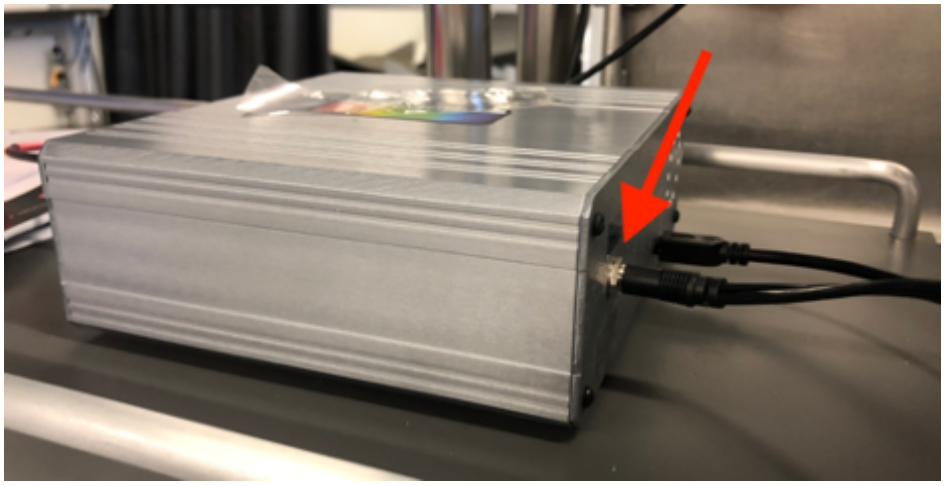
LED testing in GIANTFab

Hardware

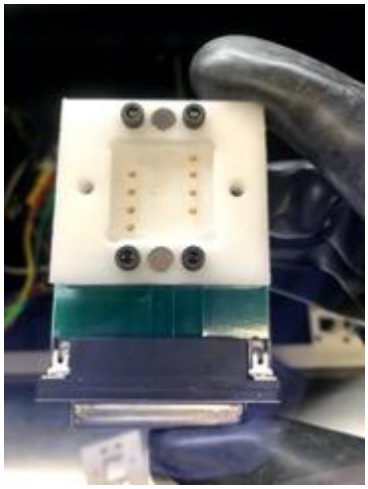
To increase signal to noise at long wavelengths or with long integration times, plug the power cord into the spectrometer to turn on the thermoelectric cooler. **Remember to unplug the thermoelectric cooler when you are finished or it can be irreversibly (and expensively!) damaged!**

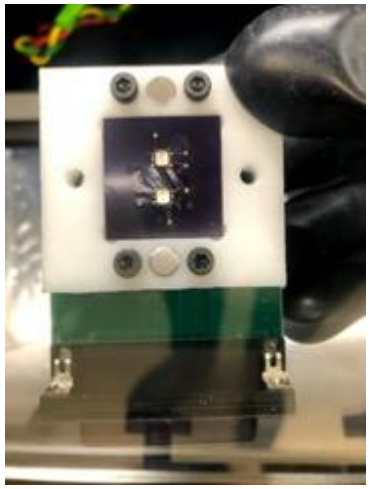


Ensure that the four banana cables from the Keithley are plugged directly into the relay board. Your device should be hooked up so that the red and white leads are connected to the anode (ITO) contact. The black and green leads should be connected to the top electrode.

If you are using the relay box and breakout board, use the breakout board appropriate for your device architecture (**Regular** or **Inverted**) and attach the cables to their corresponding colored jacks (white goes to yellow).

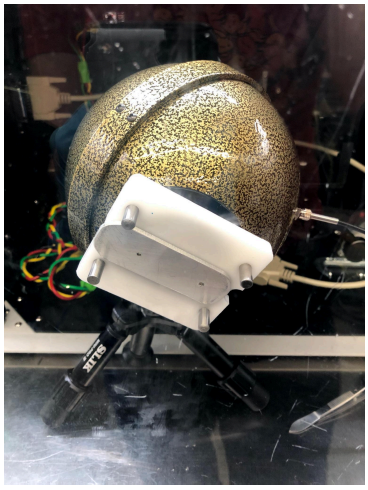
In the box, place your fabricated device in the substrate holder, with the electrodes on the bottom so that they touch the gold spring pins.



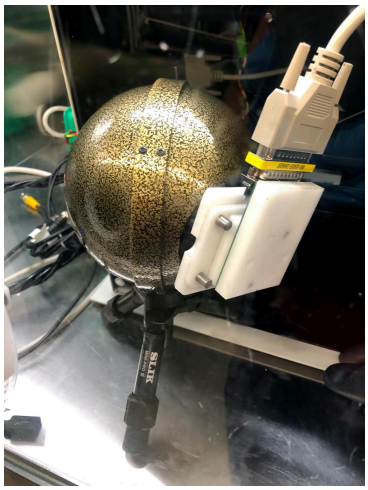


Place the lid on top of the substrate holder. Attach the DB25 cable to the substrate holder.

Set up the integrating sphere in a spot where you can comfortably work on it. Remove the protective cap from the fiber optic port of the integrating sphere. Attach the fiber optic to the fiber optic port and screw the ferrule finger tight. Slide the protective metal cover off the aperture in the integrating sphere cap:

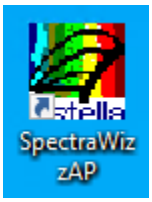


Slide the assembled substrate holder onto the rods until they click in place with the magnets. Setup is complete.

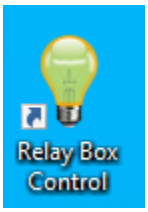


Software

There are four programs you will be using for LED testing:

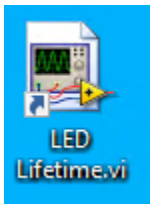


SpectraWiz (for directly operating the spectrometer)



DRMv3 (for controlling the relay box)

