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NUMERICAL ANALYSIS OF A DOUBLE-GATE MOSFET WITH DOPING

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Abstract

This paper presents a systematic study of doping effect on symmetric double-gate (DG) MOSFETs. One-dimensional approach has been carried out to investigate the doping effect in Double Gate MOSFET. Absolute theoretical analysis has been carried out for Gaussian doping using 1-D Poisson's equation. A relation has been obtained for electric potential and charge density. The results show that doping reduces the threshold voltage thus the conduction takes place at lower voltage.

Index Terms : DGMOSFET, Gaussian doping, SCE

I. INTRODUCTION

Rapid advances in the semiconductor industry have led to proliferation of electronic devices and information technology. The double-gate (DG) MOSFET is considered as a promising device for CMOS scaling to deep sub-100 nm, gate lengths has become very attractive for scaling CMOS devices down to nanometer size [1,2].Double gate allows for higher current drive capability compared with single gate MOSFET and lower output conductance for analog applications [3,4].

In DGMOSFET lightly doped body is desirable for resistance against dopant fluctuation effects which give rise to threshold-voltage variation and also for reduced drain-to-body capacitance and higher carrier mobility, which provide improved circuit performance. The threshold voltage of a lightly doped DGMOSFET is adjusted by tuning the work function of the gate material [5, 6].

In the present paper the device characteristics have been studied using 1-D Poisson's equation [7] for a doped double gate MOSFETs to reduce the device threshold for further extend. Analytical expression for surface potential and charge density has been derived for non uniform Gaussian doping and all the respective parameters has been discussed in details.

Device structure is described below.

Fig. 1 shows the schematic diagram of a symmetric double gate MOSFET. V_{g1} and V_{g2} are the voltages applied at top and bottom gate respectively, t_{si} is silicon thickness and t_{ox} is the thickness of oxide layer. Doping in the channel is Gaussian and source and drain are assumed to be uniformly doped.

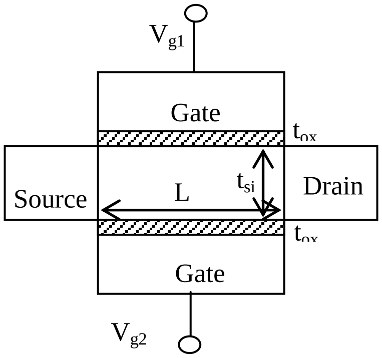


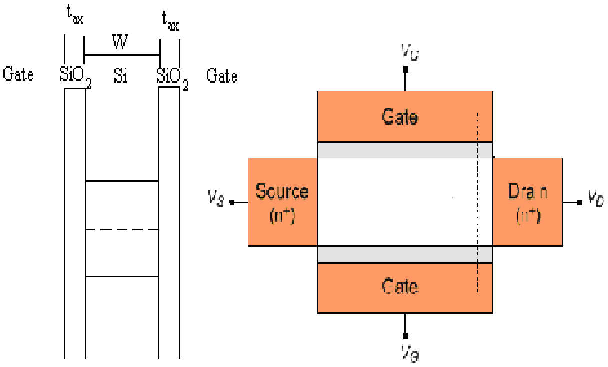
Fig:1 Schematic of a symmetric double gate MOSFET

Fig.2 shows the schematic band diagram of symmetric double-gate MOSFET. At zero voltage, the position of the silicon band is largely determined by the applied gate work function, the applied voltage is same at both the gates. Since the device is already doped, at zero bias the bands will remain flat because of no contact to the silicon body. As the gate voltage increases mobile charge density becomes appreciable and the conduction band of silicon body bends near the conduction band of the source-drain.

II. ANALYTICAL APPROACH

One dimensional Poisson's equation for the silicon region with only one mobile charge density (in this case, electron) is

$$\frac{d^2\psi(x)}{dx^2} = \frac{q}{\varepsilon_{si}} n_i e^{q\psi/kT} \qquad (1)$$



(a) (b)

Fig:2 .(a) Schematic band diagram of a symmetric double-gate n-MOSFET at zero gate voltage. (b) Diagram for a (DG) nMOSFET.

where q is the electronic charge, ε_{si} is the permittivity of silicon, n_i is the intrinsic carrier density.

