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Scale Length Determination of Gate All Around (Regular Hexagonal Cross Section) Junctionless Transistor

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Abstract:

This paper presents scale length determination of Gate all around (Regular Hexagonal cross section) Junctionless Transistor. The scale length expression is obtained by solving the 3D Poisson's equation. Variation of scale length with gate oxide thickness, side length of the hexagon and dielectric constant are shown. The Transverse and central electrostatic potential profiles are also shown for different values of gate oxide thickness, side length of the hexagon, channel length, drain voltage, and gate voltage. Longitudinal electric field profile for different value of drain voltage is also shown. The scale length value decreases with decreasing gate oxide thickness and side length of the hexagon and increasing dielectric constant.

Key Words: Hexagonal Cross Section, Junctionless Transistor, Poisson's Equation, Scale Length

I. INTRODUCTION

In the last few decades, tremendous advancements in the field of VLSI design increased the need of ultra miniaturization of devices that in turn increased the need of alternative to conventional MOSFETs. As a result, new devices and device structures are being investigated. Out of which Junction less transistor (JLT) is a device showing great potential in the field of VLSI design. The theory of JLT is reported in [1]-[4]. In this paper, we are investigating Gate all around (regular hexagonal cross section) fully depleted JLT. Hexagonal structure has the advantages of having a very high packing density and a comparatively lower corner effect than the square and triangular structures. In the investigation of a device for miniaturization, one of the most important parameters is scale length. The scale length expression for the device is obtained by solving the Poisson's equation for transverse electrostatic potential. The scale length is the length of the portion of the channel that is under the control of drain [5]. The channel length of the device should be 5-10 times of the scale length to avoid short channel effect [5].

II. SCALE LENGTH DETERMINATION

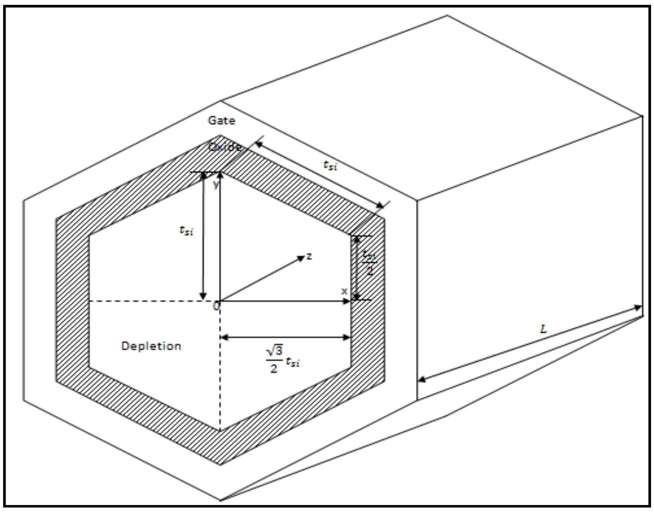

Fig1: Hexagonal JLT

The 2 D Poisson's equation for JLT can be written as [5],

$$\frac{d^2\phi(x,y,z)}{dx^2} + \frac{d^2\phi(x,y,z)}{dy^2} + \frac{d^2\phi(x,y,z)}{dz^2} = \frac{qNa}{\epsilon_{Si}} \qquad (1)$$

One solution of Poisson's equation can be assumed as [5],

$$\phi(x, y, z) = C_0(z) + C_1(z)x + C_2(z)y + C_3(z)x^2 + C_4(z)y^2 \qquad (2)$$

For Full Depletion,

At x=0, y=0,

$$\phi(x, y, z) = C_0(z) = \phi_0(z)$$

At x=0, y=0,

$$\frac{d\phi(x,y,z)}{dx} = \frac{d\phi(x,y,z)}{dy} = C_1(z) = C_2(z) = 0$$

At x=$\frac{\sqrt{3}}{2}t_{si}$, y=0,

$$\frac{d\phi(x,y,z)}{dx} = \sqrt{3}t_{si}C_3(z) = \frac{\epsilon_{ox}}{\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)$$

Or $C_3(z) = \frac{\epsilon_{ox}}{\sqrt{3}t_{si}\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)$

At x=0, y=t_{si},

$$\frac{d\phi(x,y,z)}{dy} = 2t_{si}C_4(z) = \frac{\epsilon_{ox}}{\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)$$

Or $C_4(z) = \frac{\epsilon_{ox}}{2t_{si}\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)$

Therefore,

$$\phi(x,y,z) = \phi_0(z) + \frac{\epsilon_{ox}}{\sqrt{3}t_{si}\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)x^2 + \frac{\epsilon_{ox}}{2t_{si}\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)y^2 \quad (3)$$

At x=0, y=t_{si} , $\phi(x,y,z) = \phi_s = \phi_0(z) + \frac{\epsilon_{ox}}{2t_{si}\epsilon_{Si}t_{ox}}\left(\phi_{gs} - \phi_s\right)(t_{si})^2$

