: Swing of the channel potential curve for different channel lengths

<table>
<thead>
<tr>
<th>Channel length</th>
<th>SCP</th>
<th>SCP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated model (V)</td>
<td>Reference model [33] (V)</td>
</tr>
<tr>
<td>0.3µm</td>
<td>0.79</td>
<td>0.6</td>
</tr>
<tr>
<td>0.55µm</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>0.8µm</td>
<td>1.17</td>
<td>0.9</td>
</tr>
<tr>
<td>1.2µm</td>
<td>0.935</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 4.3: Change in the channel potential with the change in the $V_{ds}$ at $x/L_g=1$

<table>
<thead>
<tr>
<th>Change in $V_{ds}$ (V)</th>
<th>CCP</th>
<th>CCP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated model (V)</td>
<td>Reference model [33] (V)</td>
</tr>
<tr>
<td>0–1</td>
<td>0.36</td>
<td>0.4</td>
</tr>
<tr>
<td>1–2</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>2–3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 4.3 gives the change in channel potential (CCP) with the change in $V_{ds}$ and it shows that the change is constant for the constant change in $V_{ds}$. Satisfactory agreement between the reference model [33] and the 2D model developed is achieved.
Fig. 4.8 shows the channel potential versus normalized distance for various illuminations. The gate biasing potential becomes more positive due to the optical potential at the gate.

Fig. 4.9 gives current–voltage \( (I_{ds} - V_{ds}) \) curves which show the variation of the current for different \( V_{gs} \). It shows that the current increases with reduction in the reverse biasing gate potential \( (V_{gs}) \). The current plot indicates that the device enters from linear into saturation region with the increase in \( V_{ds} \).

Fig. 4.10 shows current–voltage \( (I_{ds} - V_{ds}) \) curve for different illuminations. It can be seen that there is an increase in current with the increase in the illumination because the potential barrier at the gate is lowered by the increase in the illumination. Hence, there is increase in the conductance.

### 4.2.2 Numerical Technique (Monte Carlo Finite Difference Method)

Fig. 4.11 shows the variation of channel potential with channel length \( (L_x) \) and channel depth \( (L_y) \) for different illuminations. It is clear from the plot that the channel potential increases towards the drain side. This is because the biasing is applied at the drain.

Fig. 4.12 shows the variation of the channel potential along the channel length for different illuminations. It can be clearly seen that the channel potential increases with the increase in illumination due to optical potential developed at the gate.

Fig. 4.13 shows the variation of horizontal field \( (E_x) \) with gate length \( (L_x) \) for various \( V_{ds} \). The plot indicates that field is maximum near drain and it increases with increase in \( V_{ds} \). The effect is prominent near the drain where biasing potential is applied.

Fig. 4.14 shows the variation of electric field along gate length \( (E_x - L_x) \) for different illuminations. It is observed that there is very small change in the field with illumination as it is applied in the \( y \)–direction (perpendicular direction).

Fig. 4.15 shows the variation of vertical field \( (E_y) \) with gate width \( (L_y) \) for various \( V_{ds} \). The field is maximum in the depletion region and increases with increase in \( V_{ds} \).

Fig. 4.16 shows the variation of vertical field \( (E_y) \) with gate width \( (L_y) \) for different illuminations. It is observed that the change in the field with illumination is more prominent as compared with \( E_x \) because the field \( E_y \) and illumination are along same direction. It is also observed that the effect of illumination is prominent near the source as compared to drain since biasing is applied at the drain.

Fig. 4.17 shows the variation in mobility with the field. The mobility is constant till threshold field and decreases for higher fields.
Figure 4.11: Channel potential along gate length and gate width for different illuminations

Figure 4.12: Channel potential vs. normalized distance for different illuminations
Figure 4.13: Electric field along gate length for various $V_{ds}$

Figure 4.14: Electric field along gate length for different illuminations
Figure 4.15: Electric field along gate width for various $V_{ds}$

Figure 4.16: Electric field along gate width for different illuminations
Figure 4.17: Mobility vs. field

Figure 4.18: Carrier velocity vs. field
Figure 4.19: Drain current vs. drain voltage ($I_{ds}$–$V_{ds}$) for different illuminations

Figure 4.20: Comparison of drain current vs. drain voltage ($I_{ds}$–$V_{ds}$) for different illuminations with 3µm (LD) and 0.25µm (SD) channel length.
Table 4.4: Comparison of small channel devices and large channel devices for sensitivity at $V_{ds}=0.75V$ for different illuminations

<table>
<thead>
<tr>
<th>Optical Power (W/m$^2$)</th>
<th>$I_{ds}$ (A) (LD)</th>
<th>$I_{ds}$ (A) (SD)</th>
<th>% Change in current (LD)</th>
<th>% Change in current (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{opt1}$</td>
<td>0.004609</td>
<td>0.03494</td>
<td>3.8%</td>
<td>8.9%</td>
</tr>
<tr>
<td>$P_{opt2}$</td>
<td>0.004868</td>
<td>0.03805</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{opt3}$</td>
<td>0.005025</td>
<td>0.03993</td>
<td>3.2%</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

Fig. 4.18 shows the variation of the carrier velocity with the electric field. It indicates that for low field the velocity of the carrier increases with the increase in the field and after threshold field the velocity reaches saturation and remains constant.

Fig. 4.19 gives the variation of current with voltage ($I_{ds}$–$V_{ds}$) under dark and illumination (dark=0W/m$^2$, Illuminated condition: $P_{opt}=0.5W/m^2$). There is an increase in current with the illumination because of the increase in channel potential with the increase in illumination.

Fig. 4.20 gives the variation in current with voltage ($I_{ds}$–$V_{ds}$) for different illuminations for 3µm and 0.25µm channel length. It clearly shows that the short channel devices are more sensitive to optical illumination as compared to long channel devices and the results are presented in table 4.4. Therefore, short channel devices find application as high speed optical detector.

4.3 Verification

Table 4.5 gives the change in channel potential (CCP) with the change in $V_{ds}$. It indicates that the change is constant for the constant change in $V_{ds}$. Satisfactory agreements between the reference model [39] and the 2D simulation model using analytical and numerical technique is obtained.

Table 4.5: Change in the channel potential with the change in $V_{ds}$ at $x/L_s=1$

<table>
<thead>
<tr>
<th>Change in $V_{ds}$ (V)</th>
<th>CCP Simulated model (V) (Analytical)</th>
<th>CCP Simulated model (V) (Numerical)</th>
<th>CCP Reference model [39] (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1</td>
<td>0.36</td>
<td>0.346</td>
<td>0.4</td>
</tr>
<tr>
<td>1–2</td>
<td>0.34</td>
<td>0.365</td>
<td>0.35</td>
</tr>
<tr>
<td>2–3</td>
<td>0.3</td>
<td>0.374</td>
<td>0.4</td>
</tr>
</tbody>
</table>
4.4 Conclusion

A 2D simulation model for non-uniformly doped GaAs MESFET is developed. The semiconductor model is developed using the basic 2D Poisson’s equation. The model is applied to simulate the characteristics for different illuminations. The results discuss about the variation of channel potential for various gate length, drain potential and illuminations. It also includes the current–voltage characteristics under various biasing and illumination conditions. It has been observed from the results that the characteristics of the device are strongly influenced by the incident optical illumination. The results obtained from the simulation compares satisfactorily with reported results for similar structures.

The analytical approach requires more computational time. The numerical technique (Monte Carlo finite difference method) for solving the 2D Poisson’s equation was developed which was not used by earlier researchers. The results of the numerical and analytical model are comparable. The new model developed shows better approximation of device parameters.