ECT201 SOLID STATE DEVICES

COURSE COMPLETION PROJECT

Submitted By:

Jose C S

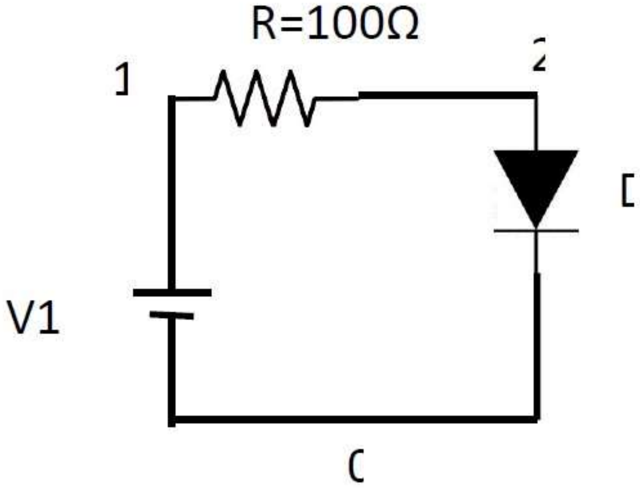
S3 EC-B

Roll Number:27

University Register Number: KNR23EC053

PN-JUNCTION PROJECT

1. *Plot the I-V characteristics of a Si P-N junction diode. Keep the breakdown voltage as 50V. Change the breakdown voltage to 5V and plot the I-V characteristics. What is the difference in the observed outputs? Why?*



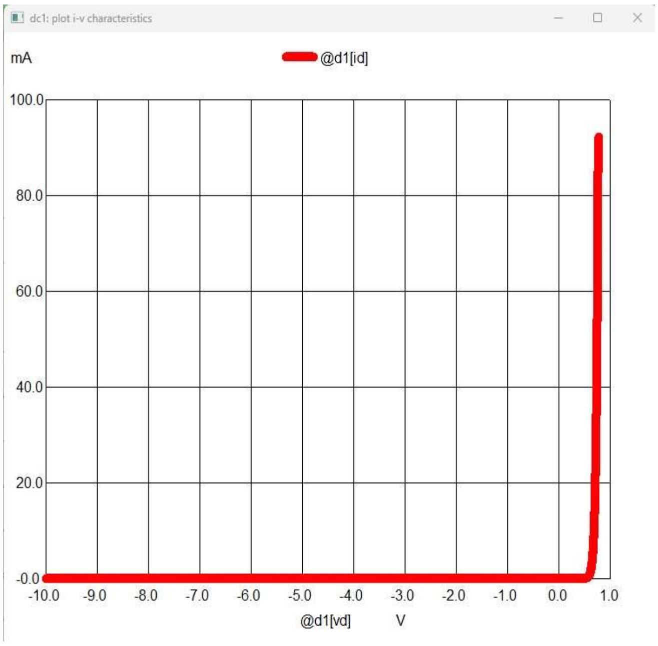
PROGRAM :

```
* Define DC voltage source
V1 1 0 dc 0
* Define current-limiting series resistor
R1 1 2 0.1k
* Define diode
D1 2 0 myd
* Define diode model parameters
* IS is reverse saturation current, VJ is cut-in voltage, BV is breakdown voltage
.model myd D(
 IS = 100p
 + N = 1.45
 + RS = 0
 + TT = 4.3u
 + CJ0 = 40p
 + VJ = 0.7
 + M = 0.33
 + EG = 1.11
 + XTI = 3
 + KF = 0
```

