



Model created in COMSOL Multiphysics 6.4

# MOSFET with Explicit Metal and Dielectric Domains



## Introduction

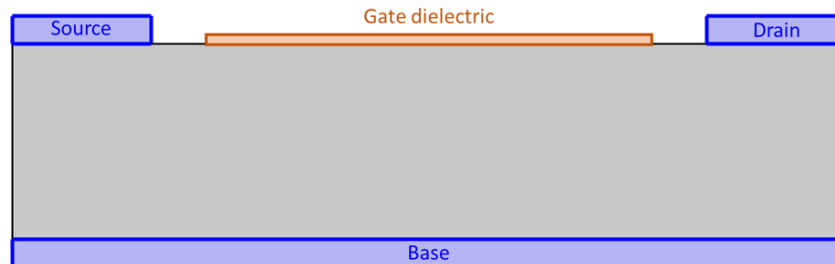
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This example is an adaptation of the [DC Characteristics of a MOS Transistor \(MOSFET\)](#) model (Application Library path **Semiconductor\_Module/Transistors/mosfet**). In this adaptation the metallic and dielectric domains are modeled explicitly and not via an effective boundary condition. Therefore, for instance the potential profile inside the metal and inside the insulator can be observed. The coupling between the semiconductor and the metal is achieved by including an electric currents interface.

## Model Definition

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[Figure 1](#) shows the model geometry composed of the semiconductor, metallic domains, namely, source, drain, and base, as well as the gate dielectric domain. The model uses the Semiconductor interface for the semiconductor and gate dielectric domains, and the Electric Currents interface to account for the metallic domains. The coupling between the two interfaces is achieved by defining the **Normal Current Density** under the Electric Currents interface and the **Metal Contact** under the Semiconductor interface.



*Figure 1: Model geometry indicating different domains including explicit definition of metal and dielectric domains.*

The procedure of the implementation is described in detail in the [Modeling Instructions](#) section.

## Results and Discussion

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[Figure 2](#) shows the electric potential profile for the MOSFET with explicit metal and dielectric domains.

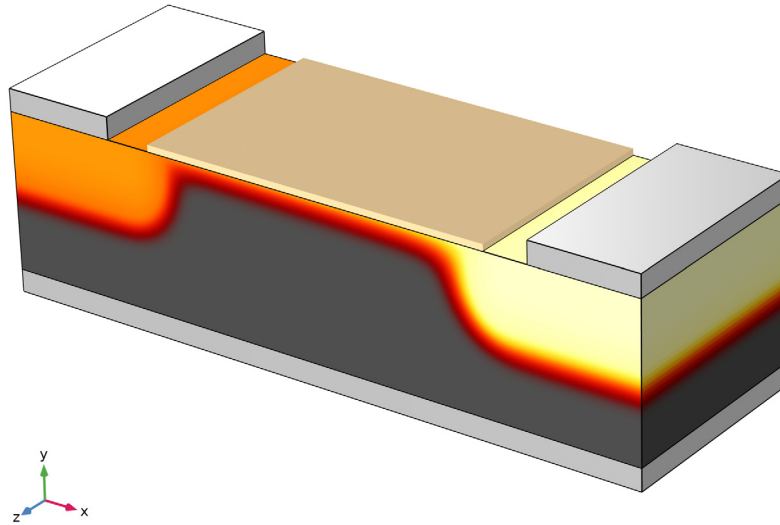


Figure 2: Electric potential profile of a MOSFET with explicit metal and dielectric domains.

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**Application Library path:** Semiconductor\_Module/Transistors/  
mosfet\_with\_explicit\_metal\_and\_dielectric


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### *Modeling Instructions*


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From the **File** menu, choose **New**.

#### **NEW**

In the **New** window, click  **Model Wizard**.

#### **MODEL WIZARD**

- 1 In the **Model Wizard** window, click  **2D**.
- 2 In the **Select Physics** tree, select **AC/DC** > **Electric Fields and Currents** > **Electric Currents (ec)**.
- 3 Click **Add**.

