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Experiment-03

Study of I-V Characteristics, Verification of CVD Model and Implementation of Logic Gates of Diode

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To study the current-voltage characteristics, i.e. I-V characteristics of silicon p-n junction diodes
2. To verify the Constant Voltage Drop (CVD) model of a diode
3. To implements Logic Gates of diode

Equipment

1. p-n junction diode (1N4007)
2. Resistance ($1k\Omega$, $2.2k\Omega$, $2.7k\Omega$, $10k\Omega$)
3. Function Generator
4. Oscilloscope
5. DC power suply
6. Trainer Board
7. Breadboard, Wires
8. Digital Multimeter

Background Theory

I-V Characteristics

I-V characteristic defines the relationship between current flow and voltage across two terminals of a device or element. It is a tool for understanding the operation of the circuit. The I-V characteristics are found by evaluating the response of a device/element under different conditions. The behavior of a device depends on the applied excitation and can change if the excitation changes. For example, a device may act as an "open circuit" under certain input conditions and as "voltage source" in another. A diode acts as an open circuit below a specific threshold voltage and acts differently beyond it. A simple circuit with a voltage source and an electronic device is shown in the figure above. The voltage source acts as an excitation medium for the device. Varying the voltage source would result in change in the current flow, I_d across the device. By plotting this current with respect to the voltage across the device, V_d, the I-V characteristics of this device can be determined.

I-V characteristics illustrates the behaviour of a device which is enough to know the device. Depending on the I-V characteristics, the devices can be divided into two categories:

(1) Linear Devices (2) Non-linear Devices

If the current through a device is a linear function of the applied voltage across it, it is a linear device.

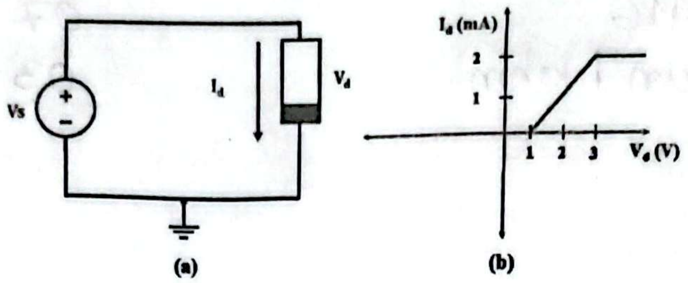


Figure 1: *(a) A circuit with a voltage source, (b) I-V characteristic of the device*

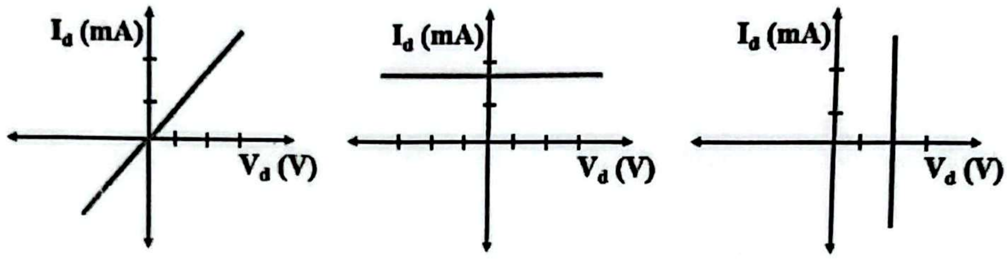


Figure 2: *I-V characteristics of some linear elements*

If the current through a device is a non-linear function of the applied voltage across it, it is a non-linear device.

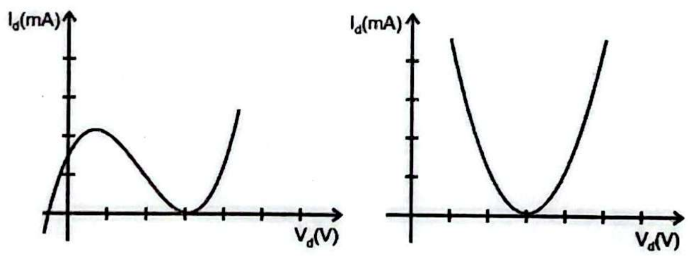


Figure 3: *I-V curves of some non-linear elements*

In this experiment, we will study the I-V characteristics of diodes which is an electronic device. We will observe that, diodes exhibit non-linear I-V characteristics.

