

## **Abstract**

This is the report of the 3 lab sessions of the course Electronic Devices. Lab session 1 was about exploring the characteristics of forward bias and reverse bias of diodes. Lab session 2 required conducting a basic research on Bipolar Junction Transistor(BJT). Lab session 3, however, was a coursework regarding the Junction Field-effect Transistor(JFET). All of these three components are essential to modern electronic engineering. These three lab sessions provided valuable hands-on experience and a deeper understanding of fundamental semiconductor devices.

## **Introduction**

### **Semiconductor**

A substance that can conduct electricity is named a conductor, in the opposite, a substance that can not conduct electricity is named insulator. Semiconductors, however, have conducting properties which are between conductor and insulator. Due to their unique characteristics, semiconductor-related technologies are widely applied in electronic industries such as ICs(integrated circuits) production.[1]

### **Doping**

The majority of semiconductors are silicon. Unfortunately, the pure silicon's conductivity is too small( $\sigma \approx 1.56 \times 10^{-3} S/m$ ). Therefore, doping is required for industrial practices. There are two types of doping. N-type means adding elements whose valence electrons are more than that of silicon such as phosphorus. P-type indicates adding elements whose valence electrons are less than that of silicon, for example, boron. A very small amount of doping can significantly increase the conductivity of semiconductors.

Intrinsic (Undoped)

Extrinsic (Doped)

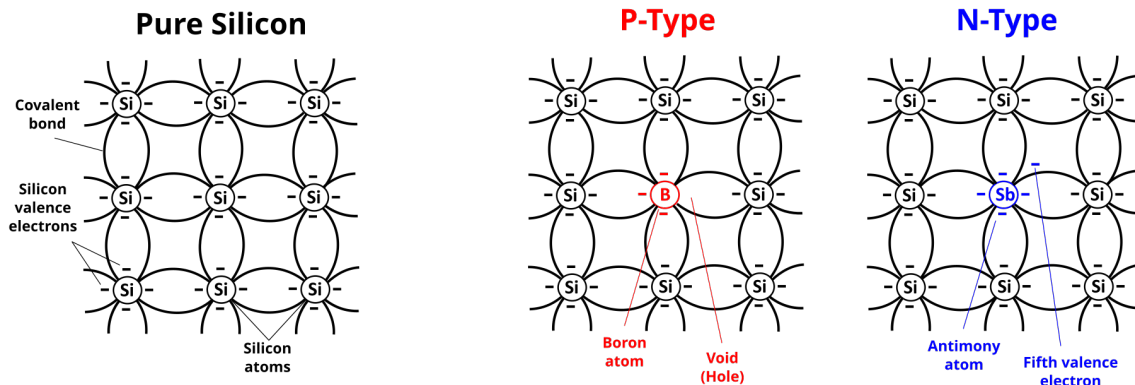


Figure 1: Doping

## PN junction and diodes

A diode is constructed with a P-type semiconductor and a N-type Semiconductor connected in series.

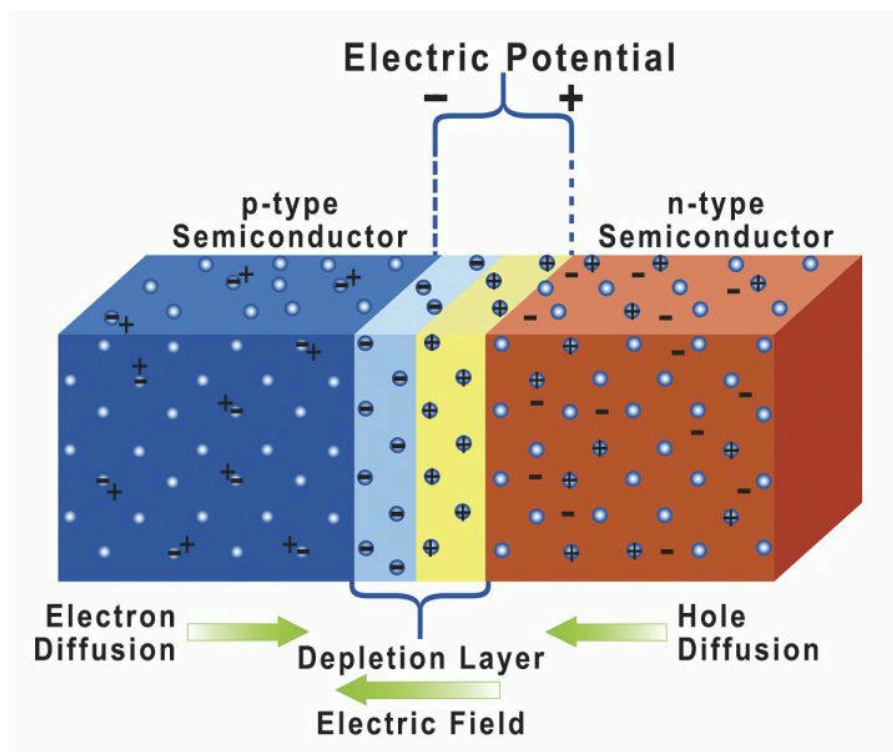
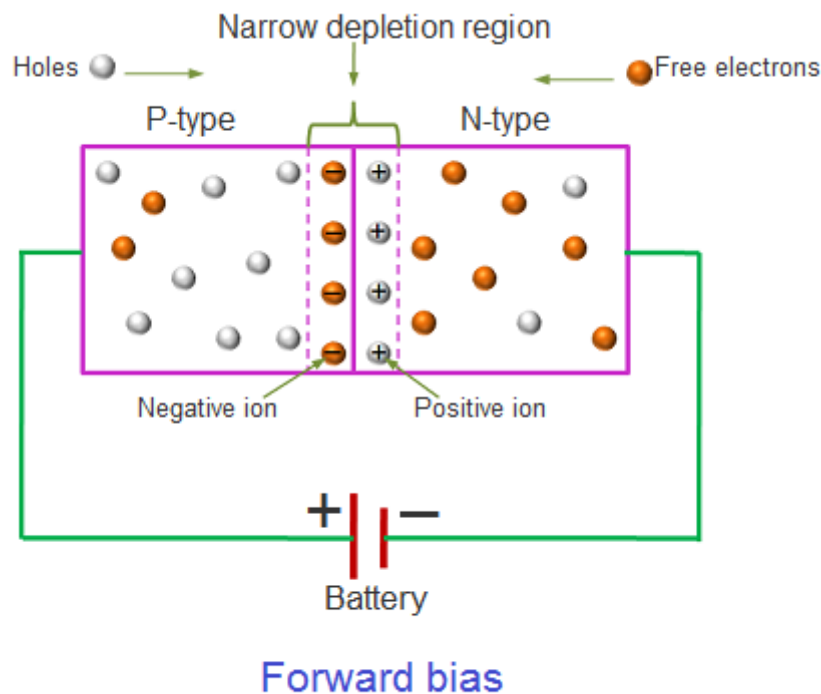


