CHAPTER 3

ANALYTICAL MODEL OF IMPURITY SCATTERING IN
SILICON NANOWIRE TRANSISTORS

3.1 INTRODUCTION

Semiconductor nanowires are attractive components for future nanoelectronics since they exhibit a wide range of device function and at the same time they serve as bridging wires that connect to larger scale metallization. The nanoscale FETs based on SiNWs have notable attention for their potential applications in electronics industry. In a continuous effort to increase current drive and better control on SCEs, Silicon-On-Insulator (SOI) MOS transistors have evolved from classical, planar, single-gate devices into 3D devices with a multi-gate structure (double-, triple- or gate-all-around devices). These Multi-Gate nanowire FETs are now widely recognized as one of the most auspicious solutions for meeting the roadmap requirements in the deca-nanometer scale.

Multi-Gate device structures of SiNW MOSFETs have better electrostatic control which results higher mobility and current. Various device structures such as double gate, trigate and all around gate have been extensively investigated to restrict SCEs within a limit, while achieving the primary advantages of scaling, i.e., higher performance, lower power, and ever increasing integration density. Among these novel architectures, the Cylindrical Surrounding Gate Nanowire MOSFET has all the potentialities to become alternative CMOS structures to meet the scaling challenges for designing future generation VLSI/ULSI based circuits and systems.
In this chapter, an analytical model for Near Ballistic SiNW MOSFET is developed by including the impact of Impurity-limited mobility or Discrete Random Dopant Scattering (DRS) using Natori’s quasi-ballistic transport model for Si NW MOSFETs, which is derived by directly solving the BTE. The performance of Current-Voltage and analog characteristics of above model is analyzed.

![Schematic diagram of cylindrical surrounding gate NWFET](image)

**Figure 3.1 Schematic diagram of cylindrical surrounding gate NWFET**

(Auth & Plummer 1997) have presented a scaling theory for fully depleted, cylindrical GAA MOSFETs. Schematic diagram of Cylindrical Surrounding Gate NWFET is shown in Figure 3.1. The theory of this device was derived from the cylindrical form of Poisson’s equation by assuming a parabolic potential in the radial direction. Numerical device data simulations for DIBL and subthreshold slope were compared with numerical simulations for validating the data. A new scale length for 2D effects in MOSFETs was derived by (Frank et al 1998). They considered the difference in permittivity between the silicon channel and the gate insulator, and hence allow an accurate understanding of the effects of using insufficiently scaled oxide or thicker and higher permittivity gate insulators.

(Roldan et al 2003) developed a semiempirical model for calculating the inversion charge of Cylindrical Surrounding Gate transistors, including quantum effects. 2D Poisson and Schrodinger equations were solved using a self
consistent simulator. Compact modeling of SG MOSFETs with doped channel in subthreshold region was proposed by (Byung-Kil Choi 2008). The modeling of surface potential and diffusion current in SG MOSFETs with doped channel in the subthreshold region was performed in this study. The compact models were verified in terms of channel length, Fin body width, and body doping concentration at a given gate source voltage and compared with the results of a 3D simulator.

A compact analytical threshold voltage model for Surrounding Gate MOSFETs with interface trapped charges has been reported by (Te-Kuang Chiang 2012). With the effects of equivalent oxide charges on flat band voltage, a compact analytical threshold voltage model was developed based on the parabolic potential approach. This model shows how interface charge density, damaged zone, oxide thickness, and diameter of silicon body affects the threshold voltage. It was used to explore the hot carrier induced threshold voltage behavior of Surrounding Gate MOSFETs for its memory device applications.

A new physically based classical model for the potential distribution of an undoped body cylindrical GAA nanowire device has been proposed by (Ray & Mahapathra 2008). This model was valid for a) long and short channel devices, b) weak and strong inversion regimes, and c) body centre and surfaces. Using the proposed model, it was demonstrated that the body potential versus gate voltage characteristics for the devices having equal channel lengths but different body radii pass through a single common point called crossover point. Using this crossover point, the effect of body radius on the threshold voltage of the multigate nanowire transistors was studied.

A compact, physical surface potential model for undoped GAA nanoscale MOSFETs has been derived by (Gaffar et al 2010). This model
included a mobile charge term and the results were validated by comparing with a numerical simulator. The role of different phonon scattering mechanisms on the performance of a cylindrical Surrounding Gate Nanowire MOSFET has been studied by (Aldegunde and Martinez 2012). The study was carried out using Non Equilibrium Green’s Function (NEGF) formalism in the effective mass approximation. Based on the comprehensive energy band structure of the strained silicon and solving 2D Poisson equation of the potential distribution in the channel, an analytical threshold voltage model of the strained surrounding gate n channel MOSFET was developed by (Yao Liu & Zunchao Li 2012). The dependence of the threshold voltage on the gate length, channel doping concentration and Ge content of the relaxed SiGe is studied using this model.

An analytical model for surface potential and threshold voltage which was included the fringe capacitances in Cylindrical Surrounding Gate devices have been developed by (Gupta & Baishya 2013). This model is computed the charge induced in the drain/source region due to the fringing capacitances and considered an effective charge distribution in the cylindrically extended source/drain region for the development of a simple and compact model.

3.2 DEVICE STRUCTURE

A variety of novel device architectures have been proposed to alleviate the problem of short channel effects and extending the scalability of CMOS technology as far as possible. The structure that theoretically offers the best possible control of the channel region by the gate, and hence the best possible electrostatic integrity is the surrounding-gate nanowire MOSFET. A cylindrical Surrounding Gate structure in the fully depleted regime has better control of short channel effects than in other multi gate devices. This is because of the tight capacitive coupling of the surrounding gate to the device channel region from all directions.
The Gate All Around SiNW MOSFET can be considered as a quantum wire where the electrons are confined within a cylindrical potential wall. The silicon body is surrounded with a very thin layer of an oxide, and the oxide is enclosed either by a Silicon gate. The schematic diagram of Gate All Around SiNW MOSFET is shown in Figure 3.2. The channel width and thickness of oxide layer are represented by ‘r’ and ‘t\textsubscript{ox}’ respectively. The source is on the left side, whereas the drain is on the right side. With the superiorly enhanced gate controllability, the device can greatly relax the stringent process requirements with more flexible device design, such as relaxed channel doping design and allowably thicker gate dielectric. This device has the benefits of both reducing the short channel effects and improving the sub threshold slope, as well as potentially higher packing densities.