Introduction to Diode

Diode is a semiconductor device that allows current flow only in one direction, from p to n or anode to cathode. The schematic diagram, diode notation and circuit symbol are shown in the figure above. Diodes are usually marked with a dot or a bar appearing on the cathode side. This mark helps identify the diode terminals.

I-V Characteristics of a Real Diode

Real diodes are made of semiconductor materials, which have highly non-linear I-V characteristics. However, under certain conditions and approximations, the real diode behaves like an ideal diode.
For a real diode, the current I_D when a voltage V_D is applied across it is given by:

$$I_D = I_S\left(\exp\left(\frac{V_D}{nV_T}\right) - 1\right)$$

Here,

- I_S is called the reverse saturation current
- n is called the diode ideality factor, and it has a value between 1 and 2

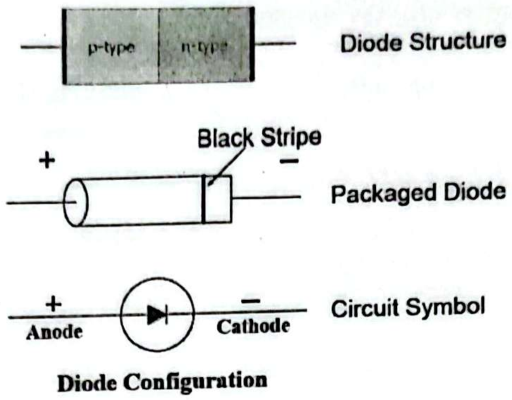


Figure 4: ***Diode Structure, Packaged Diode and Circuit Symbol***

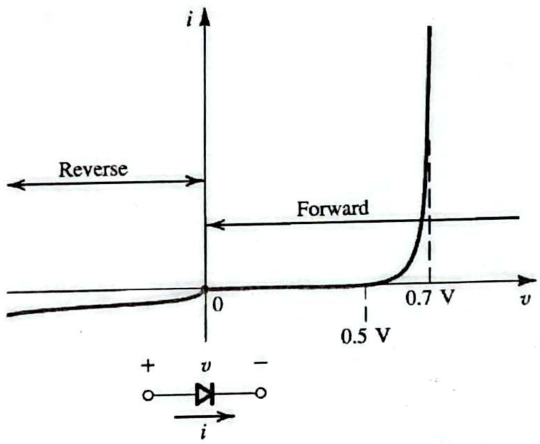


Figure 5: ***I-V Characteristics of a Real Diode***

- V_T is called the thermal voltage, which has a value of 25 mV at 27° C

However, there are 2 special cases:

- When $V_D >> nV_T$: in this case, $exp(V_D/nV_T)$ will be much higher that 1, and hence we can ignore 1. The equation becomes, $I_D \approx I_S\ \exp(V_D/nV_T)$
- When $V_D < 0$: in this case, $\exp(V_D/nV_T)$ will be negligible compared to 1, and hence we can ignore the $\exp(V_D/nV_T)$ term and the equation becomes, $I_D \approx -I_S$

Diode Resistance

As the diode I-V characteristic is not linear, it will have different resistances at different points on the curve. A dynamic or AC resistance for the diode is defined as,

$$r_d = \frac{d}{di}(v) \approx \frac{nV_T}{I_D}$$

The static or DC resistance at any point is defined as, $R_D = V_D/I_D$

Diode Specification

There are many specifications for each type of diode, the most important two are:

1. Peak inverse Voltage (PIV): maximum voltages the diode can tolerate in reverse direction.

2. Maximum Forward Current (I_F) the maximum current the diode can conduct in forward biased condition without exceeding the safe limit.

Diodes are widely used in applications such as mixers, detectors, protection circuits. In this experiment you will investigate its I-V characteristics.