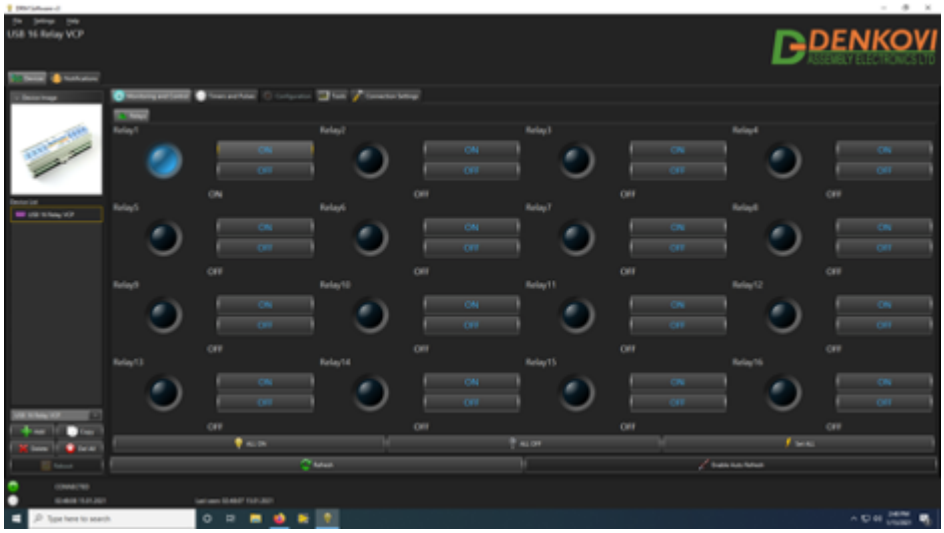
LEDMeasure (for running the LED testing program itself)



LED Lifetime (for LED lifetime measurements)

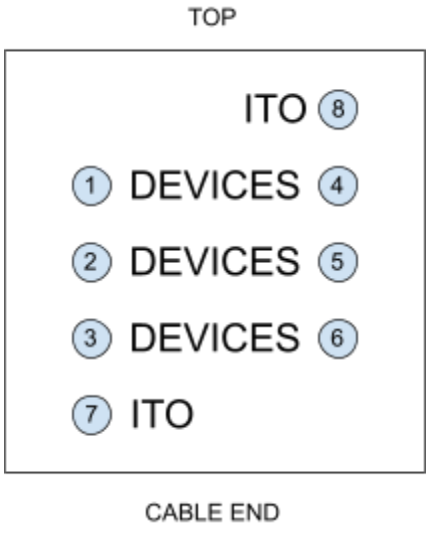
Relay Box Software

The first step after setting up the hardware is to launch the relay box control software. This will allow you to turn individual LED devices on the substrate on and off. Open the **Relay Box Control** shortcut on the desktop. Hopefully, it will correctly initialize and connect to the relay box, displaying the screen shown below:



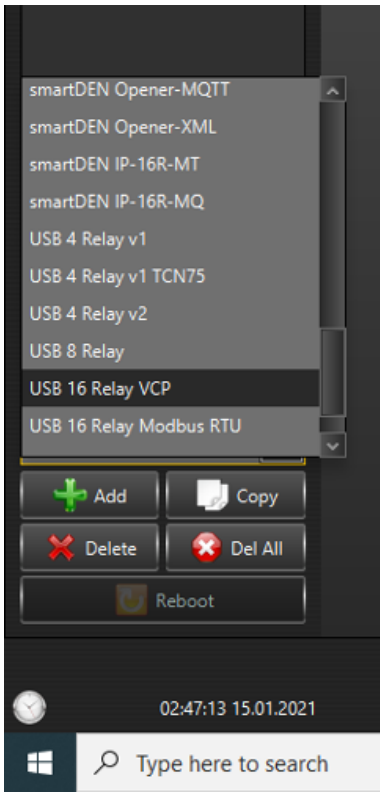
If that happens, you are now ready to turn on the appropriate relays. The ITO contact is connected to **Relays 7 and 8**, so turn those two on and keep them on. You can then turn on devices 1-6 by turning on **Relays 1-6**. You may turn on more than one device at a time if you wish by turning on multiple relays. Each device will be connected in parallel.

Using the standard substrate holder, the pins correspond to the relays numbered as shown:



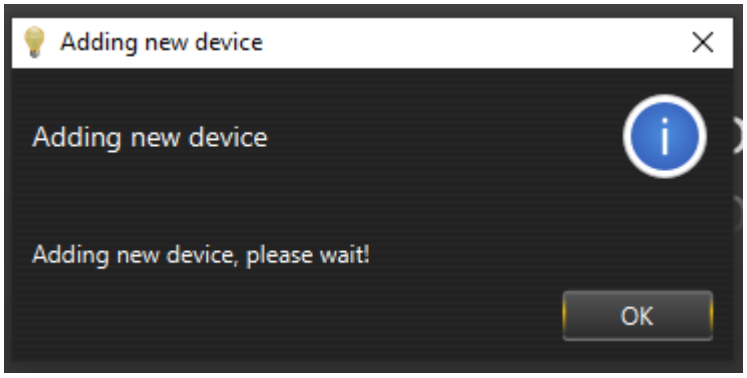
If for some reason you do not see the screen above, you will have to add the relay box to the control panel as follows:

In the lower left hand corner, choose USB 16 Relay VCP from the pop-up menu.



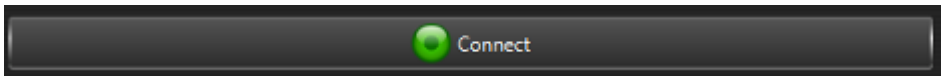
Press the  button.

Wait for the Adding new device window to close:



In the **Configuration** window, next to **VCP Device ID**, choose **DAE06L8d**:

Then press **Connect**:



If connection is succesful, the bottom row of buttons will change to disable **Connect** and enable **Disconnect**:

Switch to the **Monitoring and Control** tab to display the relay controls:

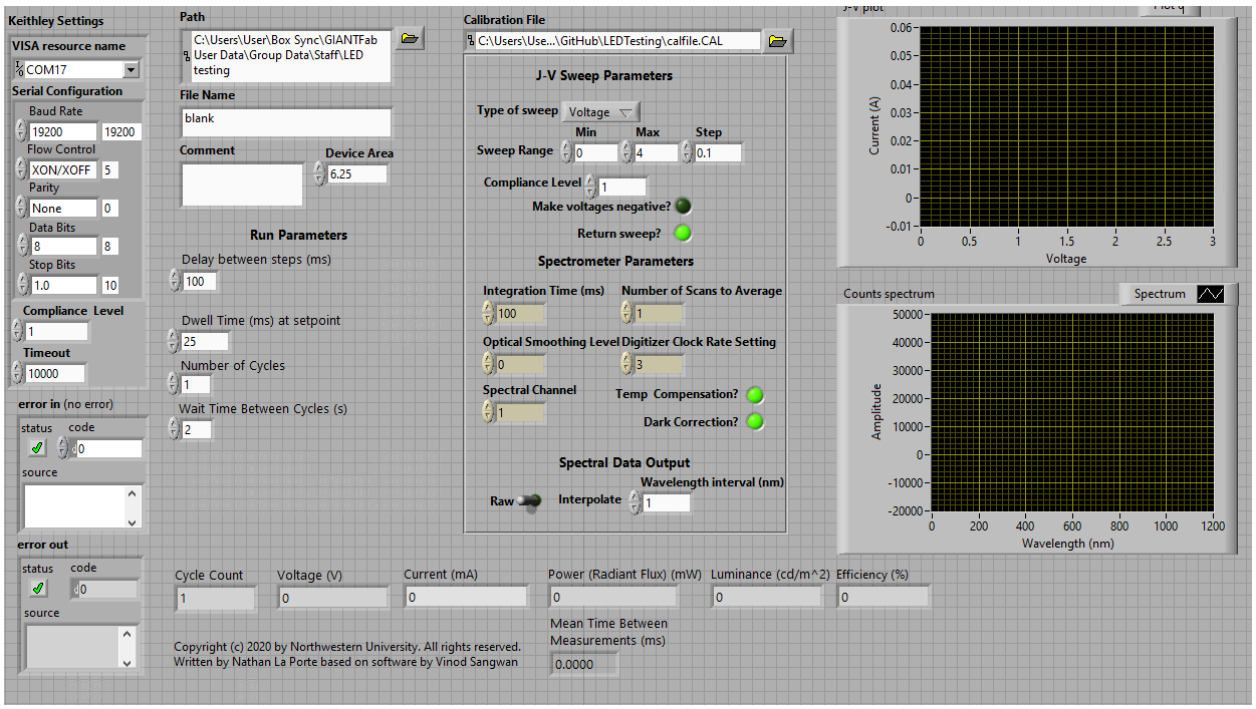
At this point you are ready to turn on the appropriate relays. You may then minimize the relay controls and open up the LabVIEW program.

Testing Program (LED Testing RS-232)

Open the testing program:

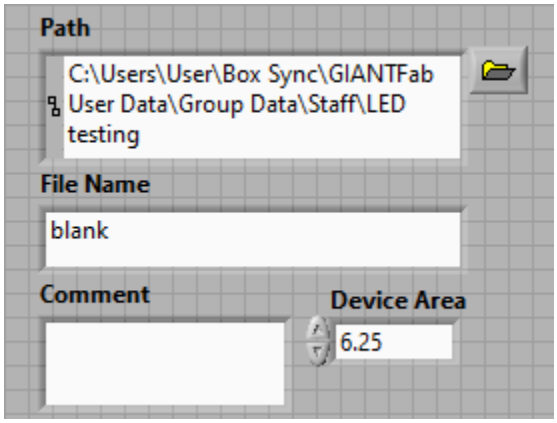
Select YES when prompted to allow this program to make changes to your device:

The front panel window will open:



Make sure that the **Operate** tool  is selected in the Tools panel. You may then set the various operating parameters as described below:

File name, path, and comment:



Path: directory in which all the output files will be saved.

File Name: base file name for the output files. The actual filenames will be as follows:

IV curve only: `<filename>-1_IV.txt`

IVL curve: `<filename>-1_IVL.txt`

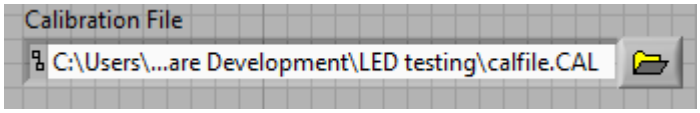
Full spectra and IVL data: `<filename>-1_spectra.txt`

Sucessive repeats will increment the number.

Comment: Any other text you want to include in the data files. Could be used for a more detailed description of the device, setup, or any other conditions you want to make sure to preserve with your data.

Device Area: Area of your device active area in mm^2. Required for correct calculation of current density and luminance.

Calibration File:

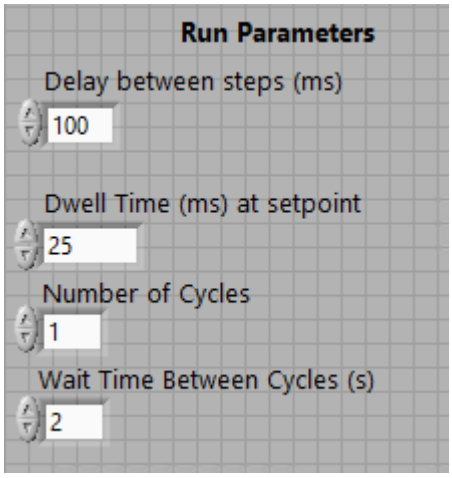


The file containing wavelength-by-wavelength watts/nm calibration data for the particular combination of spectrometer and optics installed. Format is a tab-delimited file as follows:

```
15
172.09    0.0000E+000
172.51    0.0000E+000
172.93    0.0000E+000
173.35    0.0000E+000
173.77    0.0000E+000
174.18    0.0000E+000
174.60    0.0000E+000
175.02    0.0000E+000
175.44    0.0000E+000
...
1112.22   0.0000E+000
1112.71   0.0000E+000
```

The first line is the integration time for the calibration scan, in milliseconds. Each successive line is the wavelength for that detector pixel, followed by the watts/nm measured at that wavelength. Data is extracted from the .icf file produced by the SpectraWiz software during the calibration procedure (or the one supplied with the spectrometer if the spectrometer was factory-calibrated).