3.3 ISSUES AND PROBLEM FORMULATION

The growth of nanotechnology performance drives the scaling of transistor to the nanometer scale. As MOSFET dimension is approaching beyond micrometer scale entering the nanometer scale regime, there are some significant obstacle that must be look due to Short Channel Effects (SCEs). The selection of Gate All Around Si Nanowire MOSFET is to overcome the scaling limitations as
it possess high packing density with improved gate controllability and short channel immunity as the gate in all around the silicon pillar completely and therefore, control over the channel is increased.

When the channel length is greater than 10nm in nanometer scale carrier transport experiences various scattering effects. Introduction of scattering effects into the ballistic modeling of a MOSFET has been widely discussed by several authors using “kT-layer theory” and such models have been validated by a Monte-Carlo simulation. A few number of researches have investigated limited scattering effects using NEGF formalism, however, these models have not been clearly postulated. (Natori 2012) developed a quasi-ballistic transport model for Si NW MOSFETs by directly solving the BTE with constraint of dominant elastic scattering due to acoustic phonon. Further work by him took into account the inelastic scattering due to the optical phonon emission. However, Natori and other researchers have not paid attention on defect scattering like Impurity scattering, surface roughness scattering. For the first time, we investigate impurity scattering in supplement with elastic scattering and optical phonon emission scattering.

3.4 PROPOSED ANALYTICAL MODEL FOR IMPURITY SCATTERED SINW TRANSISTOR

![Cross section diagram of a GAA SiNW Transistor with Discrete Random dopants](image-url)
The physics-based analytical model of Near ballistic Silicon Nanowire MOSFET is essential towards the understanding of the device operation and for analyzing the Current-Voltage and analog characteristics of the device. The cross section view of a GAA SiNW MOSFET with Discrete Random dopants is shown in Figure 3.3. The electronic structure of the NWs is computed with a sp$^3$d$^5$s$^*$ tight-binding model and the source and drain are made of n-type regions. The intermediate channel region is 20 nm long which consists of randomly distributed charged impurities with doping concentration of 10$^{18}$ cm$^{-3}$. 2 nm thick Silicon-di-oxide (SiO$_2$) is used as the gate dielectric with the current direction along the $x$-axis and the cross section of the wire in the $y$–$z$ plane (see Figure 3.2).

Four main steps have been proposed to find an analytical expression of Near ballistic Silicon Nanowire MOSFET by considering different Scattering mechanism. First one is the Impurity limited Electron mobility, which is derived by using the impurity concentration (per unit volume). In the second step is calculating the Fermi energy at source and drain using Fermi Dirac distribution function. As Fermi distribution function greatly depends on electron mobility, the Fermi energy of the scattered SiNW MOSFET is varied in accordance with scattered mobility.

In the third step, we calculate the transmission parameter by directly solving Boltzmann transport equation (BTE) with constraint of dominant elastic scattering due to acoustic phonon and inelastic scattering due to optical phonon emission.

In Fourth step, the drain current for Near ballistic Silicon Nanowire MOSFET considering different Scattering mechanism is evaluated by Landauer formalism from the source to the drain under drain bias $V_D$. Landauer formalism incorporates Fermi energy and transmission parameter which is calculated in...
previous steps. Analog parameters like Transconductance \( (g_m) \), Transconductance generation factor \( (g_m I_{DS}) \) and Early Voltage \( (V_a) \) are also calculated from derived drain current.

Impurity scattering does not alter the carrier energy but it makes the change in mobility on the other hand carrier-carrier scattering and optical phonon emission alters the carrier energy so, we include these to effects in terms of Transmission coefficient.

The value of the impurity limited mobility \( \mu_{imp} \) has been calculated from carrier density. To account for this mechanism, first we compute the self-consistent conduction band wave functions of the homogeneous nanowire at the target carrier density \( n \). Then we calculate the density-density response function of the conduction band electrons with these wave functions, and hence solve the Poisson’s equation for the screened Dopant potential in the linear-response approximation region. This is equivalent to the so-called Random Phase Approximation (RPA) for the free carriers (Landauer 1982).

We have finally computed the impurity resistance with Linearized Boltzmann transport equation (LBTE). In the non-perturbative Landauer-B’uttiker approach has explained by (Grosso et al 1989) the SiNWs are coupled to ideal semi-infinite leads. The total transmission probability is computed as a function of the electron energy \( \varepsilon \) through standard decimation technique or a newly implemented “knitting” algorithm (Kazymyrenko & Waintal 2008) (for diameters \( d \geq 5 \) \( \text{nm} \)). We have also considered sufficiently diluted systems and/or a generic source of incoherence (e.g., phonons) so that interference effects induced by multiple scattering events involving more than one impurity can be neglected.
The resistance of a single impurity is then:

\[ R_{\text{imp}}(\mu, T) = \frac{1}{G_i(\mu, T)} - \frac{1}{G_b(\mu, T)} \]  
(3.1)

where \( G_i \) is the conductance of the nanowire with impurity, \( G_b \) is the conductance of the nanowire without impurity at temperature \( T \) and chemical potential \( \mu \). The data presented in this work have been computed at room-temperature. Both \( G_i \) and \( G_b \) are obtained by the finite temperature Landauer-Buttiker formula. Impurity mobility is obtained using conductivity as:

\[ \mu_{\text{imp}} = \frac{\sigma}{n_e} \]  
(3.2)

where conductivity \( \sigma = \frac{16}{\pi^2 d^4} n_{\text{imp}} R_{\text{imp}} \) and \( R_{\text{imp}} \) Impurity resistance is obtained from “knitting” algorithm, \( n_{\text{imp}} \) is the impurity concentration (per unit volume). Here, we use doping concentration as \( n_{\text{imp}} = 10^{18} \text{ cm}^{-3} \), \( n \) is the free carrier density.