Figure 2: PN junction

The region where two types of materials contact forms the PN junction[2]. The holes which carry positive charges in P-type semiconductors can move freely, while the electrons which carry negative charges in N-type

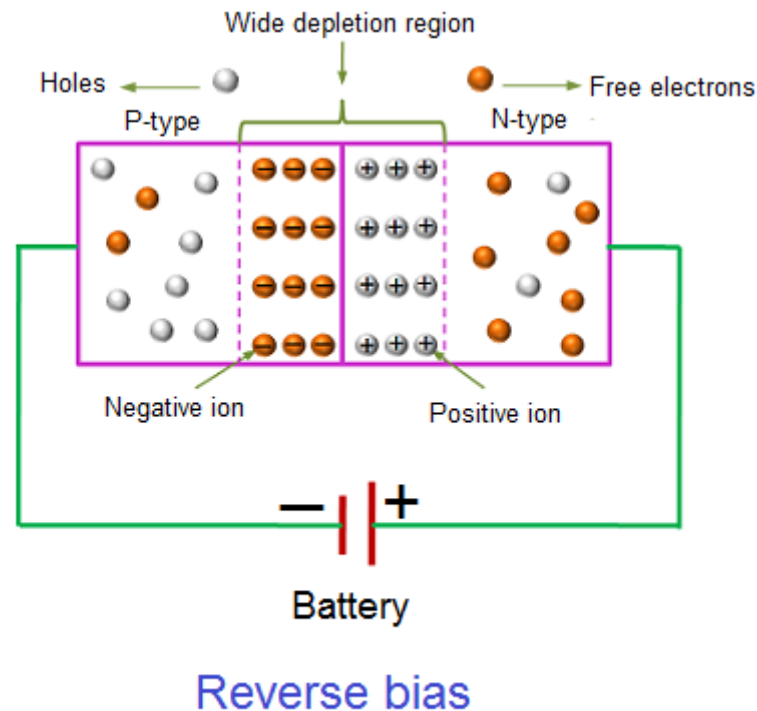
semiconductors can move freely. They both initially flow to another type because of concentration difference. As the holes and electrons carry different types of charges, they will neutralize in region near the contact forming the depletion layer. As these carriers continued to move, the holes that have entered N-type semiconductor and the electrons that have entered P-type semiconductor will form an electric field from N region to P region. This electric field will prevent more carriers from diffusion. A stable depletion layer will establish with this negative feedback mechanism[3]. When a positive voltage is applied between the P region and N region like Figure 3, the external voltage can promote the carriers' diffusion, thinning the depletion layer. The current can be easily established.



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Figure 3: Forward bias

The opposite setup in Figure 4, which is called reverse bias, will thicken the depletion layer and prevent current from establishing.



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Figure 4: Reverse bias

This explains the one-way conduction property of diodes.

## Bipolar Junction Transistor(BJT)

The bipolar junction transistors(BJTs) consists of three blocks of semiconductors. Depending on permutations, it can categorized as NPN(Figure 5) and PNP(Figure 6).BJT can be used to amplify the current or work as a switch to control the current. The two terminals of BJT are called emitter and collector, the pole connected to the central region is called the base. A BJT contains two PN junctions. The BJT have four working states—cutoff, active, saturation and breakdown.