Or $\phi_s(1 + \frac{\epsilon_{ox}t_{si}}{2t_{ox}\epsilon_{Si}}) = \phi_0(z) + \frac{\epsilon_{ox}t_{si}}{2t_{ox}\epsilon_{Si}}\phi_{gs}$

$$\phi_s = \phi_0(z)\frac{2t_{ox}\epsilon_{Si}}{2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox}} + \frac{\epsilon_{ox}t_{si}}{2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox}}\phi_{gs} \quad (4)$$

Putting $\phi_s$from (4) in (3),

$$\phi(x,y,z) = \phi_0(z) + \frac{2\epsilon_{ox}}{\sqrt{3}t_{si}(2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox})}\left(\phi_{gs} - \phi_0(z)\right)x^2 + \frac{\epsilon_{ox}}{t_{si}(2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox})}\left(\phi_{gs} - \phi_0(z)\right)y^2 \quad (5)$$

Putting $\phi(x,y)$from (5) in (1) and y=0,

$$\frac{d^2\phi_0(z)}{dz^2} + \frac{4\epsilon_{ox}}{\sqrt{3}t_{si}(2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox})}\left(\phi_{gs} - \phi_0(z)\right) + \frac{2\epsilon_{ox}}{t_{si}(2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox})}\left(\phi_{gs} - \phi_0(z)\right) = \frac{qNa}{\epsilon_{Si}}$$

$$\frac{d^2\phi_0(z)}{dz^2} + \frac{(4+2\sqrt{3})\,\epsilon_{ox}}{\sqrt{3}t_{si}(2t_{ox}\,\epsilon_{Si}\,+t_{si}\,\epsilon_{ox})}\left(\phi_{gs} - \phi_0(z)\right) = \frac{qNa}{\epsilon_{Si}}$$

Or $\frac{d^2\phi_0(x)}{dx^2} + \frac{1}{\lambda^2}\left(\phi_{gs} - \phi_0(x)\right) = \frac{qNa}{\epsilon_{Si}}$ (6)

Where,

$\lambda = \sqrt{\frac{\sqrt{3}t_{si}(2t_{ox}\epsilon_{Si}+t_{si}\epsilon_{ox})}{(4+2\sqrt{3})\epsilon_{ox}}}$ is the scale length of the device .

By solving (6), central potential can be obtained as [6]

$$\phi_0(x) = \frac{\left(Vds + (\frac{qNa}{\epsilon_{Si}} - \frac{1}{\lambda^2}\phi_{gs})\lambda^2\right) e^{\frac{L}{\lambda}} - (\frac{qNa}{\epsilon_{Si}} - \frac{1}{\lambda^2}\phi_{gs})\lambda^2}{(e^{2\frac{L}{\lambda}} - 1)} e^{\frac{x}{\lambda}} - \frac{\left(Vds + (\frac{qNa}{\epsilon_{Si}} - \frac{1}{\lambda^2}\phi_{gs})\lambda^2\right) e^{\frac{L}{\lambda}} - (\frac{qNa}{\epsilon_{Si}} - \frac{1}{\lambda^2}\phi_{gs})\lambda^2 e^{2\frac{L}{\lambda}}}{(e^{2\frac{L}{\lambda}} - 1)} e^{-\frac{x}{\lambda}} - (\frac{qNa}{\epsilon_{Si}} - \frac{1}{\lambda^2}\phi_{gs})\lambda^2$$

III. RESULTS AND DISCUSSION

The variation of scale length with gate oxide thickness, side length of the hexagon and dielectric constant of gate dielectric is shown in fig2, fig3 and fig4 respectively. If side length decreases then channel thickness decreases which in turn decreases the values of scale length. Thus to design a shorter channel device the side length should be shortened. In fig3 it can be seen that to reduce channel length the gate oxide thickness also to be decreased. Use of high K dielectric can also minimize the channel length as shown in fig4. The variation of scale length with dielectric constant is nonlinear.

The central electrostatic potential profile for different values of channel Length, drain voltage, gate oxide thickness, side length and gate voltage are shown in fig5-fig9. The potential along channel length at the centre of mass of the hexagon which is equidistant from the midpoint of all the sides is plotted with position from source to drain. In the source end the potential is zero which decreases initially and then increases and become equals to drain voltage at the drain end of the channel. The longitudinal electric field variation with channel position in fig10. The transverse potential profile for different values of drain voltage, gate oxide thickness, channel length and gate voltage are shown in fig11-fig14. The electrostatic potential with respect to y-axis position starting from one vertex to the opposite vertex is plotted. In the full depletion band bending occurs throughout the thickness.