- 4 In the **Select Physics** tree, select **Semiconductor > Semiconductor (semi)**.
- 5 Click **Add**.
- 6 Click  **Study**.
- 7 In the **Select Study** tree, select **General Studies > Stationary**.
- 8 Click  **Done**.

## GLOBAL DEFINITIONS

### Parameters 1


- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
- 2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
- 3 In the table, enter the following settings:

Name	Expression	Value	Description
L	1e-6[m]	1E-6 m	Out-of-plane thickness
pdop	1e17[1/cm^3]	1E23 1/m <sup>3</sup>	p-doping
ndop	1e20[1/cm^3]	1E26 1/m <sup>3</sup>	n-doping


## GEOMETRY 1

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.
- 2 In the **Settings** window for **Geometry**, locate the **Units** section.
- 3 From the **Length unit** list, choose **µm**.

### Rectangle 1 (r1)

- 1 In the **Geometry** toolbar, click  **Rectangle**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 3.
- 4 In the **Height** text field, type 0.7.


### Polygon 1 (pol1)

- 1 In the **Geometry** toolbar, click  **Polygon**.
- 2 In the **Settings** window for **Polygon**, locate the **Object Type** section.
- 3 From the **Type** list, choose **Closed curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

x ( $\mu\text{m}$ )	y ( $\mu\text{m}$ )
0	0.67
0	0.7
0.5	0.7
0.7	0.7
2.3	0.7
2.5	0.7
3	0.7
3	0.67

*Rectangle 2 (r2)*

- 1 In the **Geometry** toolbar, click  **Rectangle**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 0.5.
- 4 In the **Height** text field, type 0.1.
- 5 Locate the **Position** section. In the **y** text field, type 0.7.

*Rectangle 3 (r3)*

- 1 Right-click **Rectangle 2 (r2)** and choose **Duplicate**.
- 2 In the **Settings** window for **Rectangle**, locate the **Position** section.
- 3 In the **x** text field, type 2.5.

*Rectangle 4 (r4)*

- 1 Right-click **Rectangle 3 (r3)** and choose **Duplicate**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 1.6.
- 4 In the **Height** text field, type 30 [nm].
- 5 Locate the **Position** section. In the **x** text field, type 0.7.

*Rectangle 5 (r5)*

- 1 Right-click **Rectangle 4 (r4)** and choose **Duplicate**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 3.
- 4 In the **Height** text field, type 0.1.

5 Locate the **Position** section. In the **x** text field, type 0.

6 In the **y** text field, type -0.1.

#### *Form Union (fin)*

1 In the **Model Builder** window, click **Form Union (fin)**.


2 In the **Settings** window for **Form Union/Assembly**, locate the **Form Union/Assembly** section.

3 From the **Repair tolerance** list, choose **Absolute**.

4 In the **Absolute repair tolerance** text field, type  $3.0E-6$ .

#### *Mesh Control Edges 1 (mce1)*

1 In the **Geometry** toolbar, click  **Virtual Operations** and choose **Mesh Control Edges**.

2 Click the  **Zoom Extents** button in the **Graphics** toolbar.

3 On the object **fin**, select Boundary 6 only.

#### **ADD MATERIAL**

1 In the **Materials** toolbar, click  **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Semiconductors > Si - Silicon**.

4 Click the **Add to Component** button in the window toolbar.

5 In the **Materials** toolbar, click  **Add Material** to close the **Add Material** window.

#### **MATERIALS**

##### *Si - Silicon (mat1)*

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 Click  **Clear Selection**.

3 Select Domain 2 only.

##### *Metal*

1 In the **Model Builder** window, right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type Metal in the **Label** text field.

