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Lab 11

Figure 1. Illustrations of I-V characteristics of different diode models.

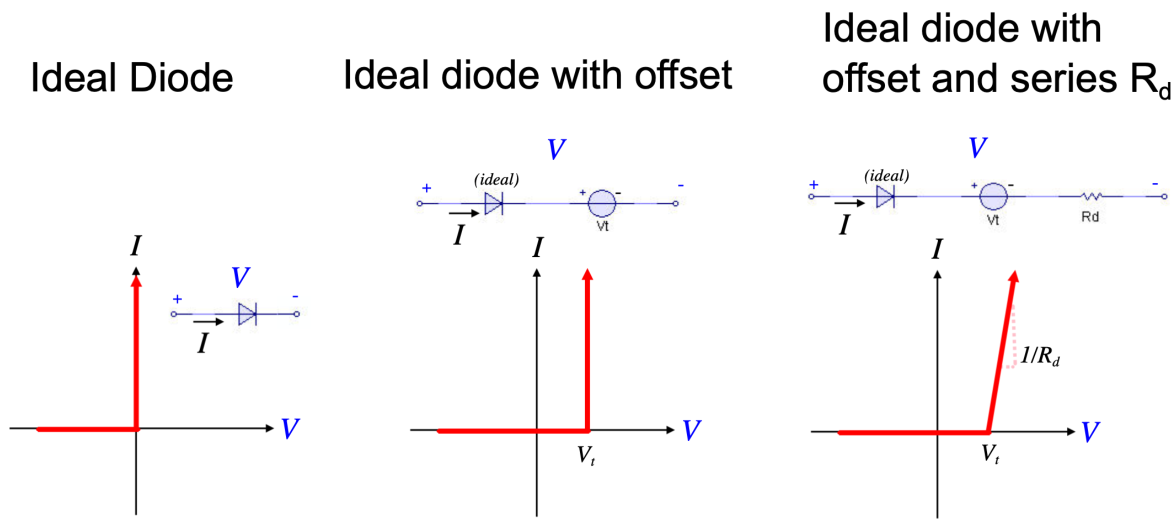


Figure 2. Non-LED diodes used in this lab.

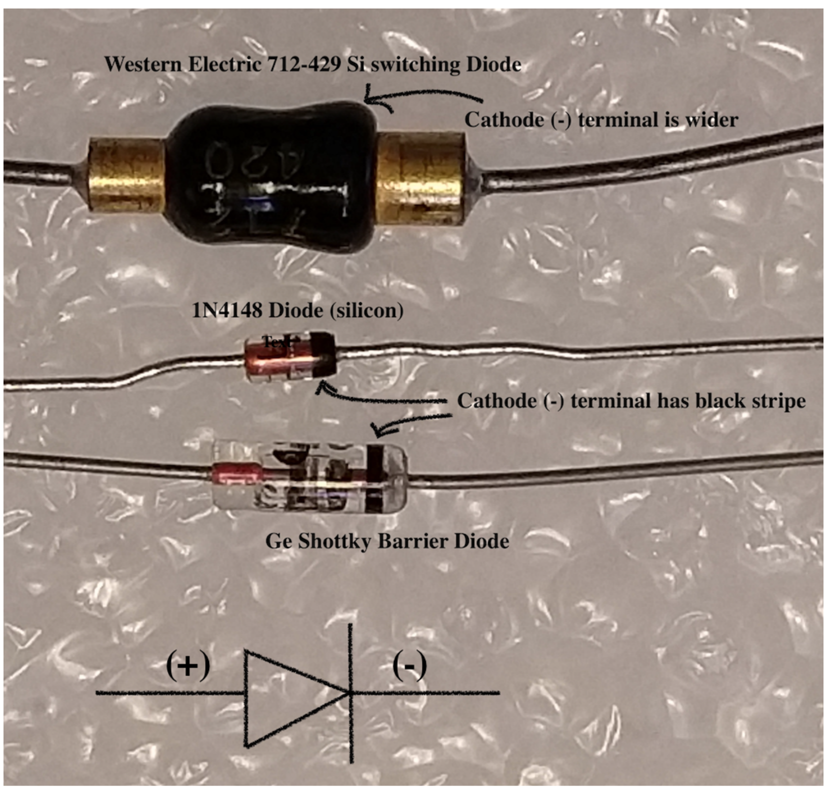
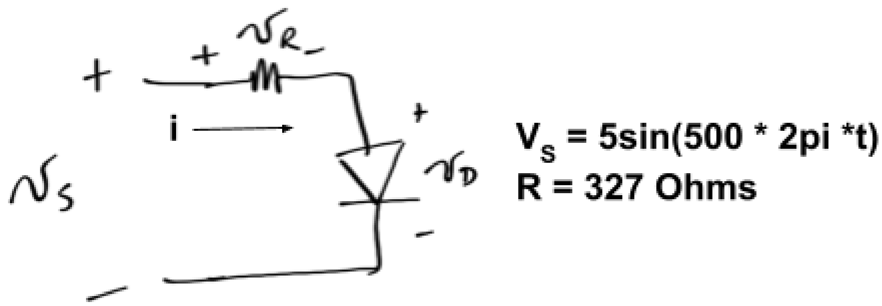


