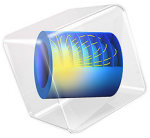

Model created in COMSOL Multiphysics 6.4

Metal–Insulator–Metal (MIM) Diode

Introduction

The MIM (Metal–Insulator–Metal) tunnel diode is a type of diode where a layer of insulating material with a thickness of a few nanometers is placed between two metal electrodes. By applying a small voltage, electrons on the metal side with energies close to the Fermi level can tunnel through the insulator layer due to a quantum-mechanical effect. In contrast, classical physics treats the layer as an impenetrable barrier, despite its extreme thinness. Electron tunneling enables MIM diodes to switch rapidly and operate efficiently at high frequencies.

This model shows how to model a simple MIM diode using the WKB tunneling model.

Model Definition

This model compares the terminal current of a MIM diode with and without considering the tunneling effect. The MIM tunnel diode is modeled as a 1D domain with a 5 nm thick insulator material. The two metal electrodes are defined at the two ends of the domain using a Metal Contact feature. A WKB Tunneling Model feature, defined at the Metal Contact, accounts for the quantum tunneling effect across the potential barrier.

The Modeling Instructions section describes the setup in detail.

Results and Discussion

Figure 1 compares the terminal current versus voltage for the two studies, with and without tunneling.

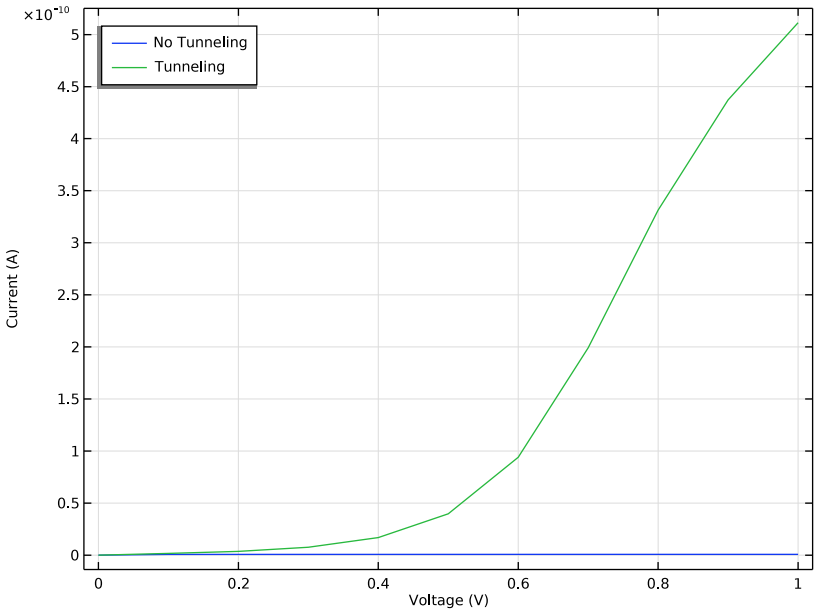

Figure 1: Current versus voltage, with and without tunneling effect.

Application Library path: `Semiconductor_Module/Device_Building_Blocks/mim_diode`

Modeling Instructions

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

NEW

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

MODEL WIZARD

1 In the **Model Wizard** window, click **1D**.

2 In the **Select Physics** tree, select **Semiconductor** > **Semiconductor (semi)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces** > **Semiconductor Equilibrium**.

6 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
V0	0[V]	0 V	Voltage
wf	1.03 [V]	1.03 V	Metal work function

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 **nm**.

Interval 1 (i1)

1 Right-click **Component 1 (comp1)** > **Geometry 1** and choose **Interval**.

2 In the **Settings** window for **Interval**, locate the **Interval** section.

3 In the table, enter the following settings:

Coordinates (nm)
0
5

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** > **C - Diamond**.

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.

SEMICONDUCTOR (SEMI)

1 In the **Settings** window for **Semiconductor**, locate the **Model Properties** section.

2 From the **Solution** list, choose **Majority carriers only**.

3 Click to expand the **Discretization** section. From the **Formulation** list, choose **Finite element quasi Fermi level (quadratic shape function)**.

Metal Contact 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Metal Contact**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Metal Contact**, locate the **Terminal** section.