Run Parameters



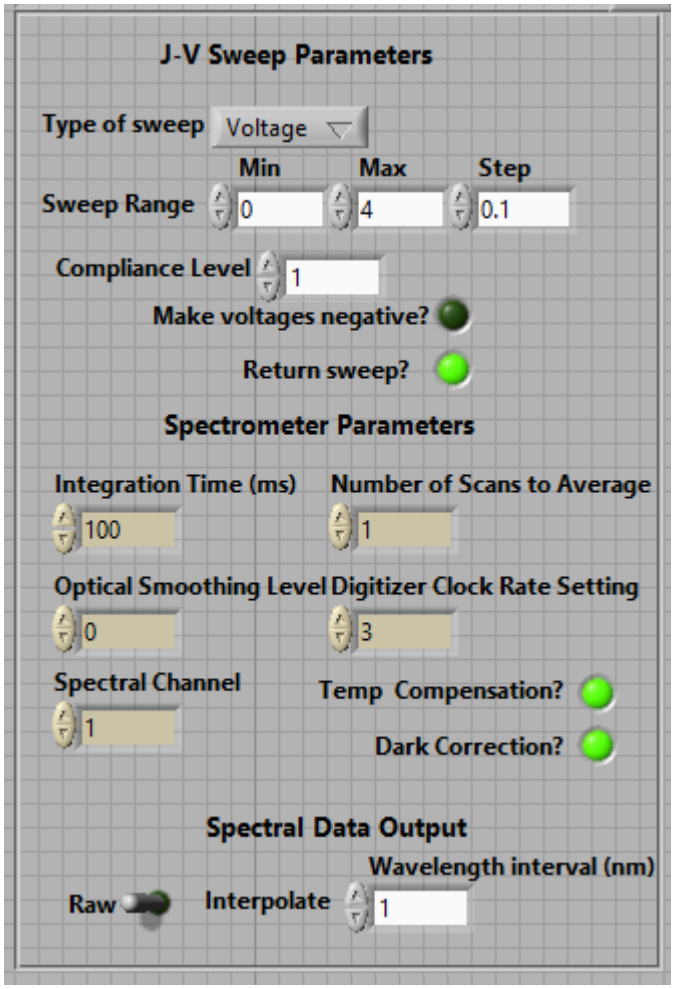
Delay between steps (ms): Time in milliseconds software will wait after each step, before setting the next voltage or current

Dwell Time (ms) at setpoint: Time in milliseconds software will wait after setting voltage or current before measuring current or voltage and spectrum

Number of Cycles: Number of times the software will repeat the entire set of measurements

Wait Time Between Cycles: Time in seconds the software will wait between sets of measurements

Keithley and Spectrometer Parameters



J-V Sweep Parameters

Type of sweep: Choose a voltage sweep or a current sweep. The parameter selected will be stepped at even intervals, and the other parameter will be measured.

Sweep range: Minimum and maximum voltages (in V) or current (in A), step increment. Sweep will begin at minimum, increase by step up to maximum, then decrease back to minimum again (if **Return sweep** is selected).

Compliance Level: If voltage sweep is selected, the output current will not exceed this value in A. If current sweep is selected, the output voltage will not exceed this value in V. Make sure to set it high enough to allow your device to be fully scanned (suggested values are 1 A for voltage sweep, 5-10 V for current sweep depending on your device). Used to prevent damage to the device from shorts or other electrical faults.

Make voltages negative: If you hooked up your device backwards (HI to the cathode and LO to the anode), you can select this option to invert the voltages rather than changing your cabling, if you wish.

Return sweep? If this is selected, after sweeping from the minimum to the maximum, a return sweep will be performed. Useful for investigating device hysteresis.

Spectrometer Parameters

Integration Time: Time in milliseconds (1–480,000) that the spectrometer will integrate the signal. Longer times will give more sensitive detection, but could saturate the detector if the light is too bright. Integration times below 15 ms will result in diminished accuracy of results. If the signal saturates even at low integration times, an inline filter holder can be used to attenuate the signal with a neutral density filter (https://www.stellarnet.us/spectrometers-accessories/inline-filter-holder/).

Number of Scans to Average: Spectrometer will average the specified number of scans to produce a lower-noise signal. Averaging at least 3 scans is recommended.

Optical Smoothing Level: Spectrometer will perform a box-car average on a number of adjacent of pixels in the wavelength dimension to produce a lower-noise signal. StellarNet recommends a 5-pixel average (setting **1**). Setting this at **0**/**1**/**2**/**3**/**4** results in an average of 0/5/9/17/33 pixels, respectively.

Digitizer Clock Rate Setting: Leave at 3 for integration times longer than 1 ms. Set to 1 for 1 ms integration time. More information can be found in the SpectraWiz help menu.

Spectral Channel: For systems with multiple spectrometers connected, this option selects which spectrometer to use.

Temp Compensation? If this option is selected (which it is by default) the spectrometer will read the first 30 detector pixels, which are always dark, and use their values to approximate the sensor dark current, then subtract that value from the total spectrum to adjust for fluctuating tempertures.

Dark Correction? If this option is selected (which it is by default), the software will take a baseline scan before applying any voltage to the device. This baseline scan will then be subtracted from every subsequent scan. This compensates for any stray light entering the detector.

Spectral Data Output

Raw/Interpolate: Use this toggle switch to choose between raw and interpolated spectrum data. If Raw is chosen, output wavelengths will be the actual calibrated wavelengths for each detector pixel. If Interpolated is chosen, the spectral data will be interpolated to an even spacing determined by Wavelength Interval.

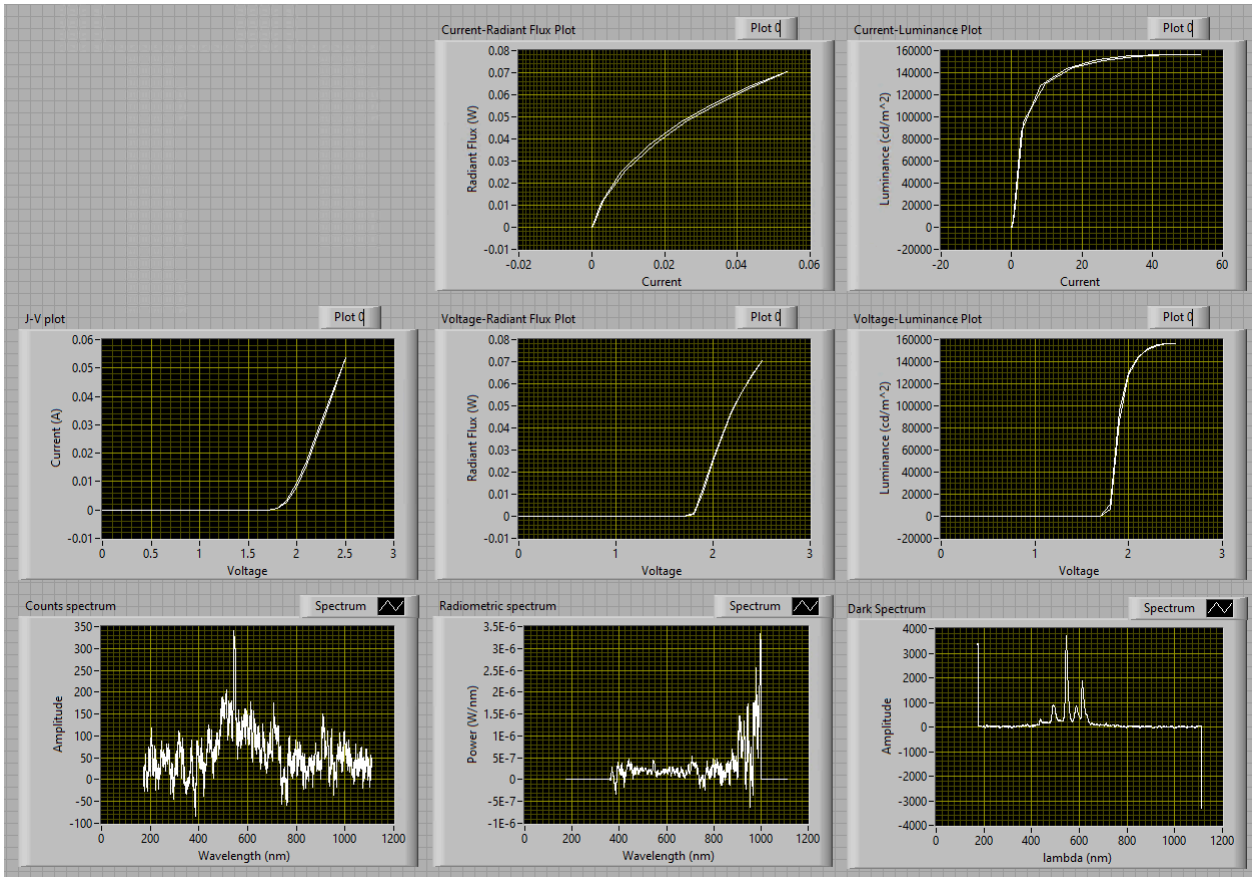
Wavelength Interval: The spacing of wavelengths in the interpolated output.