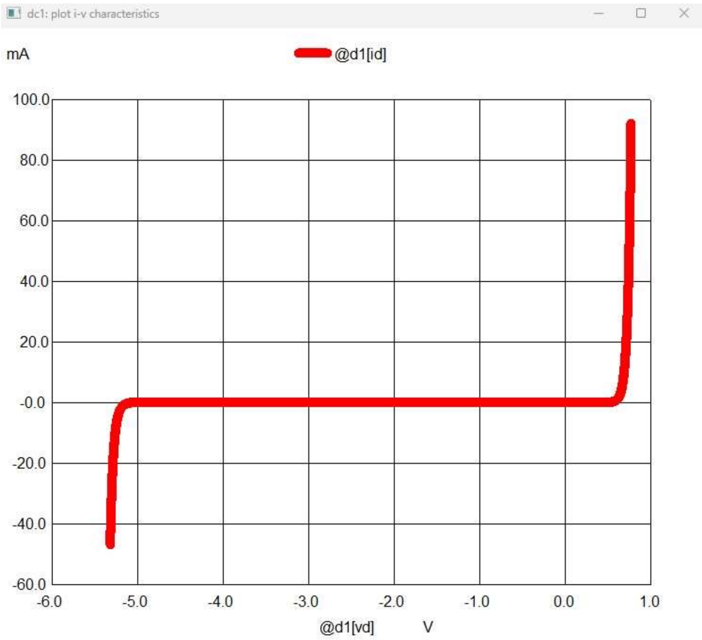
```
 + AF = 1
 + FC = 0.5
 + BV = 50
 + IBV = 10u
)

.control
 * Save diode current and voltage values
 save @D1[id] @D1[vd]

 * Run DC analysis from 5V less than breakdown voltage to 10V greater than cut-in voltage
 dc V1 -10 10 0.01

 * Set background color as white, grid lines black, plot line red, and line width = 10
 set color0 = white
 set color1 = black
 set color2 = red
 set xbrushwidth = 10

 * Plot current flowing through diode vs. diode voltage
 plot @D1[id] vs @D1[vd]
.endc
.END
```

Wave Form :

BV = 50



BV = 5



Observations on Diode I-V Characteristics

Circuit Configuration: The circuit is set up to analyze the I-V characteristics of a silicon P-N junction diode. A DC voltage source (V1) is connected in series with a current-limiting resistor (R1) and the diode (D1). The resistor R1 (0.1 kΩ) helps limit the current flowing through the diode, preventing it from reaching excessive values.

Diode Model: The diode D1 is defined using a specific model (myd) with parameters that closely reflect real diode characteristics:

- **Reverse Saturation Current (IS)** : Set to 100 pA, representing the leakage current when the diode is reverse-biased.
- **Junction Potential (VJ)** : Initially set to 0.7V, which is the threshold or "cut-in" voltage where significant current starts to flow.
- **Breakdown Voltage (BV)** : Initially set to 50V, indicating the point at which the diode enters breakdown when reverse-biased.

Afterward, the breakdown voltage is changed to 5V to observe the differences in the I-V characteristics.

Analysis Process:

- **DC Sweep** : A DC sweep is performed with the voltage V1 ranging from -10V to 10V, covering both forward and reverse bias conditions. This range allows observation of the diode's behavior as it approaches breakdown in the reverse bias region and reaches the threshold in the forward bias region.

Plotting Parameters:

- The background color is set to white, with black grid lines and a red plot line for clarity.
- The line width is increased for better visibility of the I-V curve.

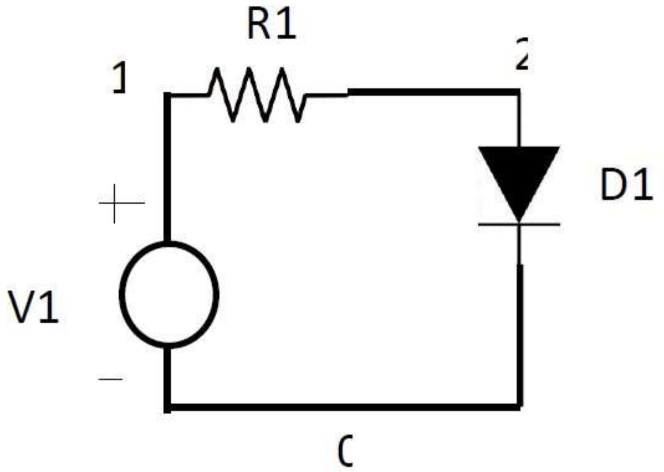
Observations from I-V Characteristics:

1. **Forward Bias Region** : As V1 approaches the cut-in voltage (VJ = 0.7V), the diode current increases exponentially, illustrating the typical forward bias behavior.
2. **Reverse Bias Region (BV = 50V)** : When V1 is negative and far below 0.7V, the current remains close to the reverse saturation value. As V1 approaches -50V (breakdown voltage), the diode would theoretically enter breakdown, leading to a sharp increase in current. However, the series resistor R1 limits this current.
3. **Reverse Bias Region (BV = 5V)** : Changing the breakdown voltage to 5V results in a significant difference in the reverse bias behavior. When V1 approaches -5V, the diode enters breakdown, and the current dramatically increases. The current at this voltage will be much higher than in the previous configuration with a 50V breakdown voltage, and the series resistor will have less effect on limiting the current during breakdown.

