4. Experiment contents

1) Measure the far-field distribution of the beam and calculate its vertical and horizontal divergent angles.
2) Measure the voltage-current characteristics.
3) Measure the relationship between output optical power and current, and acquire its threshold current.
4) Measure the relationship between the output of optical power and current at different temperatures, and analyze its temperature characteristics.
5) Measure the polarization characteristics of the output light beam and calculate its polarization ratio.
6) Optional experiment: verify Malus's law.

5. Experiment procedure

Precautions:

a) The normal working voltage of the semiconductor laser is about 2.5 V. The maximum should not exceed 4 V. Otherwise it will reduce its life time.

b) The maximum setting temperature of the temperature control is 80 °C. It is recommended to rise to maximum 70 °C for the experiment. Setting higher than 70 °C will need long heating time.

c) Do not direct the laser light into the eye to avoid eye hurt.

A. Measure Far Field Characteristics of Semiconductor Laser

1) Wiring: connect cables between the suitcase and the corresponding devices on the platform including angle sensor, temperature control, fan, laser power supply (Laser+/Laser- terminals), and photo detector of power meter. Connect the red and black wires on the panel of the suitcase according to the circuit diagram. Place the slide rail at the end of the laser device platform with close contact.

2) Turn on the main power switch. Set the temperature of the “Temp Control” to 30 °C. Place the toggle switch on the panel circuit diagram to the side "1", i.e. the voltmeter is used to measure the voltage applied to the laser. Adjust “V. Adj” potentiometer to get a stabilized voltage reading on the semiconductor laser at about 2.4 V. At this time, the laser outputs red laser. Place the photo detector on the rotary arm, and adjust its height to let the laser enter the small hole in front of the detector.

3) Unscrew the lens on the front of the laser (note that there is a spring inside, do not lose it). Turn the arm to one side, and move the white screen to 10 cm position on the rail. At this time, the far-field distribution of the laser is observed on the white screen. Turn the knob on the front of the laser to see different distribution patterns in the vertical and horizontal directions.

4) Fix the horizontal or vertical direction, rotate the arm to read the laser power value at different angles, and draw the far-field distribution curve.

5) Rotate the arm to find the half power points at both left and right sides. The corresponding angle difference is recorded as the divergence angle in vertical direction ($\theta_{\perp}$) or horizontal direction ($\theta_{//}$).

B. Measure *V-I* Characteristics of Semiconductor Laser

1) Wiring: same as above experiment. Remain the "Temp Control" at 30 °C.

2) Adjust the voltage applied to the laser from the minimum (1.25 V) to increase gradually Toggle the selection switch to "1" to measure the voltage applied to the laser, and to "2" to measure the voltage across the sampling resistance (30 ohm) and convert it to current. Record the corresponding voltage and current values.

3) According to the measured voltage and current values, draw the *V-I* characteristic curve of the semiconductor laser.

C. Measure *P-I* Characteristics of Semiconductor Laser at Constant Temperature

1) Wiring: same as above experiment. Remain the "Temp Control" at 30 °C.

2) Install back the lens onto the laser. Rotate the arm to make the laser light exactly enter the hole in front of the detector. Note that the lens in front of the laser can be adjusted to minimize the spot to enter the detector.

3) Adjust the voltage applied to the laser. Record the current through the laser and the output laser power value, and plot the P-I curve. Since the *P-I* curve is linear after the threshold current is exceeded, the threshold current I_{th} can be calculated.

D. Measure Temperature Characteristics of Semiconductor Laser

1) Wiring: same as above experiment.

2) Measure the laser current value and output optical power value at different temperatures, and plot the *P-I* characteristic curve at different temperatures.

E. Measure Polarization Characteristics of Semiconductor Laser

1) Wiring: same as above experiment. Place the analyzer and the detector on the rail. Let the laser beam enter the detector hole in normal direction.

2) Adjust the voltage applied to the laser to 2.4 V. Turn the analyzer to measure the optical power value at different angles. Calculate the degree of polarization of the semiconductor laser.

3) Optional experiment: verify Malus's law. Rotate the analyzer to maximize the optical power reading, that is, the polarization direction of the analyzer is consistent with the direction of the maximum intensity of the partially polarized light of the laser. Add a polarizer in between the previous analyzer and the detector. Rotate the polarizer to measure the optical power at different angles to verify Malus's law.

6. Examples of Data Recording and Processing

Note: Following data are for reference purpose only, not the criteria for apparatus performance:

A. Measure Far Field Characteristics of Semiconductor Laser

Measurement conditions: constant temperature control at 30 °C, voltage of laser 3.0 V.

Measured data of the horizontal divergence angle and the optical power are shown in Table 1.

Table 1 Data of horizontal angle and optical power

Angle (°)	80.9	81.7	82.4	83.3	84.4	85.5	86.2	87.1
Power (uW)	0.09	0.17	0.28	0.52	0.99	1.77	2.42	3.32
Angle (°)	88.5	89.3	90.2	91.1	92.1	93.4	94.2	95.4
Power (uW)	4.86	5.73	6.47	6.86	6.78	5.98	5.31	3.87
Angle (°)	96.2	97.1	98.3	99.8	100.5	101.1	102.0	103.6
Power (uW)	3.03	2.05	1.25	0.53	0.33	0.24	0.15	0.11

The plot is shown in Figure 7.