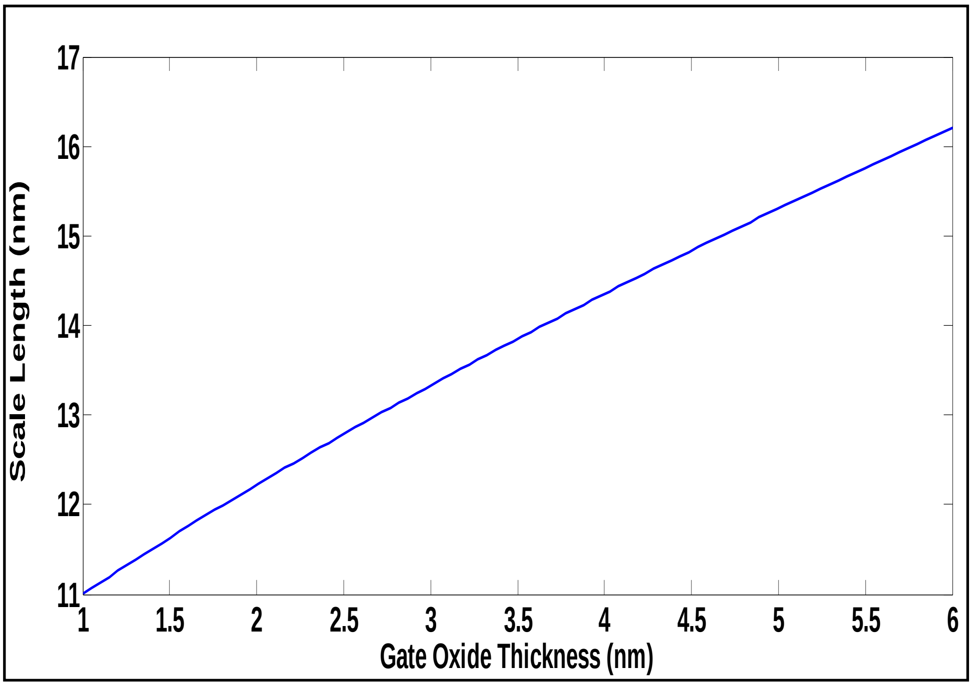

Fig2: Scale length variation with Gate oxide thickness

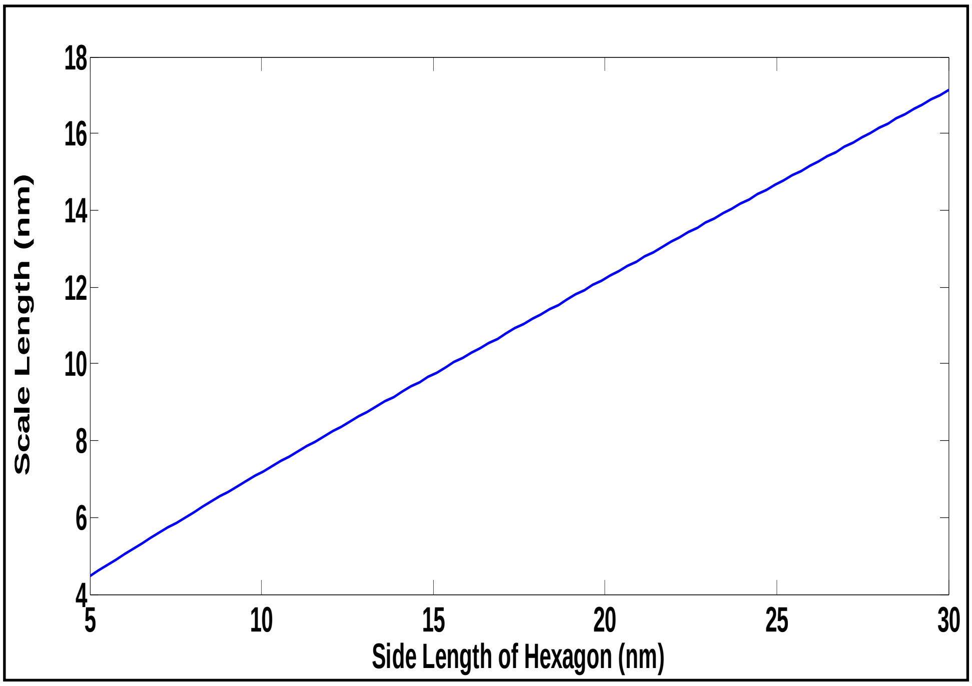

Fig3: Scale length variation with side length of the hexagon

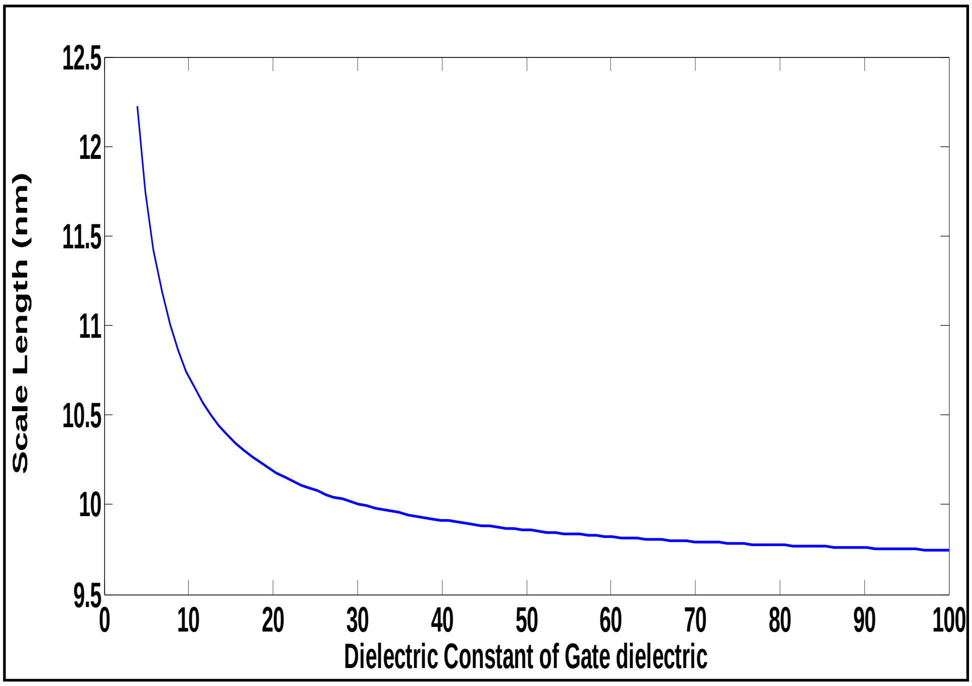

