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Effect of Channel Doping Concentration on the Impact ionization of n-Channel Fully Depleted SOI MOSFET

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***Abstract*— Impact ionization in fully depleted (FD) Silicon On Insulator (SOI) n-Channel MOSFET is investigated as a function of the doping concentration. We have found that impact ionization increases with the decrease in the doping concentration and vice versa. Simulation results obtained from Sentaurus TCAD with the higher doping concentration can control the threshold voltage (V_{th}). Furthermore we have examined the effect of doping concentration on the transconductance (g_m) and have observed that transconductance is inversely proportional of the doping concentration.

***Keywords*— Impact ionization, channel doping concentration, threshold voltage, transconductance

I. INTRODUCTION

The FD SOI MOSFET is very well known for its better subthreshold slope along with small parasitic capacitance. FD SOI devices with thin Silicon film thickness and high doping density holds the better subthreshold slope due to the high doping concentration in channel region. When a high electric field is applied then carriers come closer to the surface. This facilitate the gate to control the carriers which results in a improvement of subthreshold slope [1], [2]. FD SOI MOSFET switches signal faster at very low operating voltage and contain high speed also, there is a reduction in short channel effects and negligible drain to substrate capacitance [3]. In electronic devices impact ionization plays an important role to enhance the drain current. When high energy electrons collide with the lattice atoms then a large number of electron-hole pairs generated. This phenomenon is referred to the impact ionization. The electric fields which required to produce the impact ionization phenomenon depends on the band-gap of the material. It ranges from 104 Vcm-1 for low band-gap material to 105 Vcm-1 for the wide band-gap material. Impact ionization is the function of doping concentration, when the doping concentration becomes lower and decreases when doping concentration is high. R. Rao et al [4] reported that threshold voltage depends on the doping concentration.

Increasing doping concentration threshold voltage also increases. Therefore we can better control the threshold voltage by varying the doping concentration of the channel. In our present work, we have examined the effect of doping concentration which plays a very important role in the impact ionization. Impact ionization of the n-channel FD SOI MOSFET for different concentration has been investigated at different operating temperature. The paper has organized in the following Sections. Section II is based on device structure with proper dimension of the device . Section III explains the effect of doping on the device electrical behaviour and in Section IV we have concluded our results.

II. STIMULATED STRUCTURE

Figure 1 shows a schematic cross sectional view of the n-Channel FD SOI MOSFET along with the doping profile

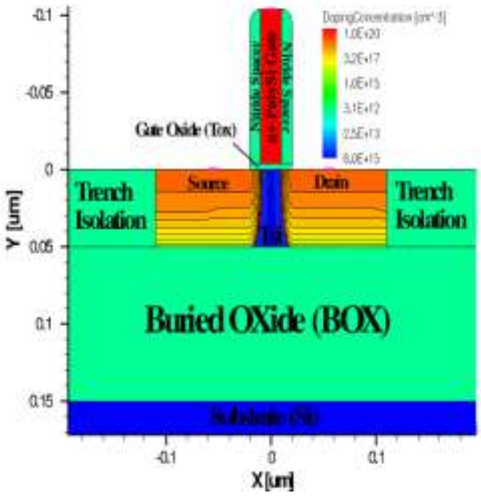

Figure 1. A cross-section view of the n-Channel FD SOI MOSFET.

parameter because due to scaling the short channel effect reduces [2]. The main advantages of the SOI MOSFET are containing the improved isolation, reduced drain to source capacitance, low operating voltage and faster switching signals [3].Many authors reported the effects of temperature on the SOI For designing the device, we used sentaurus