Once all the parameters are correctly set, press the Run button to start the measurement. The software will count down the wait time, and then begin.

At the bottom of the screen, a stop button will appear:

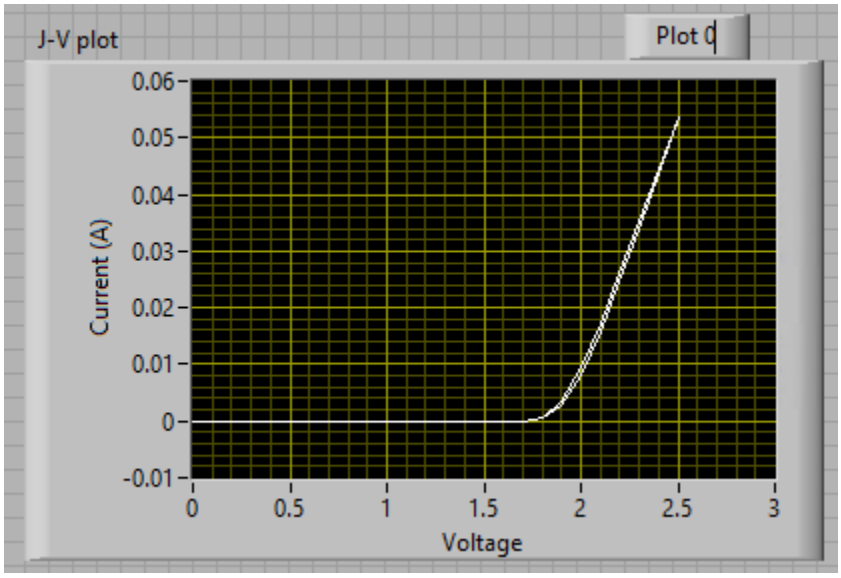
If you need to stop the data collection before the end of the run, press that button to stop the run and save the data already collected.

As data are collected, they will appear on screen.

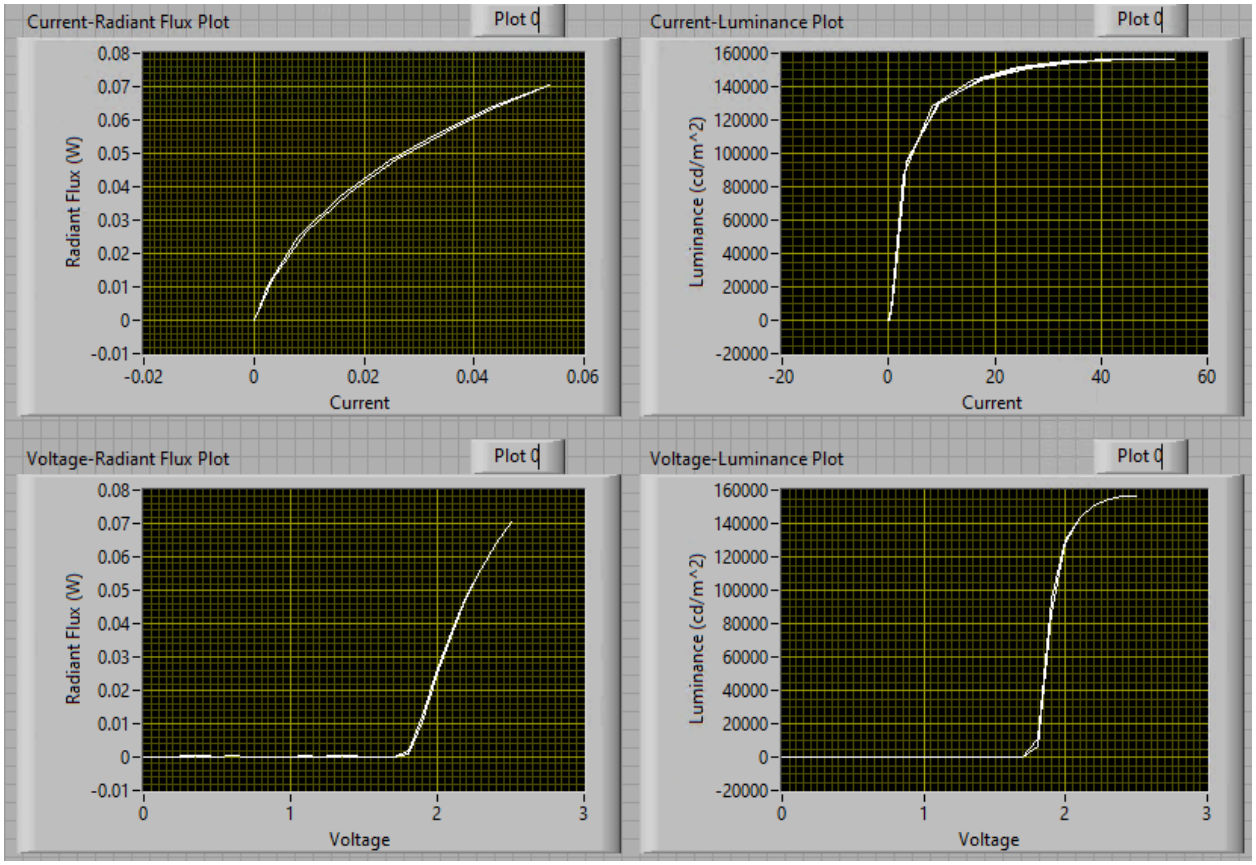


At the bottom, the voltage will be displayed alongside the current, luminance, and device efficiency at that voltage point.