Fig4: Scale length variation with Dielectric Constant

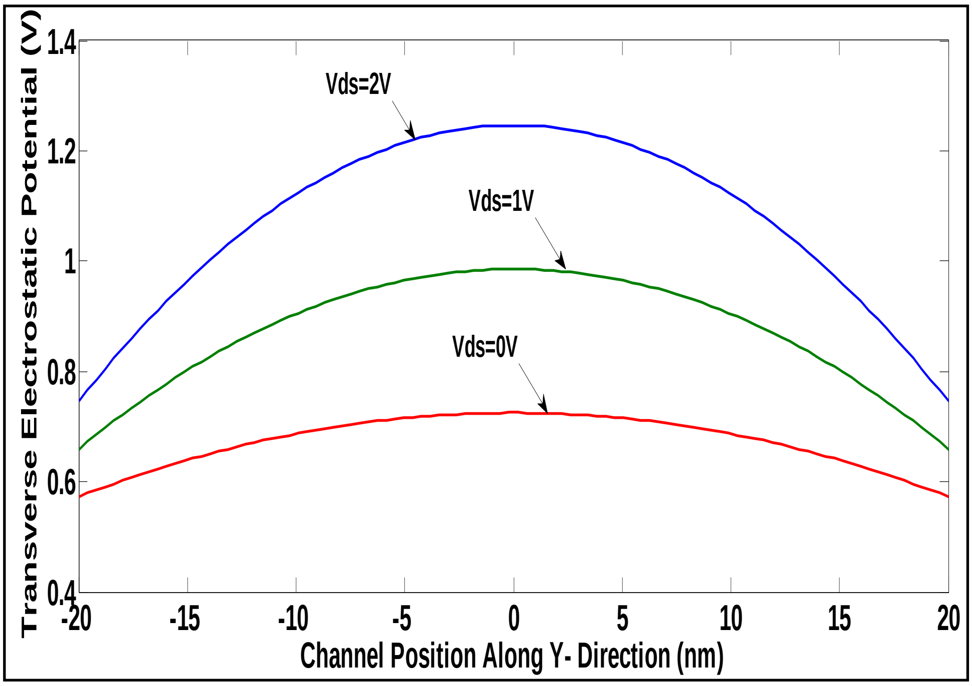

Fig5: Central potential variation of GAA (hexagonal cross-section) JLT for different value of Channel Length with tsi=20nm, tox=2nm, Vgs=0V, Vds=0V Gate oxide SiO2.