3 Select Domains 1, 3, and 5 only.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Electric conductivity	sigma_iso ; sigma_ii = sigma_iso, sigma_ij = 0	1e7	S/m	Basic
Relative permittivity	epsilon_r_iso ; epsilon_rii = epsilon_r_iso, epsilon_r_ij = 0	1		Basic

*Oxide*


- 1 Right-click **Materials** and choose **Blank Material**.
- 2 In the **Settings** window for **Material**, type Oxide in the **Label** text field.
- 3 Select Domain 4 only.
- 4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permittivity	epsilon_r_iso ; epsilon_rii = epsilon_r_iso, epsilon_r_ij = 0	4.5		Basic


#### **ELECTRIC CURRENTS (EC)**

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electric Currents (ec)**.
- 2 Select Domains 1, 3, and 5 only.
- 3 In the **Settings** window for **Electric Currents**, locate the **Thickness** section.
- 4 In the  $d$  text field, type L.


*Normal Current Density 1 - Ground left*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Normal Current Density**.
- 2 In the **Settings** window for **Normal Current Density**, type Normal Current Density 1 - Ground left in the **Label** text field.
- 3 Select Boundary 6 only.
- 4 Locate the **Normal Current Density** section. In the  $J_n$  text field, type semi.nJ.


#### *Normal Current Density 2 - Drain*

- 1 Right-click **Normal Current Density 1 - Ground left** and choose **Duplicate**.
- 2 In the **Settings** window for **Normal Current Density**, type Normal Current Density 2 - Drain in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 16 only.


#### *Normal Current Density 3 - Ground bottom*

- 1 Right-click **Normal Current Density 2 - Drain** and choose **Duplicate**.
- 2 In the **Settings** window for **Normal Current Density**, type Normal Current Density 3 - Ground bottom in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 4 only.


#### *Ground left*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Electric Potential**.
- 2 In the **Settings** window for **Electric Potential**, type Ground left in the **Label** text field.
- 3 Select Boundary 7 only.

#### *Ground bottom*

- 1 Right-click **Ground left** and choose **Duplicate**.
- 2 In the **Settings** window for **Electric Potential**, type Ground bottom in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 2 only.

#### *Drain*

- 1 Right-click **Ground bottom** and choose **Duplicate**.
- 2 In the **Settings** window for **Electric Potential**, type Drain in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 17 only.
- 5 Locate the **Electric Potential** section. In the  $V_0$  text field, type 1.

#### **SEMICONDUCTOR (SEMI)**


- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Semiconductor (semi)**.
- 2 Select Domains 2 and 4 only.
- 3 In the **Settings** window for **Semiconductor**, locate the **Thickness** section.

4 In the  $d$  text field, type L.


#### *Charge Conservation 1*

- 1 In the **Physics** toolbar, click  **Domains** and choose **Charge Conservation**.
- 2 Select Domain 4 only.


#### *Gate*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Terminal**.
- 2 In the **Settings** window for **Terminal**, type Gate in the **Label** text field.
- 3 Select Boundary 12 only.
- 4 Locate the **Terminal** section. In the  $\Phi_c$  text field, type 4.1[V].
- 5 From the **Terminal type** list, choose **Voltage**.
- 6 In the  $V_0$  text field, type 2.


#### *Metal Contact 1 - Ground left*

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Metal Contact**.
- 2 In the **Settings** window for **Metal Contact**, type Metal Contact 1 - Ground left in the **Label** text field.
- 3 Select Boundary 6 only.
- 4 Locate the **Terminal** section. In the  $V_0$  text field, type V.

#### *Metal Contact 2 - Drain*

- 1 Right-click **Metal Contact 1 - Ground left** and choose **Duplicate**.
- 2 In the **Settings** window for **Metal Contact**, type Metal Contact 2 - Drain in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 16 only.

#### *Metal Contact 3 - Ground bottom*

- 1 Right-click **Metal Contact 2 - Drain** and choose **Duplicate**.
- 2 In the **Settings** window for **Metal Contact**, type Metal Contact 3 - Ground bottom in the **Label** text field.
- 3 Locate the **Boundary Selection** section. Click  **Clear Selection**.
- 4 Select Boundary 4 only.

#### *Analytic Doping Model 1*

- 1 In the **Physics** toolbar, click  **Domains** and choose **Analytic Doping Model**.