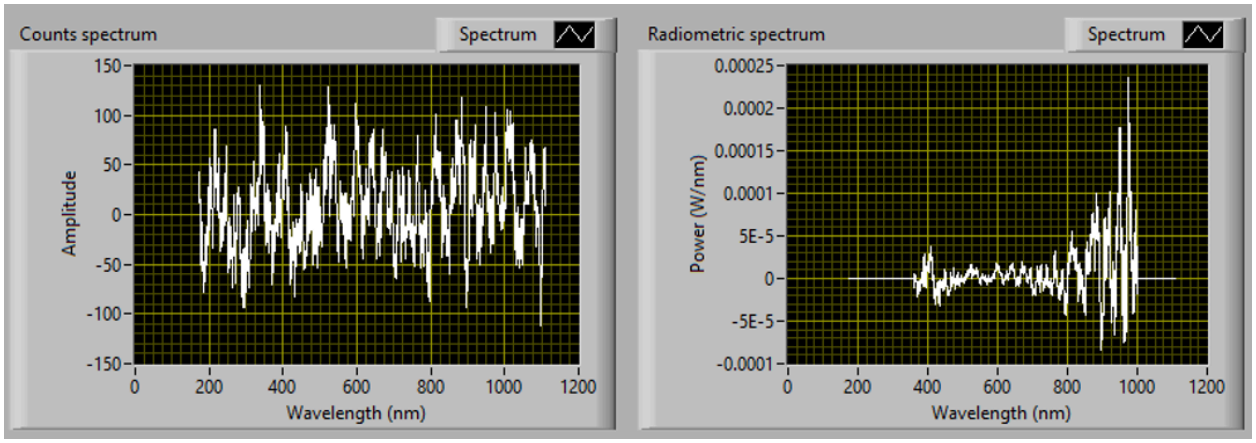
Next to the parameters section, the current–voltage (sometimes called I–V or J–V) will be plotted.



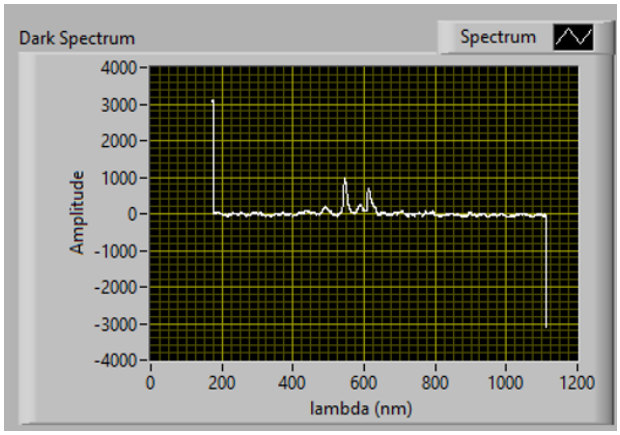
Next to that are the radiant flux (light output power) and luminance (perceived brightness per unit area) plotted versus the voltage and the current.



Underneath those are shown the current spectrum in arbitrary counts (left) and power (right):



Finally, the dark spectrum is shown for reference:



At the conclusion of the run, the data will be saved. If a data file with the same name already exists, a new file will be created with the name and a number appended in parentheses.

The data files are saved in tab-delimited format. They can be pasted or imported into Excel or the data processing application of your choice for futher analysis.

CIE chromaticity data can be calculated using an Origin package found here:
https://www.originlab.com/fileExchange/details.aspx?fid=446

Another software package that works well is this one from Osram:
https://www.osram.us/cb/tools-and-resources/applications/led-colorcalculator/index.jsp

Examples are shown below:

LED test board device 1-blue-1_IVL.txt:

```
blank-1_
Wednesday, May 26, 2021 11:29:44 AM

Device Area (mm^2): 6.250

------Current-Voltage Scan Parameters------
Scan type: Voltage Sweep

Sweep min: 0.000000
Swep max: 2.500000
Step size: 0.100000
Make voltages negative? No
Step Time (ms): 100
Dwell Time (ms): 25

------Spectrometer Parameters------
Integration Time (ms): 100
Number of Scans to Average: 1
Optical Smoothing Level: 0
Digitizer Clock Rate Setting: 3
Spectral Channel: 1
Temperature Compensation? Yes
Dark Correction? Yes

Voltage (V)     Current (A)     Current Density (mA/mm^2)  Power
(Radiant Flux) (W)    Luminous Flux (lm)    Luminance (cd/m^2)
Efficiency (%)
0.00  -4.057146E-10    -6.491434E-8     2.243914E-4      4.924550E-3
7.837664E-4      668215644970.50
0.10  -3.887443E-10    -6.219909E-8     -1.159118E-7     -4.129443E-3
-6.572213E-4     -297931.53
```

0.20 -3.676192E-10 -5.881907E-8 1.489138E-4 2.237286E-3
3.560752E-4 202459446.09
0.30 -3.538028E-10 -5.660845E-8 2.503724E-4 6.033740E-3
9.602996E-4 235798675.33
0.40 -3.432401E-10 -5.491842E-8 2.398262E-5 7.743815E-4
1.232466E-4 17467564.50
0.50 -3.310254E-10 -5.296406E-8 1.915523E-4 4.269328E-3
6.794846E-4 115714632.69