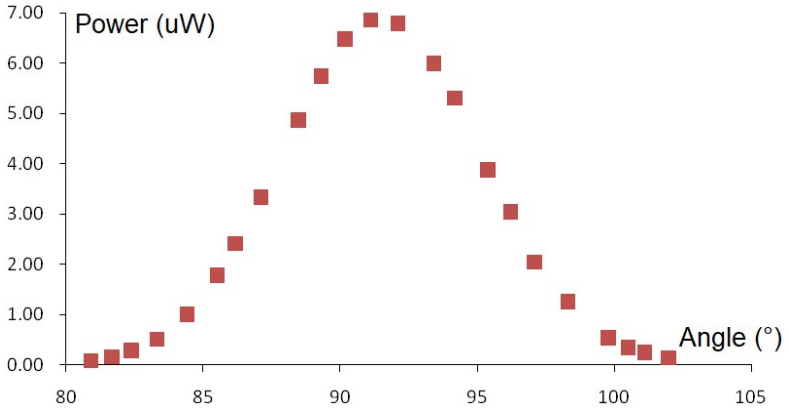

Figure 7 Far field distribution curve in horizontal direction

From the plot, the half power points at left and right are respectively 87.2° and 95.8°, so the measured divergence angle in horizontal direction is 8.6°.

Measured data of the vertical divergence angle and the optical power are shown in Table 2.

Table 2 Data of horizontal angle and optical power

Angle (°)	65.5	67.7	69.4	71.4	73.5	75.6	77.4	79.1
Power (uW)	0.77	0.99	1.21	1.52	1.96	2.49	3.05	3.58
Angle (°)	81.3	84.1	86.5	88.9	90.5	92.7	94.8	97.4
Power (uW)	4.37	5.41	6.16	6.64	6.74	6.87	6.58	5.94
Angle (°)	100.2	103.0	105.4	108.0	110.2	113.1	115.6	117.5
Power (uW)	5.07	4.09	3.29	2.41	1.86	1.37	1.06	0.88

The plot is shown in Figure 8.

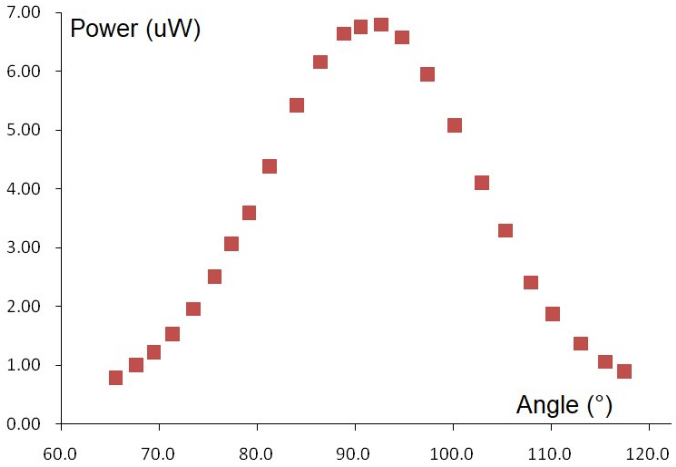

Figure 8 Far field distribution curve in vertical direction

From the plot, the half power points at left and right are respectively 78.6° and 105,0°, so the measured divergence angle in horizontal direction is 26.4°.

B. Measure *V-I* Characteristics of Semiconductor Laser

Measurement conditions: temperature control at 30 °C, current sampling resistance 30 Ω.

The measured data is shown in Table 3.

Table 3 Data of working voltage and current

Laser Voltage (V)	1.25	1.39	1.49	1.58	1.66	1.75	1.82	1.89	1.93	1.98
Sampled Voltage (V)	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.06	0.10	0.17
Laser Current (mA)	0	0	0	0	0	0	1	2	3	6
Series Resistance (KΩ)	/	/	/	4.7	5.0	5.3	1.8	0.9	0.6	0.3
Laser Voltage (V)	2.02	2.09	2.13	2.19	2.24	2.28	2.32	2.35	2.40	
Sampled Voltage (V)	0.23	0.34	0.42	0.55	0.66	0.77	0.87	0.96	1.00	
Laser Current (mA)	8	11	14	18	22	26	29	32	33	
Series Resistance (KΩ)	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	

The V-I characteristic curve is shown in Figure 9.

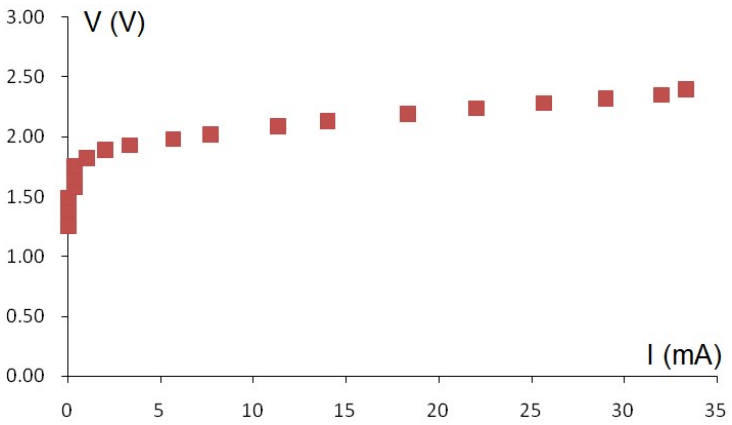

Figure 9 V-I characteristic curve

The relationship curve between the series resistance and the current is shown in Figure 10.