Figure 3. Circuit diagram.



Channel 1 of Scopy's wave generator function was used to provide the source voltage V_S. A DMM was used to measure the resistance R. Scopy was used to measure V_R and V_D for the above circuit built with a number of different diodes. Channel 1 of the oscilloscope was connected across the resistor to measure V_R, while Channel 2 of the oscilloscope was connected across the diode to measure V_D. Each dataset was exported and loaded into Python.

Diodes used in this lab:

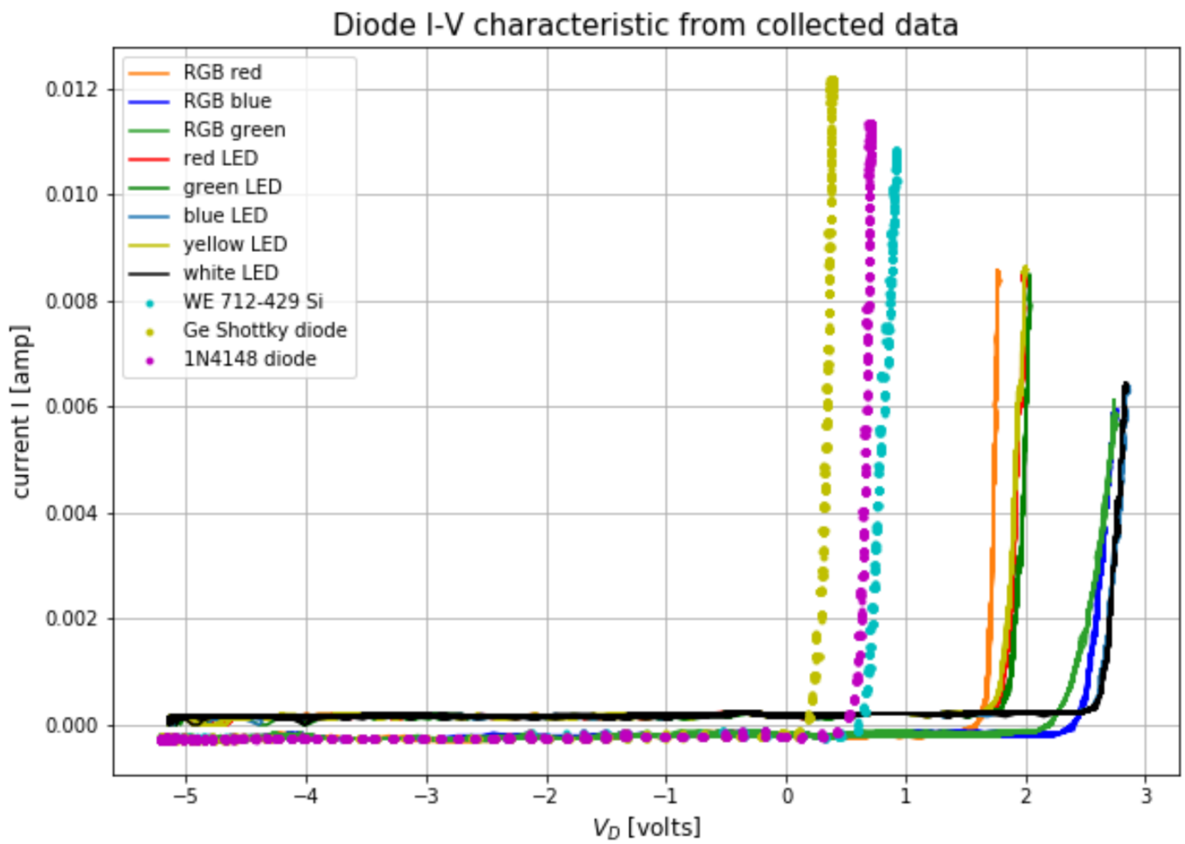
- White LED
- Red LED
- Blue LED
- Green LED
- Yellow LED
- Red leg of RGB diode
- Green leg of RGB diode
- Blue leg of RGB diode
- Western Electric 712-429 Si switching diode.
- 1N4148 Si diode
- AA-442 Ge Schottky diode

