Created in COMSOL Multiphysics 6.3

Shockley Diode

Introduction

The Shockley diode is a four-layer semiconductor device with alternating P- and N-type semiconductor materials. Unlike conventional diodes, a Shockley diode has more than one p–n junction, forming a PNPN structure. The mode of operation for the Shockley diode is as follows: Upon a small-value forward bias, no current would flow due to the weak internal electric field to overcome the depletion region at the junction. Therefore, the device remains in its OFF state. When the forward bias exceeds a certain voltage, the depletion region shrinks, switching the device to turn ON and allowing current to flow. The Shockley diode remains in its ON state until the current drops and the device switches back to OFF.

The I–V curve of a Shockley diode typically has a loop. This means that a stationary study fails to compute the I–V curve because there are multiple solutions for a specific applied voltage. This model shows how to model a Shockley diode using a time-dependent study to obtain the I–V curve.

Model Definition

Figure 1 shows a 1D model of the PNPN structure of a Shockley diode together with the net doping concentration along the device. The device consists of four domains with alternating P- and N-doped domains defined by an Analytic Doping Model node. The electrodes are defined on both ends using a Metal Contact node. The cathode contact is grounded and a time-dependent voltage, based on a triangle function, is applied to the anode contact.

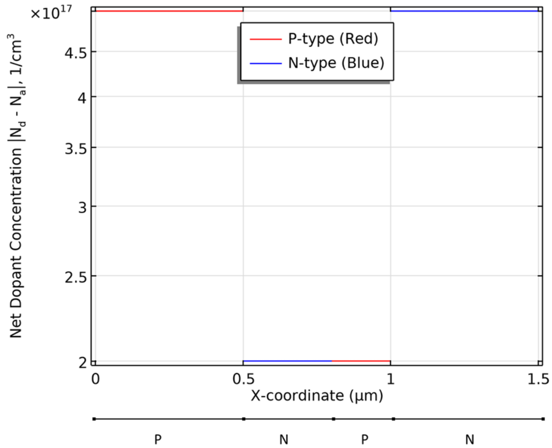

Figure 1: Net doping concentration along the PNPN structure of the Shockley diode, where the 1D-modeled device is shown at the bottom.

The Modeling Instructions section describes the setup in detail.

Results and Discussion

Figure 2 shows the I–V characteristics of the Shockley diode.

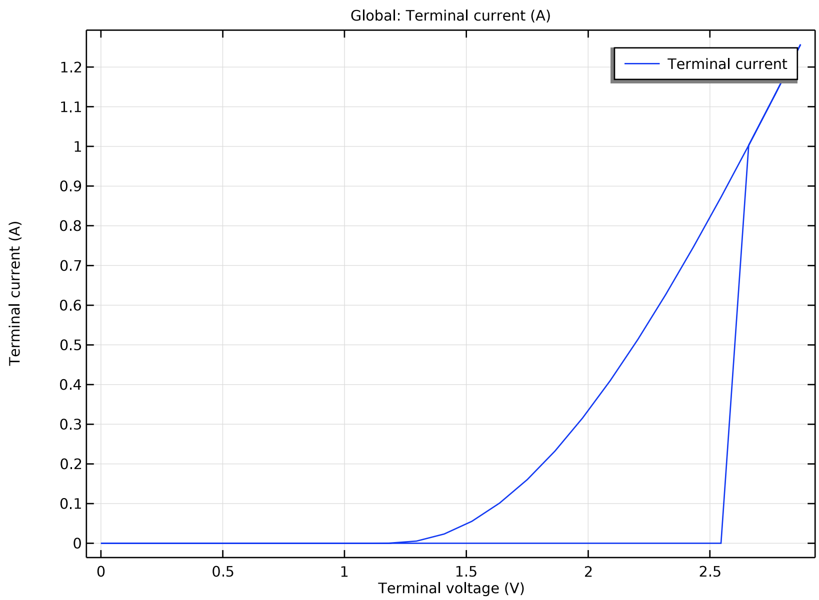

Figure 2: Current versus voltage characteristics of the Shockley diode.

