Equation Based Modeling of MOSFET

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INTRODUCTION: We present a technique to simulate a MOSFET using the PDE interfaces in COMSOL Multiphysics®. The idea behind such a methodology is to show the coupling between the semiconductor equations and Poisson's equation.

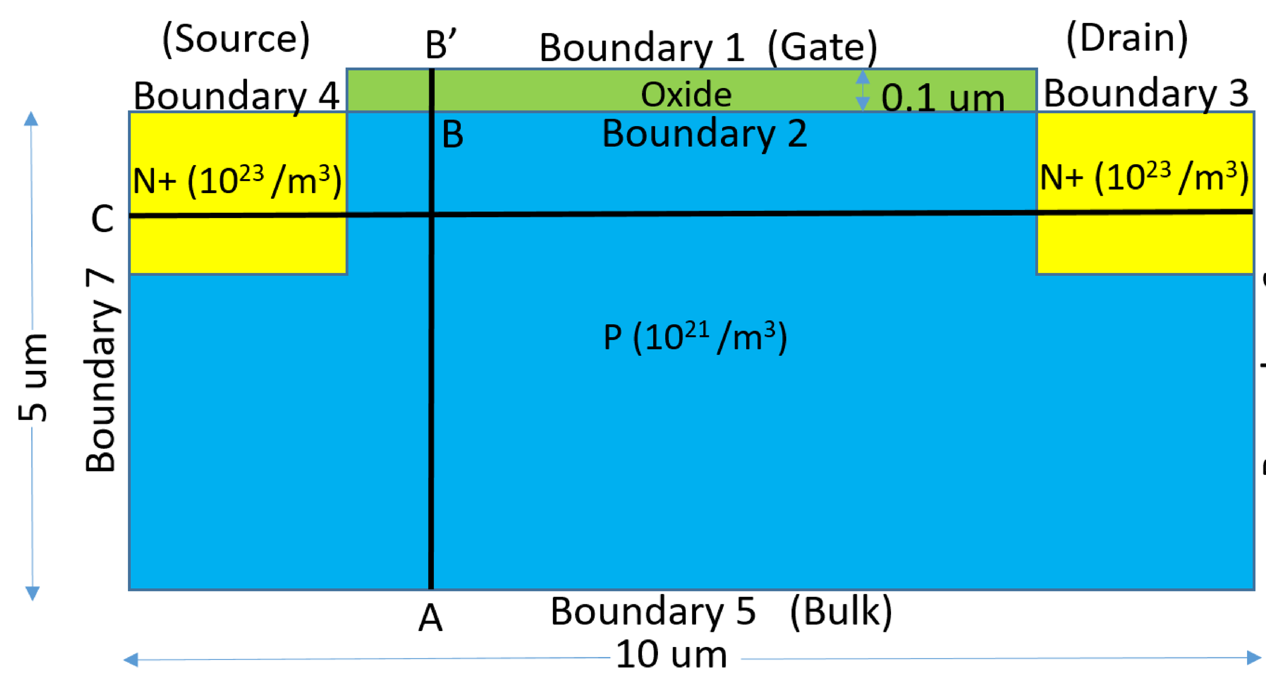

Figure 1. MOSFET structure shown with 3 cut lines AB, AB' and CD

COMPUTATIONAL METHODS: The variables to be solved for are hole concentration (p), electron concentration (n) and potential (Ψ). The variables p, n and Ψ were solved in the semiconductor domain and only the variable Ψ was solved in the oxide domain. The semiconductor equations are :-

1. $J_n = qD_n \nabla n + qn\mu_n E$
2. $J_p = -qD_p \nabla p + qp\mu_p E$
3. $\frac{\partial n}{\partial t} = \left(\frac{1}{q}\right) \nabla . J_n - \frac{\delta n}{\tau}$
4. $\frac{\partial p}{\partial t} = \left(\frac{1}{q}\right) \nabla . J_p - \frac{\delta p}{\tau}$
5. $E = -\nabla \Psi$
6. $\nabla . E = \frac{\rho}{\epsilon}, \ \rho = q(p - n + N)$

These were framed into the Coefficient form PDE interface.

Boundary	p	n	Ψ
1	N.A.	N.A.	$-4.05 + Vg$
2	$n_i exp\left(-\frac{(psi + 4.6)}{0.026}\right)$	$n_i exp\left(\frac{(psi + 4.6)}{0.026}\right)$	Ψ
3	10^9	10^{23}	$-4.1914 + Vd$
4	10^9	10^{23}	-4.1914
5	10^{21}	10^{11}	-4.887

Table 1. Boundary conditions for p, n and Ψ

Boundaries 6 and 7 have zero flux boundary condition.
In this model, the reference potential is the vacuum level. The potential at any point is given by :

$$\Psi = V_a - \chi - \frac{E_g}{2} + \frac{kT}{q} ln\left(\frac{\frac{N}{2} + \sqrt{\left(\frac{N}{2}\right)^2 + n_i^2}}{n_i}\right)$$

where V_a is the applied voltage at the contact and the other symbols have their usual meanings in the context of semiconductors. A proper choice of initial conditions, solver configuration and adaptive meshing were needed to obtain converging solutions.