...
0.60 -3.719229E-10 -5.950767E-8 2.830143E-4 8.573783E-3
1.364560E-3 126798895.54
0.50 -3.892937E-10 -6.228699E-8 1.466621E-4 4.049658E-3
6.445232E-4 75336316.68
0.40 -4.019083E-10 -6.430533E-8 3.230769E-4 9.132785E-3
1.453528E-3 200962467.70
0.30 -4.149740E-10 -6.639584E-8 1.689434E-4 4.026499E-3
6.408372E-4 135656529.89
0.20 -4.326448E-10 -6.922317E-8 1.808177E-4 4.105855E-3
6.534671E-4 208887736.19
0.10 -4.342967E-10 -6.948747E-8 1.146508E-4 3.293325E-3
5.241490E-4 263781851.05
0.00 -4.461609E-10 -7.138575E-8 1.334321E-4 1.026616E-3
1.633910E-4 358726353172.73

LED test board device 1-blue-1_spectra.txt:

```
blank-1_
Wednesday, May 26, 2021 11:29:44 AM

Device Area (mm^2): 6.250

------Current-Voltage Scan Parameters------
Scan type: Voltage Sweep

Sweep min: 0.000000
Swep max: 2.500000
Step size: 0.100000
Make voltages negative? No
Step Time (ms): 100
Dwell Time (ms): 25

------Spectrometer Parameters------
Integration Time (ms): 100
Number of Scans to Average: 1
Optical Smoothing Level: 0
Digitizer Clock Rate Setting: 3
Spectral Channel: 1
Temperature Compensation? Yes
Dark Correction? Yes
```

Voltage ->	0	0	0.1	0.1	...
Current ->	-4.06E-10	-4.06E-10	-3.89E-10	-3.89E-10	...
Current Density (mA/mm^2)->	-6.49E-08	-6.49E-08	-6.22E-08	-6.22E-08	...
Power (Radiant Flux) (W)->	2.24E-04	2.24E-04	-1.16E-07	-1.16E-07	...
Luminous Flux (lm)->	4.92E-03	4.92E-03	-4.13E-03	-4.13E-03	...
Luminance (cd/m^2)->	7.84E-04	7.84E-04	-6.57E-04	-6.57E-04	...

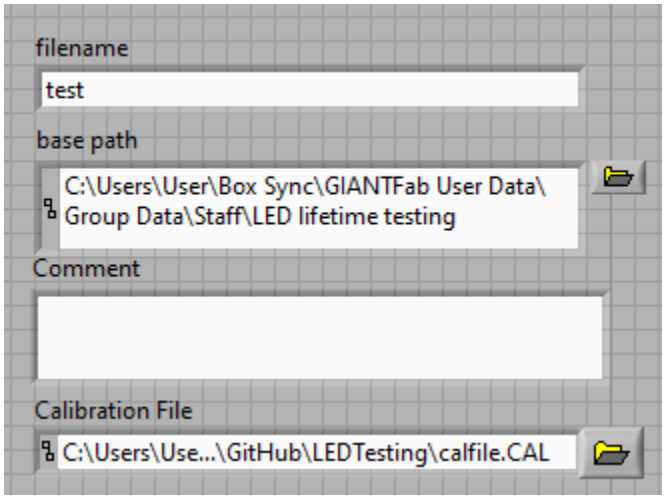
Efficiency ->	6.6822E+11	6.6822E+11	-297931.53	-297931.53	...
Wavelength	Counts (arb.)	Power (W/nm)	Counts (arb.)	Power (W/nm)	...
172.09	42	0.00E+00	21	0.00E+00	...
172.51	37	0.00E+00	29	0.00E+00	...
172.93	43	0.00E+00	25	0.00E+00	...
173.35	52	0.00E+00	29	0.00E+00	...
...					
1105.78	60	0.00E+00	121	0.00E+00	...
1106.28	46	0.00E+00	123	0.00E+00	...
1106.77	27	0.00E+00	136	0.00E+00	...
1107.27	29	0.00E+00	151	0.00E+00	...
1107.76	26	0.00E+00	148	0.00E+00	...
1108.26	38	0.00E+00	144	0.00E+00	...
1108.75	40	0.00E+00	147	0.00E+00	...
1109.25	35	0.00E+00	129	0.00E+00	...
1109.74	57	0.00E+00	128	0.00E+00	...
1110.24	60	0.00E+00	119	0.00E+00	...

LED Lifetime Testing

Make sure your devices are hooked up following the instructions in the Hardware section above.

Open the LED Lifetime program:

Set the file parameters:



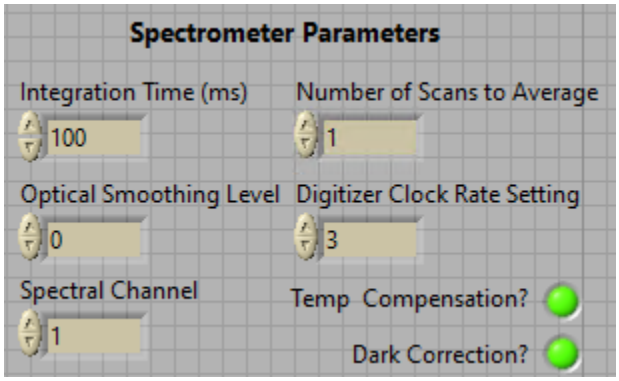
Filename: base file name for your results. The actual filename will be <filename>_lifetime.txt. If a file with that name already exists, a new file will be created with a number in parentheses appended/

Base Path: the folder to store your data files in.

Comment: free-form field to add any extra information you want to your data file.

Calibration file: location of the calibration file provided with the spectrometer (see calibration file section above).

Set the spectrometer parameters:



Integration Time: Time in milliseconds (1–480,000) that the spectrometer will integrate the signal. Longer times will give more sensitive detection, but could saturate the detector if the light is too bright. Integration times below 15 ms will result in diminished accuracy of results. If the signal saturates even at low integration times, an inline filter holder can be used to attenuate the signal with a neutral density filter (https://www.stellarnet.us/spectrometers-accessories/inline-filter-holder/).

Number of Scans to Average: Spectrometer will average the specified number of scans to produce a lower-noise signal. Averaging at least 3 scans is recommended.

Optical Smoothing Level: Spectrometer will perform a box-car average on a number of adjacent of pixels in the wavelength dimension to produce a lower-noise signal. StellarNet recommends a 5-pixel average (setting **1**). Setting this at **0**/**1**/**2**/**3**/**4** results in an average of 0/5/9/17/33 pixels, respectively.

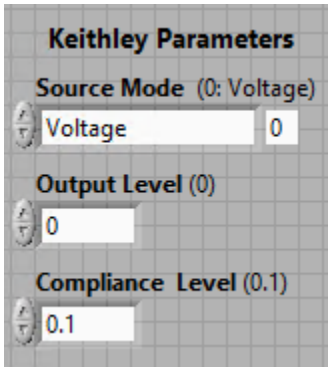
Digitizer Clock Rate Setting: Leave at 3 for integration times longer than 1 ms. Set to 1 for 1 ms integration time. More information can be found in the SpectraWiz help menu.