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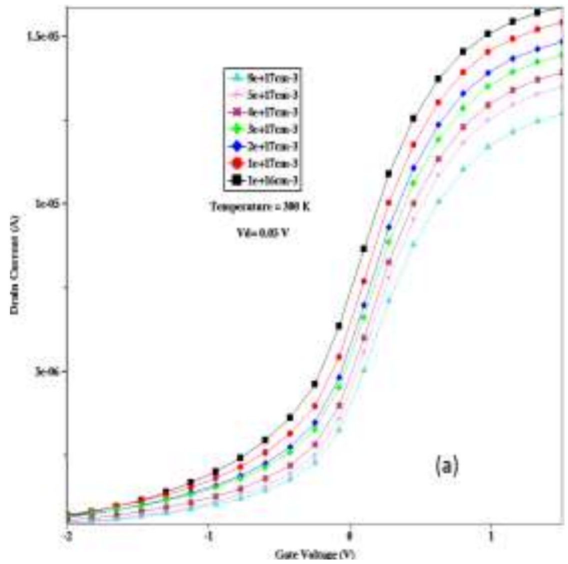
structure editor for the simulation of the proposed device structure. To design a device the important feature to keep in the mind are high saturation current and low on resistance. The n-Channel FD SOI-MOSFET with t_{Si} = 50 nm has selected as shown in Figure 1. Gate oxide thickness (t_{ox}) and buried oxide (BOX) thickness is 5 nm and 100 nm. The doping concentration in the substrate under the BOX (N_{sub}) is $1x10^{15}$ cm^{-3}. We take the doping concentration of drain/source is 1×10^{18} cm^{-3} and of Poly-silicon gate is 1×10^{19} cm^{-3}. The gate length, height and doping concentration is selected to be 20 nm ,100 nm and 1×10^{20} cm^{-3}. The channel doping is varying from 1×10^{16} cm^{-3} to 8×10^{17} cm^{-3}.

III. Results And Discussion

Figure 2 reveals the I_d-V_g characteristics curves for linear region with different channel doping concentrations at temperature of 300 and 600 K [5]. By increasing the gate voltage from -2 V the drain current does not rise so abruptly. As, the gate voltage increases from - 0.47346 V for the channel



doping concentration for 1×1016 cm-3 then there is sharp increase in the drain current was observed. Further increase in gate voltage, drain current comes into the saturation region. At 300 K , minimum numbers of electron-hole pairs are produced due to the small number of collision which is only governed by the low drain voltage. Therefore at lower voltage the drain current has a maximum value. At higher temperature minimum drain current was observed due to large number of collisions as shown in figure 2.

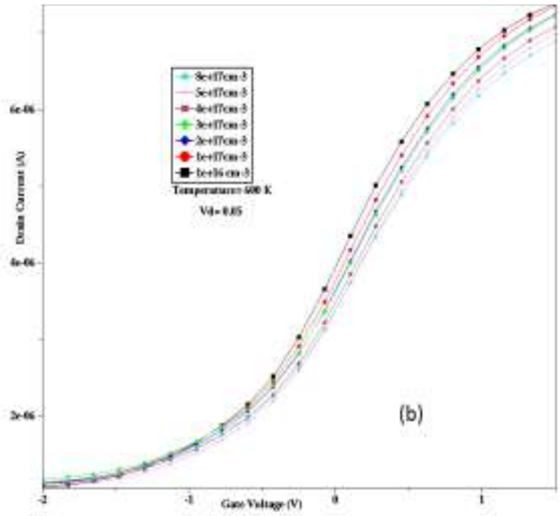


Figure 2. Simulated Id-Vg characteristics with different doping concentrations at (a) 300 K (b) 600 K

Figure 3 shows the I_d-V_d curves for n-Channel FD SOI MOSFET for different doping concentrations for higher operating voltage. The drain current rises swiftly at lower concentration as shown in output characteristics curve for gate voltage of 2 V. For low doping concentration, the impact ionization in the device is higher than heavy concentration in the channel region. For low doping concentration, the number of collisions to loss the energy will less which increase the mobility of electrons in the device. So, the drain current rises sharply and leads the impact ionization phenomenon in the output characteristics curves as shown in figure 3(a) and 3(b). Temperature also plays a vital role in the device output characteristics curves. As the temperature rises then the number of collisions increases which degrade the mobility due to which drain current decreases with increase in the temperature as shown in the figure 3(a) and 3(b).

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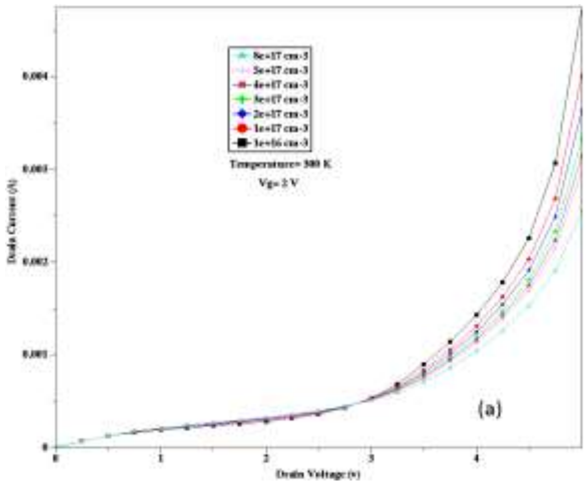