I-V Characteristics of an Ideal Diode

Ideally, we want a diode to behave like an electronic valve. It allows any amount of current in one direction, while blocking all the currents in the opposite direction. This behavior can be characterized using the current and voltage relation between the diode (or for any electronic device) which is also known as the I-V characteristics of the device.

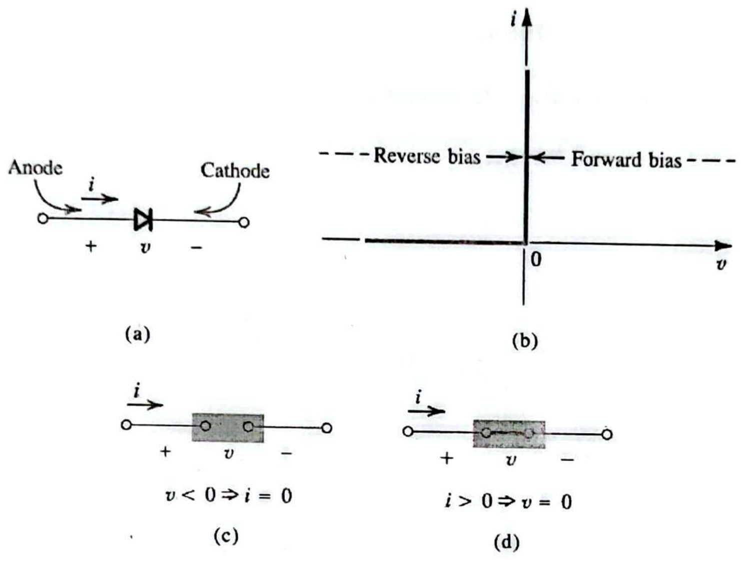


Figure 6: ***I-V Characteristics of an ideal diode***

Ideal Diode Model

In the ideal diode model, the diode acts as a perfect conductor (short circuit) when forward-biased and a perfect insulator (open circuit) when reverse-biased. While this simplifies analysis, it does not accurately reflect real behavior since real diodes exhibit a measurable voltage drop and internal resistance.

Constant Voltage Drop (CVD) Model

To improve on the ideal model, the **CVD model** introduces a constant forward voltage drop V_γ. It assumes that once the diode is forward-biased beyond this threshold, it conducts current freely with no resistance. This model is expressed as:

$$V_D \approx V_\gamma$$

This approximation is acceptable at moderate current levels but fails to explain why the diode voltage slightly increases with increasing current.

CVD + r_d Model (Series Resistance Model)

The **CVD +** r model improves accuracy by including a small internal (dynamic) resistance r_d in series with the constant voltage drop. This series resistance models the diode's real internal resistance due to the bulk semiconductor material and junction properties.

The forward voltage of the diode is given by:

$$V_D = V_\gamma + I \cdot r_d$$

where:

- V_D is the total voltage across the diode,
- V_γ is the constant threshold voltage (typically 0.7 V),
- I is the forward current through the diode,
- r_d is the dynamic (or differential) resistance of the diode in the conducting region.

This equation shows that the diode behaves like a voltage source V_γ in series with a resistor r_d. The model is linear beyond the knee voltage and simplifies circuit analysis using Ohm's Law.

Diode Logic Gates

Diode logic gates use the fundamental property of diodes - allowing current flow in only one direction - to implement basic Boolean operations. In a diode OR gate, multiple diodes have their anodes connected to different inputs and their cathodes tied together at the output, along with a pull-down resistor to ground. When any input goes HIGH, its corresponding diode becomes forward-biased and conducts, pulling the output HIGH; when all inputs are LOW, the diodes block current and the resistor pulls the output LOW, thus implementing the OR function where the output is HIGH if any input is HIGH. Conversely, a diode AND gate uses diodes with cathodes connected to inputs and anodes tied together at the output with a pull-up resistor to the supply voltage. Here, if any input is LOW, its diode conducts and pulls the output LOW; only when all inputs are HIGH do all diodes block, allowing the pull-up resistor to bring the output HIGH, implementing the AND function where the output is HIGH only when all inputs are HIGH. While diode logic offers simplicity and low cost using just passive components, it suffers from voltage drops across diodes (typically 0.7V), inability to provide signal amplification, and cannot implement inversion (NOT gates), which led to its replacement by transistor-based logic in modern circuits.