RESULTS: The important plots after sweeping V_g (V_d= 0 V) and V_d($V_g = 5\ V$) have been shown below :-

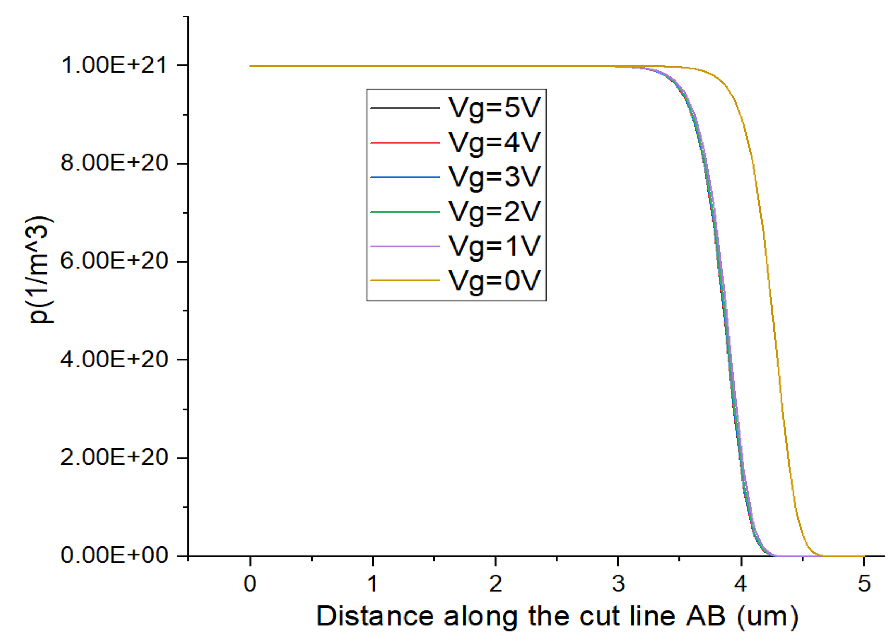

Figure 2. p - V_g along cut line AB

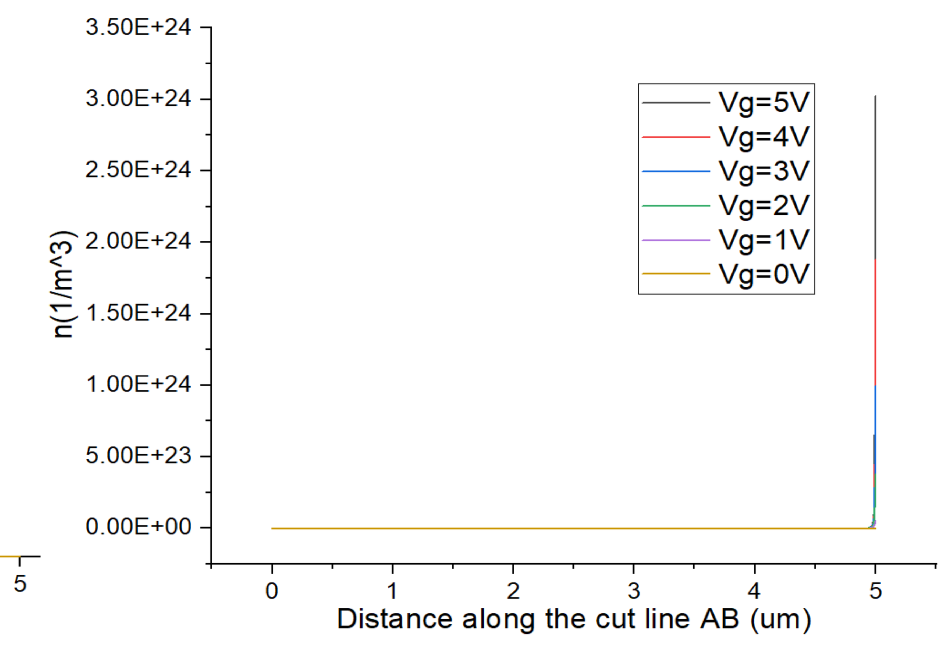

Figure 3. n - V_g along cut line AB

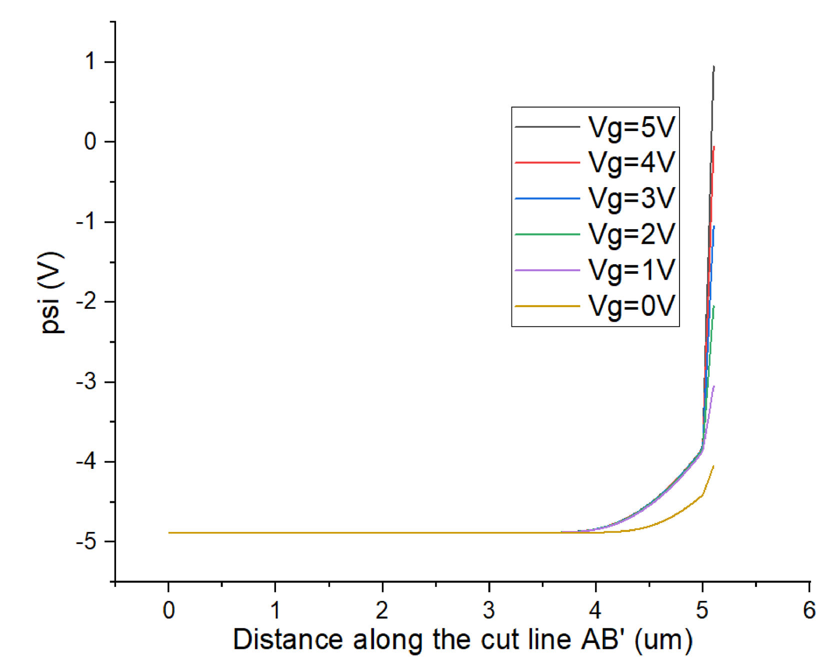

Figure 4. Ψ - V_g along cut line AB'

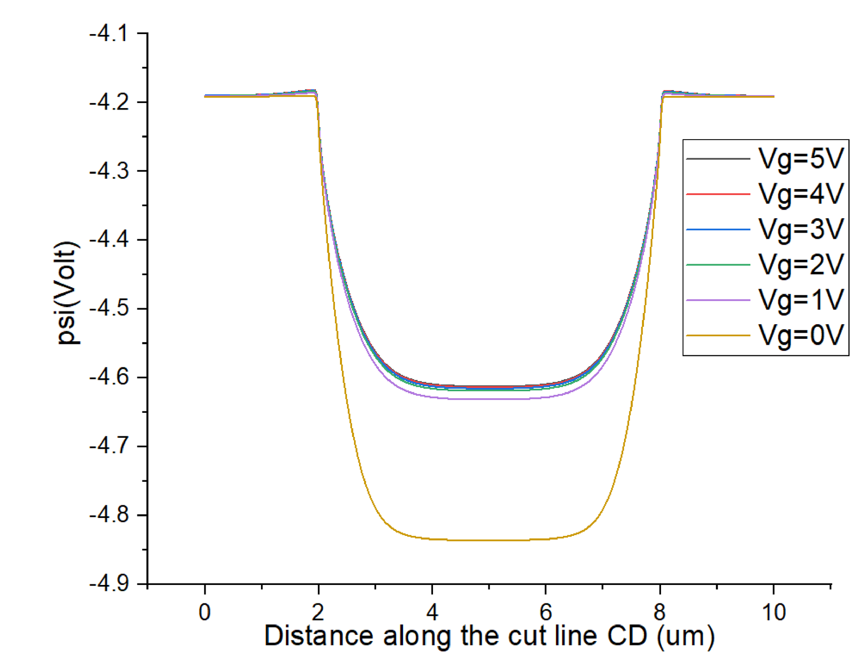

Figure 5. Ψ- V_g along cut line CD

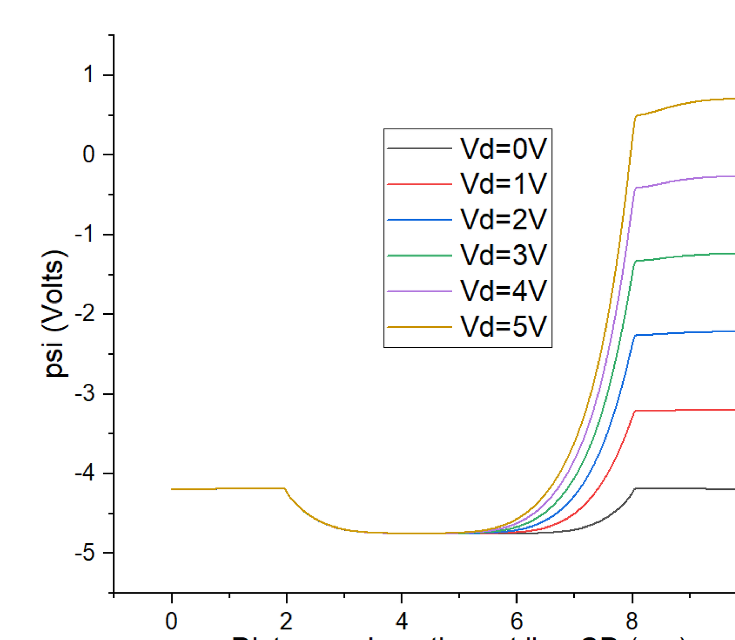

Figure 6. Ψ - V_d along cut line CD

The above simulated results are in qualitative agreement with the physics based model.

CONCLUSIONS: This work demonstrates the techniques to simulate a MOSFET using the Equation based interface in COMSOL Multiphysics®. This technique will further be extended to study MEMS structures coupling beam mechanics with semiconductor equations.

REFERENCES:

1. COMSOL Multiphysics® example "DC Characteristics of a MOS Transistor (MOSFET)" model , "v 3.5a".
2. COMSOL Multiphysics® example "The KdV Equations and Solitons" model, "v 5.4".

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