# Experimental Contents

1) Measure the diffusion current versus junction voltage of a PN junction, and verify the exponential distribution law of the measured relationship through data processing.
2) Acquire Boltzmann constant with relatively high accuracy (e.g. ~ 2%).
3) Build a current-voltage converter using op-amp to measure weak current ($10^{-6}$~$10^{-8}$ A).
4) Measure PN junction voltage versus temperature, and acquire the sensitivity of the PN junction temperature sensor.
5) Acquire the prohibited bandwidth of silicon material at 0 K approximately.
6) Measure temperature and resistance using Platinum resistance in a DC bridge.

# 7. Experimental Procedure

Prior to experiment, connect the red and black terminals of the two apparatus units in pairs with one-to-one relationship using the thick red and black connection wires, then connect the signal cable between the two units on the side of the units. Ensure correct connections.

7.1 Measure diffusion current vs junction voltage of PN junction & derive Boltzmann constant

1) Based on the circuit diagram shown in Figure. 1, make circuit panel connections per Figure 4. $U_1$ is the 3-1/2 digits voltmeter while $U_2$ is the 4-1/2 digits voltmeter. TIP31 is a power transistor with heat sink. Place the TIP31 transistor in the drywell of the heater. To remain the PN junction at the same temperature as surroundings, the TIP31 transistor should be immersed in transformer oil or thermal grease in the drywell (oil or grease needs to be prepared by user). By pressing down the RED "Reset" button, the temperature in the drywell can be displayed (see Appendix 2 "Temperature Controller").

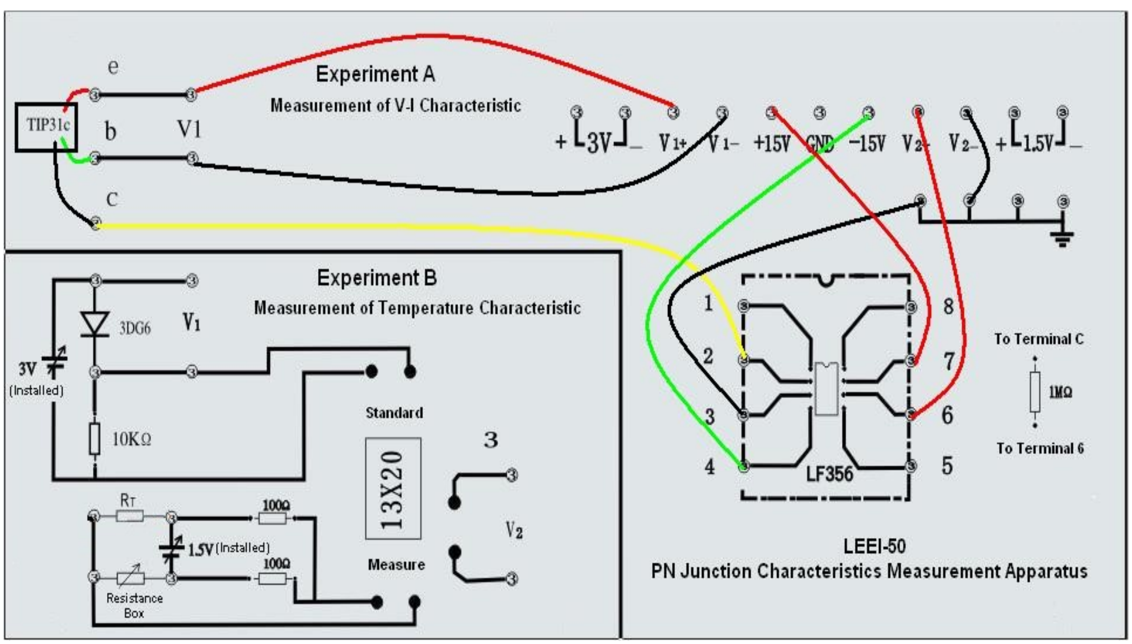


Figure 4 Panel circuit connections for measuring diffusion current vs junction voltage

2) Under room temperature, measure voltage $U_1$ between the emitter and the base of the transistor versus $U_2$ by changing $U_1$ from 0.3 V to 0.45 V with a step of 0.01 V while recording $U_2$ at each step until $U_2$ reaches saturation. Record the temperature ($\theta$) of the transformer oil at the beginning and the end of data recording, and take an average as $\bar{\theta}$.