Key Takeaways:

- **Forward Conduction** : The diode conducts significantly when the applied voltage is above the threshold voltage (0.7V), showing exponential current increase typical for semiconductor diodes.
- **Reverse Saturation and Breakdown** : In reverse bias, the diode maintains a very low current until breakdown voltage is reached.
- **Impact of Breakdown Voltage** : The difference in breakdown voltage significantly affects the current behavior. With a breakdown voltage of 50V, the diode can withstand higher reverse voltages without conducting significant current, whereas with a breakdown voltage of 5V, the diode enters breakdown at a much lower voltage, leading to a higher reverse current. This highlights the importance of breakdown voltage in diode applications and protection against high reverse currents.

2.Apply a square wave input (-10V to 10V) of time period 2ms to a diode through a series resistor and observe the output. Change the time period from 2ms to 20us and observe the output. What is the difference in the observed outputs? Why? Explain the behavior of current flowing through the diode



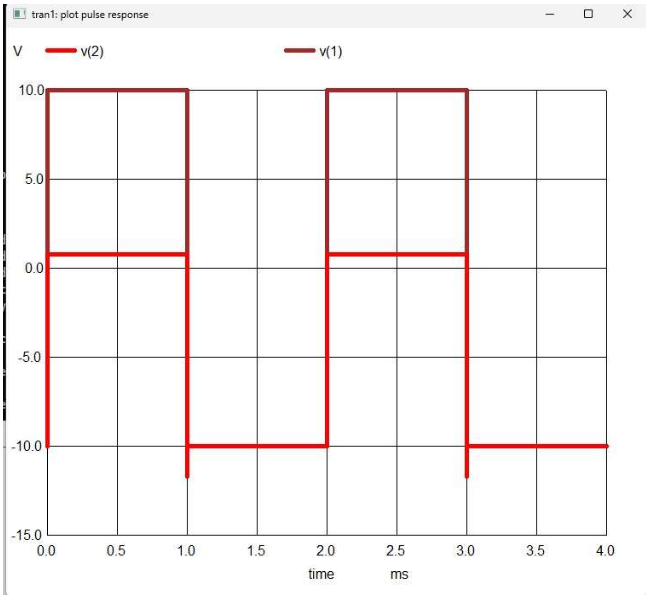
PROGRAM:

```
* Define pulse voltage source
V1 1 0 pulse(-10 10 0.1u 0.1u 0.1u 1m 2m)

* Define current-limiting series resistor
R1 1 2 0.1k

* Define diode
D1 2 0 myd

* Define diode model parameters
* IS is reverse saturation current, VJ is cut-in voltage, BV is breakdown voltage
.model myd D(
 IS = 100p
 + N = 1.45
 + RS = 0
 + TT = 4.3u
 + CJ0 = 40p
 + VJ = 0.7
 + M = 0.33
 + EG = 1.11
 + XTI = 3
 + KF = 0
 + AF = 1
```

