Spectral Measurement Using a Monochromator, Thermopile Detector, and Lock-In Amplifier

September 18, 2012

The University of Toledo
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Where are We, Where we are Going? (the next three weeks and beyond)

✓ Igor (or comparable), LabView
✓ Properties of the Sun

☐ Understand Components in Optical Measurement System
   ☐ Physics
   ☐ Role in experiments

☐ Set Them Up!
   ☐ Bread Board Layout
   ☐ Interface to Computer
   ☐ Develop software

☐ Characterize output of lamp/monochromator (three weeks)
☐ Onward to reflection, transmission, absorption, QE, J/V, and a host of other interesting measurements!
Lab Due Dates, and other Info

Previously – Due on Monday before the lab, noon.

Rationale – wanted students to look at lab report requirements/topics early, so we could help if needed

Now – Due on Tuesday, by Lab time

Think about your report and potential stumbling blocks early! Interface with group members early!

Late policy will be strictly enforced!

Next Lab Report Due October 3 – 1st day after Fall Break

First Quiz on September 25
The “Set-Up”

Light Source

Tungsten – halogen bulb

Sample or Detector

A lens or two

Monochromator

Samples – semiconductor layers, transparent conductive layers, PV devices
Detectors – calibrated thermopile, photodiode
Spectral Products, CM110 1/8\textsuperscript{th} meter monochromator

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Czerny-Turner, dual-grating turrets</td>
</tr>
<tr>
<td>Focal Length:</td>
<td>110mm</td>
</tr>
<tr>
<td>f/#:</td>
<td>3.9</td>
</tr>
<tr>
<td>Beam Path:</td>
<td>Straight through standard, right angle provided on request.</td>
</tr>
<tr>
<td>Wavelength Drive:</td>
<td>Worm and wheel with microprocessor control and anti-backlash gearing. Bi-directional. Usable in positive or negative grating orders.</td>
</tr>
<tr>
<td>Wavelength Precision:</td>
<td>0.2nm</td>
</tr>
<tr>
<td>Wavelength Accuracy:</td>
<td>± 0.6nm</td>
</tr>
<tr>
<td>Slewing Speed:</td>
<td>&gt;100nm/second</td>
</tr>
<tr>
<td>Stray Light:</td>
<td>&lt;10\textsuperscript{-5}</td>
</tr>
<tr>
<td>Slits:</td>
<td>Standard Set includes; 0.125mm, 0.15mm, 0.30mm, 0.6mm, 1.2mm and 2.4mm x 4.0mm. For other sizes, consult SP.</td>
</tr>
<tr>
<td>Max Resolution:</td>
<td>&lt;1nm w/1200G/mm grating and standard slits</td>
</tr>
<tr>
<td>Gratings:</td>
<td>One to two gratings. (30 x 30mm) must be purchased. See Appendix A for options</td>
</tr>
<tr>
<td>Software:</td>
<td>Demonstration control program and LabView driver included.</td>
</tr>
<tr>
<td>Power:</td>
<td>UL listed 110/220V power pack</td>
</tr>
<tr>
<td>Interface:</td>
<td>RS232 standard</td>
</tr>
<tr>
<td>Warranty:</td>
<td>One year</td>
</tr>
</tbody>
</table>
| Options:                    | • Hand-held control module with function keys and display for local control  
                                • IEEE-488 interface  
                                • Interface cables  
                                • Gold optics      |
                                See options and accessories
Czerny-Turner Monochromator

focal length, f
Characterize lamp/monochromator output (photon flux) at the sample plane (three week duration)

How many Photons/s/nm are incident at the sample plane?
You have two lenses per set-up

1) Both 1” diameter
2) One has a focal length of 1”
3) The other has a focal length of 2”

A bit more bulbous

CM110

f = 1”

f = 2”
Details on the CM110 monochromator

- Note that the CM110 has a double-grating turret -- one side has our 1200 g/mm grating (make sure you know what g/mm means); the other side has a flat aluminum mirror. The “Select11x2.vi” enables you to select the turret to be in position 1 or 2 (one is the grating, the other the mirror).