In Python, the current i was calculated using Ohm's Law and the measured resistance and V_R data. $V_R = iR$, so $i = V_R/R$. The calculated current for each dataset was then used to generate I-V curves for each diode.

Figure 4. Python code to calculate current.

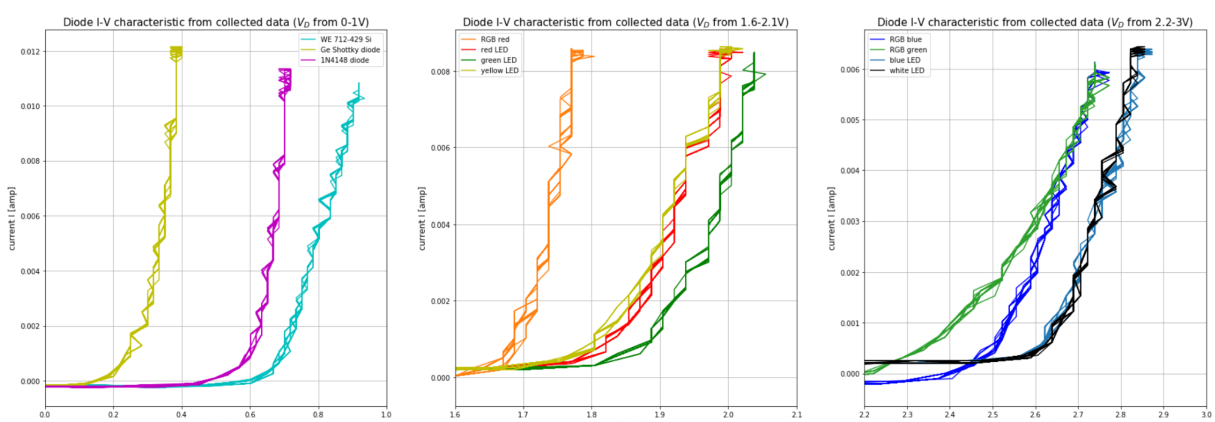
```python
# calculate current --> vr = i * R
r = 327    # Ohms

#i = vr / r
i_green = vr_green / r
i_g_rgb = vr_g_rgb / r
i_blue = vr_blue / r
i_b_rgb = vr_b_rgb / r
i_red = vr_red / r
i_r_rgb = vr_r_rgb / r
i_yellow = vr_yellow / r
i_white = vr_white / r
i_we = vr_we / r
i_ge = vr_ge / r
i_n = vr_n / r
```

Figure 5. I-V curves plotted with Python.



Plotting each diode's I-V curve on the same graph obscures some of the data, as several of the diodes display very similar behavior. Using limits on the x-axis, I separated the I-V curves into three separate plots to better see each individual I-V curve.

Figure 6. Separated I-V curves plotted with Python.



To estimate the values of V_t and R_d for each diode, I used a linear regression function in Python to fit a line of best fit to the portion of the I-V curve where current is greater than 0.002 Amps. This was chosen to avoid the "knee" region of the graph while still having sufficient data points.

By visual inspection of the plotted I-V curves, all of the diodes used seem to fit the model of an ideal diode with an offset and series resistance. From the given background information, V_t is the x-intercept of a line fit to the I-V curve and R_d is the inverse of that line's slope.