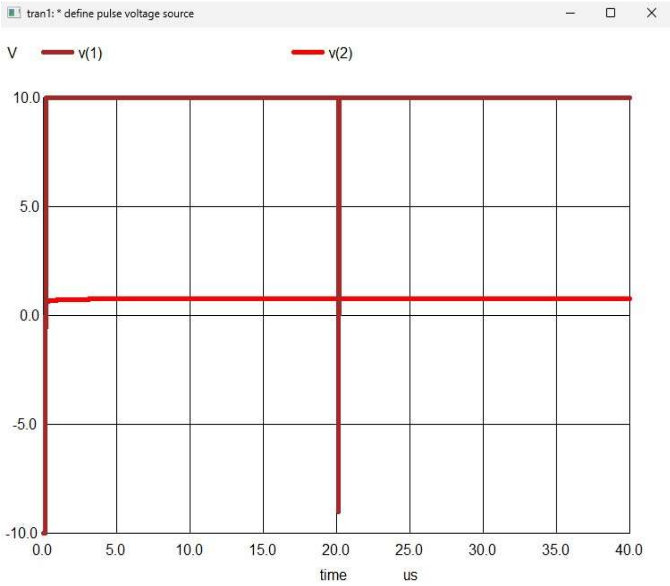
```
  + FC = 0.5
  + BV = 50
  + IBV = 10u
)

.control
  * Save diode current and voltage values, and node voltages
  save @D1[id] @D1[vd] v(1) v(2)

  * Run transient analysis for pulse response
  tran 0.01u 4m

  * Set background color as white, grid lines black, plot color red, and line width = 5
  set color0 = white
  set color1 = black
  set color2 = red
  set color3 = brown
  set xbrushwidth = 5

  * Plot input and output voltages
  plot @D1[id]
  plot v(1) v(2)
.endc

.END
```

WAVE FORMS :

2ms:



2us:



Observations on Diode Response to Square Wave Input

1. **Circuit Configuration:**
   - A square wave voltage source connects to a diode via a series resistor.
   - The square wave alternates between -10V and +10V.
   - Two simulation scenarios are observed:
     - First Simulation: 2 ms period
     - Second Simulation: 20 µs period
2. **Components:**
   - Pulse Voltage Source (V1): Defined as V1 1 0 pulse -10 10 0.1u 0.1u 0.1u 1m 2m for the 2 ms period and V1 1 0 pulse -10 10 0.1u 0.1u 0.1u 1m 20u for the 20 µs period.
   - Series Resistor (R1): 0.1 kΩ.
   - Diode (D1): Modeled with parameters that specify reverse saturation current, cutoff voltage, and breakdown voltage.

Observations:

1. **Output Behavior with a 2 ms Period:**

- The diode conducts when the voltage is positive (+10V) and stops conducting when the voltage is negative (-10V).
- Due to the longer period, the current through the diode gradually reaches a steady state, showing a smooth rise and fall in response to the input.
- This longer time allows the diode to charge and discharge more fully, resulting in a steady waveform.

2. **Output Behaviour with a 20 µs Period:**
    - The diode still conducts during the positive half of the cycle, but due to the shorter period, it doesn't have enough time to fully charge up to its maximum current.
    - The current shows a quick rise and fall, creating a sharper response compared to the 2 ms case.
    - The output oscillates more rapidly, and the current doesn't stabilize as it did with the longer period.

Comparison of Observed Outputs:

- Current Fluctuations: At 20 µs, the current fluctuates more abruptly, creating higher-frequency oscillations in the diode's response. In contrast, with a 2 ms period, the current transitions more smoothly, resulting in stable current levels.
- Charging and Discharging: With the 2 ms period, the diode has sufficient time to reach steady-state current, whereas in the 20 µs case, the diode is switching on and off before fully stabilizing. This produces lower average current in the shorter period.

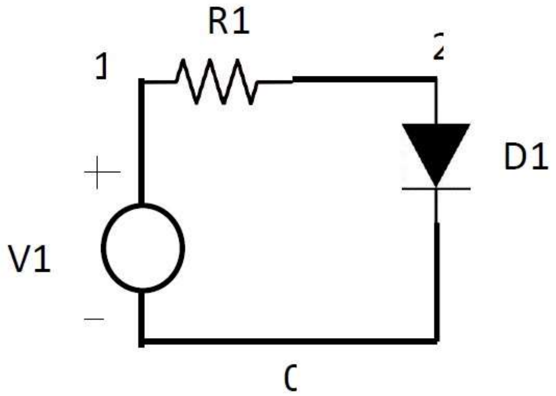
Explanation of Diode Current Behaviour:

- Charging and Discharging Dynamics: The time available for the diode to charge and discharge affects current flow. A longer period allows for greater current stability, while a shorter period leads to faster switching without full charging, yielding a lower average current.
- Response to Frequency: As the input frequency increases (shorter time periods), the diode shifts from a steady-state behavior to a rapid on-off switching pattern.