In this model we are considering a n-MOSFET with $q\psi/kT >> 1$ so that the hole density is negligible. For the symmetry boundary conditions $d\psi/dx|_{x=0}=0$, integrating (1), we obtain

$$\frac{d\psi}{dx} = \sqrt{\frac{2kTn_i}{\varepsilon_{si}}\left(e^{q\psi/kT} - e^{q\psi_0/kT}\right)} \qquad (2)$$

for $0 \le x \le W/2$,the potential at the center of the silicon film is $\psi_o = \psi$ (at x=0). Substituting (2) in (1) and integrating with the symmetry boundary condition $d\psi/dx|_{x=0} = 0$ and $\psi_s \equiv \psi(x = W/2)$, we obtained equation (3) as

$$\frac{q(\psi_s - \psi_0)}{2kT} = -\ln\left[\cos\left(\sqrt{\frac{q^2 n_i}{2\varepsilon_{si} kT}} e^{q\psi_0/2kT} \frac{W}{2}\right)\right] (3)$$

In the above equation $\psi_o = 0$, where ψ_o is the potential at the center of the silicon film, ψ_s is the surface potential, x is a variable depicting the position in silicon body.

We are discussing a doped model with uniform Gaussian doping concentration $N(x)$ [8].1-D Poisson's equation has been used to carry out the analysis of doping effect

$$\frac{d^2\psi(x)}{dx^2} = \frac{q}{\varepsilon_{si}} N(x) \qquad (4)$$

$$N(x) = \frac{Q}{\sigma\sqrt{2\pi}} \exp\left[-\left(\frac{x - R_P}{\sigma\sqrt{2}}\right)^2\right] \qquad (5)$$

where, q is the electronic charge, ε_{si} is the permittivity of silicon, Q is implement dose per unit area, R_P is the projected range parameter and σ is straggle parameter.

From equation (4) and (5), applying the symmetry boundary condition $d\psi/dx|_{x=0} = 0$ and integrating, the obtained equation for potential is given below, where $\psi_o = 0$ at x=0

$$\psi(x) = -\frac{qQ}{2\varepsilon}\left[\begin{array}{l} -R_P erf\left(\frac{x-R_P}{\sigma\sqrt{2}}\right) + x.erf\left(\frac{x-R_P}{\sigma\sqrt{2}}\right) + \\ \frac{e^{-\left(\frac{x-R_P}{\sigma\sqrt{2}}\right)^2}}{\sqrt{\pi}}\sigma\sqrt{2} - x.erf\left(\frac{R_P}{\sigma\sqrt{2}}\right) \end{array}\right] \qquad (6)$$

For the boundary condition the width is $-W/2 \le x \le W/2$ and the potential defined at centre is ψ (0) = 0, therefore equation (6) becomes

$$\psi_s - \psi_0 = -\frac{qQ}{2\varepsilon}\left[\begin{array}{l} -R_P erf\left(\frac{\frac{W}{2} - R_P}{\sigma\sqrt{2}}\right) + \frac{W}{2} erf\left(\frac{\frac{W}{2} - R_P}{\sigma\sqrt{2}}\right) \\ + \frac{e^{-\left(\frac{\frac{W}{2}-R_P}{\sigma\sqrt{2}}\right)^2}}{\sqrt{\pi}}\sigma\sqrt{2} - \frac{W}{2} erf\left(\frac{R_P}{\sigma\sqrt{2}}\right) + \\ R_P erf\left(\frac{-R_P}{\sigma\sqrt{2}}\right) \frac{-e^{(-R_p/\sigma\sqrt{2})^2}}{\sqrt{\pi}}\sigma\sqrt{2} \end{array}\right] \qquad (7)$$

The net surface potential for a doped DGMOSFET has been obtained from (3) and (7) is given as

$$\psi_s = \frac{-2kT}{q}\ln\left[\cos\left(\sqrt{\frac{q^2 n_i}{2\varepsilon_{si}kT}}\frac{W}{2}\right)\right] - \frac{qQ}{2\varepsilon_{si}}\left[\begin{array}{l} -R_P erf\left(\frac{\frac{W}{2} - R_p}{\sigma\sqrt{2}}\right) + \frac{W}{2} erf\left(\frac{\frac{W}{2} - R_P}{\sigma\sqrt{2}}\right) \\ + \frac{\sigma\sqrt{2}.e^{-\left[\left(\frac{W}{2}-R_P\right)^2\right]/\left(\sigma\sqrt{2}\right)^2}}{\sqrt{\pi}} \\ + R_P erf\left(\frac{-R_p}{\sigma\sqrt{2}}\right) - \frac{\sigma\sqrt{2}.e^{-(R_P)^2/2\sigma^2}}{\sqrt{\pi}} \end{array}\right] + \frac{WQq}{4\varepsilon_{si}} erf\left(\frac{-R_P}{\sigma\sqrt{2}}\right) (8)$$

III. SIMULATION RESULTS

Equation (8) gives the detailed analysis for the DGMOSFET under doped condition. It consists of two parts uniform doping and doped analysis of a symmetric DGMOSFET.