Task-01: Diode I-V Characteristics

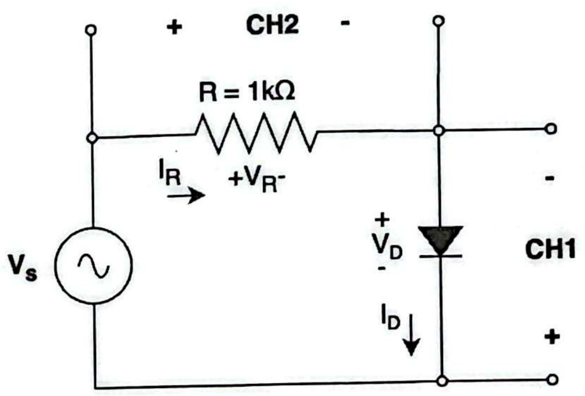


Figure 7: *Circuit-1*

Procedure

1. Construct the circuit given above. Use the function generator to generate a 2V(p-p), 100Hz sine wave for the supply voltage V_S.
2. Connect the CH1 and CH2 of the oscilloscope to the circuit as shown in the figure above.
3. Observe the I-V characteristics of the diode in the XY mode of the oscilloscope and capture the image. To use the XY mode:
   (a) Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).
   (b) We need to invert the CH1 in the oscilloscope due to its inverted connection to the circuit. To do so: Press **CH1** button → Press the **Invert** button which can be found on the bottom of the display of the oscilloscope to select the option **On**.
   (c) Press the **Acquire** button → Press the **XY** button which can be found below the display → Press the **Triggered XY** button which can be found on the right side of the display.

(d) Change the scaling and position of the plot using the **Scale** knob and **Position** knob of both channels, respectively if you need.

You will see a small screen showing the I-V characteristics graph using the XY mode of the oscilloscope. The XY mode plots the voltage data of CH1 and CH2 in the x-axis and y-axis respectively. So, the x-axis represents V_D. As, $I_D = I_R \propto V_R$, the y-axis represents I_D.

(e) Observe the I-V graph and capture it with a camera.

Task-02: Verification of CVD model

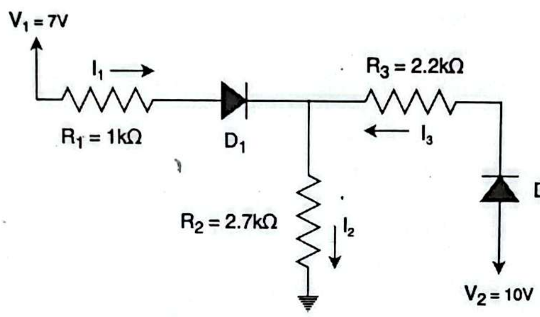


Figure 8: ***Circuit-2***

Procedure

1. Use the Digital Multimeter to measure the resistances R_1, R_2, and R_3, as well as the forward voltage drops V_{Do_1} and V_{Do_2} of diodes D_1 and D_2, respectively. Fill in the tables below with the measured values.
2. Construct the ***Circuit-2*** given above.
3. Use the DC Power Supply to set $V_1 = 7V$ and $V_2 = 10V$ with 0.5A current limit
4. Now, measure the voltages across the resistances and fill out the tables.
5. For theoretical analysis, assume the diode follows the Constant Voltage Drop (CVD) model with a forward voltage drop of V_{D0}. Use the experimental values for both V_{D0} and the resistor in calculations to minimize error.