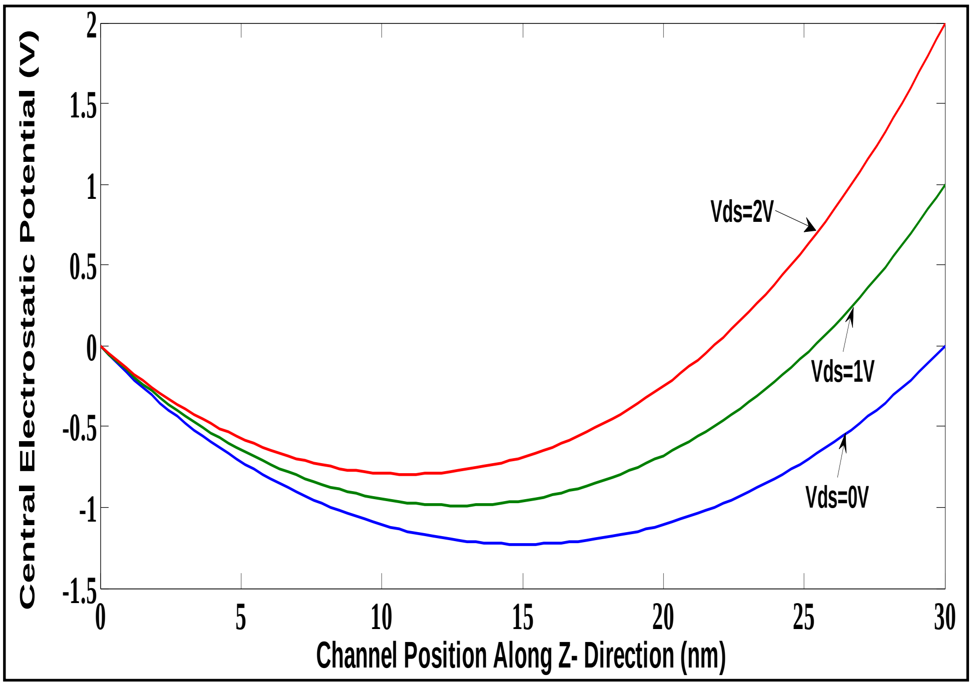

Fig6: Central potential variation of GAA (hexagonal cross-section) JLT for different value of Vds with tsi=20nm, tox=2nm, Vgs=0V, Gate oxide SiO2.

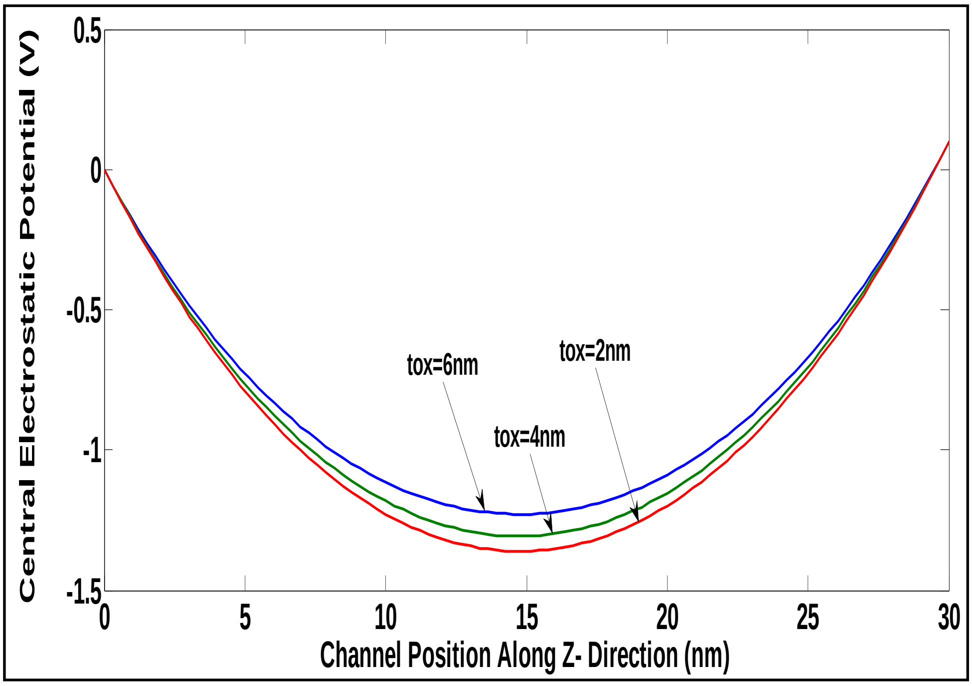

Fig7: Central potential variation of GAA (hexagonal cross-section) JLT for different value of gate oxide thickness with tsi=20nm, Vgs=0V, Vds=0.1V Gate oxide SiO2.

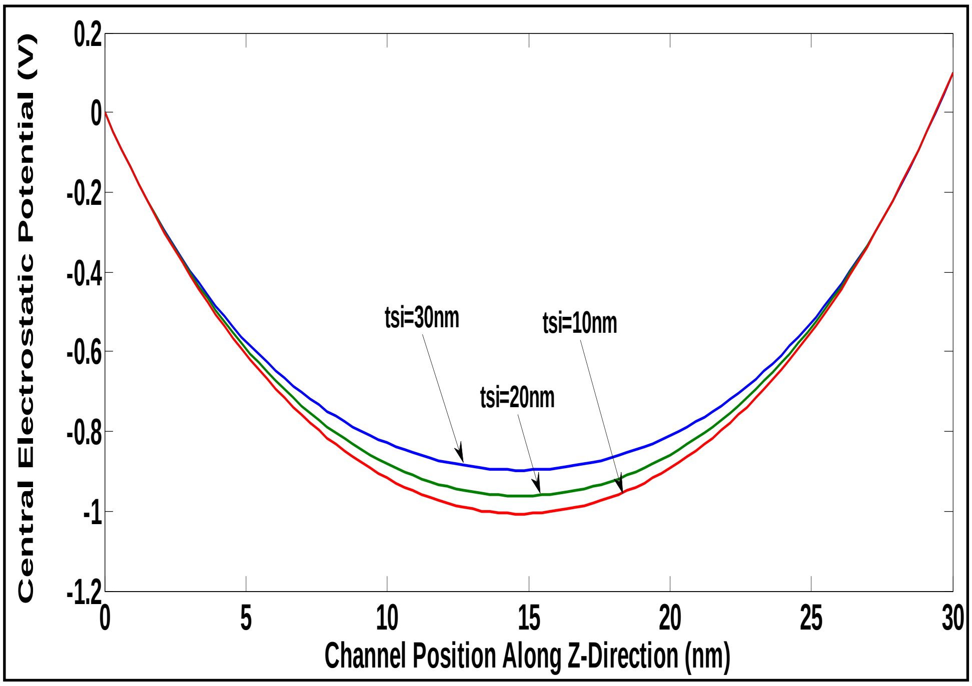

Fig8: Central potential variation of GAA (hexagonal cross-section) JLT for different value of channel thickness tox=2nm, L=30nm, Vgs=0V, Vds=0.1V Gate oxide SiO2.