Theoretical investigation has been carried out for the device and results are obtained using MATLAB for a range of parameters. Fig. 3 shows a graph between the electric potential and position in silicon for W= 20nm, t_{ox}= 2nm for different values of implant dose per unit area (Q), the projected range parameter R_P = 5nm and the straggle parameter σ = 4nm has been considered[9, 10].

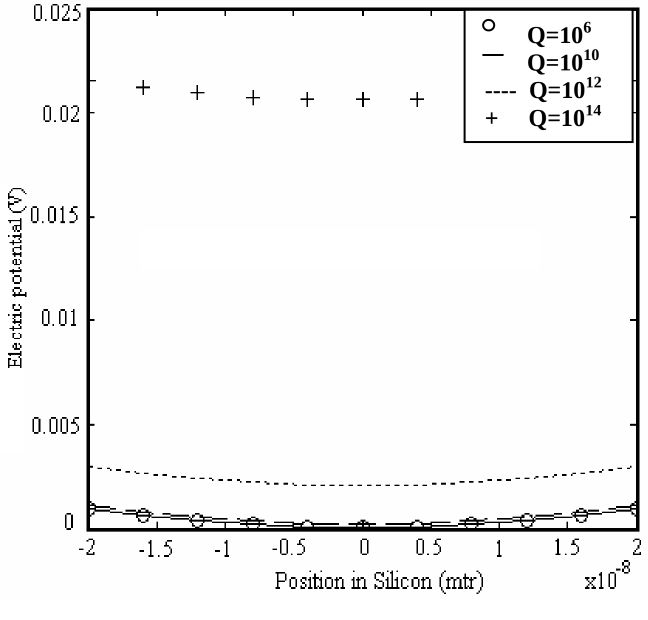


Fig. 3. Plot between electric potential ψ_s as a function of position in silicon for different values of implanted dose per unit area (Q).

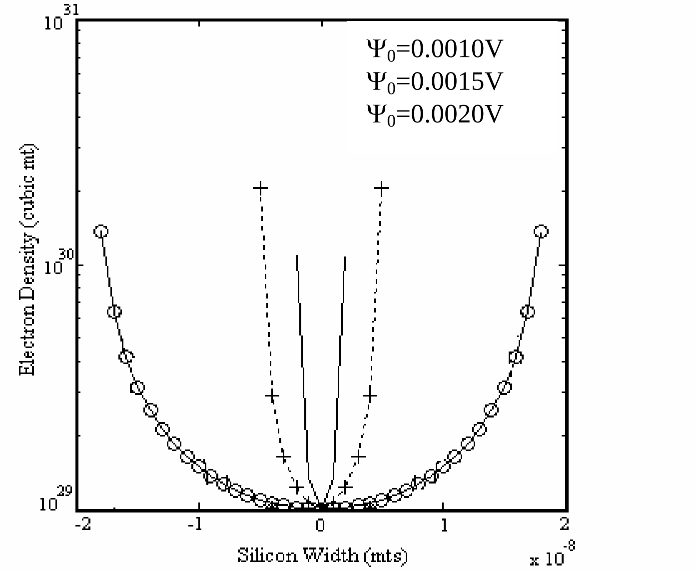


Fig.4. The electron density of mobile charges for different values of potential (Ψ_0) with varying silicon width.

Analysis of figure 3, explains that doping reduces the threshold voltage and the device can be operated even at low voltages because the strong inversion takes place with small variation in gate voltage. Below the threshold voltage the mobile charge density is low and $\psi_s \approx \psi_0$.We have studied the variation of electric potential (Ψ_S) for various values of implanted dose per unit area (Q) and result shows that Q= 10^{14} cm^{-2} is the most significant value, below this the inversion layer formed will not be strong enough for the conduction of charge carriers, across the junction.

Net electron volume density of mobile charges is given as $n = N(x) + n_i \exp(q\psi / kT)$, where n_i is the intrinsic charge density and *N(x)* is the doping concentration. Graph shown in figure 4 has been plotted for different values of electron density as a function of position in the silicon film for various values of potential. Results illustrate that potential is uniformly distributed in the silicon width towards both side of centre and the most prominent variation is for ψ_0=0.002V, which covers the maximum silicon width.