Conclusion:

- The diode's response to square wave inputs is highly dependent on the input period. Shorter periods lead to high-frequency oscillations with limited current stabilization, while longer periods allow for steady-state behavior and higher current levels.

3.Apply a square wave input (-10V to 10V) of time period 2ms to a diode through a series resistor and observe the output. Keep the breakdown voltage to 50V. Change the breakdown voltage to 5V and observe the output voltage. What is the difference in the observed outputs? Why?

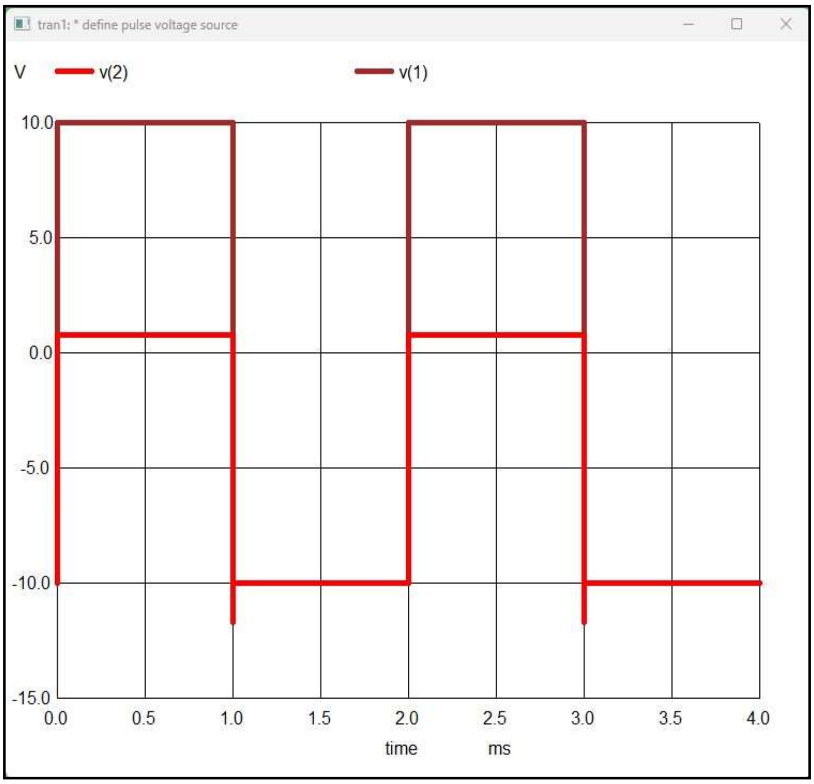


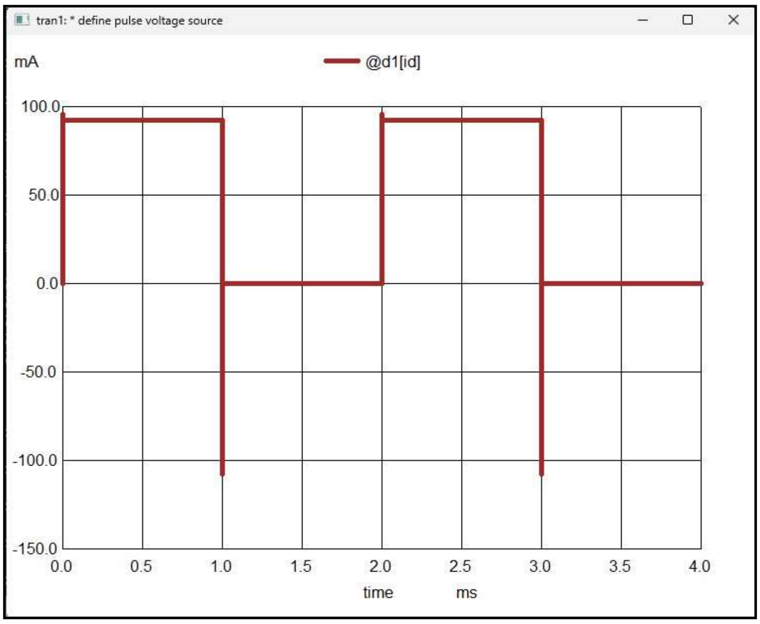
PROGRAM:

```
* Program: Plot Pulse Response

* Define pulse voltage source
V1 1 0 pulse(-10 10 0.1u 0.1u 0.1u 1m 2m)

* Define current-limiting series resistor
R1 1 2 0.1k

* Define diode
D1 2 0 myd

* Define diode model parameters
* IS: reverse saturation current, VJ: cut-in voltage, BV: breakdown voltage
.model myd D(
 IS = 100p
 + N = 1.45
 + RS = 0
 + TT = 4.3u
 + CJ0 = 40p
 + VJ = 0.7
 + M = 0.33
 + EG = 1.11
 + XTI = 3
 + KF = 0
 + AF = 1
```