- You’ll get the brightest output when selecting the mirror (output only at 0 nm, where it is specularly reflecting); using the grating, you’ll get a blend of wavelengths out when set to 0 nm (m = 0), and you can select a specific wavelength.
Thermopile Detector (Dexter Research, Model 2M)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typical</th>
<th>Max</th>
<th>Symbol</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Area size</td>
<td>2 x 2</td>
<td></td>
<td></td>
<td>AA</td>
<td>mm</td>
<td>Hot junction size, per element.</td>
</tr>
<tr>
<td>Element Area</td>
<td>4</td>
<td></td>
<td></td>
<td>A</td>
<td>mm²</td>
<td>Per element.</td>
</tr>
<tr>
<td>Number of Junctions</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Channels</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Per detector package.</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>(V_s)</td>
<td>(\mu V)</td>
<td>DC, (H=330\ \mu W/cm²) (3)</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio</td>
<td>12.739</td>
<td>19.531</td>
<td>33.333</td>
<td>SNR</td>
<td>(\sqrt{Hz})</td>
<td>DC, (SNR=V_s/V_n)</td>
</tr>
<tr>
<td>Responsivity</td>
<td>15.2</td>
<td>18.9</td>
<td>22.7</td>
<td>(\rho)</td>
<td>(\mu W)</td>
<td>DC, (\rho=V_s/HA) (2)</td>
</tr>
<tr>
<td>Resistance</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>R</td>
<td>(k\Omega)</td>
<td>Detector element</td>
</tr>
<tr>
<td>Temperature Coefficient of (\rho)</td>
<td>-.30</td>
<td></td>
<td></td>
<td></td>
<td>%/°C</td>
<td>Best linear fit, 0° to 85°C (1)</td>
</tr>
<tr>
<td>Temperature Coefficient of R</td>
<td>-.2</td>
<td></td>
<td></td>
<td></td>
<td>%/°C</td>
<td>Best fit, 0° to 85°C (1)</td>
</tr>
<tr>
<td>Noise Voltage</td>
<td>9.0</td>
<td>12.8</td>
<td>15.7</td>
<td>(V_n)</td>
<td>(nV/\sqrt{Hz})</td>
<td>(V_n^2=4kTR)</td>
</tr>
<tr>
<td>Noise Equivalent Power</td>
<td>.40</td>
<td>.68</td>
<td>1.03</td>
<td>NEP</td>
<td>(nW/\sqrt{Hz})</td>
<td>DC, (NEP=V_n HA/V_s) (2)</td>
</tr>
<tr>
<td>Detectivity</td>
<td>1.9</td>
<td>3.0</td>
<td>5.0</td>
<td>(D^*)</td>
<td>(10^8\mu V/cm²/Hz/W)</td>
<td>DC, (D^*=V_d/V_s HVA) (2)</td>
</tr>
<tr>
<td>Time Constant</td>
<td>1.9</td>
<td>3.0</td>
<td>5.0</td>
<td></td>
<td>ms</td>
<td>Chopped, -3dB point (1)</td>
</tr>
<tr>
<td>Field of View</td>
<td>36°</td>
<td>95°</td>
<td></td>
<td>FOV</td>
<td>Degrees</td>
<td>See Assembly Drawings for FOV Description.</td>
</tr>
<tr>
<td>Package Type</td>
<td>TO-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard package hole size: (\varnothing) 150°</td>
</tr>
</tbody>
</table>

**General Specifications:** Flat spectral response from 100nm to > 100μm. Linear signal output from \(10^{-5}\) to 0.1W/cm². Maximum incident radiance 0.1W/cm².