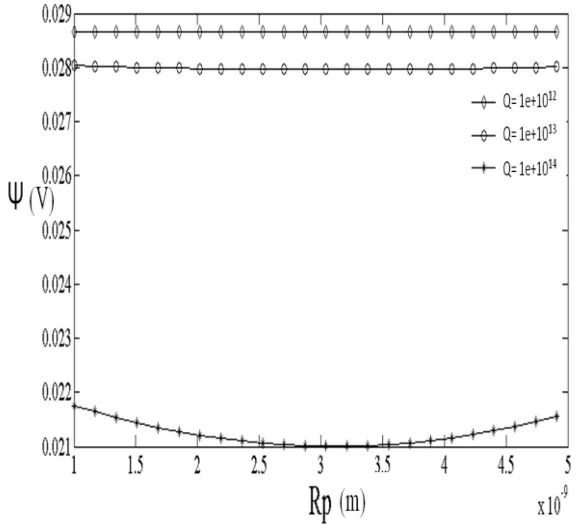


Fig.5: Variation of electric potential with range parameter (R_p) for Q= 10^{12},10^{13} and 10^{14} cm^{-2} respectively.

Graph 5 and 6 are plotted to see the variation of electric potential with varying projected range parameters (R_p)and the straggle parameter (σ) for different implanted dose per unit area.

Figure 5 shows that the potential varies in parabolic manner with R_p and the most appropriate values can be selected for Q=10^{14} cm^{-2}. For other values of Q, variation in voltage remains almost fixed with varying values of R_p.

Fig 6 shows variation in potential with straggle parameter (σ) for various values of implanted dose (Q), results illustrate that the maximum value of implanted dose can be considered as Q=10^{14} cm^{-2}. If we go below this value, results are not good enough for proper conduction, thus the values of σ = 4nm and above are acceptable for excellent results.

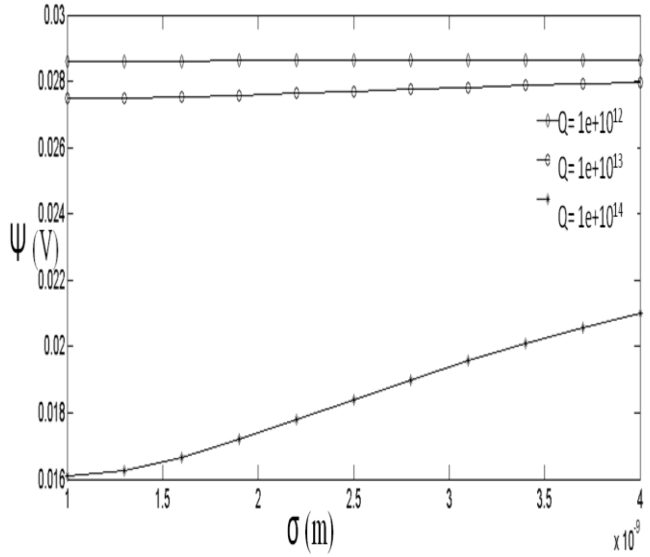


Fig.6: Variation of electric potential with straggle parameter (σ) for different values of implanted dose per unit area Q.

Results show that doping helps to work even at lower voltage. Curves are essentially flat for electron density less than 10^{22}/cm^3.At x=0, i.e., at the centre of the device, charge density is almost negligible but near the surface of silicon film charge density increases up to 10^{28}/cm^3.Density of charge carrier increases near the centre of silicon film with increasing potential at the centre of the Si film.

Values of R_p and σ has been considered as 5 nm and 4 nm for good quality results and implantation dose per unit area limits to a maximum value of 10^{14} cm^{-2}.

IV. CONCLUSION

For scaled down power-supply voltage of CMOS logic circuits, present doped model is showing better results as compared to undoped DGMOSFET. To obtain the desired threshold voltage we can implant the dopant accordingly. In the present symmetrical DGMOSFET model we have carefully opted value of implanted dose per unit area as $Q = 10^{14}\text{cm}^{-2}$, for accurate operation of the device. Threshold voltage varies significantly for various values of ion-implant doses. Straggle and projected range parameter are again important factors to discuss when doping has been taken in to account. In our model we have selected the values with precision in such a way that device can be an appropriate 1-D model for low power nano-scale VLSI designing.

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