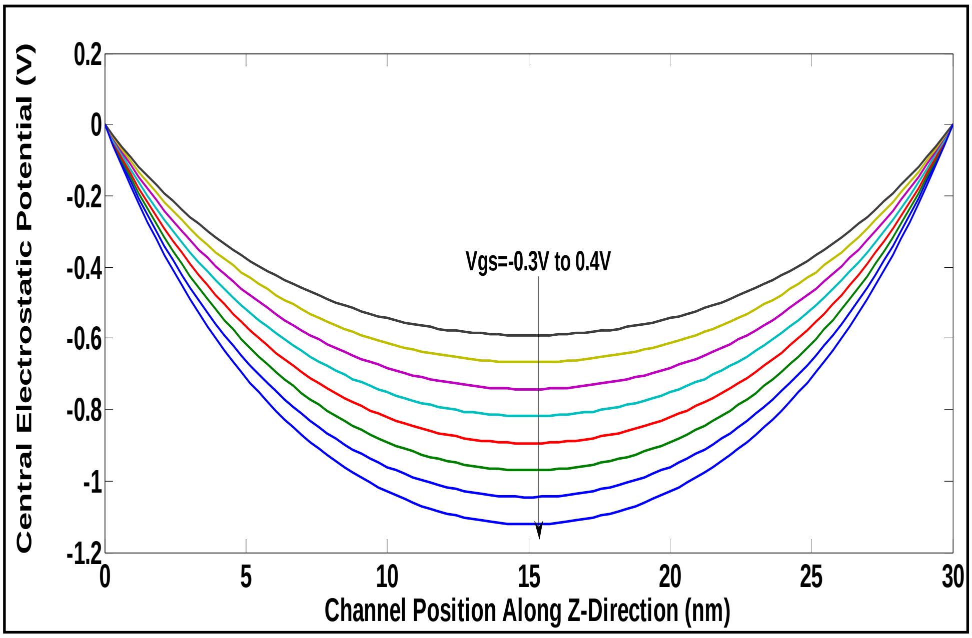

Fig10: Central Potential variation of GAA (hexagonal cross-section) JLT for Vgs = −0.3 V to 0.4 V, stepping 0.1V with tsi=20nm, tox=2nm, L=30nm, Vds=0V, Gate oxide SiO2.

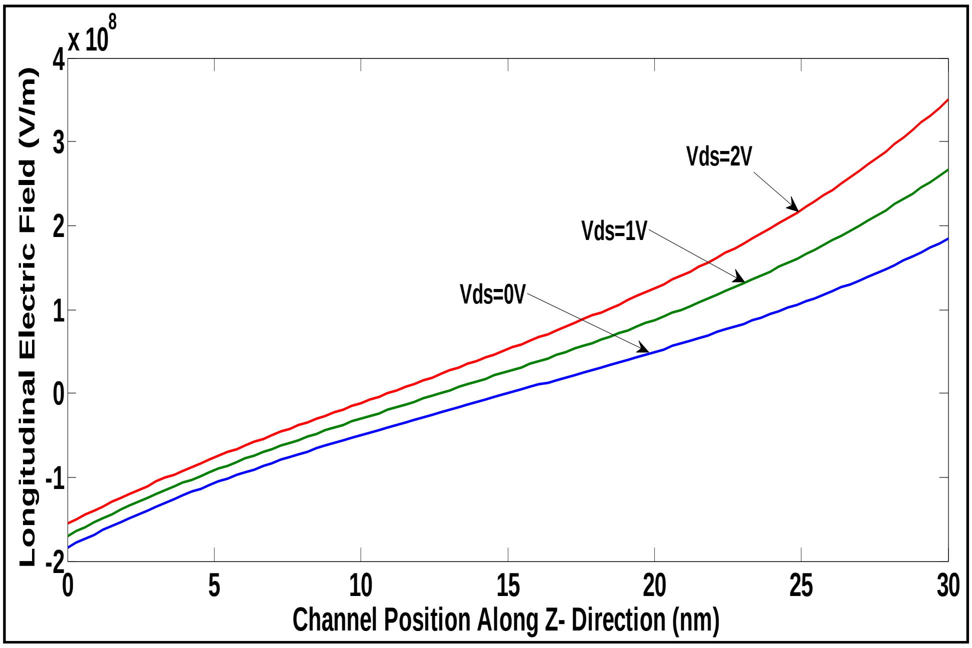

Fig9: Longitudinal electric field variation of GAA (hexagonal cross-section) JLT for different value of Vds with tsi=20nm, tox=2nm, L=30nm, Vgs=0V, Gate oxide SiO2.