Working states	PN junction near emitter	PN junction near collector
Cutoff	Reverse biased	Reverse biased
Active	Forward biased	Reverse biased
Saturation	Forward biased	Forward biased
Breakdown	Reversed biased	Breakdown

Table 1: Working states of BJT

This lab session focused on the active and saturation regions. In active regions, the BJT satisfies:

$$I_E = I_B + I_C$$

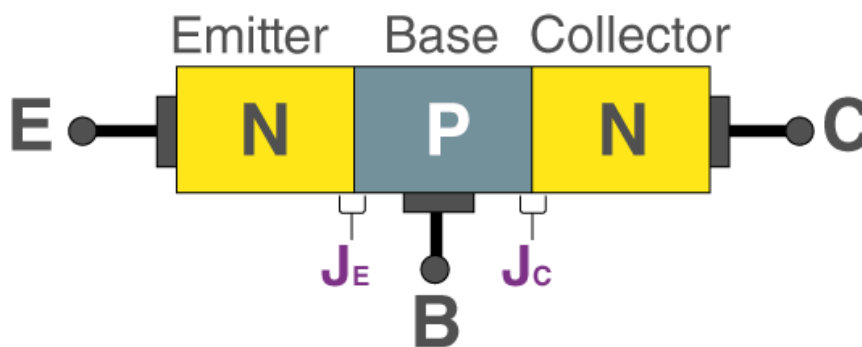
$$I_C = \beta I_B$$

$$V_{CE} > V_{ce \text{ saturation}}$$

Ideally, in this region,  $I_C$  only depends on  $I_B$  regardless of  $V_{CE}$ .

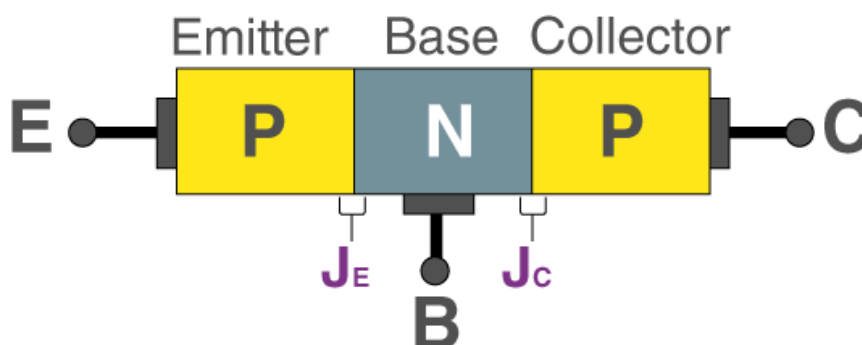
When  $I_B \approx 0$ ,  $I_C \approx 0$ , BJT is in the cutoff region.

In saturation region,  $I_C$  mainly depends on  $V_{CE}$  and it can be complex.