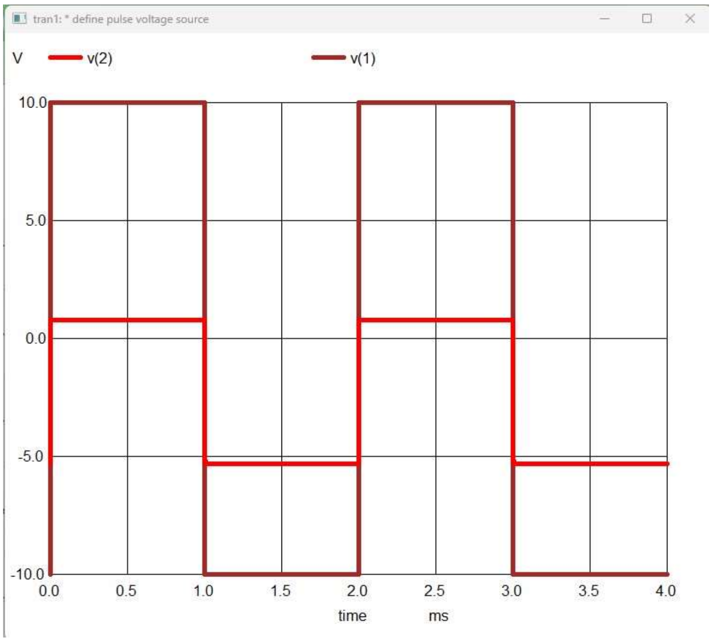
```
  + FC = 0.5
  + BV = 50
  + IBV = 10u
)

.control
  * Save diode current, voltage, and node voltages
  save @D1[id] @D1[vd] v(1) v(2)

  * Run transient analysis for pulse response
  tran 0.01u 4m

  * Set plot colors and line width
  set color0 = white
  set color1 = black
  set color2 = red
  set color3 = brown
  set xbrushwidth = 5

  * Plot input and output voltages
  plot @D1[id]
  plot v(1) v(2)
.endc

.END
```

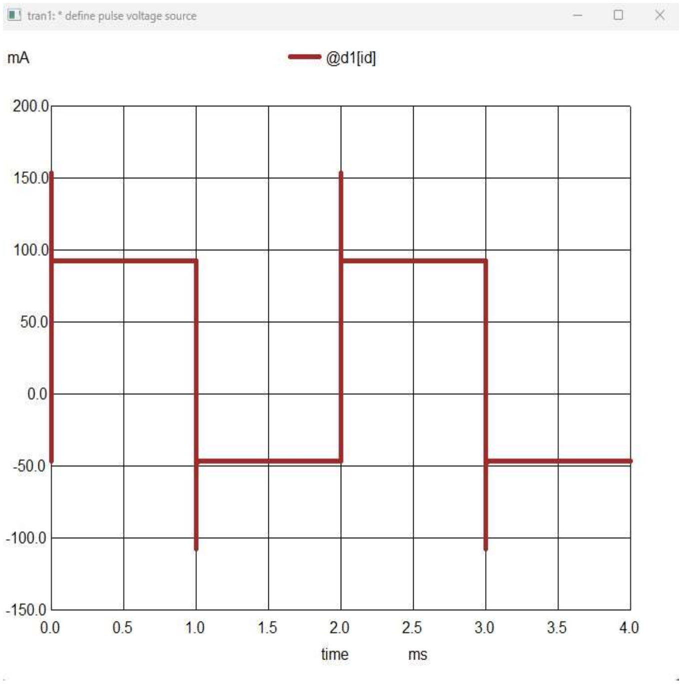
Wave Form :
BV=50V





BV = 5V





Observations on Diode Behavior with Varying Breakdown Voltage

- **Breakdown Voltage Set to 50V:**
  - The diode demonstrates typical behavior when subjected to a square wave input varying from -10V to +10V.