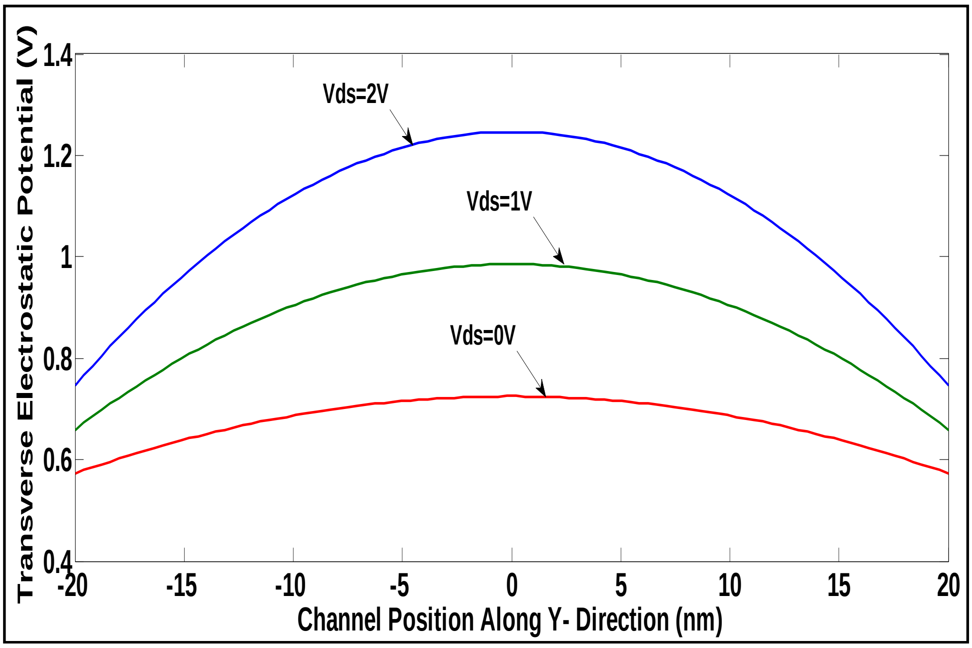

Fig11: Transverse potential variation of GAA (hexagonal cross-section) JLT for different value of Vds with tsi=20nm, tox=2nm, L=30nm, Vgs=0V, Gate oxide SiO2.

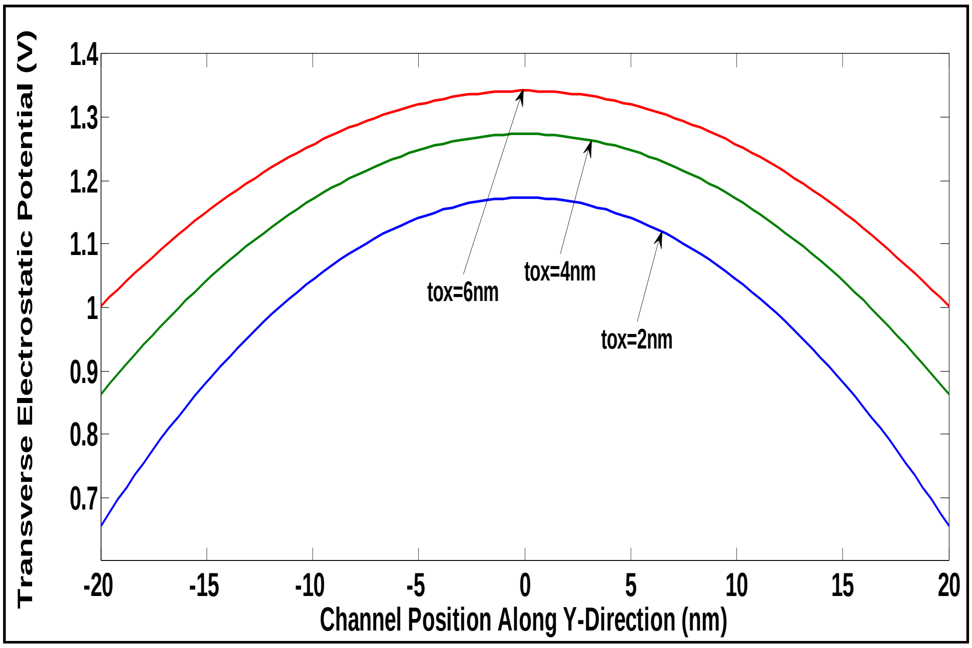

Fig12: Transverse potential variation of GAA (hexagonal cross-section) JLT for different value of Gate Oxide Thickness with tsi=20nm, L=30nm, Vgs=0V, Vds=0V, Gate oxide SiO2.