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Figure 5: NPN BJT



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Figure 6: PNP BJT

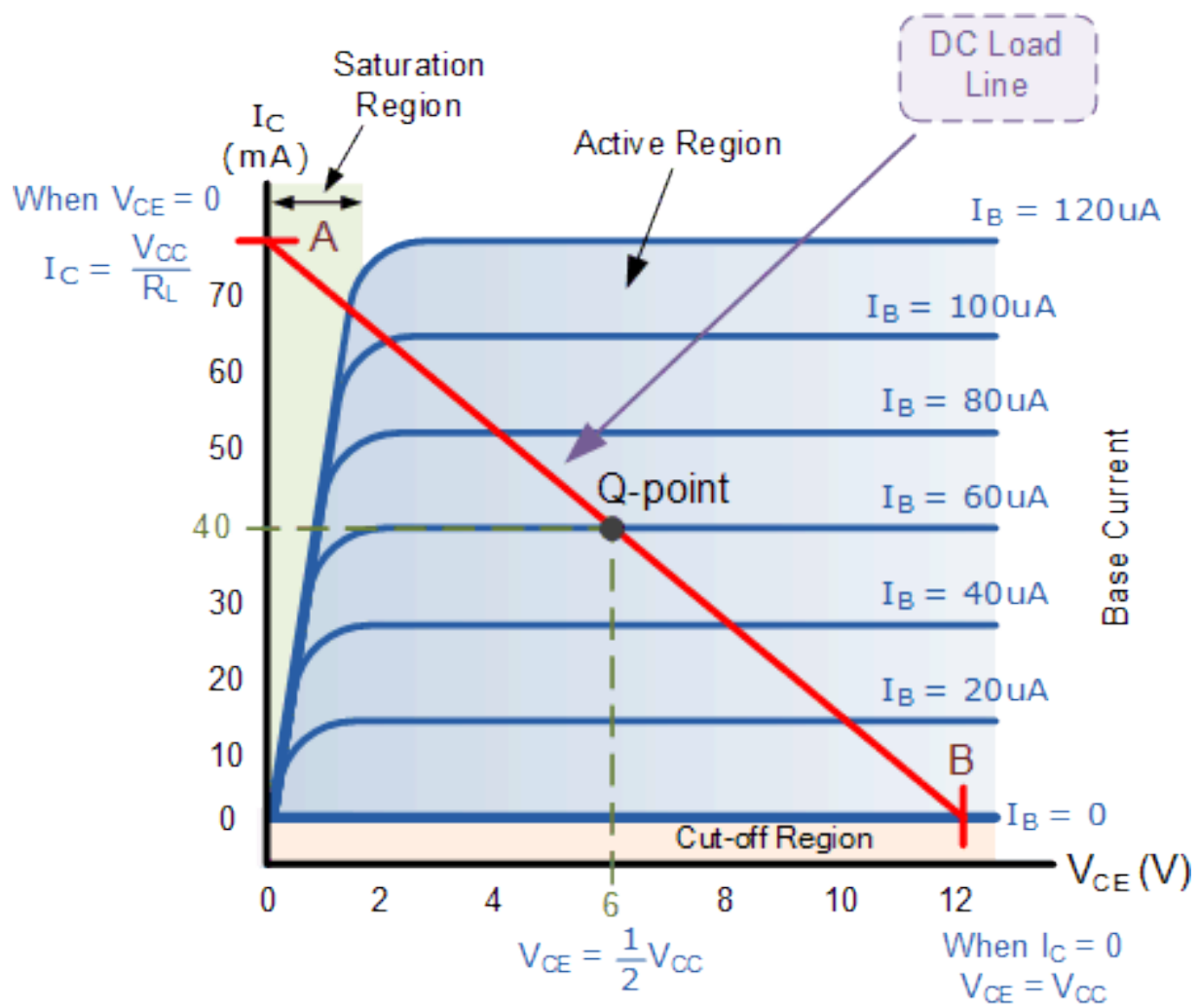


Figure 7: Working regions of BJT

## Junction Field-effect Transistor(JFET)

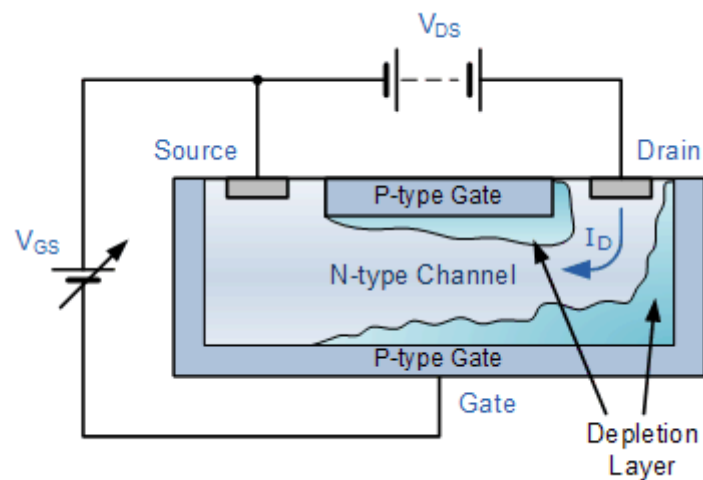


Figure 8: JFET

A typical JFET has the structure like Figure 8. Similarly depending on materials' permutations, there is N-channel and P-channel JFET[4].

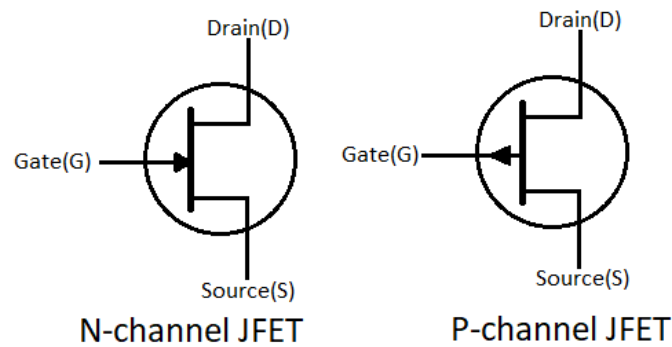


Figure 9: Symbols of two types of JFET

In a certain working condition(e.g certain temperature), a JFET has a unique  $V_P$ . The working states and its relevant information is listed in Table 2.

Linear Region	Condition
Cutoff	$V_{GS} \leq V_p$
Linear	$V_{GS} > V_P, V_{DS} < V_{GS} - V_P$
Saturation	$V_{GS} > V_P, V_{DS} \geq V_{GS} - V_P$

Table 2: JFET Working regions

## Methods

For lab session 1, I built a simple circuit that connecting a diode to a variable voltage source and measure the current across the diode.

For lab session 2 and lab session 3, I used LTSpice to perform simulation and used Jupyter notebook to analyze the data.

## Results

### Lab session 1

#### Forward biased

The voltage-current relationship is shown in Table 3 and Figure 10.