The potential of single charged impurity (P or N) which is randomly distributed in the cross section of the NW is calculated by semi-analytical Fourier-Bessel series. This potential is further screened by the free carriers in the conduction or valence band of the NWs within a self-consistent linear response approximation. Here, the doping concentration of \( 10^{18} \text{ cm}^{-3} \) is considered and it makes 0.79 dopant atoms per nanometer then the impurity-limited mobility \( \mu_{\text{imp}} \) is given as:

\[ \mu_{\text{imp}} = \frac{1}{en_{\text{imp}} ns^2 R_{\text{imp}}} \]  
(3.3)

Where \( e \) is the elementary charge and \( S \) is the cross-sectional area of the NW which is calculated as:

\[ S = \frac{\pi d^2}{4} \]  
(3.4)
(Natori 2012) developed a quasi-ballistic transport model for Si NW MOSFETs by directly solving the BTE with constraint of dominant elastic scattering due to acoustic phonon. Further work by him took into account the inelastic scattering due to the optical phonon emission. However, Natori and other researchers have not paid attention on Defect scattering like Impurity scattering, Surface Roughness scattering and so on.

Here we use Natori’s quasi ballistic model, in this model electronic structures were represented by quantum mechanical approaches and carrier transport is obtained by a direct solution of the Boltzmann transport equation (BTE).

Natori’s quasi ballistic model is used to evaluate drain current for our scattered SiNW MOSFET model by Landauer formalism from the source to the drain under drain bias $V_D$

$$I_D = \frac{q}{\pi \hbar} \sum_i \int [f(\epsilon, \mu_{impS}) - f(\epsilon, \mu_{impD})] \Gamma_i(\epsilon) d\epsilon$$  \hspace{1cm} (3.5)

Here, $q$ indicates the carrier charge; $\hbar$ indicates the reduced Planck’s constant. Summation over $i$ represents a summation of contributions from various subbands. $\Gamma_i(\epsilon)$ denotes the transmission coefficient of a carrier injected into the ith subband ($i = 0, 1, 2, ..$) $f(\epsilon, \mu_{impS}) , f(\epsilon, \mu_{impD})$ are fermi levels associated with the source and drain electrodes respectively while considering the Discrete Random Dopants scattering.

Fermi distribution function $f(\epsilon, \mu_{impS})$ at source electrode is given as

$$f(\epsilon, \mu_{impS}) = \frac{1}{1 + \exp\left(\frac{\epsilon - \mu_{impS}}{K_B T}\right)}$$  \hspace{1cm} (3.6)

and Fermi distribution function $f(\epsilon, \mu_{impD})$ at drain electrode is given as

$$f(\epsilon, \mu_{impD}) = \frac{1}{1 + \exp\left(\frac{\epsilon - \mu_{impD}}{K_B T}\right)}$$  \hspace{1cm} (3.7)
The mobility of carriers at source and drain electrode are related as
\[ \mu_{impD} = \mu_{impS} - qV_D \quad (3.8) \]

Then the equation (3.7) becomes
\[ f(\varepsilon, \mu_{impD}) = \frac{1}{1 + \exp\left(\frac{\varepsilon - \mu_{impS} + qV_D}{k_BT}\right)} \quad (3.9) \]

The difference in Fermi energy level between Source and Drain electrode is obtained as
\[ f(\varepsilon, \mu_{impS}) - f(\varepsilon, \mu_{impD}) = \frac{1}{1 + \exp\left(\frac{\varepsilon - \mu_{impS}}{k_BT}\right)} - \frac{1}{1 + \exp\left(\frac{\varepsilon - \mu_{impS} + qV_D}{k_BT}\right)} \quad (3.10) \]

Assuming,
\[ x_1 = \left(\frac{\varepsilon - \mu_{impS}}{k_BT}\right) \quad (3.11) \]
\[ x_2 = \left(\frac{\varepsilon - \mu_{impS} + qV_D}{k_BT}\right) \quad (3.12) \]

The above equation is modified as,
\[ f(\varepsilon, \mu_{impS}) - f(\varepsilon, \mu_{impD}) = \frac{1}{1 + \exp(x_1)} - \frac{1}{1 + \exp(x_2)} \quad (3.13) \]
\[ f(\varepsilon, \mu_{impS}) - f(\varepsilon, \mu_{impD}) = (1 + \exp(x_1))^{-1} - (1 + \exp(x_2))^{-1} \quad (3.14) \]
\[ f(\varepsilon, \mu_{impS}) - f(\varepsilon, \mu_{impD}) = 1 - \exp(x_1) - 1 + \exp(x_2) \quad (3.15) \]

The above equation obtained through binomial series expansion
\[ f(\varepsilon, \mu_{impS}) - f(\varepsilon, \mu_{impD}) = \exp(x_2) - \exp(x_1) \quad (3.16) \]
Expanding the above expression using exponential series function,
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = \left(1 + \frac{x_2}{1!} + \frac{x_3}{2!} + \frac{x_4}{3!} + \cdots\right) - \left(1 + \frac{x_1}{1!} + \frac{x_2}{2!} + \frac{x_3}{3!} + \cdots\right) \]

Neglecting 3\textsuperscript{rd} and higher order terms in the above equation we obtain,
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = \left(1 + \frac{x_2}{2!}\right) - \left(1 + \frac{x_1}{1!}\right) \]

\[ (3.17) \]
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = 1 + x_2 \cdot \frac{1}{2} - x_1 \]

\[ (3.18) \]
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = (x_2 - x_1) + \frac{1}{2} (x_2^2 - x_1^2) \]

\[ (3.19) \]

The values of \( x_1 \) and \( x_2 \) are again substituted in the above simplified expression for difference in Fermi energy level then the above equation becomes
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = \left(\frac{\epsilon - \mu_{imps} + qV_D}{k_B T} - \frac{\epsilon - \mu_{imps}}{k_B T}\right) + \frac{1}{2} \left[\left(\frac{\epsilon - \mu_{imps} + qV_D}{k_B T}\right)^2 - \left(\frac{\epsilon - \mu_{imps}}{k_B T}\right)^2\right] \]

\[ (3.20) \]

Carrying out further simplification we obtain the final expression for difference in Fermi energy level between Source and Drain electrode
\[ f(\epsilon, \mu_{imps}) - f(\epsilon, \mu_{impd}) = \frac{qV_D}{k_B T} \left[1 - \frac{\mu_{imps}}{k_B T} + \frac{qV_D}{2k_B T} + \frac{\epsilon_i}{k_B T}\right] \]

\[ (3.21) \]

Optical phonon emission is considered as inelastic scattering. The influence of this Optical phonon emission is included in this device in terms of Transmission coefficient \( \Gamma_i(\epsilon_i) \) is described by (Natori 2012).
Transmission coefficient $\Gamma_i(\epsilon_i)$ from the source to the drain of a carrier at the incident energy level including elastic scattering and optical phonon emission have three different solutions in accordance with the injected kinetic energy $\epsilon_i$ from the source edge into the channel.