A Python method was written and used to determine the linear fit to any of the datasets. This fit was then used to calculate V_t and R_d.

Figure 7. Method written in Python to determine the linear fit of an I-V curve at current > 0.002A.

```python
def findFit(vd, i):
    lin_i_indices = np.asarray(np.where(i > 0.002))
    num_pts = lin_i_indices.size
    lin_vd = np.zeros(num_pts)
    lin_i = np.zeros(num_pts)

    for j in range(num_pts):
        current_index = lin_i_indices[0,j]
        lin_vd[j] = vd[current_index]
        lin_i[j] = i[current_index]

    slope, intercept, r_value, p_value, std_err = stats.linregress(lin_vd, lin_i)
    line = (slope * lin_vd) + intercept

    return  line, lin_vd, slope, intercept
```

Using the fit-finding method, V_t and R_d were calculated for each diode. To check the fit, the calculated line and V_t values were plotted with the original data and inspected visually.

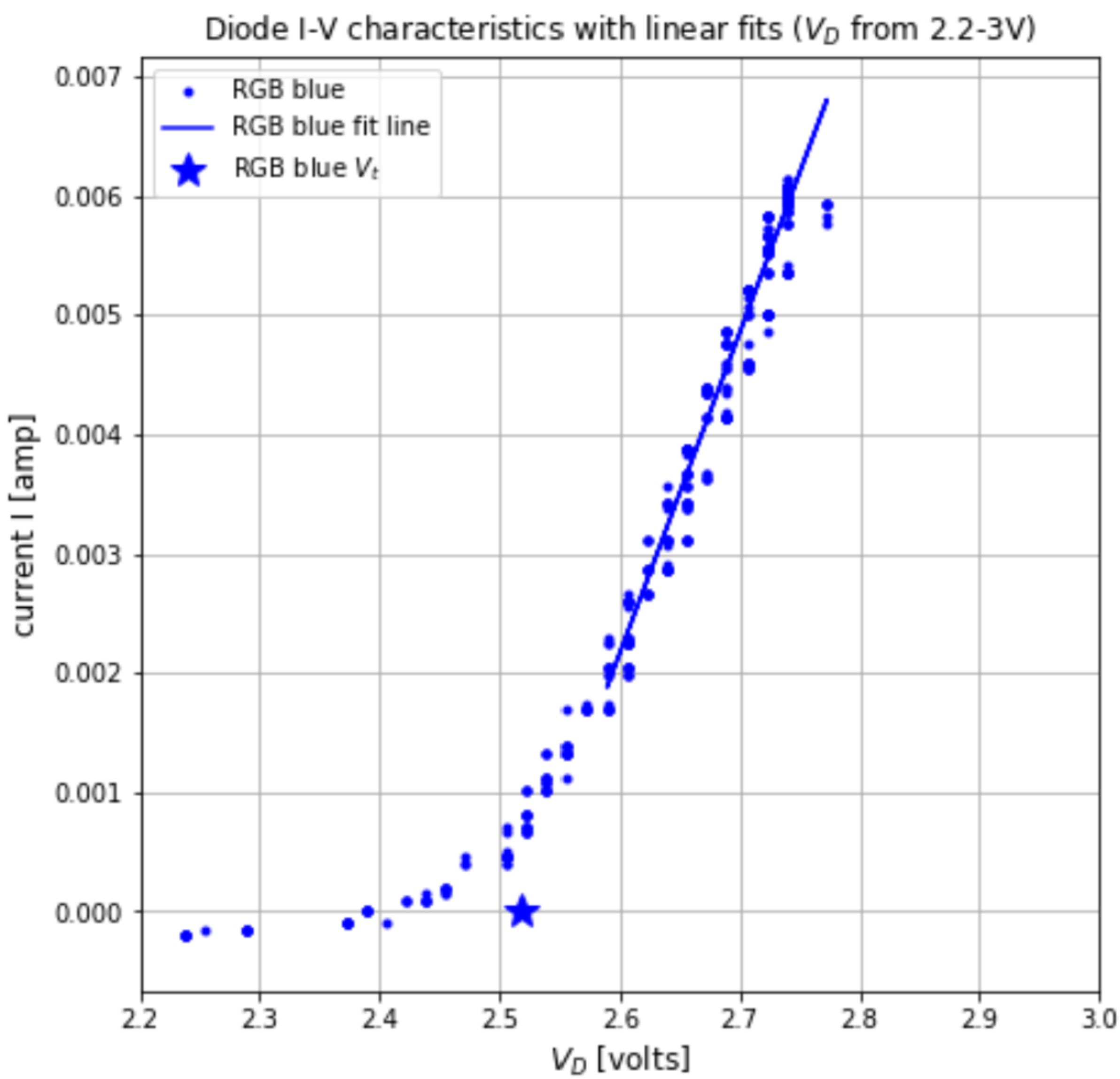
Figure 8. Example calculation of fit line, V_t, and R_d for the blue leg of the RGB diode.

```python
# linear fit to region where current > 0.002amp
fit_b_rgb = findFit(vd_b_rgb,i_b_rgb)
# vt = x-intercept of linear fit = (-y-intercept)/slope
vt_b_rgb = (-1*fit_b_rgb[3])/fit_b_rgb[2]
# Rd = 1 / slope
rd_b_rgb = 1 / fit_b_rgb[2]

print('RGB BLUE')
print('vt =', np.round(vt_b_rgb, 3), 'V')
print('Rd =', np.round(rd_b_rgb, 3), 'Ohms')
#print('\n')
```

```
RGB BLUE
vt = 2.519 V
Rd = 37.3 Ohms
```

