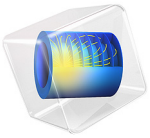

Model created in COMSOL Multiphysics 6.4

Reverse Bias Leakage Current

Introduction

In a diode or a transistor, upon a reverse-biased p–n junction, ideally no current should flow. However, due to presence of minority carriers (electrons on the p-side and holes on the n-side), a small current, known as the reverse-bias leakage current, does flow. While the reverse-bias leakage current is typically small, it plays a crucial role in the overall behavior and performance of semiconductor devices. Managing and minimizing this current is essential for optimizing power efficiency and precision for various applications.

This example shows how a mixed formulation is beneficial for calculating the small leakage current accurately.

Model Definition

Figure 1 shows the 1D model of a PIN diode together with the net doping concentration along the device. The diode consists of three domains, each 1 μm in length. The doping levels corresponding to each domain are defined using the **Analytic Doping Model** feature and the electrodes are defined on both ends using the **Metal Contact** feature. In order to compare the accuracy of the mixed formulation in calculating small leakage currents, two studies are performed. First, with the finite-element quasi-Fermi level discretization, and second, with mixed finite-element log formulation.

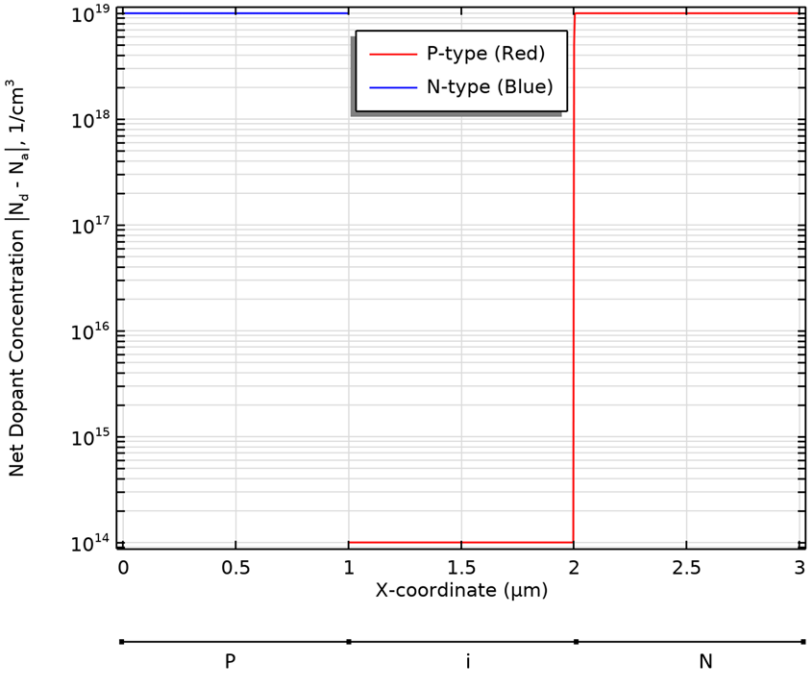

Figure 1: Net doping concentration along the PIN diode, where the 1D modeled device is shown at the bottom.

The procedure of the implementation is described in detail in the Modeling Instructions section.

Results and Discussion

Figure 2 shows the comparison of electron and hole current densities calculated with different discretizations, namely the FEM and mixed formulations.

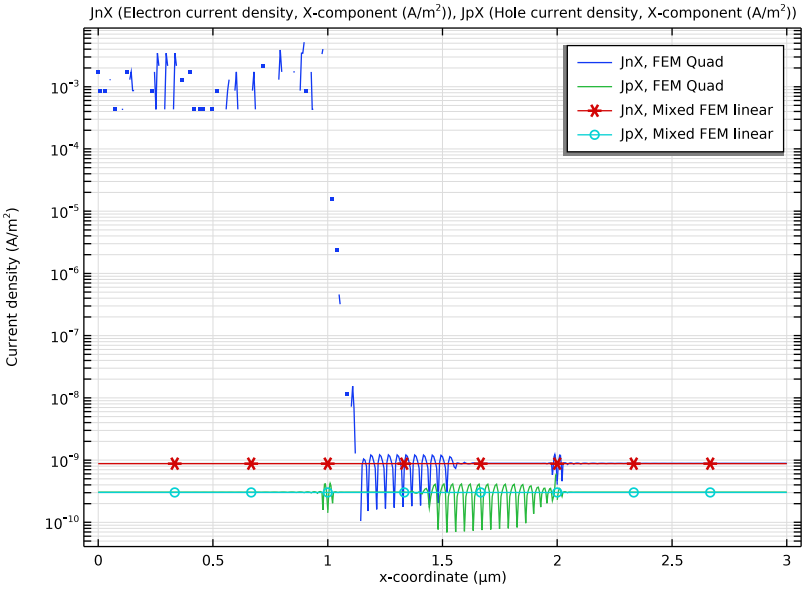

Figure 2: Comparison between current densities calculated with FEM versus Mixed Formulation.

Application Library path: `Semiconductor_Module/Photonic_Devices_and_Sensors/reverse_bias_leakage_current`

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 **ID**.

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

3 Click **Add**.

4 Click **Add**.

5 Click **Study**.

6 In the **Select Study** tree, select **General Studies** > **Stationary**.

7 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
Ndop	1e19[1/cm^3]	1E25 1/m³	
Va	1[V]	1 V	

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**.

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 From the **Coordinate source** list, choose **Vector**.

4 In the **Coordinates** text field, type `0,1,2,3`.

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.