Voltage(V)	Current(A)
0.3	0.012
0.4	0.02
0.5	0.045
0.6	0.105
0.7	0.18
0.9	0.35
1.1	0.529
1.2	0.623
1.3	0.717
1.4	0.812
1.5	0.907
1.6	1.002
1.7	1.098
1.8	1.194
1.9	1.29
2.0	1.387

Table 3: Forward biased

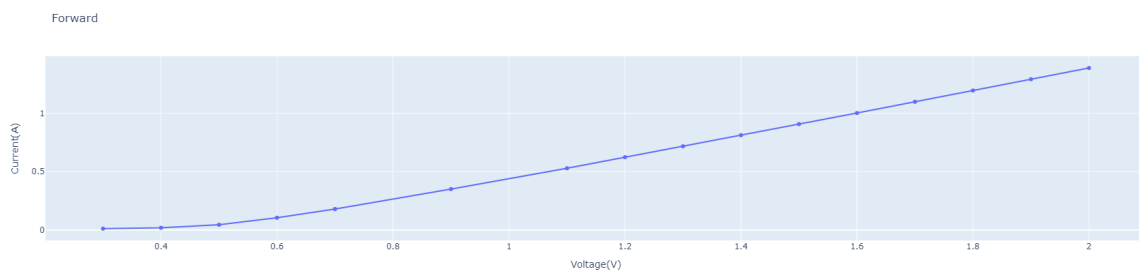


Figure 10: Forward biased

## Reversed biased

The voltage-current relationship is shown in Table 4 and Figure 11.



Voltage(mV)	Current(A)
733	0.16
826	0.18
910	0.18
1002	0.183
1134	0.184
1190	0.188
1267	0.191
1375	0.193
1468	0.203
1561	0.208
1654	0.209
1747	0.209
2210.0	0.21
2670.0	0.21
4530.0	0.48
4720.0	0.48