Spectral Channel: For systems with multiple spectrometers connected, this option selects which spectrometer to use.

Temp Compensation? If this option is selected (which it is by default) the spectrometer will read the first 30 detector pixels, which are always dark, and use their values to approximate the sensor dark current, then subtract that value from the total spectrum to adjust for fluctuating tempertures.

Dark Correction? If this option is selected (which it is by default), the software will take a baseline scan before applying any voltage to the device. This baseline scan will then be subtracted from every subsequent scan. This compensates for any stray light entering the detector.

Keithley Parameters:

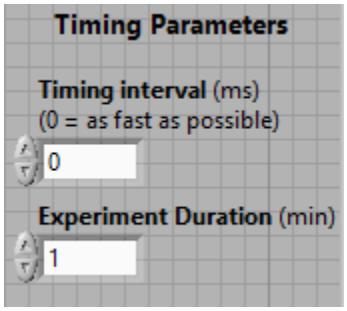


Source mode (Voltage or Current): choose whether to run the lifetime measurement in constant voltage mode or constant current mode.

Output level: Choose the output voltage (in V) or the output current (in A).

Compliance Level: If voltage mode is selected, the output current will not exceed this value in A. If current mode is selected, the output voltage will not exceed this value in V. Make sure to set it high enough to allow your device to be fully scanned (suggested values are 1 A for voltage sweep, 5-10 V for current sweep depending on your device). Used to prevent damage to the device from shorts or other electrical faults.

Timing Parameters:



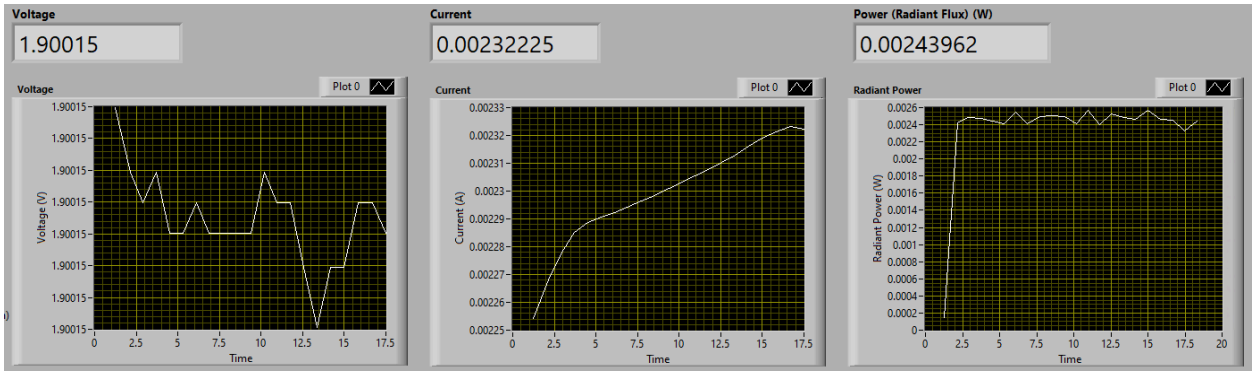
Timing interval: the software will take data points at this interval in ms. Each scan will take at least 500 ms so it may not be possible to capture data faster than that.

Experiment Duration: number of minutes to run the lifetime scan. The scan can always be stopped and the data saved before the end if desired.

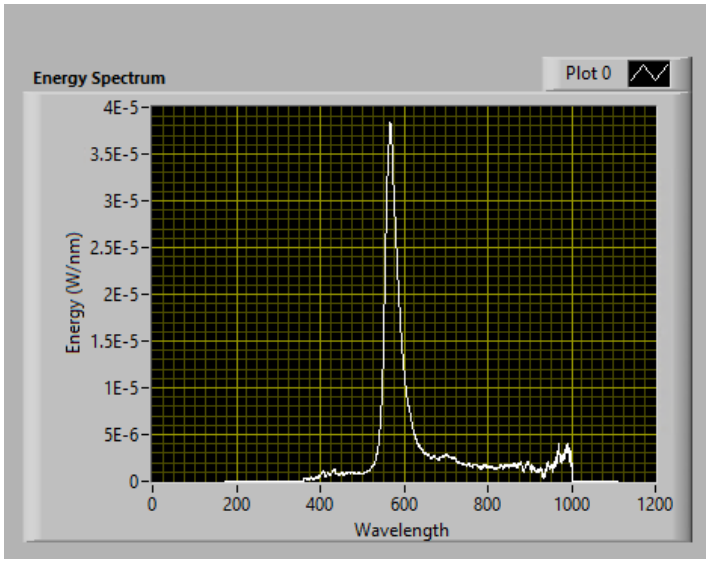
Running the program

When all the parameters are set, press the run button in the toolbar: 

The program will begin collecting data. The voltage, current, and radiant power will all be displayed and plotted:



The LED output spectrum in W/nm will also be displayed:



Finally, a timer will show the experiment elapsed time. If you wish to end the experiment early, press the STOP AND SAVE button to stop data collection, reset the Keithley, and save your data:

The data will be saved in the folder specified in tab-delimited format suitable for pasting directly into Excel or another graphing or analysis program. At each timepoint, the voltage, current, radiant flux, and spectrum will be recorded.

```
test
Tuesday, June 1, 2021 11:00:25 AM
comment

------Spectrometer Parameters------
Integration Time (ms): 100
Number of Scans to Average: 1
Optical Smoothing Level: 0
Digitizer Clock Rate Setting: 3
Spectral Channel: 1
Temperature Compensation? Yes
Dark Correction? Yes
```

Time since start (s)->	0	0.908	1.662	...
Voltage (V)->	1.9	1.9	1.9	...
Current (A)->	2.25E-03	2.27E-03	2.28E-03	...
Power (Radiant Flux) (W)->	1.51E-04	2.42E-03	2.48E-03	...
Wavelength	Power (W/nm)	Power (W/nm)	Power (W/nm)	...
172.09	0.00E+00	0.00E+00	0.00E+00	...
172.51	0.00E+00	0.00E+00	0.00E+00	...
172.93	0.00E+00	0.00E+00	0.00E+00	...
...	...	...	...	...
1110.73	0.00E+00	0.00E+00	0.00E+00	...