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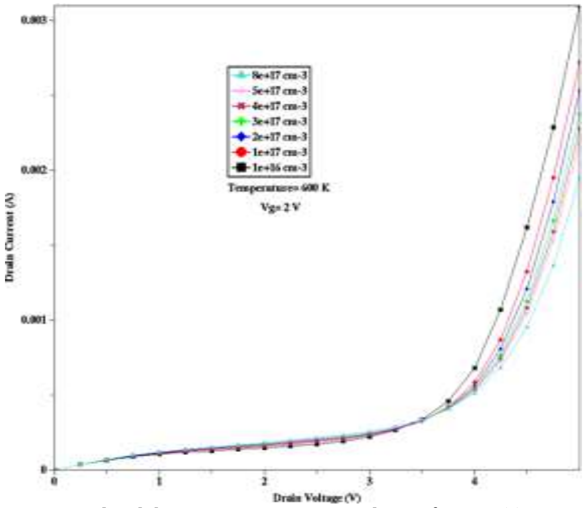

Figure 3. Simulated the I_d-V_d curves at gate voltage of 2 V at (a) 300 K (b) 600 K

Threshold voltage (V_{th}) variation is also a function of channel doping concentration as shown in figure 4. Threshold voltage increases with increasing the doping concentration in the channel. The reason is that when we increase the channel doping concentration then Fermi potential increases. Depletion charge also increases with increasing the doping concentration. So, the device requires more effort to deplete the whole channel [7]. At lower operating voltage, There is a slightly increase in the threshold voltage as shown in figure 4(a). Threshold voltage increases reasonably with increasing the channel doping concentration as shown in figure 4(b). The reason is that at higher operating voltage, carriers having high energy to cross the Fermi potential as compared to low operating voltage.

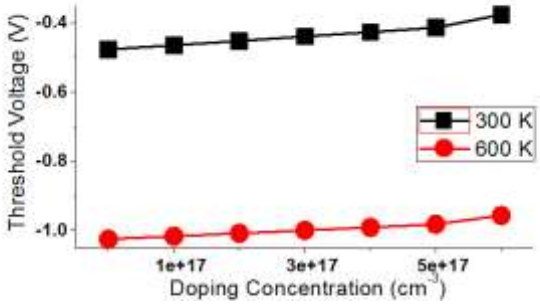

Figure 4(a). V_{th} variation at different doping concentrations at fixed V_d(Drain Voltage) =0.05 V

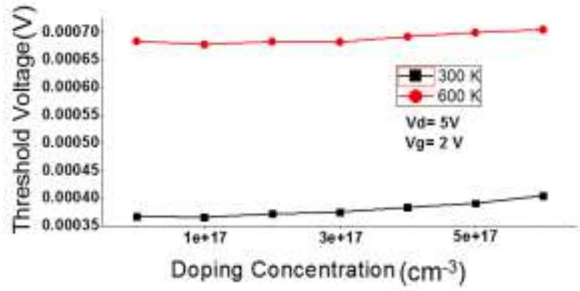

Figure 4(b): threshold variation at different doping concentrations at fixed V_d(Drain Voltage)= 5 V

Figure 5 shows the effect of the doping concentration on the transconductance for different operating voltage. At low operating voltage transconductance slightly decreases with the increase in the doping concentration [8] as shown in figure 5(a). Transconductance increases quite fairly at higher operating voltage with increasing the channel doping concentrations. The reason is that at lower voltage very minor concentration of charge carriers is accelerated. This results in a small number of collisions so there is less mobility degradation. Drain.

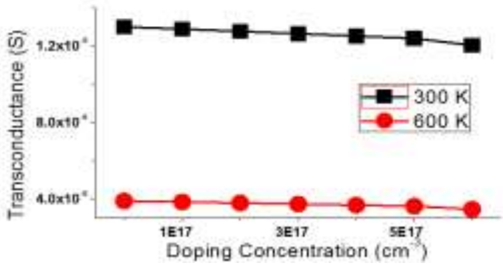

Figure 5(a). Effect transconductance with the dependence of doping concentrations at V_d(Drain Voltage)=0.05V.