3) Plot $U_2$ versus $U_1$, and do curve fitting using exponential function $U_2=a\times\exp(bU_1)$ to derive the corresponding values of $a$ and $b$.

4) Calculate $e/k$: using the known electron charge $e$ to derive the Boltzmann constant $k$ and compare it with the recognized value.

7.2 Measure junction voltage vs temperature of PN junction to derive the sensitivity of PN junction temperature sensor, and calculate prohibited bandwidth of silicon material at 0 K

1) The experimental and temperature measurement circuits are shown in Figures 5 and 6, respectively. Based on Figures 5 and 6, make circuit panel connections per Figure 7. Digital voltmeter $V_2$ is used as the zeroing indicator of the temperature measurement bridge as well as the monitor of PN junction current through a double-pole double-throw switch. Place the C9013 transistor and the thermostat in drywells respectively.

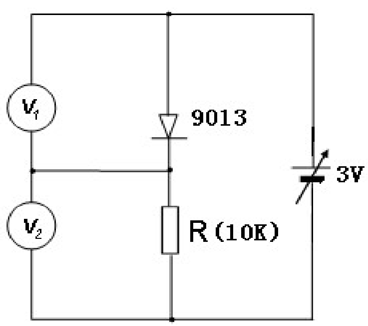


Figure 5 Experimental circuit

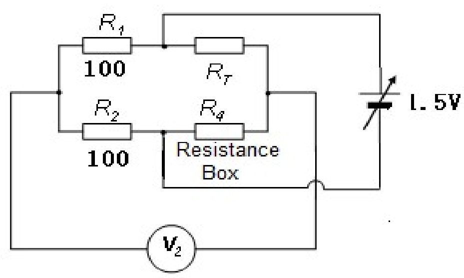


Figure 6 Temperature measurement circuit

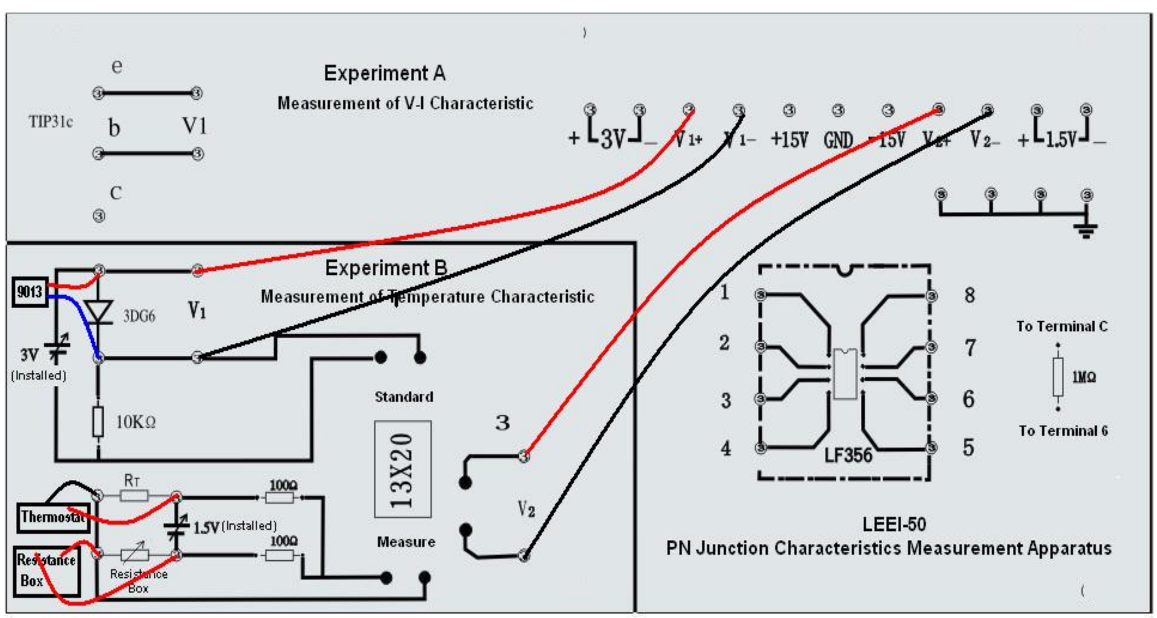


Figure 7 Panel circuit connections for measuring junction voltage vs temperature

2) Set the switch to “Standard”, adjust the power supply voltage (0~3V) as shown in Figure 5 to bring the voltage on resistance $R$ at 1.000 V (i.e. $I$=100 μA, displayed on the middle voltmeter). Next, change the switch to “Measure” and set the temperature of the Temperature Controller to 80 °C to heat the PN junction. From room temperature, at every 5 °C-10 °C, measure the junction voltage ($U_{be}$) (i.e. $V_1$, displayed on the left voltmeter) while recording the resistance value ($R_T$) of the platinum resistor on the electric bridge through the resistance box as shown in Figure 6 (**note**: keep balancing the bridge by adjusting the resistance box in this process). From the lookup table of temperature and platinum resistance, the actual temperature $\theta$ of the thermostat can be acquired. Finally, plot the relationship $U_{be}$~$T$. (Take at least 6 pairs of measurement points.)
3) Plot $U_{be}$~$T$ curve and do curve fitting using Eq. (7) to derive the temperature sensitivity ($S$) of the PN junction and the prohibited bandwidth $E_{go}$ at temperature 0 K of silicon material.

# 8. Examples of Data Recording and Processing

Note: the following data are for reference purposes only, not the criteria for apparatus performance.

1. Measure diffusion current vs junction voltage of PN junction & derive Boltzmann constant

Under room temperature: $\theta_1$=27.10 °C, $\theta_2$=27.30 °C, so $\bar{\theta}$ =27.20 °C.

Table 1 Measurement data of diffusion current vs voltage of PN junction

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $U_1$ (V) | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 |
| $U_2$ (V) | 0.053 | 0.075 | 0.111 | 0.162 | 0.239 | 0.352 | 0.52 | 0.78 |
| $U_1$ (V) | 0.39 | 0.4 | 0.41 | 0.42 | 0.43 | 0.44 | 0.45 | |
| $U_2$ (V) | 1.127 | 1.662 | 2.446 | 3.494 | 5.286 | 7.765 | 11.379 | |

Plot $U_2$ vs a function of $U_1$ as shown in Figure 8, and conduct curve fitting with the exponential function $U_2 = a\exp(bU_1)$.