4 In the V_0 text field, type `-V0`.

5 Locate the **Contact Type** section. From the **Type** list, choose **Ideal Schottky**.

6 Locate the **Contact Properties** section. In the Φ text field, type `wf`.

Metal Contact 2

1 Right-click **Metal Contact 1** and choose **Duplicate**.

2 In the **Settings** window for **Metal Contact**, locate the **Boundary Selection** section.

3 Click **Clear Selection**.

4 Select Boundary 2 only.

5 Locate the **Terminal** section. In the V_0 text field, type `0[V]`.

Metal Contact 3

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Semiconductor (semi)** right-click **Metal Contact 1** and choose **Duplicate**.

2 In the **Settings** window for **Metal Contact**, click to expand the **Extra Current Contribution** section.

3 From the **Extra electron current** list, choose **WKB tunneling model**.

WKB Tunneling Model, Electrons 1

1 In the **Physics** toolbar, click **Attributes** and choose **WKB Tunneling Model, Electrons**.

2 In the **Settings** window for **WKB Tunneling Model, Electrons**, locate the **Potential Barrier Domain Selection** section.

3 Click to select the **Activate Selection** toggle button.

4 Select Domain 1 only.

5 Locate the **Opposite Boundary Selection** section. Click to select the **Activate Selection** toggle button.

6 Select Boundary 2 only.

STUDY 1 - NO TUNNELING

1 In the **Model Builder** window, click **Study 1**.

2 In the **Settings** window for **Study**, type `Study 1 - No Tunneling` in the **Label** text field.

Step 1: Semiconductor Equilibrium

1 In the **Model Builder** window, under **Study 1 - No Tunneling** click **Step 1: Semiconductor Equilibrium**.

2 In the **Settings** window for **Semiconductor Equilibrium**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** checkbox.

4 In the tree, select **Component 1 (comp1)** > **Semiconductor (semi)** > **Metal Contact 3**.

5 Click **Disable**.

Step 2: Stationary

1 In the **Study** toolbar, click **Stationary**.

2 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** checkbox.

4 In the tree, select **Component 1 (comp1)** > **Semiconductor (semi)** > **Metal Contact 3**.

5 Click **Disable**.

6 Click to expand the **Study Extensions** section. Select the **Auxiliary sweep** checkbox.

7 Click **Add**.

8 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
V0 (Voltage)	`range(0,0.1,1)`	V

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

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

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

3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies** > **Stationary**.

4 Click the **Add Study** button in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2 - TUNNELING

In the **Settings** window for **Study**, type `Study 2 - Tunneling` in the **Label** text field.

Step 1: Stationary

1 In the **Model Builder** window, under **Study 2 - Tunneling** click **Step 1: Stationary**.

2 In the **Settings** window for **Stationary**, click to expand the **Values of Dependent Variables** section.

3 Find the **Initial values of variables solved for** subsection. From the **Settings** list, choose **User controlled**.

4 From the **Method** list, choose **Solution**.

5 From the **Study** list, choose **Study 1 - No Tunneling, Stationary**.

6 From the **Parameter value (V0 (V))** list, choose **First**.

7 Locate the **Study Extensions** section. Select the **Auxiliary sweep** checkbox.

8 Click + **Add**.

9 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
V0 (Voltage)	`range(0,0.1,1)`	V

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

RESULTS

Net Dopant Concentration (semi), Net Dopant Concentration (semi) 1

Right-click and choose **Delete**.

I-V Curve

1 In the **Results** toolbar, click ∿ **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `I-V Curve` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **None**.

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** checkbox. In the associated text field, type `Voltage (V)`.

6 Select the **y-axis label** checkbox. In the associated text field, type `Current (A)`.

7 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

No Tunneling

1 Right-click **I-V Curve** and choose **Global**.

2 In the **Settings** window for **Global**, type `No Tunneling` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1 - No Tunneling/ Solution 1 (sol1)**.

4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
`abs(semi.IO_1)`	A	

5 Click to expand the **Legends** section. Find the **Include** subsection. Select the **Label** checkbox.

6 Clear the **Solution** checkbox.

7 Clear the **Description** checkbox.

Tunneling

1 Right-click **No Tunneling** and choose **Duplicate**.

2 In the **Settings** window for **Global**, type `Tunneling` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 2 - Tunneling/ Solution 3 (sol3)**.

4 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
`abs(semi.IO_3)`	A	

5 In the **I-V Curve** toolbar, click **Plot**.