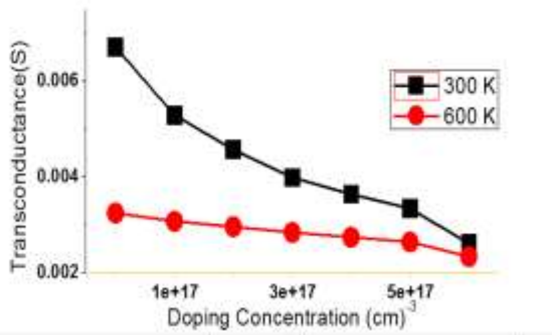

Figure 5(b). Effect transconductance with the dependence of doping concentrations at Vd (Drain Voltage)= 5 V

The drain current variation with respect to doping concentration at different operating voltage is shown in figure 6(a,b) and 7(a,b). At higher operating voltage the reduction in drain current will maximum because of large number of collision as shown in figure 6 (b) and 7(b). There is a mobility

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degradation at lower operating voltage and results in the high drain current as shown in figure 6(a) and 7(a). Drain current decreases sharply at higher temperature due to large number of collisions as in case of 600 K and becomes high at lower temperature as shown in figure 6 and 7.

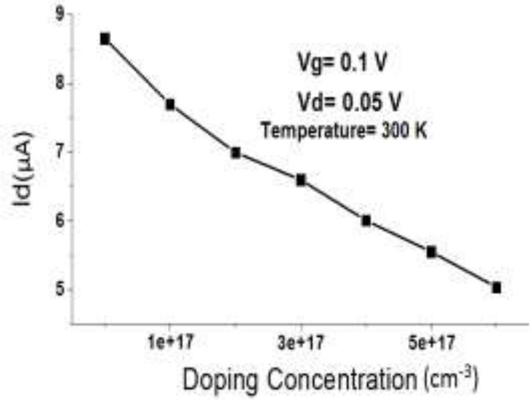

Figure 6(a). Variation of I_d with doping concentration at low operating voltages at 300 K Temperature

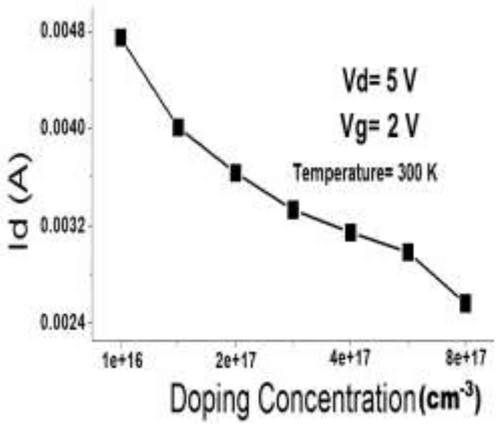

Figure 6(b). Variation of I_d with doping concentration at high operating voltages at 300 K Temperature

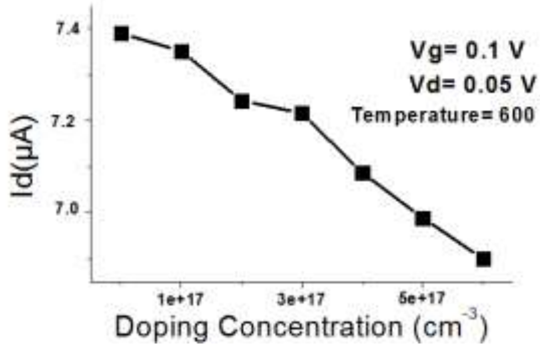

Figure 7(a). Variation of I_d with doping concentration at low operating voltages at 600 K Temperature.

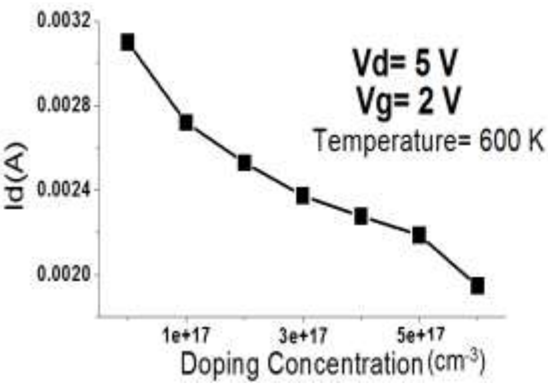

Figure 7(b). Variation of I_d with doping concentration at higher operating voltages at 600K Temperature.

IV. CONCLUSIONS

Impact ionization of n-Channel FD SOI MOSFET has been simulated with different channel doping concentration. It has been found that Impact ionization Increases with the decreases of the doping concentration. It has also examined that the threshold voltage increases with increasing the doping concentration. With increasing or decreasing the doping concentration we can better controls the threshold voltage. On the basis of the obtained results, it has examined that the drain current increases with decreasing the channel doping concentration. The effect of the doping concentration on the transconductance has also studied. It has been found that transconductance of the n-Channel FD SOI MOSFET is inversely proportional to the channel doping concentration.

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