The transmission coefficient is evaluated by considering scattering dynamics within the NW channel. Approximate energy dispersion of carriers in the $i$th subband with origin at the band bottom, i.e.,

$$\epsilon_i(k) = \epsilon_{i0} + \frac{\hbar^2}{2m_i} k^2$$  \hspace{1cm} (3.22)

Carrier dynamics in the incident energy level, within the Inelastic Zone is described by the 1-D Boltzmann transport equation (BTE) is

$$\frac{q}{\hbar} E \frac{\partial f_i(x,k)}{\partial k} + \frac{\hbar k}{m_i} \frac{\partial f_i(x,k)}{\partial x} + B_i \{f_i(x,k) - f_i(x,-k)\} = 0$$  \hspace{1cm} (3.23)

where $f_i(x, k)$ is the distribution function of carriers in the $i$th subband, and $B_i$ is the intrasubband backscattering probability between states $(x, k)$ and $(x, -k)$ due to elastic scattering.

The BTE (3.23) is rigorously solved. We introduce two functions $F(x)$ and $G(x)$ that are defined by the expressions

$$f_i(x, |k|) = h F_i(x) \partial \left( \frac{\hbar^2 k^2}{2m_i} - qE_x - \epsilon_i \right)$$  \hspace{1cm} (3.24)

$$f_i(x, |k|) = h G_i(x) \partial \left( \frac{\hbar^2 k^2}{2m_i} - qE_x - \epsilon_i \right)$$  \hspace{1cm} (3.25)

Here Consider

$$\int_0^\infty f_i(x, k) \frac{\hbar k \partial k}{m_i 2\pi} \approx F_i(x)$$  \hspace{1cm} (3.26)
\[ \int_{-\infty}^{0} f_i(x, k) \frac{\hbar k}{m_i 2\pi} \, dk = -G_i(x) \] (3.27)

Scattering probability \( B_i \) is assumed to be proportional to the 1-D density of states (DOS) in the final state and is inversely proportional to the square root of the kinetic energy

\[ B_i = B_0 \frac{1}{\sqrt{qE_x + \varepsilon_t}} \] (3.28)

Where, \( B_0 \) is a constant representing the intensity of scattering. Substituting (3.24) (3.25) and (3.28) into (3.23), we obtain a pair of flux equations that characterize the flux distribution, namely, \( F(x) \) and \( G(x) \), in the channel, i.e.,

\[ \frac{2}{\sqrt{m_t}} (qE_x + \varepsilon_t) \frac{dF}{dx} + B_0 \frac{1}{\sqrt{qE_x + \varepsilon_t}} (F - G) = 0 \] (3.29)

\[ -\frac{2}{\sqrt{m_t}} (qE_x + \varepsilon_t) \frac{dG}{dx} + B_0 \frac{1}{\sqrt{qE_x + \varepsilon_t}} (G - F) = 0 \] (3.30)

These equations basically represent the continuity of carrier flow. Notice that the sum of (3.29) and (3.30) yields \( d(F - G)/dx = 0 \). Since \( F - G \) is the net flux in the \( x \)-direction, this relation implies the continuity of the net flux along \( x \).

By a change of variable from \( x \) to \( p \equiv (qE)^{-1} \ln[x + \varepsilon_t/(qE)] \), (3.29) and (3.30) are transformed into a simpler form, i.e.,

\[ \sqrt{\frac{2}{m_t}} \frac{dF}{dp} + B_0 (F - G) = 0 \] (3.31)

\[ -\sqrt{\frac{2}{m_t}} \frac{dG}{dp} + B_0 (G - F) = 0 \] (3.32)

They are easily solved using a boundary condition of \( F(0) = F_0 \) and \( G(x_0) = G_{x_0} \), and we obtain
The transmission coefficient of a carrier from \( x = 0 \) to \( x_0 \) surviving elastic backscattering is

\[
F(x) = \frac{\left[qE + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{qE\epsilon_0 + \epsilon_i}\right)\right] F_0 + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{\epsilon_i}\right) G_{x0}}{qE + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{\epsilon_i}\right)}
\] (3.33)

\[
G(x) = \frac{\left[qE + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{qE\epsilon_0 + \epsilon_i}\right)\right] F_0 + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{\epsilon_i}\right) G_{x0}}{qE + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{\epsilon_i}\right)}
\] (3.34)

Similarly, the transmission coefficient from the source to the drain of a carrier at the incident energy level in consideration of elastic scattering and Optical Phonon (OP) emission is derived as

\[
\Gamma_{i0}(\epsilon_i) = 1 - \frac{G(Q)}{F_0} = \frac{qE(1-R)}{qE + \frac{m_i}{\sqrt{2}B_0} \ln\left(\frac{qE\epsilon_0 + \epsilon_i}{\epsilon_i}\right)(1-R)}
\] (3.36)

Where \( R \) is a Back injection ratio, \( B_0 \) is a constant representing the intensity of scattering, \( D_0 \) is a constant representing optical phonon emission. The flux equation is transformed into a simple form by the change of variable from \( x \) to \( p^* = (qE)^{-\frac{1}{2}} \ln \left[\frac{1}{e} + qE(x - x_0) / \epsilon_i^* \right] \):

\[
\sqrt{\frac{2}{m_i}} \frac{dF}{dp^*} + B_0 (F - G) + 2D_0 F = 0
\] (3.37)

\[
-\sqrt{\frac{2}{m_i}} \frac{dg}{dp^*} + B_0 (G - F) + 2D_0 G = 0
\] (3.38)