- 2 Select Domain 2 only.
- 3 In the **Settings** window for **Analytic Doping Model**, locate the **Impurity** section.
- 4 In the  $N_{A0}$  text field, type pdop.

*Analytic Doping Model 2*

- 1 Right-click **Analytic Doping Model 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Analytic Doping Model**, locate the **Distribution** section.
- 3 From the list, choose **Box**.
- 4 Locate the **Impurity** section. From the **Impurity type** list, choose **Donor doping (n-type)**.
- 5 In the  $N_{D0}$  text field, type ndop.
- 6 Locate the **Uniform Region** section. Specify the  $r_0$  vector as

0.6[um]	Y
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- 7 In the  $W$  text field, type 0.6[um].
- 8 In the  $D$  text field, type 0.1[um].
- 9 Locate the **Profile** section. Select the **Specify different length scales for each direction** checkbox.
- 10 Specify the  $d_j$  vector as

0.2[um]	X
0.25[um]	Y


- 11 From the  $N_b$  list, choose **Acceptor concentration (semi/adm I)**.

*Analytic Doping Model 3*

- 1 Right-click **Analytic Doping Model 2** and choose **Duplicate**.
- 2 In the **Settings** window for **Analytic Doping Model**, locate the **Uniform Region** section.
- 3 Specify the  $r_0$  vector as

2.4[um]	X
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*Trap-Assisted Recombination 1*

- 1 In the **Physics** toolbar, click  **Domains** and choose **Trap-Assisted Recombination**.
- 2 Select Domain 2 only.

**MESH 1**


- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

- 2 In the **Settings** window for **Mesh**, locate the **Sequence Type** section.
- 3 From the list, choose **User-controlled mesh**.


#### *Size*

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Mesh 1** click **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Finer**.
- 4 Click to expand the **Element Size Parameters** section.


#### *Mapped 1*

- 1 In the **Mesh** toolbar, click  **Mapped**.
- 2 Drag and drop below **Size**.
- 3 In the **Settings** window for **Mapped**, locate the **Domain Selection** section.
- 4 From the **Geometric entity level** list, choose **Domain**.
- 5 Select Domain 6 only.

#### *Distribution 1*

- 1 Right-click **Mapped 1** and choose **Distribution**.
- 2 In the **Settings** window for **Distribution**, locate the **Boundary Selection** section.
- 3 Click  **Paste Selection**.
- 4 In the **Paste Selection** dialog, type 21 in the **Selection** text field.
- 5 Click **OK**.
- 6 In the **Settings** window for **Distribution**, locate the **Distribution** section.
- 7 From the **Distribution type** list, choose **Predefined**.
- 8 In the **Number of elements** text field, type 10.
- 9 In the **Element ratio** text field, type 5.
- 10 From the **Growth rate** list, choose **Exponential**.
- 11 Select the **Reverse direction** checkbox.

#### *Distribution 2*


- 1 In the **Model Builder** window, right-click **Mapped 1** and choose **Distribution**.
- 2 In the **Settings** window for **Distribution**, locate the **Boundary Selection** section.
- 3 Click  **Paste Selection**.
- 4 In the **Paste Selection** dialog, type 23 in the **Selection** text field.
- 5 Click **OK**.

- 6 In the **Settings** window for **Distribution**, locate the **Distribution** section.
- 7 In the **Number of elements** text field, type 400.


#### *Size 1*

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Mesh 1** click **Size 1**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Fine**.

#### *Size 2*


- 1 In the **Model Builder** window, click **Size 2**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Finer**.
- 4 Click  **Build All**.

#### **STUDY 1**


In the **Study** toolbar, click  **Compute**.

#### **RESULTS**

##### *Surface 1*

- 1 In the **Model Builder** window, expand the **Electron Concentration (semi)** node, then click **Surface 1**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `semi.log10N`.
- 4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Rainbow**.
- 5 From the **Scale** list, choose **Linear**.
- 6 In the **Electron Concentration (semi)** toolbar, click  **Plot**.


