PHYSICAL MODEL OF A METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR

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ABSTRACT

A physical model of a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) was constructed through computer simulation. Simulation was done to view the electrostatic potential and to study the dependence of voltage drop on the thickness of the oxide layer of the MOSFET. The simulation was done using the Simulation Generation Framework (SGFramework) software designed to solve problems in semiconductor device physics through simulation. The SGFramework software is supported by Visual C++ programming language.

INTRODUCTION

A field-effect transistor (FET) is a type of transistor that is used for weak-signal amplification. The FET can amplify analog or digital signals. In the FET, current flows along a semiconductor path called the *channel where* there is an electrode called the *source and* another electrode called the *drain at the other end*. The physical diameter of the channel is fixed, but varying the voltage applied to a control electrode called the gate can vary its effective electrical diameter. The conductivity of the FET depends on the electrical diameter of the channel. A small change in gate voltage can cause a large variation in the current that flows from the source to the drain. This is how the FET amplifies signals.

One of the major types of the FET is the *metal-oxide- semiconductor FET (MOSFET)*. In the MOSFET, the channel can be either n-type or p-type semiconductor. The gate electrode is a piece of metal whose surface is oxidized. The oxide layer electrically insulates the gate from the channel. Because the oxide layer acts as a dielectric, there is essentially never any current between the gate and the channel during any part of the signal cycle. This gives the MOSFET very large input impedance.

The threshold voltage is the point at which the transistor turns on. Its value must be within the voltage range of a circuit design. For a MOSFET, the magnitude of the threshold voltage depends on the semiconductor doping, oxide charge and oxide thickness.

MATERIALS AND METHODS

In this project, a model of MOSFET with a p-type semiconductor was constructed. Simulations were then conducted on the model. A positive gate-to-source voltage, V_{GS} of 1.0 V (less than the threshold voltage) was applied to the gate of the MOSFET model. The oxide thickness was varied between 5×10^{-8} m and 25×10^{-8} m.

RESULTS AND DISCUSSION

Figure 1 shows the electrostatic potential of the MOSFET model.

It can be seen that the potential in the bulk semiconductor (substrate) is zero. Also, the potential in the drain region and the potential in the source region have equal magnitude.

This indicates the drain to source voltage, $V_{DS} = 0$.

From the results obtained from the simulation, a graph of voltage versus thickness was plotted as shown in Figure 2. From the graph, we can see that a rapid linear drop in the voltage occurs in the oxide. Figure 2 also shows that the voltage drop in the oxide increases when the oxide thickness is increased.

For oxide thickness 5×10^{-8} m, the voltage drop in the oxide is approximately:

$$1.00\ V - 0.25\ V = 0.75\ V$$

For oxide thickness 25×10^{-8}m, the voltage drop in the oxide is approximately:

$$1.00\ V - 0.15\ V = 0.85\ V$$

When a positive voltage that is less than the threshold voltage is applied to the gate of a MOS capacitor with a p-type semiconductor, this induces a negative space charge region at the oxide-semiconductor interface. This region is similar to that in a pn junction and can be called the depletion width, W. Electric field, E penetrates the semiconductor out to a distance W.

The density of the negative space charge can be assumed to be a constant with magnitude r = $-eN_A$. The field lines end at a constant rate with increasing x, given by:

$$\frac{dE}{dx} = \frac{p}{\varepsilon} = -\frac{eN_A}{\varepsilon}$$

Upon integration, this gives

$$E = \frac{-eN_A x}{\varepsilon} + c \text{ ; c is a constant}$$

or,

$$E = E(x=0) - \frac{eN_A x}{\varepsilon} \quad \text{........................(1)}$$

where x = 0 is at the oxide-semiconductor interface and x increases with distance from the gate.

E (x = 0) is the electric field at the oxide-semiconductor interface. This is the oxide electric field, E_{ox}. The field is zero at x = W because there are no fields outside the depletion region.

So, at x = W, E = 0 ; which gives

$$E_{ox} = E(x=0) = \frac{eN_A W}{\varepsilon}$$

The voltage dropped in the oxide,

$$V_{ox} = E_{ox} t_{ox} = \frac{eN_A W t_{OX}}{\varepsilon}$$

$$= \frac{eN_A W t_{OX}}{\varepsilon_{OX}\varepsilon_O} \quad \text{........................(2)}$$

Equation 2 indicates a linear voltage drop in the oxide, as seen in Figure 2.

From Equation 1, the electric field in the semiconductor,

$$E = -\frac{eN_A(W-x)}{\varepsilon}$$

From $E = -\frac{dV}{dx}$,

$$\frac{dV}{dx} = \frac{eN_A(W-x)}{\varepsilon}$$

which upon integration gives,

$$V(x) = \frac{eN_A}{\varepsilon}(W - x^2/2) + c'$$

, c' is a constant

Or,

$$V(x) = V(x=0) - \frac{eN_A}{\varepsilon}(W - x^2/2)$$

$$\text{........................(3)}$$

where V (x = 0) is the potential at the oxide-semiconductor interface. The potential drop in the semiconductor is the difference between the potential at the oxide-semiconductor interface,