The sum and difference of (3.37) and (3.38) yield a pair of equations related to \((F + G)\) and \((F - G)\), which allows a solution exponentially dependent on \( p^* \). We employ an exponentially decaying solution for an increase in \( p^* \), i.e.,

\[
F(x) = F(x_0) \exp\left(-\sqrt{2m_iD_0(B_0 + D_0)} p^* \right)
\] (3.39)

\[
G(x) = \sqrt{\frac{B_0 + D_0 - \sqrt{P_0}}{B_0 + D_0 - \sqrt{P_0}}} F(x_0) \exp\left(-\sqrt{2m_iD_0(B_0 + D_0)} p^* \right)
\] (3.40)
In contrast to the initial elastic zone (IEZ), the net flux \( F - G \) in the incident energy level is no longer conserved but decays in the optical phonon emission zone (OPEZ). The back-injection ratio \( R \) from the zone \( x_0 \leq x \) into the zone \( 0 \leq x \leq x_0 \) due to elastic backscattering within \( x_0 \leq x \) is

\[
R = \frac{G(x_0)}{F(x_0)} = \frac{\sqrt{B_0+D_0} - \sqrt{D_0}}{\sqrt{B_0+D_0} - \sqrt{B_0}}
\]  

(3.41)

Eventually, the transmission coefficient \( \Gamma_i(\varepsilon_i) \) for the \( i \)th subband is summarized as

\[
\Gamma_i(\varepsilon_i) = \frac{2\sqrt{D_0}qE}{\sqrt{(B_0+D_0)qE + \sqrt{2m_iD_0B_0} \ln \left( \frac{\varepsilon_0 + \varepsilon_i}{\varepsilon_i} \right)}} \ , \varepsilon_i \leq \varepsilon^* - qV_D
\]  

(3.42)

\[
\Gamma_i(\varepsilon_i) = \frac{2\sqrt{D_0}qE}{\sqrt{(B_0+D_0)qE + \sqrt{2m_iD_0B_0} \ln \left( \frac{\varepsilon^*}{\varepsilon_i} \right)}} \ , \varepsilon^* - qV_D \leq \varepsilon_i \leq \varepsilon^*
\]  

(3.43)

\[
\Gamma_i(\varepsilon_i) = \frac{qE}{qE + \frac{m_i}{2} (B_0+D_0) \ln \left( \frac{\varepsilon^* + \varepsilon_i}{\varepsilon_i} \right)} \ , \varepsilon^* \leq \varepsilon_i
\]  

(3.44)

Under small drain bias, the kinetic energy at the drain edge is less than constant energy \( (\varepsilon_i < \varepsilon^* - qV_D) \) and it is not defined within the channel. The Inelastic zone is not defined for high-energy carriers with an incident energy \( (\varepsilon_i > \varepsilon^*) \) hence the Drain current \( I_D \) is evaluated by considering transmission coefficient \( \Gamma_i(\varepsilon_i) \) in the limit \( \varepsilon^* - qV_D \leq \varepsilon_i \leq \varepsilon^* \)

\[
\Gamma_i(\varepsilon_i) = \frac{2\sqrt{D_0}qE}{\sqrt{(B_0+D_0)qE + \sqrt{2m_iD_0B_0} \ln \left( \frac{\varepsilon^*}{\varepsilon_i} \right)}} \ , \text{for } \varepsilon^* - qV_D \leq \varepsilon_i \leq \varepsilon^*
\]  

(3.45)
Where $\varepsilon' = 63 \text{ meV}$ for silicon, $B_0$ (is the intensity of elastic scattering) $= 1.54 \times 10^{12} \text{ (eV)}^{1/2} \cdot \text{s}^{-1}$ and $D_0$ (is the intensity of optical phonon emission) $= 1.46 \times 10^{12} \text{ (eV)}^{1/2} \cdot \text{s}^{-1}$.

The value of drain current $I_D$ is obtained by substituting the value of difference in Fermi energy level between source and drain electrode (3.9) and the transmission coefficient $\Gamma_i(\varepsilon_i)$ (3.45) in (3.5):

$$I_D = \frac{q}{\hbar \pi} \sum_i \int_{\varepsilon_i-qV_D}^{e_i} \left\{ \frac{V_D}{K_BT} \left[ 1 - \frac{\mu_{\text{mps}}}{2K_BT} + \frac{\varepsilon_i}{K_BT} \right] \frac{2\sqrt{D_0}qE}{(\sqrt{B_0+D_0}+\sqrt{D_0})qE+2m_iD_0n(\varepsilon_i/\varepsilon_i)} \right\} d\varepsilon_i$$

(3.46)

For arriving at a solution to the above integral, let us consider the following assumption:

$$A = 2\sqrt{D_0}qE$$

(3.47)

$$B = (\sqrt{B_0+D_0}+\sqrt{D_0})qE$$

(3.48)

$$C = \sqrt{2m_iD_0}$$

(3.49)

Simplified drain current taking on the above assumption is given as

$$I_D = \frac{q}{\hbar \pi} \sum_i \int_{\varepsilon_i-qV_D}^{e_i} \left\{ \frac{V_D}{K_BT} \left[ 1 - \frac{\mu_{\text{mps}}}{2K_BT} + \frac{\varepsilon_i}{K_BT} \right] \frac{A}{B+C\ln(\varepsilon_i/\varepsilon_i)} \right\} d\varepsilon_i$$

(3.50)

$$I_D = \frac{q}{\hbar \pi} \sum_i \int_{\varepsilon_i-qV_D}^{e_i} \left\{ \frac{V_D}{K_BT^2} \left[ (qV_D - \frac{qV_Dn_{\text{mps}}}{K_BT^2} + \frac{q^2V_D^2}{2K_BT^2}) \frac{A}{B+C\ln(\varepsilon_i/\varepsilon_i)} \right] d\varepsilon_i + \frac{qV_D}{K_BT^2} \int_{\varepsilon_i-qV_D}^{e_i} A\varepsilon_i/B+C\ln(\varepsilon_i/\varepsilon_i) d\varepsilon_i \right\}$$

(3.51)

Let us consider the change of variable in above equation $x = \frac{\varepsilon'}{\varepsilon_i}$, then differentiating on both sides and simplified we get
\[ dx = -\frac{\varepsilon}{\varepsilon_i} \, d\varepsilon_i \quad (3.52) \]
\[ d\varepsilon_i = -dx \frac{\varepsilon_i^2}{\varepsilon} \quad (3.53) \]