Figure 9. Example plot of fit line, V_t, and I-V curve for the blue leg of the RGB diode.

```
plt.figure(figsize=(7,7))
plt.title('Diode I-V characteristics with linear fits ($V_D$ from 2.2-3V)')
plt.xlabel('$V_D$ [volts]', fontsize=12)
plt.xlim(2.2,3)
plt.ylabel('current I [amp]', fontsize=12)

plt.plot(vd_b_rgb,i_b_rgb,'b.', label='RGB blue')
plt.plot(fit_b_rgb[1],fit_b_rgb[0],'b-', label='RGB blue fit line')
plt.plot(vt_b_rgb, 0, 'b*', markersize=15,label='RGB blue $V_t$')

plt.legend()
plt.grid()
```



Looking at the graph, the spread of the data points around the line seems to be abou 0.05V.

Figure 10. Table of calculated V_t and R_d values.

Diode	**V_t in volts**	**V_t uncertainty**	**R_d in Ohms**
RGB blue leg	2.519	± 0.05V	37.3
RGB green leg	2.442	± 0.05V	51.043
Blue LED	2.628	± 0.05V	36.173
White LED	2.643	± 0.05V	30.807
RGB red leg	1.696	± 0.05V	9.522
Green LED	1.904	± 0.05V	16.606
Red LED	1.837	± 0.05V	19.631
Yellow LED	1.82	± 0.05V	21.137
WE 712-429 Si switching diode.	0.682	± 0.05V	22.458
AA-442 Ge Schottky diode	0.281	± 0.05V	9.677
1N4148 Si diode	0.615	± 0.05V	9.308

The ideal diode model has no offset, and no series resistance. It is vertical at V_D=0V. The AA-442 Ge Schottky diode is the closest to the ideal diode model. It has the smallest V_t, so it has the lowest offset, and so its linear portion is closest to the y-axis. It also has a very small R_d of 9.677 Ohms. The 1N4148 Si diode is also very close to the ideal diode model. It has the smallest R_d of 9.308 Ohms and a fairly small offset, with a V_t of 0.615V. Visual inspection of the plotted I-V curves also supports these diodes' similarities to the ideal diode model. They are the closest to vertical of all the plotted diode I-V curves.

In general, the "warm" color LEDs (red, yellow) have lower V_t and also lower R_d compared to the "cool" color LEDs (blue, green, white). The warm color LEDs have V_t from about 1.9V to 1.7V, and R_d from about 9.5 Ohms to 21 Ohms. The cool color LEDs have V_t from about 2.4V to 2.65V and R_d from about 30 Ohms to 51 Ohms. There are some exceptions - the green LED is included in the "warm" color range - but otherwise, the colors with longer wavelengths have lower V_t and R_d than the colors with shorter wavelengths.