**Notes:** (1) Parameter is not 100% tested. 90% of all units meet these specifications. (2) A is detector area in cm². (3) Test Conditions: 500K Blackbody source; Detector active surface 10cm from 0.6513cm Diameter Blackbody Aperture.
Goals of this Unit

1) Build an optical set-up to permit development of a LabView program to acquire (directly into the DAQ board), plot, and store signals from the thermopile detector. The detector is to be excited by the chopped output of the CM110 monochromator. Determine the time constant of the detector, and identify the gas used for packaging. Useful resources are under “Effects of Encapsulation Gas on Thermopile Detectors” and “Thermopile Time Constant Determination” at the http://www.dexterresearch.com/?module=Page&sID=technical-library

2) Acquire plot and store data from the thermopile using the lock-in technique. Compare to data from (1), and understand how the measured voltage relates to the thermopile’s response.

3) Develop a program to measure, plot and store the output of the monochromator, in terms of # of photons/nm-cm2-s, as function of wavelength, for various lamp powers, and several slits widths. How does your measured spectrum compare to a Black Body spectrum? How does your measured spectrum compare to the AM 1.5 spectrum? Use Igor Pro to develop a correction file to convert measured spectrum into either BB or AM 1.5.

Additional guidance for Part 3

- Include information about calculations and assumptions (step by step).
- Include a comparison of measured data to the AM 1.5 and AM0 spectra in units of #photons/(s-cm²-nm).
- Specify definition of correction files as AM X(λ)/measured spectra (λ).
- Plot (measured spectra x correction file) for each case versus AM X spectra.
Stanford Research Systems, Model SR510 Lock-In Amplifier

Typical experimental setup for lock-in detection

light source → chopper → test object → photo detector → lock-in amplifier → gauge

chopper control
• Also known as a “phase-sensitive detector”;
• Can extract a signal with a known carrier wave (modulation frequency) from an otherwise very noisy environment;
• Requires a reference signal, which is effectively multiplied by the input signal;
• When a sinusoidally varying signal of frequency $\nu_1$ is multiplied by another sinusoidally varying wave of frequency $\nu_1 \neq \nu_2$, and integrated over many cycles, the result is zero; thus for a noisy signal with a component at the carrier (reference) frequency, the result of long time integration is non-zero;
• Modulation of the signal can be achieved by (using light as a relevant example) an optical chopper (note that our chopper has a “reference” signal output, but pay careful attention to what this signal looks like);
• Practical aspects of an LIA: the need to set the phase correctly (controlled through the Reference Input section); the sensitivity setting; the display; the scaling of the “Output” signal; the role of the Time Constant.

The output from a lock-in amplifier is generally calibrated to indicate the actual signal amplitude (e.g., in Volts).

However, the measured signal amplitude does depend on the specifics of the Reference signal. For example, for sinusoidal modulation, the output is generally the root-mean-square signal at the modulation frequency, so a factor of $\sqrt{2}$ comes into play – note that you can test this by comparing the actual signal amplitude (as measured by the DAQ analog-to-digital (AI)) to the signal detected by the lock-in amplifier.

For a non-sinusoidal modulation, the value may be different. What is the shape of our signal modulation? Sinusoidal?

What do we mean by “time constant”? 

\[ V(t) = V_0 e^{-\left(\frac{t}{\tau}\right)} \]

http://en.wikipedia.org/wiki/Time_constant
Spectrometer sensitivity calibration: black body radiation, grating efficiency, detector sensitivity

![Graph showing black body radiation as a function of wavelength for different temperatures.](image-url)
Solar Radiation Spectrum

Sunlight at Top of the Atmosphere

Green line marks bandgap of Si

5250°C Blackbody Spectrum

Radiation at Sea Level
Resources:


http://www.thinksrs.com/products/SR510530.htm

http://www.dexterresearch.com/?module=Page&sID=technical-library

http://www.pariss-hyperspectral-imaging.com/GratingOrders_Movie/GratingOrders_Movie.html