The change of integration limit for the new variable \( x \) is obtained as follows,

**Lower limit:** when \( \varepsilon_i = \varepsilon' = qV_D, \quad x = \frac{\varepsilon'}{\varepsilon' - qV_D} \)

**Upper limit:** when \( \varepsilon_i = \varepsilon', \quad x = 1 \)

Applying this change of variable and limits in the above equation (3.51)

\[
I_D = \frac{a}{\hbar n} \sum_i \left[ - \int_{\varepsilon'/qV_D}^{\varepsilon} \left( \frac{qV_D}{K_B T} - \frac{qV_D \mu_{mps}}{K_B T^2} + \frac{q^2 V_D^2}{2K_B T^2} \right) \frac{A}{x + B + C ln(x)} \, dx \right] \frac{\varepsilon_i^2}{\varepsilon} \quad (3.54)
\]

By carry out changing the limits and we obtain

\[
I_D = \frac{a}{\hbar n} \sum_i \left[ \int_{1}^{\varepsilon'/qV_D} \left( \frac{qV_D}{K_B T} - \frac{qV_D \mu_{mps}}{K_B T^2} + \frac{q^2 V_D^2}{2K_B T^2} \right) \frac{A}{x + B + C ln(x)} \, dx \right] \frac{\varepsilon_i^2}{\varepsilon} + \quad (3.55)
\]

Let us consider the following change of variable for the above integral

\[ u = B + C ln(x) \quad (3.57) \]

Differentiating on both sides and simplifying, we get

\[ du = C \frac{1}{x} \, dx \quad (3.58) \]
The change of integral limit for the new variable \( u \) is obtained as follows

Lower limit: \( h = 1, \int \)

Upper limit: \( h = \ast, \int \)

Applying these change of variable and limits in above \( I_D \) equation and carry out simplification

\[
I_D = \frac{q}{\pi} \sum_i \left[ \left( \frac{qV_D}{K_BT} - \frac{qV_D \mu_n \mu_p S}{K_BT^2} \right) \frac{\epsilon_i^2}{\epsilon^2} \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du + \right]
\]

\[
\left( \frac{qV_D \epsilon_i^3}{K_BT^2} e^\epsilon \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du \right)
\]

\[
= \frac{q}{\pi} \sum_i \left[ \left( \frac{qV_D}{K_BT} - \frac{qV_D \mu_n \mu_p S}{K_BT^2} \right) \frac{\epsilon_i^2}{\epsilon^2} \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du + \right]
\]

\[
\left( \frac{qV_D \epsilon_i^3}{K_BT^2} e^\epsilon \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du \right)
\]

Applying the limits to the above integrated equation

\[
I_D = \frac{q}{\pi} \sum_i \left[ \left( \frac{qV_D}{K_BT} - \frac{qV_D \mu_n \mu_p S}{K_BT^2} \right) \frac{\epsilon_i^2}{\epsilon^2} \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du - \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \ln(B) \right] + \frac{qV_D \epsilon_i^3}{K_BT^2 e^\epsilon} \left[ \int_B^{B+Cln\left(\frac{\epsilon^*}{e^{v_q}}\right)} \frac{Ax}{u} du - \ln(B) \right]
\]

\[
(3.63)
\]
The Final simplified expression for the drain current of our model is obtained by considering

\[
Z = \frac{A}{\varepsilon} \ln \left( \frac{B + C \ln \left[ \frac{\varepsilon^*}{e^* - qV_D} \right]}{B} \right)
\]  

(3.65)

\[
I_D = \frac{q}{\hbar \pi} \sum_i \left[ \left( \frac{qV_D}{k_B T} - \frac{qV_{D\text{lim}ps}}{k_B^2 T^2} + \frac{q^2 V_D^2}{2k_B T} \right) \frac{\varepsilon_i^*}{\varepsilon^* - qV_D} \varepsilon_i^* Z + \frac{qV_D^2}{k_B^2 T^2} \varepsilon_i^2 Z \right]
\]  

(3.66)

Substituting \( x = \frac{\varepsilon_i}{e_i} \) in the above equation:

\[
I_D = \frac{q}{\hbar \pi} \sum_i \left[ \left( \frac{qV_D}{k_B T} - \frac{qV_{D\text{lim}ps}}{k_B^2 T^2} + \frac{q^2 V_D^2}{2k_B T} \right) \varepsilon_i Z + \frac{qV_D^2}{k_B^2 T^2} \varepsilon_i^2 Z \right]
\]  

(3.67)

\[
= \frac{q}{\hbar \pi} \sum_i \frac{qV_D^2}{(k_B T)^2} \left[ \left( k_B T - \frac{\mu_{\text{lim}ps} + \frac{qV_D}{2}}{z} \right) \varepsilon_i + \varepsilon_i^2 \right]
\]  

(3.68)

Substituting the value of Impurity limited scattering mobility (3.3) in (3.68) we get

\[
I_D = \frac{q}{\hbar \pi} \sum_i \frac{qV_D^2}{(k_B T)^2} \left[ \left( k_B T - \frac{1}{en_{\text{lim}ps} n_{\text{lim}ps}^2 R_{\text{lim}} s^{2}} + \frac{qV_D}{2} \right) \varepsilon_i + \varepsilon_i^2 \right]
\]  

(3.69)

Thus the drain current for Impurity Scattering influenced Near Ballistic SiNW MOSFET is obtained from the above equation.

The different analog parameters like transconductance (\( g_m \)), Transconductance Generation Factor (TGF) and Early voltage (\( V_a \)) have derived from the above equation (3.69).
Transconductance of a device is defined as the ratio of the change in drain current to the change in gate voltage. Transconductance is derived by differentiating the drain current in terms of gate overdrive voltage. The Transconductance \( g_m \) is obtained as

\[
g_m = \frac{\partial I_D}{\partial V_g} = \frac{q}{\hbar \pi} \sum_i \frac{qZ_i}{(I_{BT})^2} \left[ \left( K_B T - \frac{1}{en_{imp} n^2 S^2 R_{imp}} + q(V_{G_S} - V_t) \right) \varepsilon_i + \varepsilon_i^2 \right] \tag{3.70}
\]

Ratio between transconductance and current ratio \( (g_m/I_{DS}) \) is known as the Transconductance Generation Factor (TGF), it plays a key role in the design of low-power analog sub threshold applications.