Table 4: Reversed biased

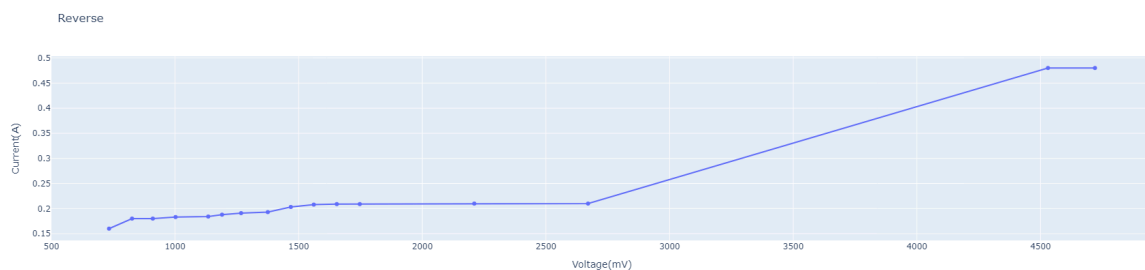


Figure 11: Reversed biased

## Lab session 2

I established a Spice model shown in Figure 12

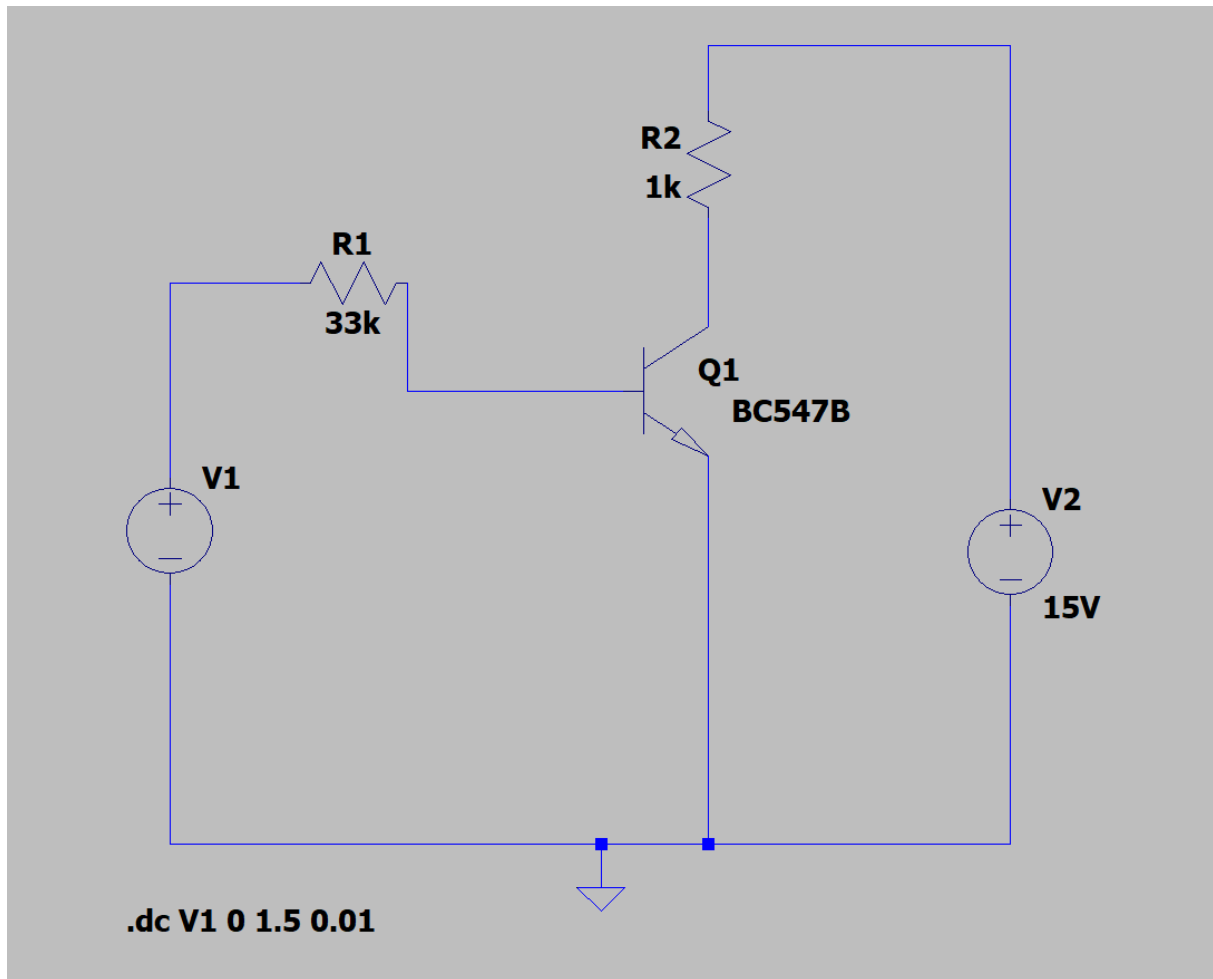


Figure 12: Lab session 2 circuit

For task 1, I observed the relations between  $I_C$  and  $V_{BE}$  when  $V_{CC}$  is equal to a series of values. Four figures was selected and displayed in Figure 13

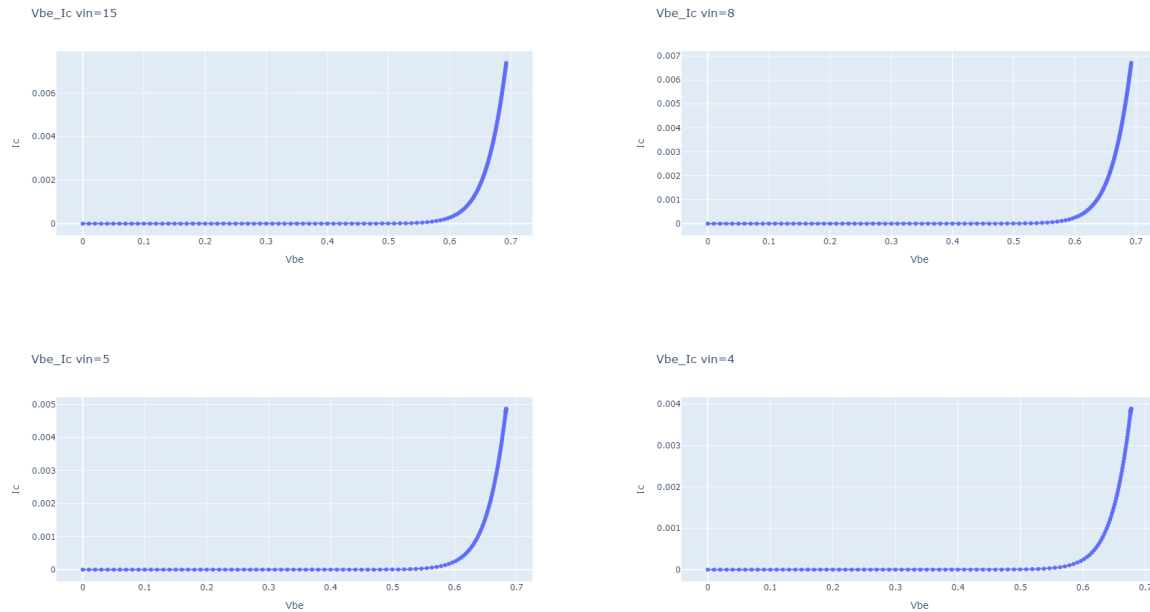


Figure 13: Lab session 2 task1

For task 2, I set  $V_{CC}$  to be 5V. Then,  $V_{BE}$  was adjusted to approximately 1.241 V ensuring that  $V_{CE}$  was close to 5V. Then,  $V_{CC}$  was modified while  $V_{BE}$  was fixed to make  $V_{CE}$  to be 0,0.2,1,3,5,10 V.  $I_C$  is measured meanwhile. The results are shown in Table 5 and Figure 14.

$V_{CE}(V)$	$I_C(mA)$
0	0
0.2	0.171
1	0.935
3	2.88
5	4.64
10	4.99

Table 5: Lab session 2 taks2



Figure 14: Lab session 2 task2

## Lab session 3

I established a Spice model shown in Figure 15.