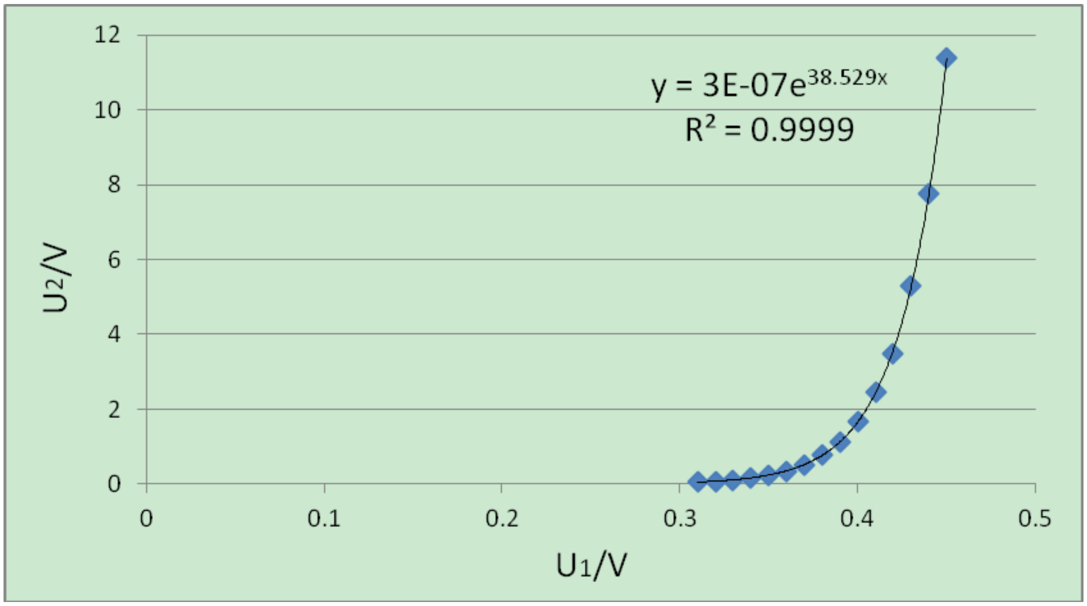


Figure 8 Diffusion current versus voltage curve of PN junction

From the fitted constants in Figure 8, we have

$e/k=bT=38.529\times(273.15+27.20)=1.1572\times10^{4}$ CK/J, so we get

$k=1.602\times10^{-19}$ C/$1.1575\times10^{4}$ CK/J=$1.384\times10^{-23}$ J/K.

This result is consistent with the recognized value ($k=1.381\times10^{-23}$ J/K).

2. At current $I$=100 μA, measure junction voltage versus temperature, find the sensitivity of PN junction temperature sensor, calculate the prohibited bandwidth at 0 K of silicon material, and determine the resistance of platinum resistance as a function of temperature.

Table 2 Measurement data of junction voltage vs temperature

| $R_T$ (Ω) | $\theta$ (°C) | $T$ (K) | $U_{be}$ (V) |
|---|---|---|---|
| 112 | 30 | 303.15 | 0.542 |
| 113 | 33 | 306.15 | 0.529 |
| 116 | 41 | 314.15 | 0.511 |
| 119 | 48 | 321.15 | 0.495 |
| 121 | 53 | 326.15 | 0.479 |
| 124 | 61 | 334.15 | 0.466 |
| 126 | 66 | 339.15 | 0.454 |
| 128 | 71 | 344.15 | 0.445 |
| 129 | 74 | 347.15 | 0.437 |
| 130 | 76 | 349.15 | 0.429 |
| 132 | 82 | 355.15 | 0.422 |

Plot $U_{be}$ as a function of $T$ and then conduct a straight line curve fitting as shown in Figure 9.

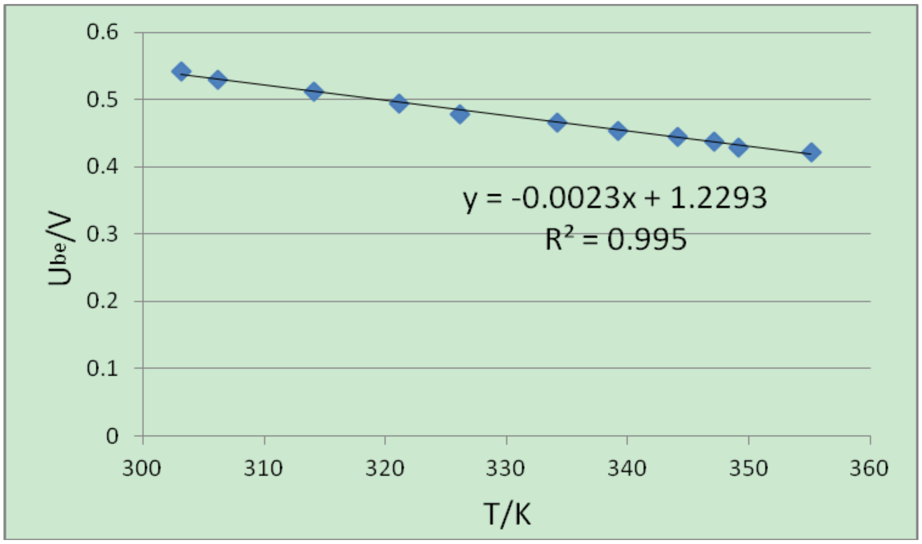


Figure 9 Voltage versus temperature curve of PN junction

The fitted slope of the line in Figure 9 is the sensitivity of PN junction temperature sensor, as

$S$=-2.3 mV/K

The fitted intercept is

$U_{go}$=1.2293 K (at 0 K), so

$E_{go}=eU$=1.2293 eV

The recognized value of the prohibited bandwidth of silicon material at 0 K is $E_{go}$=1.205 eV. The deviation is caused by the nonlinear items in Eq. (7) that cannot be completely ignored at low temperature. Thus, the experimental result of $E_{go}$=1.2293 eV is just a linear approximation.