Using Equation (3.70), Transconductance Generation Factor (TGF) can be expressed as

\[
TGF = \frac{q}{\hbar \pi} \sum_i \frac{qZ_i}{I_D(K_BT)^2} \left[ \left( K_B T - \frac{1}{en_{imp} n^2 S^2 R_{imp}} + q(V_{G_S} - V_t) \right) \varepsilon_i + \varepsilon_i^2 \right] \tag{3.71}
\]

Early voltage of a device is defined as the ratio of drain current to the output conductance. Output conductance is obtained by the ratio between the changes in drain current to the change in drain voltage.

\[
\frac{\partial I_D}{\partial V_D} = \frac{q}{\hbar \pi} \sum_i \frac{qZ_i}{(I_{BT})^2} \left[ \left( K_B T - \frac{1}{en_{imp} n^2 S^2 R_{imp}} + qV_D \right) \varepsilon_i + \varepsilon_i^2 \right] \tag{3.72}
\]

Substituting the output conductance and Drain current, the final expression for Early voltage is obtained as

\[
V_a = \frac{q}{\hbar \pi} \sum_i \frac{qZ_i}{(V_{BT})^2} \left[ \left( K_B T - \frac{1}{en_{imp} n^2 S^2 R_{imp}} + qV_D \right) \varepsilon_i + \varepsilon_i^2 \right] \tag{3.73}
\]

Thus the different Analog parameters for Impurity Scattering influenced Near Ballistic SiNW MOSFET are obtained from the above equations.
3.5 RESULTS AND DISCUSSION

The analytical model is simulated with MATLAB and the results are compared with the TCAD simulations results. In order to verify the accuracy of the proposed analytical model, two-dimensional device simulation has been performed using TCAD Sentaurus simulator. Synopsys TCAD offers a comprehensive suite of products that includes industry leading process and device simulation tools, as well as a powerful graphical user interface (GUI)-driven simulation environment for managing simulation tasks and analyzing simulation results. The parameters used in the Simulation of Impurity Scattering influenced Near Ballistic SiNW MOSFET are listed in Table 3.1.

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doping of source</td>
<td>(N_A)</td>
<td>(10^{19}) cm(^{-3})</td>
</tr>
<tr>
<td>Doping of drain</td>
<td>(N_D)</td>
<td>(10^{19}) cm(^{-3})</td>
</tr>
<tr>
<td>Doping of channel</td>
<td>(N_i)</td>
<td>(10^{18}) cm(^{-3})</td>
</tr>
<tr>
<td>Oxide thickness</td>
<td>(t_{OX})</td>
<td>2 nm</td>
</tr>
<tr>
<td>Silicon body thickness</td>
<td>2r</td>
<td>4 nm</td>
</tr>
<tr>
<td>Channel length</td>
<td>L</td>
<td>20 nm</td>
</tr>
<tr>
<td>Channel width</td>
<td>W</td>
<td>9 nm</td>
</tr>
<tr>
<td>Channel height</td>
<td>H</td>
<td>9 nm</td>
</tr>
</tbody>
</table>

Based on the analytical model developed in the previous section, threshold voltage is simulated with MATLAB. The model is validated by commercially available TCAD sentaurus device simulator.

The present work explores the impact of impurity Scattering in supplement with elastic scattering and optical phonon emission. It discusses the detailed behavior of current-voltage characteristics and analog parameters like Transconductance \((g_m)\), Transconductance Generation Factor (TGF), Early voltage \((V_a)\) at room temperature.
3.5.1 Drain Current ($I_D$) Variation

Figure 3.4 $I_D$–$V_D$ characteristics of near ballistic SiNW MOSFET with impurity scattering for various gate overdrive voltages

Figure 3.4 shows the modeled and simulated values of Drain current - Drain to source voltage ($I_D$–$V_{DS}$) characteristics of impurity scattered Near Ballistic SiNW MOSFET at various gate over drives. There is a gradual increase in the drain current when gate over drive voltage increases because number of electrons in the channel increased. These results have been compared with the simulated results obtained from the TCAD simulation software, and a good agreement is achieved.

3.5.2 Comparison with Quasi Ballistic Model

Figure 3.5 demonstrate the impact of Impurity scattering in Near Ballistic SiNW MOSFET and the Drain current values are compared with (Natori’s 2012) Quasi Ballistic SiNW MOSFET. The comparison of drain current versus the biasing voltage for various gate over drive voltages is plotted here. The magnitude of the Near ballistic current is decreased because the current is endorsed to an increase in the access resistance ($R_{imp}$).
Figure 3.5  I_D–V_D characteristics of Near Ballistic SiNW MOSFET with Impurity Scattering is compared with Quasi ballistic model for various Gate overdrive voltages

From the results it is clearly seen that the calculated values of the analytical model tracks the simulated values very well.

3.5.3  Mobility (μ_imp) Variation

Figure 3.6  Electron mobility comparison of impurity scattering influenced near ballistic SiNW MOSFET with quasi ballistic model for various effective field
Mobility Variation of Near ballistic SiNW MOSFET with Discrete Random dopants against Electric field has been evaluated and compared with Quasi ballistic model by Natori 2012 as shown in Figure 3.6. The plot shows that value of the mobility depends on impurity scattering, this act to decrease the field mobility of our proposed model. The high electric field behavior shows that the carrier mobility declines with electric field because, as the carrier gains energy from electric field, it can take part in a wider range of scattering processes.

3.5.4 **Comparison with Quasi Ballistic and Ballistic Model**

Figure 3.7 compares the $I_D$–$V_D$ characteristics of Near Ballistic SiNW MOSFET with Impurity Scattering with (Natori’s 2012) Quasi Ballistic SiNW MOSFET model and (Natori’s 2008) Ballistic SiNW MOSFET model at Gate overdrive voltages $V_{gs}$–$V_t$ =0.1V and 0.3V. Drain current saturates in Ballistic model but it increases gradually in our proposed model.