	V_{Do_1} (V)	V_{Do_2} (V)	R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)	V_{R1} (V)	V_{R2} (V)	V_{R3} (V)	$I_1 = \frac{V_{R1}}{R_1}$ (mA)	$I_2 = \frac{V_{R2}}{R_2}$ (mA)	$I_3 = \frac{V_{R3}}{R_3}$ (mA)	D_1 (on/off)	D_2 (on/off)
Experimental	0.442	0.514	0.986	2.677	2.158	0.609	5.95	3.536	0.618	2.222	1.638	on	on
Theoretical			0.986	2.677	2.158	0.989	6.451	3.035	1.003	2.409	1.406	on	on

Percentage of error $= \left\lvert \frac{\text{Experimental} - \text{Theoretical}}{\text{Theoretical}} \right\rvert \times 100\%$	For I_1	For I_2	For I_3
	38.9%	7.76%	16.5%

Task-03: Logic Gate Implementation

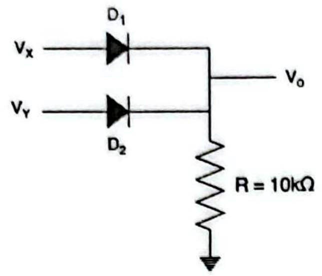


Figure 8a: *Circuit-3 (Diode OR)*

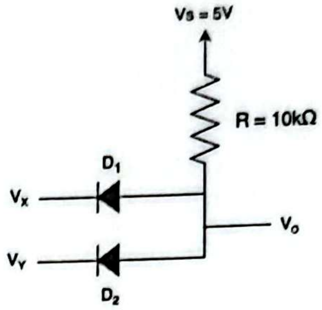


Figure 8b: *Circuit-4 (Diode AND)*

Procedure

1. On a trainer board, set up Circuit-3 (Diode OR).
2. Connect the gate terminals V_X and V_Y to data switches. These switches provide approximately 5V.
3. The Boolean outputs can also be determined by the state of an LED. Connect V_O to one of the LEDs and check it. When the LED is ON, the Boolean output is 1. Similarly, when the LED is OFF, the Boolean output is 0.
4. Next, use the input voltage combinations from the data table of the OR gate below via data switches and observe the state of the LED.
5. Verify the truth table of the OR gate. And then disconnect the LED and measure V_O using multimeter.
6. Now repeat steps 1 through 5 for Circuit-4 (Diode AND). The only change is to connect V_S to the 5V source of the trainer board.

For OR Gate

Input Voltage, V_X (V)	Input Voltage, V_Y (V)	State of LED (On/Off)	Boolean Output (0 or 1)	Output Voltage, V_O (V) (LED Disconnected)
0V	0V	off	0	0.4 mV
0V	5V	on	1	4.15 V
5V	0V	on	1	4.1 V
5V	5V	On	1	4.36 V

For AND Gate

Input Voltage, V_X (V)	Input Voltage, V_Y (V)	State of LED (On/Off)	Boolean Output (0 or 1)	Output Voltage, V_O (V) (LED Disconnected)
0V	0V	off	0	0.494V
0V	5V	off	0	0.502v
5V	0V	off	0	0.582v
5V	5V	on	1	5.1 V

13.07.25

Signature of the lab faculty

Report Submission Guidelines

1. Attach the signed Data Sheet (if any)
2. Attach the captured images (if any)
3. Answer the questions in the "Test Your Understanding" section
4. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
   - What did you learn from this experiment?
   - What challenges did you face and how did you overcome the challenges? (if any)
   - What mistakes did you make and how did you correct the mistakes? (if any)
   - How will this experiment help you in future experiments of this course?

Test Your Understanding

Answer the following questions:

1. $R = 1k\Omega$ was used in the experiment. If we use $R = 2.2k\Omega$, will there be any problem in observing the I-V characteristics plot? Explain briefly.
   Answer:

I-V characteristics plot is the relationship between current flow and voltage across two terminal of a device. In the XY mode of the oscilloscope. CH1 is connected across the diode that plots diode's voltage in X-axis and CH2 with resistor that plots voltage in Y-axis. As the resistor is 1kΩ, we get I=V curve. But in case of 2.2kΩ we get I=0.45V curve which causes the slope of curve to be steeper than usual 1kΩ resistance.