SEMICONDUCTOR (SEMI)

1 In the **Settings** window for **Semiconductor**, click to expand the **Discretization** section.

2 From the **Formulation** list, choose **Finite element quasi Fermi level (quadratic shape function)**.

Analytic Doping Model 1

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

2 Select Domain 1 only.

3 In the **Settings** window for **Analytic Doping Model**, locate the **Impurity** section.

4 From the **Impurity type** list, choose **Donor doping (n-type)**.

5 In the N_{D0} text field, type `Ndop`.

Analytic Doping Model 2

1 Right-click **Analytic Doping Model 1** and choose **Duplicate**.

2 Select Domain 2 only.

3 In the **Settings** window for **Analytic Doping Model**, locate the **Impurity** section.

4 From the **Impurity type** list, choose **Acceptor doping (p-type)**.

5 In the N_{A0} text field, type `1e14[1/cm^3]`.

Analytic Doping Model 3

1 Right-click **Analytic Doping Model 2** and choose **Duplicate**.

2 Select Domain 3 only.

3 In the **Settings** window for **Analytic Doping Model**, locate the **Impurity** section.

4 In the N_{A0} text field, type `Ndop`.

Metal Contact 1

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

2 Select Boundary 4 only.

Metal Contact 2

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

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 `Va`.

5 Select Boundary 1 only.

SEMICONDUCTOR 2 (SEMI2)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Semiconductor 2 (semi2)**.

2 In the **Settings** window for **Semiconductor**, locate the **Discretization** section.

3 From the **Formulation** list, choose **Mixed finite element, log formulation (linear shape function)**.

SEMICONDUCTOR (SEMI)

Analytic Doping Model 1, Analytic Doping Model 2, Analytic Doping Model 3

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Semiconductor (semi)**, Ctrl-click to select **Analytic Doping Model 1**, **Analytic Doping Model 2**, and **Analytic Doping Model 3**.

2 Right-click and choose **Duplicate**.

SEMICONDUCTOR 2 (SEMI2)

Analytic Doping Model 4

Drag and drop on **Semiconductor 2 (semi2)**.

SEMICONDUCTOR (SEMI)

Metal Contact 1, Metal Contact 2

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Semiconductor (semi)**, Ctrl-click to select **Metal Contact 1** and **Metal Contact 2**.

2 Right-click and choose **Duplicate**.

SEMICONDUCTOR 2 (SEMI2)

Metal Contact 3

Drag and drop on **Semiconductor 2 (semi2)**.

STUDY 1

Step 1: Stationary

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

2 In the **Settings** window for **Stationary**, locate the **Study Settings** section.

3 From the **Tolerance** list, choose **User controlled**.

4 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, under **Component 1 (comp1)**, clear the checkbox for **Semiconductor 2 (semi2)**.

5 Locate the **Study Settings** section. In the **Relative tolerance** text field, type `1.0E-4`.

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

7 In the **Settings** window for **Study**, locate the **Study Settings** section.

8 Clear the **Generate default plots** checkbox.

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

ADD STUDY

1 In the **Study** 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.

STUDY 2

1 In the **Settings** window for **Stationary**, locate the **Study Settings** section.

2 From the **Tolerance** list, choose **User controlled**.

3 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, under **Component 1 (comp1)**, clear the checkbox for **Semiconductor (semi)**.

4 Locate the **Study Settings** section. In the **Relative tolerance** text field, type `1E-4`.

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

6 Click **Add**.

7 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Va	0 1	V

8 Click **Add**.

9 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Ndop	1e16	1/cm^3

10 From the **Sweep type** list, choose **All combinations**.

Step 2: Stationary 2

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

2 In the **Settings** window for **Stationary**, locate the **Study Settings** section.

3 From the **Tolerance** list, choose **User controlled**.

4 In the **Relative tolerance** text field, type `1E-4`.

5 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, under **Component 1 (comp1)**, clear the checkbox for **Semiconductor (semi)**.

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
Ndop	1e17 1e18 1e19	1/cm^3

9 In the **Model Builder** window, click **Study 2**.

10 In the **Settings** window for **Study**, locate the **Study Settings** section.

11 Clear the **Generate default plots** checkbox.

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

RESULTS

JnX and JpX Comparison

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

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `JnX (Electron current density, X-component (A/m<sup>2</sup>)), JpX (Hole current density, X-component (A/m<sup>2</sup>))`.

5 In the **Label** text field, type `JnX and JpX Comparison`.

6 Locate the **Plot Settings** section.

7 Select the **x-axis label** checkbox. In the associated text field, type `x-coordinate (μm)`.

8 Select the **y-axis label** checkbox. In the associated text field, type `Current density (A/m<sup>2</sup>)`.

9 Locate the **Axis** section. Select the **y-axis log scale** checkbox.

Line Graph 1

1 Right-click **JnX and JpX Comparison** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **All domains**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `semi.JnX`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type `x`.

7 Click to expand the **Legends** section. Select the **Show legends** checkbox.

8 From the **Legends** list, choose **Manual**.

9 In the table, enter the following settings:

Legends
JnX, FEM Quad

Line Graph 2

1 Right-click **Line Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `semi.JpX`.

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

Legends
JpX, FEM Quad

Line Graph 3

1 Right-click **Line Graph 2** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 From the **Parameter selection (Ndop)** list, choose **Last**.

5 Locate the **y-Axis Data** section. In the **Expression** text field, type `semi2.JnX`.

6 Locate the **Legends** section. In the table, enter the following settings:

Legends
JnX, Mixed FEM linear

7 Click to expand the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

8 From the **Positioning** list, choose **Interpolated**.

Line Graph 4

1 Right-click **Line Graph 3** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `semi2.JpX`.

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

Legends
JpX, Mixed FEM linear

5 In the **JnX and JpX Comparison** toolbar, click  **Plot**.