![Figure 3.7 I_D–V_D characteristics of near ballistic SiNW MOSFET with impurity scattering is compared with quasi ballistic and ballistic model for various gate overdrive voltages](image-url)
This is because as the applied gate over drive increases, the width of In Elastic Zone (IEZ) decreases and the backscattered flux within the zone gradually decreases, resulting in increase of Drain current.

Drain current for Ballistic, Quasi-Ballistic and Near Ballistic with Discrete Random dopants for various gate over drive voltages and their respective Ballisticity are tabulated in Table 3.2.

The effect of carrier scattering in the device is defined by ballisticity. Ballisticity of the device is defined as the current ratio in an identical bias condition. Ballisticity of impurity scattered SiNW MOSFET is the ratio between Drain current of Near Ballistic SiNW MOSFET with impurity scattering and Drain current Ballistic SiNW MOSFET.

**Table 3.2 Comparison of drain current at drain voltage=0.5V**

<table>
<thead>
<tr>
<th>Gate Overdrive (V)</th>
<th>Ballistic (µA)</th>
<th>Quasi Ballistic (µA)</th>
<th>Near ballistic with impurity scattering (µA)</th>
<th>Ballisticity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>4.38</td>
<td>3.01</td>
<td>2.78</td>
<td>63.29</td>
</tr>
<tr>
<td>0.2</td>
<td>7.14</td>
<td>4.88</td>
<td>4.48</td>
<td>62.81</td>
</tr>
<tr>
<td>0.3</td>
<td>10.74</td>
<td>7.27</td>
<td>6.68</td>
<td>62.22</td>
</tr>
<tr>
<td>0.4</td>
<td>14.76</td>
<td>9.93</td>
<td>9.13</td>
<td>61.84</td>
</tr>
<tr>
<td>0.5</td>
<td>19.28</td>
<td>12.95</td>
<td>11.90</td>
<td>61.72</td>
</tr>
</tbody>
</table>

3.5.5 Comparison with Numerical simulation

Figure 3.8 shows the modeled and simulated values of \( I_{D}V_{DS} \) characteristics of impurity scattered Near Ballistic SiNW MOSFET with gate over drive voltages 0.2V and 0.3V, which is compared with Numerical simulation discussed by (Jin et al 2008).
Figure 3.8  $I_D-V_D$ characteristics of near ballistic SiNW MOSFET with impurity scattering is compared with analytical model discussed by Jin et al for various gate overdrive voltages. The agreement is satisfactory because Numerical simulation (Jin et al 2008) has the ballisticity of 63.5% at a Gate overdrive of 0.2V when compared with 62.81% in our proposed model as shown in Table 3.2. Analytical results are in excellent agreement with TCAD simulation results.

3.5.6 Transconductance ($g_m$) Variation

Figure 3.9 shows the Transconductance against gate overdrive of Near Ballistic SiNW MOSFET with Discrete Random dopants compared with (Natori’s 2012) Quasi Ballistic SiNW MOSFET model and (Natori’s 2008) Ballistic SiNW MOSFET model. Transconductance has been extracted from the linear region of $I_D-V_G$. The transconductance of Near ballistic with Dopants SiNW MOSFET device is degrading severely as the gate voltage increases due to the considerable reduction of the mobility along the channel.
Figure 3.9 Transconductance against gate to source voltage of near ballistic SiNW MOSFET with impurity scattering is compared with quasi-ballistic and ballistic model.

The model predictions correlate well with the simulation results proving the accuracy of our proposed analytical model.

3.5.7 Transconductance Geneation Factor ($g_m/I_{DS}$) Variation

Transconductance Generation Factor (TGF) versus gate overdrive of impurity scattered Near Ballistic SiNW MOSFET compared with (Natori’s 2012) Quasi Ballistic SiNW MOSFET model and (Natori’s 2008) Ballistic SiNW MOSFET model at a drain voltage of $V_{DS}=2V$. Transconductance Generation Factor (TGF) of Impurity scattered SiNW MOSFET model degrades severely with the increase in gate voltage as shown in Figure 3.10. Impurity scattering effect contributes considerable reduction of the mobility along the channel which reduces the Transconductance Generation Factor.
Figure 3.10 Transconductance generation factor against gate to source voltage of near ballistic SiNW MOSFET with impurity scattering is compared with quasi-ballistic and ballistic model at a drain voltage of $V_{DS} = 2V$

3.5.8 Early Voltage ($V_a$) Variation

Figure 3.11 Early voltage ($V_a$) against gate to source voltage ($V_{GS}$) of near ballistic SiNW MOSFET with impurity scattering is compared with quasi-ballistic and ballistic model at a drain voltage of $V_{DS} = 2V$
Early Voltage versus Gate to source voltage of impurity scattered Near Ballistic SiNW MOSFET has been plotted in Figure 3.1. It also compared with (Natori’s 2012) Quasi Ballistic SiNW MOSFET model and (Natori’s 2008) Ballistic SiNW MOSFET model at a drain voltage of $V_{DS}=2V$. Ratio between Drain current and Output conductance ratio ($I_{DS}/g_{ds}$) is known as the Early Voltage ($V_a$). Early Voltage degrades gradually with the increase in gate voltage. It satisfies the agreement that Early Voltage is directionally proportional to Drain current.

3.6 SUMMARY

The I–V characteristics of a Near Ballistic SiNW MOSFET with Impurity scattering have been proposed. An analytical expression had been derived for Drain current which mainly depends on drain bias, combined scattered mobility and carrier energy. The value of mobility altered by impurity scattering and elastic scattering, optical phonon emission affects Carrier energy both of these effects reduce the drain current. The value of mobility for this device mainly depends upon impurity scattering which decrease the field mobility. Proposed Near Ballistic SiNW MOSFET with impurity scattering makes a steady increase in drain current with lower magnitude when compared with Quasi Ballistic device. Transconductance have been extracted from $I_D–V_D$ relation which satisfies the agreement of transconductance. Analog performance of Near Ballistic SiNW MOSFET with dopants is compared with other SiNW MOSFET devices. An Excellent agreement between the modelled and TCAD simulated data was achieved for all the device parameters, Hence our proposed approach is appropriate for the modeling of Near Ballistic SiNW MOSFET in the presence impurity scattering.