- The output voltage closely follows the input, with the diode conducting during the positive half of the waveform and blocking during the negative half.
- When the diode is forward-biased (with input voltage greater than approximately 0.7V), the current flowing through it is positive and limited by the series resistor.
- During the negative half-cycle, the diode is reverse-biased, causing the current to approach zero, as the breakdown voltage is not reached.

 Breakdown Voltage Changed to 5V:

- The diode continues to conduct during the positive half of the waveform; however, it begins to conduct in reverse when the input voltage hits the breakdown threshold of 5V.
- The output voltage behavior changes considerably; as the input turns negative, the diode conducts in reverse when the input voltage exceeds -5V. This leads to a larger negative current flowing through the diode.
- Consequently, there is a clamping effect on the output voltage, which stabilizes at approximately -5V during the negative cycle.

 Comparison of Outputs:

- With a breakdown voltage of 50V, the output waveform remains well within the typical diode conduction limits, staying safely below the breakdown threshold during reverse bias.
- In contrast, with a breakdown voltage of 5V, the output gets clipped at -5V during negative cycles, creating a more complex waveform due to the diode's reverse conduction.

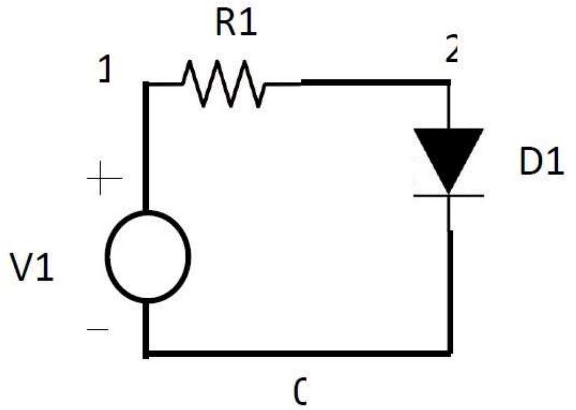
 Behavior of Current Flowing Through the Diode:

- When the breakdown voltage is higher, the diode behaves as expected for standard rectification, conducting only during forward bias.
- Reducing the breakdown voltage leads to reverse conduction, which can result in potentially damaging effects if the circuit is not designed to handle such behavior.

 Conclusion:

- The selection of breakdown voltage has a significant impact on the diode's behavior and output response within a circuit.
- Grasping these dynamics is essential for designing circuits that must perform reliably under various operational conditions.