##### *Surface 1*

- 1 In the **Model Builder** window, expand the **Hole Concentration (semi)** node, then click **Surface 1**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `semi.log10P`.
- 4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Rainbow**.
- 5 From the **Scale** list, choose **Linear**.
- 6 In the **Hole Concentration (semi)** toolbar, click  **Plot**.


#### *Study 1/Solution 1 (2) (sol1)*

- 1 In the **Model Builder** window, expand the **Results > Datasets** node.
- 2 Right-click **Results > Datasets > Study 1/Solution 1 (sol1)** and choose **Duplicate**.

#### *Selection*

- 1 In the **Results** toolbar, click  **Attributes** and choose **Selection**.
- 2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Domain**.
- 4 Select Domains 1–3 and 5 only.


#### *Extrusion 2D 1*

- 1 In the **Results** toolbar, click  **More Datasets** and choose **Extrusion 2D**.
- 2 In the **Settings** window for **Extrusion 2D**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 1/Solution 1 (2) (sol1)**.

#### *Study 1/Solution 1 (3) (sol1)*

- In the **Model Builder** window, under **Results > Datasets** right-click **Study 1/Solution 1 (2) (sol1)** and choose **Duplicate**.


#### *Selection*

- 1 In the **Model Builder** window, expand the **Study 1/Solution 1 (3) (sol1)** node, then click **Selection**.
- 2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
- 3 Click  **Clear Selection**.
- 4 Select Domain 4 only.

#### *Extrusion 2D 2*

- 1 In the **Model Builder** window, under **Results > Datasets** right-click **Extrusion 2D 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Extrusion 2D**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 1/Solution 1 (3) (sol1)**.


#### *3D representation*

- 1 In the **Results** toolbar, click  **3D Plot Group**.
- 2 In the **Settings** window for **3D Plot Group**, type 3D representation in the **Label** text field.
- 3 Click to expand the **Title** section. From the **Title type** list, choose **None**.

### Surface 1

- 1 Right-click **3D representation** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type 1.
- 4 Locate the **Data** section. From the **Dataset** list, choose **Extrusion 2D 1**.

### Material Appearance 1

- 1 Right-click **Surface 1** and choose **Material Appearance**.
- 2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.
- 3 From the **Appearance** list, choose **Custom**.
- 4 From the **Material type** list, choose **Custom**.
- 5 Set the **Metallic** value to **0.3**.
- 6 Click the  **Zoom Extents** button in the **Graphics** toolbar.



### Surface 2

- 1 In the **Model Builder** window, right-click **3D representation** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Extrusion 2D 1**.
- 4 Locate the **Expression** section. In the **Expression** text field, type V2.
- 5 Locate the **Coloring and Style** section. From the **Color table** list, choose **GrayBody**.


### Surface 3

- 1 Right-click **3D representation** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Extrusion 2D 2**.
- 4 Locate the **Expression** section. In the **Expression** text field, type 1.


### Material Appearance 1

- 1 Right-click **Surface 3** and choose **Material Appearance**.
- 2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.
- 3 From the **Appearance** list, choose **Custom**.
- 4 From the **Material type** list, choose **Sand**.
- 5 Click the  **Show Legends** button in the **Graphics** toolbar.
- 6 Click the  **Show Grid** button in the **Graphics** toolbar.
- 7 In the **Model Builder** window, expand the **Results > Views** node.

### *Camera*

- 1** In the **Model Builder** window, expand the **Results > Views > View 3D 2** node, then click **Camera**.
- 2** In the **Settings** window for **Camera**, locate the **Position** section.
- 3** In the **x** text field, type 11.
- 4** In the **y** text field, type 8.
- 5** In the **z** text field, type 13.
- 6** Locate the **Up Vector** section. In the **x** text field, type -0.15.
- 7** In the **y** text field, type 1.
- 8** In the **z** text field, type -0.25.
- 9** Click  **Update**.

### *3D representation*

- 1** In the **Model Builder** window, under **Results** click **3D representation**.
- 2** In the **3D representation** toolbar, click  **Plot**.