Application Library path: `Semiconductor_Module/Device_Building_Blocks/shockley_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

Triangle 1 (tri1)

1 In the **Home** toolbar, click f(X) **Functions** and choose **Global** > **Triangle**.

2 In the **Settings** window for **Triangle**, locate the **Parameters** section.

3 In the **Lower limit** text field, type `0.06`.

4 In the **Upper limit** text field, type `0.94`.

Parameters 1

1 In the **Model Builder** window, 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	3[V]*tri1(t/6[ms])	0 V	Anode voltage
t	0[s]	0 s	Time

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 **Specify** list, choose **Interval lengths**.

4 In the table, enter the following settings:

Lengths (µm)
0.5
0.3
0.2
0.5

ADD MATERIAL FROM LIBRARY

In the **Home** toolbar, click **Windows** and choose **Add Material from Library**.

ADD MATERIAL

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

2 In the tree, select **Semiconductors** > **InP - Indium Phosphide**.

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

SEMICONDUCTOR (SEMI)

P Doping 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**, type `P Doping 1` in the **Label** text field.

4 Locate the **Impurity** section. In the N_{A0} text field, type `5e17[1/cm^3]`.

N Doping 2

1 Right-click **P Doping 1** and choose **Duplicate**.

2 In the **Settings** window for **Analytic Doping Model**, type `N Doping 2` in the **Label** text field.

3 Locate the **Domain Selection** section. Click **Clear Selection**.

4 Select Domain 2 only.

5 Locate the **Impurity** section. From the **Impurity type** list, choose **Donor doping (n-type)**.

6 In the N_{D0} text field, type `2e17[1/cm^3]`.

P Doping 3

1 Right-click **N Doping 2** and choose **Duplicate**.

2 In the **Settings** window for **Analytic Doping Model**, type `P Doping 3` in the **Label** text field.

3 Locate the **Domain Selection** section. Click **Clear Selection**.

4 Select Domain 3 only.

5 Locate the **Impurity** section. From the **Impurity type** list, choose **Acceptor doping (p-type)**.

6 In the N_{A0} text field, type `2e17[1/cm^3]`.

N Doping 4

1 Right-click **P Doping 3** and choose **Duplicate**.

2 In the **Settings** window for **Analytic Doping Model**, type `N Doping 4` in the **Label** text field.

3 Locate the **Domain Selection** section. Click **Clear Selection**.

4 Select Domain 4 only.

5 Locate the **Impurity** section. From the **Impurity type** list, choose **Donor doping (n-type)**.

6 In the N_{D0} text field, type `5e17[1/cm^3]`.

Anode Contact

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

2 In the **Settings** window for **Metal Contact**, type `Anode Contact` in the **Label** text field.

3 Select Boundary 1 only.

4 Locate the **Terminal** section. In the V_0 text field, type `V0`.

Cathode Contact

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

2 In the **Settings** window for **Metal Contact**, type `Cathode Contact` in the **Label** text field.

3 Locate the **Boundary Selection** section. Click **Clear Selection**.

4 Select Boundary 5 only.

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

STUDY 1

Step 2: Stationary

In the **Study** toolbar, click **Study Steps** and choose **Stationary > Stationary**.

Step 3: Time Dependent

1 In the **Study** toolbar, click **Study Steps** and choose **Time Dependent > Time Dependent**.

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

3 From the **Time unit** list, choose **ms**.

4 In the **Output times** text field, type `range(0,0.1,6)`.

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

RESULTS

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.

Global 1

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

2 In the **Settings** window for **Global**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)** > **Semiconductor** > **Terminals** > **semi.I0_1 - Terminal current - A**.

3 Click **Replace Expression** in the upper-right corner of the **x-Axis Data** section. From the menu, choose **Component 1 (comp1)** > **Semiconductor** > **Terminals** > **semi.V0_1 - Terminal voltage - V**.

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