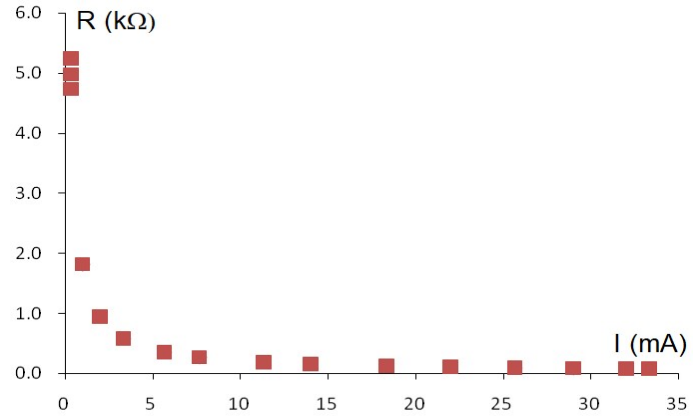

Figure 10 Relationship between series resistance and current

C. Measure *P-I* Characteristics of Semiconductor Laser at Constant Temperature

Measurement conditions: temperature control at 30 °C, current sampling resistance 30 Ω.

The measured data is shown in Table 4:

Table 4 *P-I* characteristic measurement of semiconductor laser

Sampled Voltage (V)	0.12	0.24	0.33	0.43	0.51	0.58	0.64
Working Current (mA)	4	8	11	14	17	19	21
Laser Power (mW)	0.000	0.000	0.001	0.002	0.003	0.038	0.176
Sampled Voltage (V)	0.73	0.80	0.84	0.90	0.95	0.99	1.01
Working Current (mA)	24	27	28	30	32	33	34
Laser Power (mW)	0.427	0.606	0.733	0.874	1.029	1.154	1.206

The *P-I* characteristic curve is shown in Figure 11.

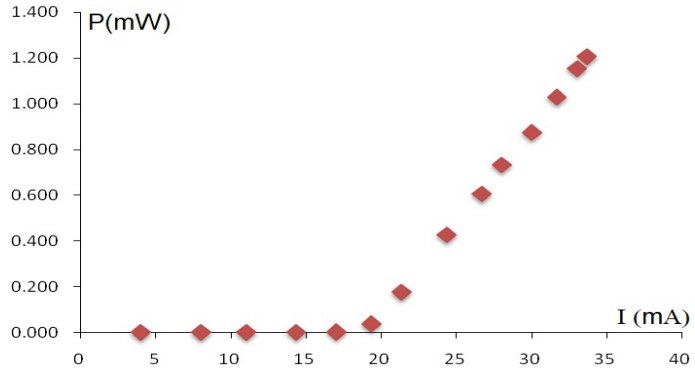

Figure 11 P-I characteristic curve of semiconductor laser

From the curve, we get the threshold current I_{th} about 18 mA.

D. Measure Temperature Characteristics of Semiconductor Laser

Measure the *P-I* characteristic curves under different temperatures: 30^oC, 40^oC, 50^oC and 60^oC. Because there are too many data, they are not listed here. The curves are shown in Fig. 12.

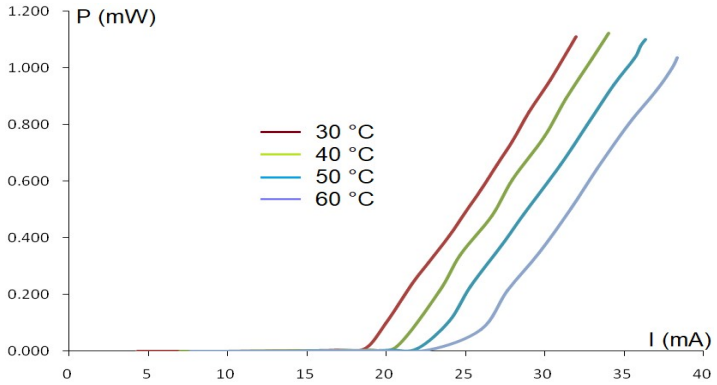

Figure 12 *P-I* characteristic curves at different temperatures

E. Measure Polarization Characteristics of Semiconductor Laser

Measurement conditions: temperature control at 30 °C, working voltage 2.4 V.

Measured data: $I_{\max} = 897uW$ and $I_{\min} = 16uW$.

We got the degree of polarization: $P¢= \dfrac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \dfrac{897 - 16}{897 + 16} = 95.6\%$.

It can be seen that the output light by the semiconductor laser is close to linearly polarized light.

Data for verifying the Malus's law are not listed here.