2. From the I-V characteristics of a diode that you obtained, which devices can be used to model the diode?
   Answer:

We obtained I-V characteristics of a diode. In real life scenario, the diode we have does not act like an ideal diode always. So, to get our required IV plot, we can use an ideal diode with a DC voltage source of 0.7V (as we are using sillicon diode) and also a small resistance.

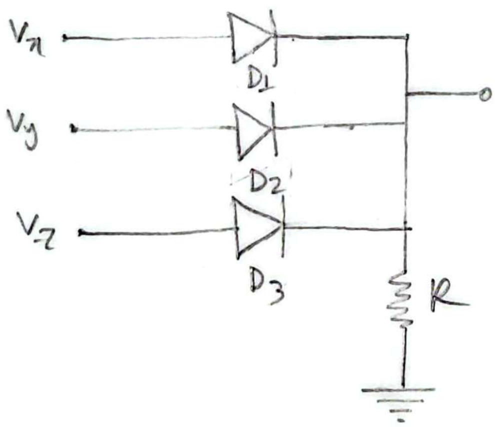
3. Compare the ideal diode model, CVD model and CVD + r model. Which model is better and why?
Answer:

Ideal model: it acts as short circuit when forward biased and open circuit when reverse biased. So, it does not show real-life behaviour accurately since diode exhibits a voltage drop and internal resistance.

CVD model: This model is better than 'Ideal model' since it introduces a constant voltage drop (V_T). In this model once the diode in forward bias reaches the threshold it conducts current without any resistance.

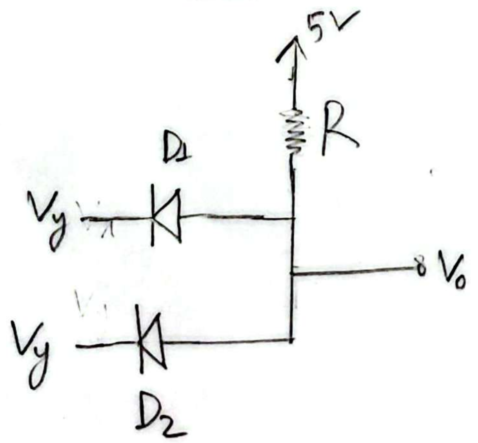
CVD+r model: This model is better than previous ones as it includes a small internal resistance (r_d) in series with the constant voltage drop. This series internal models the diode internal resistance more accurately.

4. Design a 3-input OR gate using diodes and explain why a pull-down resistor is necessary. What happens if the resistor value is too large or too small?
Answer:



Here, R is pull down resistor. It is necessary because when all the diodes are OFF, the diodes block current and the resistor pulls the output Low thus implementing the OR function. If the pull down resistance is too low then high amount of current goes through diode and resistor. If the value is too high, the output will float instead of a solid Low output.