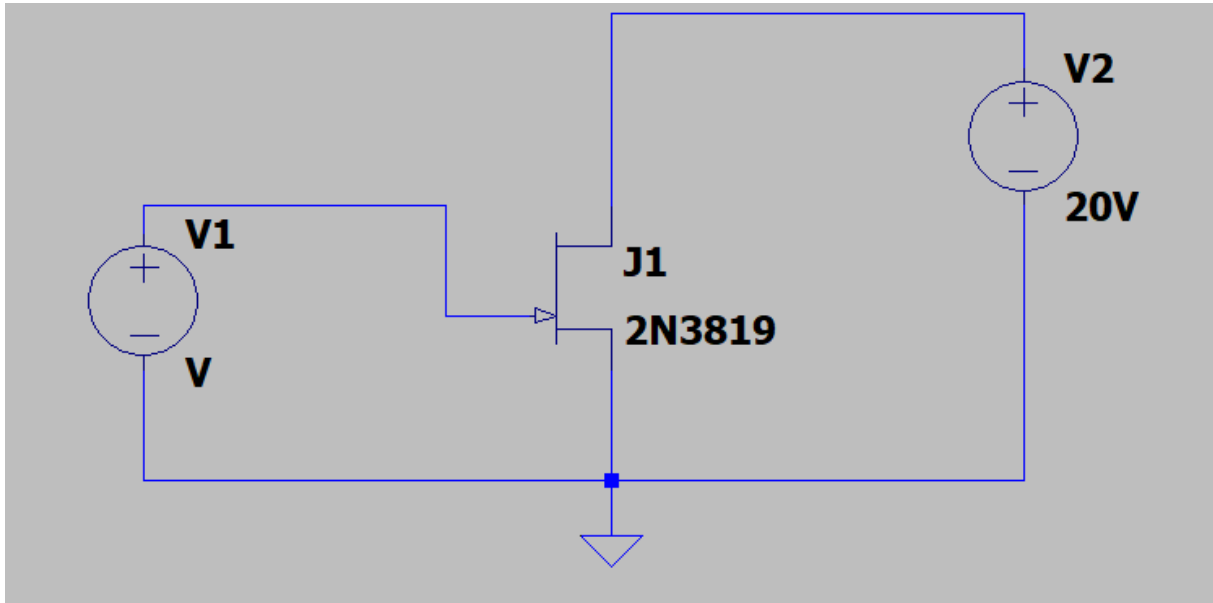
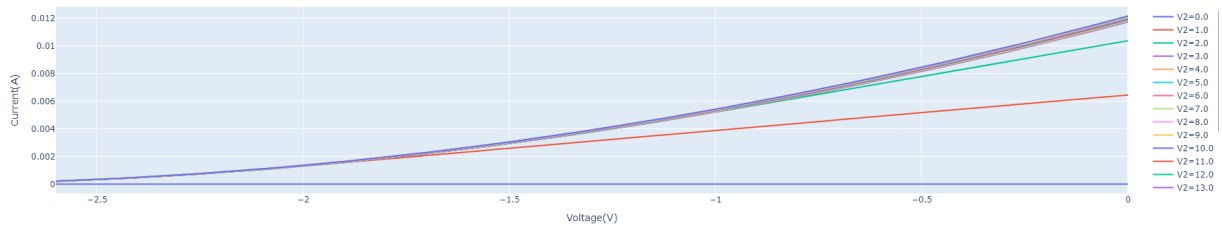
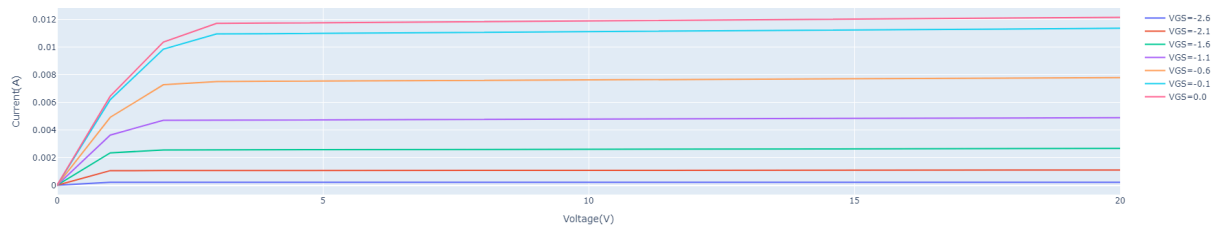


Figure 15: Lab session 3 circuit

The two figures of task 1 are shown in Figure 16.



(a)  $I_D - V_{GS}$



(b)  $I_D - V_{DS}$

Figure 16: Lab session 3 task1

For task 2, I was required to choose a proper operation point Q. When a small signal is applied,  $V_{GS} > 0$  should be avoided, thus, the medium of previous values  $V_{GS} = -1.1V$  or  $V_{GS} = -1.6V$  should be selected.

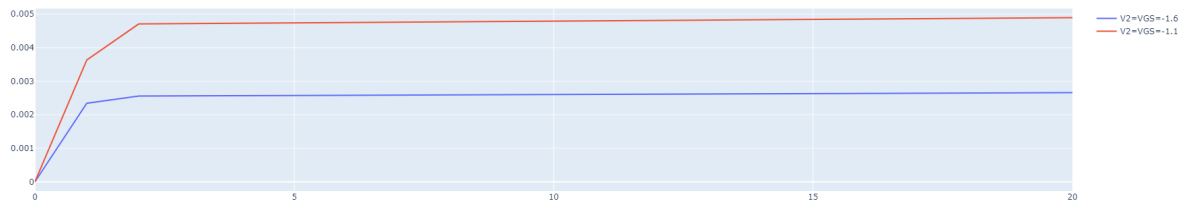


Figure 17: Lab session 3 task 2

For task 3, as the supply voltage is 20V, I should connect the the selected operation point Q and (20,0). The absolute value of slope is the value of  $R_D$ .

$$R_D \approx 1577\Omega$$

The voltage of the battery3 required to bias the gate is  $V_{GS}$  in case  $\approx 1.6V$ .