4. Apply a sine wave of Vmax=10V, Frequency=1KHz and observe the output.

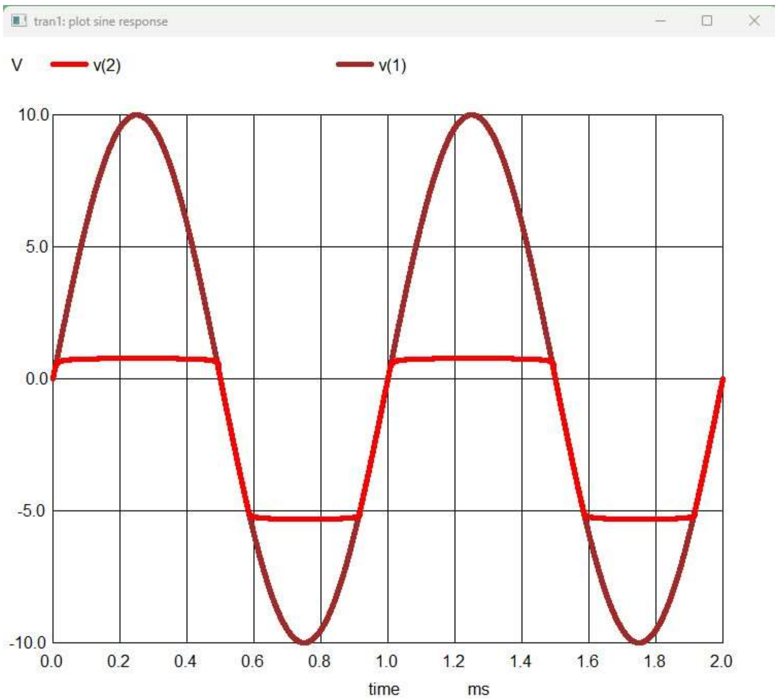


PROGRAM:

```
* Plot Sine Response
* Define sinusoidal voltage source
V1 1 0 sin(0 10 1000)

* Define current limiting series resistor
R1 1 2 0.1k

* Define diode
D1 2 0 myd

* Define diode model parameters
* IS is reverse saturation current, VJ is cut in voltage, BV is breakdown voltage
.model myd D(IS = 100p
 + N = 1.45
 + RS = 0
 + TT = 4.3u
 + CJ0 = 40p
 + VJ = 0.6
 + M = 0.33
 + EG = 1.11
 + XTI = 3
 + KF = 0
 + AF = 1
 + FC = 0.5
 + BV = 5
 + IBV = 10u)

.control
* Run transient analysis
```

```
tran 0.1u 2m

* Set background color as white, grid lines black, plot red and width of the line = 10
set color0=white
set color1=black
set color2=red
set color2=brown
set xbrushwidth=5

* Plot input and output voltages
plot v(1) v(2)
.endc

.END
```

Wave Form :



Observations on the Sinusoidal Response of the Diode Circuit

Circuit Configuration:
The circuit consists of a sinusoidal voltage source (V1) that provides an alternating current (AC) signal, a

series current-limiting resistor (R1), and a diode (D1) characterized by specific model parameters. The voltage source generates a sinusoidal waveform with an amplitude of 10V and a frequency of 1 kHz.

Diode Model Parameters:

- The diode is modeled with the following specifications:
  - Reverse saturation current (IS) of 100 pA.
  - Cut-in voltage (VJ) of 0.6V, indicating that the diode begins to conduct significantly once the input voltage exceeds this threshold.
  - Breakdown voltage (BV) of 5V, meaning that when reverse-biased beyond -5V, the diode will enter breakdown mode, clamping the output voltage.

Analysis Procedure:

A transient analysis was conducted for a duration of 2 ms, with a step size of 0.1 µs, allowing for the observation of the circuit's response across multiple cycles of the input waveform.

Waveform Observations:

1. **Positive Half-Cycle Response:**
   - During the positive half-cycle of the sinusoidal input (ranging from 0V to +10V), the diode becomes forward-biased as the input exceeds the cut-in voltage of 0.6V.
   - The output voltage across the diode closely follows the input waveform, beginning at approximately 0.6V and rising to nearly +10V as the input voltage increases.
2. **Negative Half-Cycle Response:**
   - In the negative half-cycle (from 0V to -10V), the diode is reverse-biased.
   - As the input voltage approaches -5V, the diode enters reverse breakdown, causing the output voltage to be clamped near -5V. This demonstrates the diode's ability to limit the negative excursion of the waveform.
   - The output does not drop below -5V, showcasing the diode's clamping behavior.
3. **Output Characteristics:**
   - The output waveform exhibits a clipping effect during the negative half-cycle due to the breakdown voltage, resulting in a characteristic waveform where the negative peaks are flattened.
   - The positive peaks of the output closely follow the input but start to flatten out around the cut-in voltage threshold as the diode begins to conduct.

Summary of Observations:

- The diode effectively shapes the sinusoidal waveform, allowing for amplification during forward bias while limiting the voltage during reverse bias.
- The output voltage clearly demonstrates a clamping effect at -5V, illustrating the diode's behavior under varying bias conditions.
- This circuit configuration is particularly useful in applications where signal limiting is essential to protect downstream components from excessive negative voltages while still accommodating positive signal variations.