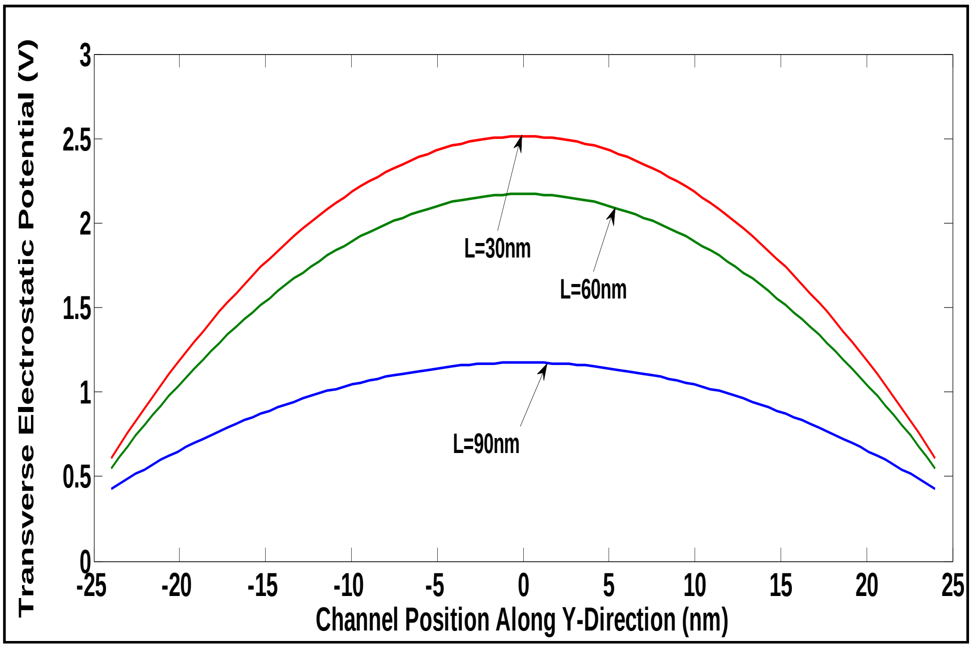

Fig13: Transverse potential variation of GAA (hexagonal cross-section) JLT for different value of Channel length with tsi=20nm, tox=2nm, Vgs=0V, Vds=0V Gate oxide SiO2.

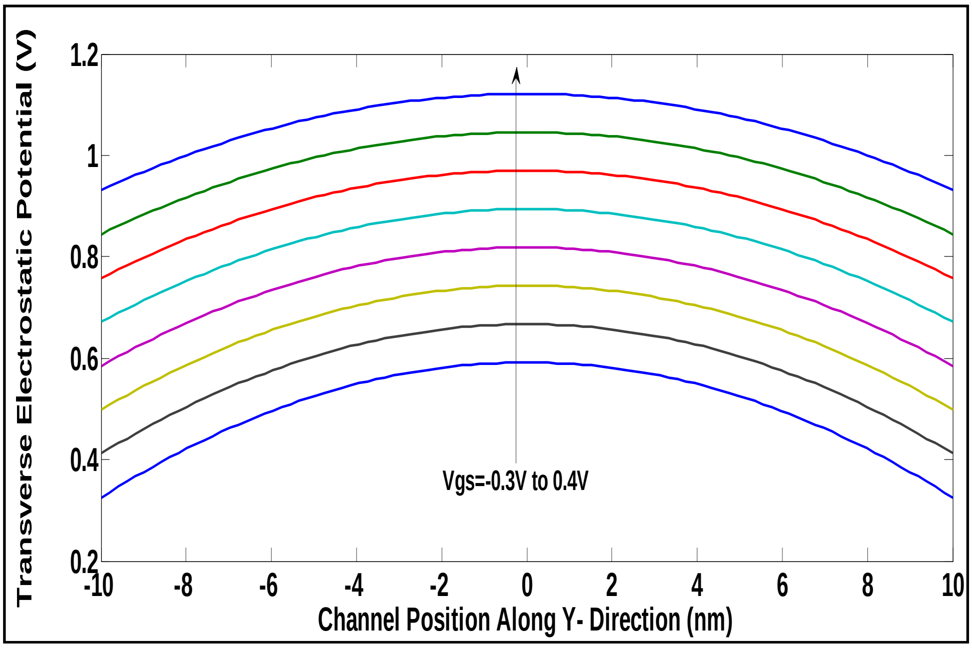

Fig14: Transverse Potential variation of GAA (hexagonal cross-section) JLT for Vgs = −0.3 V to 0.4 V, stepping 0.1V with tsi=20nm, tox=2nm, L=30nm, Vds=0V Gate oxide SiO2.

IV. CONCLUSION

The scale length expression for the GAA (regular hexagonal cross section) fully depleted JLT is obtained. Variation of scale length with gate oxide thickness, side length of the hexagon and dielectric constant are shown. The Transverse electrostatic potential profile is also shown for different values of gate oxide thickness, channel length and drain voltage and gate voltage. The central electrostatic potential profile for different values of gate oxide thickness, side length of the hexagon, Channel length, Drain voltage, gate voltage, is also shown. Longitudinal electric field profile for different value of drain voltage is also shown. It is seen that the scale length for the device decreases with decreasing side length and gate oxide thickness and increasing dielectric constant.

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