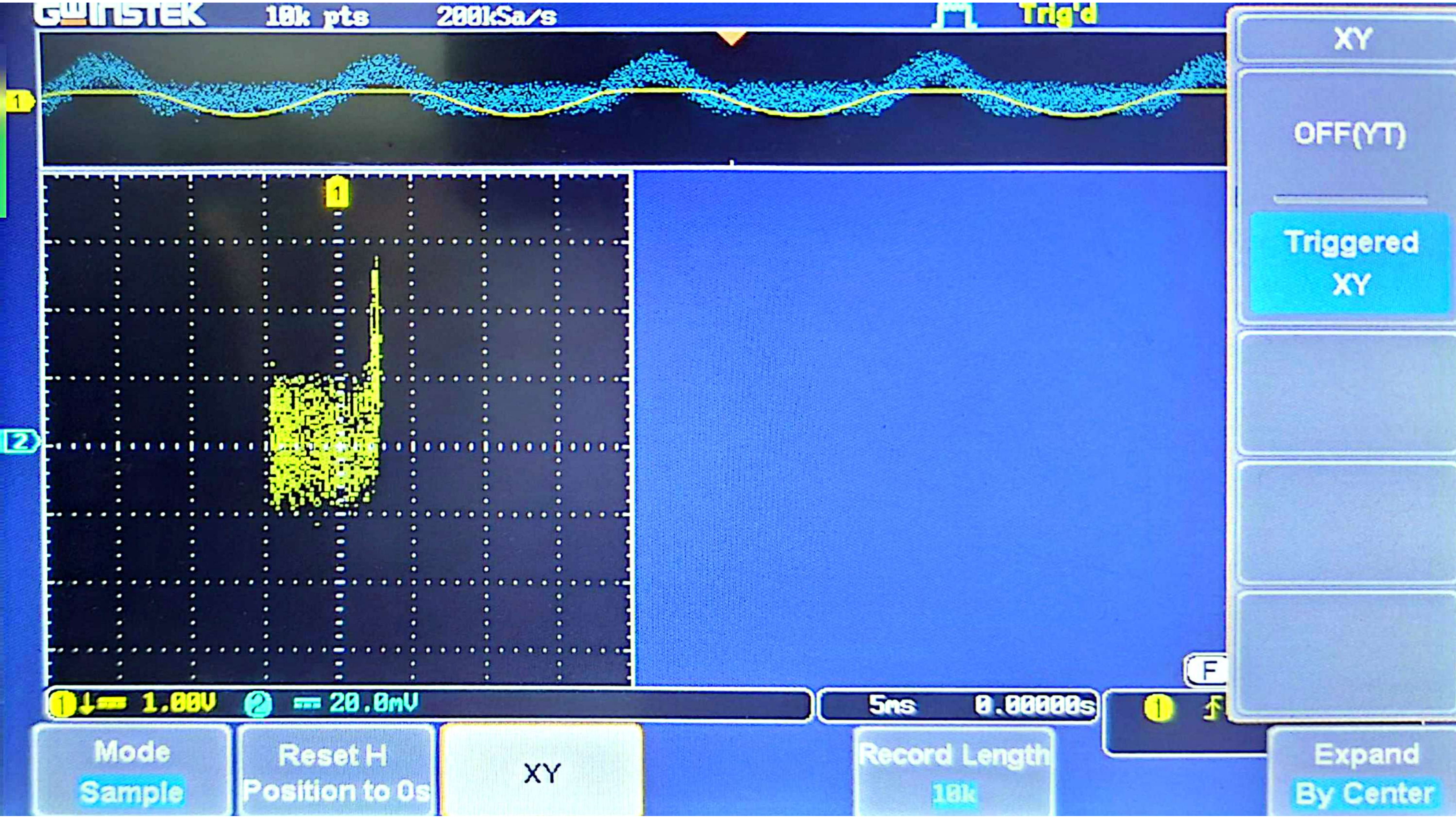
5. Implement a 2-input AND gate using diodes. If the input high level is 5V and low level is 0V, calculate the actual output levels considering 0.7V diode drops.
Answer:



input voltage V_x (V)	input voltage V_y (V)	output voltage
0 V	0 V	0.7 V
0V	5 V	0.7 V
5V	0 V	0.7 V
5V	5V	5 V

Discussion:

I learned how the I-V characteristics of a diode looks like. Then I get to verify the CVD model of diode. Lastly, implement logical AND and OR gate with diodes. These are the things we already knew from the theory. However, verifying them in practical life was interesting. We though had some problems first when plotting the IV plot. We forgot to invert CH-1. We later solved it and got our desired IV plot. We had never used a diode before so it was hard to understand where the p-type and the n-type of the diode located. But, sir explained it to us. Then we went on to complete our tasks. In this lab, we learned how diodes work in real life. It will help us understand the digital electronics better in our future. Overall, the lab was very educative and interesting



10k pts
200kSa/s
Trig'd
XY
OFF(YT)
Triggered XY
1.00V
20.0mV
5ms
0.00000s
Mode
Sample
Reset H Position to 0s
XY
Record Length
10k
Expand
By Center