For task 4.  $R_D$  is integrated and the circuit is displayed in Figure 18. A sine wave is applied.

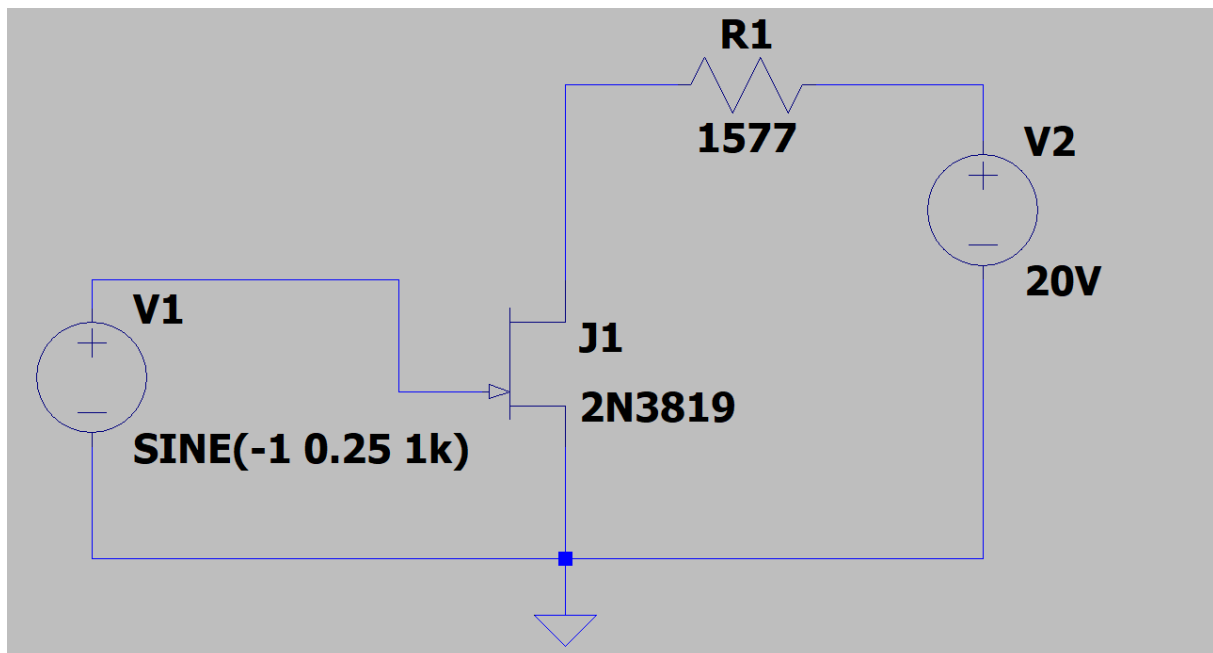


Figure 18: Lab session 3 taske4 circuit

The response to a sine wave of 1kHz  $V_{pp} = 0.25V$  is shown in Figure 19.

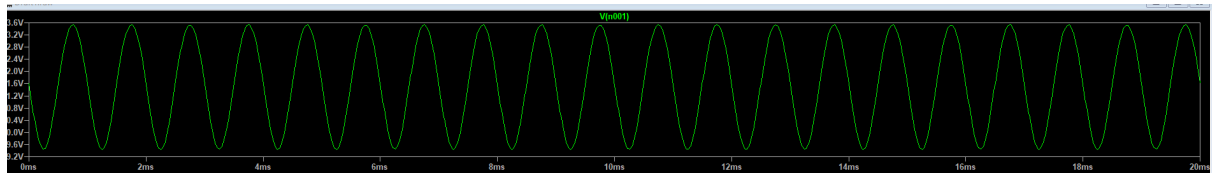


Figure 19: Response

## Discussion

Lab session 1, the diode lab is relatively easy to obtain ideal result. However, for small current, especially when it is setup with the reversed biased. It is hard to get an accurate current measurement as the instrument's limit.

Regarding lab session 2 and 3, being familiar with simulation software and plotting platform like plotly in this report is essential.

## Conclusion

Diode, BJT, and JFET are classic semiconductor devices based on the PN-junction, and they have become foundational building blocks in electronics. These devices can function as both switches and amplifiers, offering a variety of applications in circuits.

## References

- [1] Hitachi High-Tech, "What are semiconductors?," Online. Available: <https://www.hitachi-hightech.com/global/en/knowledge/semiconductor/room/about/>. [Accessed: Dec. 6, 2024].
- [2] Toshiba, "What is a pn Junction?," Online. Available: <https://toshiba.semicon-storage.com/us/semiconductor/knowledge/e-learning/discrete/chap1/chap1-6.html>. [Accessed: Dec. 6, 2024].
- [3] physics-and-radio-electronics.com, "Forward biased p-n junction diode," Online. Available: <https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/forwardbiasedpnjunctionsemiconductoriodiode.html>. [Accessed: Dec. 6, 2024].
- [4] Electronics tutorials, "Junction Field Effect Transistor," Online. Available: [https://www.electronics-tutorials.ws/transistor/tran\\_5.html](https://www.electronics-tutorials.ws/transistor/tran_5.html). [Accessed: Dec. 6, 2024].