Lab #8

Light Source Characteristics: LED Properties

Introduction

In this lab you will be measuring the optical properties of commercial light emitting diodes (LEDs) made by Everlight and Kingbright. The data sheets for these devices are available on the class webpage (we're experimenting with the Lilypad products). The RGB package from Everlight contains three different LEDs that can be operated independently – the Lilypad package provides series resistors and a connection point for each LED. The LEDs are encapsulated in plastic, but there is no lens (the plastic surface is flat). The "white" LED from Kingbright uses a UV LED and a phosphorescent encapsulent that absorbs the UV light and reemits into a broad visible spectrum. This LED is also packaged by Lilypad with a series resistor.

The LED with series resistor can be driven by either the lab bench supply or the function generator.

The quantum efficiency of the LED can be quite good, on the order of 0.8. However, because of the index mismatch between the semiconductor material and air, much of the light that is generated is totally internally reflected and cannot escape. The external efficiency η_{ex} is a measure of the number of photons that escape per electron injected. By using an encapsulant, such as a plastic lens, more of the light can get out of the semiconductor, and depending on the curvature and geometry of the lens may be able to escape into the air. Our encapsulant layer isn't "lensed", so the extraction efficiency is only modestly improved.

Summary of Measurements

LED measurements

1. Measure the power output from a LED vs. drive current. Calculate the external efficiency η_{ex} of the LED.
2. Measure the radiated power [W] as a function of viewing angle.
3. Estimate the on-axis radiant intensity of the LED [W sr^{-1}].
4. Measure and comment on the polarization state of the output radiation.
5. Measure the optical spectrum of the LED.

Background

A Light Emitting Diode (LED) is a semiconductor that generates light when electrical current is injected. The light is mostly incoherent because it does not involve the all-important step of "stimulated emission" that makes laser light so highly coherent. Rather, it involves spontaneous emission.

As described in section 17.1 of our textbook (Saleh & Teich), an LED has several efficiency factors:

η_e	extraction efficiency = how much light escapes device into air	[photon/photon]
η_i	internal quantum efficiency = # photons created per electron	[photon/e$^-$]
$\eta_{ex} = \eta_e \eta_i$	external quantum efficiency = # photons extracted per electron	[photon/e$^-$]

The extraction efficiency describes the fraction of light generated inside the LED that manages to escape into the air. Most of the light is reflected back into the LED because of the relatively large Fresnel reflectance at the interface between materials. Usually there are three materials: the LED (n ~ 3-4), a plastic cover or lens (n ~1.3-1.6), and air (n=1).

The external efficiency can be expressed as the ratio of output photon flux Φ_o [photons/s] that can be achieved for a given input electron flux i/e [electrons/s]. In this equation, i is the electrical current and e is the electron charge. This allows us to calculate the output photon flux from electrical quantities:

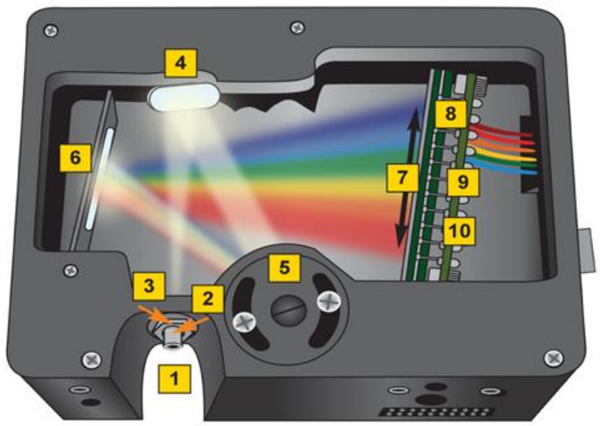
$$\Phi_o = \eta_{ex} \frac{i}{e} \qquad \text{output photon flux [ph/s]}$$

If we multiply the photon flux by the photon energy $h\nu$, we obtain the total output power from the LED:

$$P_o = h\nu\Phi_o = h\nu\eta_{ex}\frac{i}{e} \qquad \text{output power [J/s = W]}$$

New Equipment

You will use a compact grating spectrometer to measure the emission spectrum of one or more LEDs. The diagram below shows the layout of a similar instrument. Light enters from an optical fiber (1) through a slit (2,3). The light beam is collimated by a mirror (4) and dispersed into its constituent colors by a reflective diffraction grating (5). The color-dispersed light is focused in one dimension by cylindrical lenses (6,7) onto a charge-coupled device (CCD) detector array (8). Each pixel of the detector array responds to a different portion of the light spectrum. The resulting spectrum is read by a computer connected to the spectrometer by a USB cable.



1, 2, 3 = fiber SMA connector, slit, long-wave absorbing filter to reduce higher orders.
4 = collimating mirror (matched to 0.22 fiber NA)
5 = grating (rotated to select wavelength range)
6 = focusing lens (1^{st}-order)
7 = cylindrical lens (focuses light from long slit onto shorter detector pixels in one dimension)
8 = linear CCD array (3648 pixels)
9 = high-order blocking filter
10 = optional uv-blocking filter

LED measurements

1. Choose one of the RGB LEDs to measure, and use that one for all of parts 1-3. Place the LED as close to the power meter as possible, and measure the output power as a function of input current. Let the input current range from 0 to 20 mA. Calculate the external quantum efficiency in terms of output photons per input electron.

   Adjust the drive current to 20 mA and determine the radiant intensity [W/sr]. Move the power meter away from the LED a few centimeters (measure this distance!), and use an iris with known area to make a **calibrated** measurement of the on-axis (forward-looking) radiant intensity $J(0)$ [W sr^{-1}]. To determine the radiant intensity, you will need to divide the measured power [W] by the calculated solid angle [sr] of the portion of the beam transmitted through the iris. You can calculate this solid angle using the relationship $\omega = 2\pi[1-\cos(\alpha)]$, where α is the half-angle subtended by the iris at its measured distance from the LED.

   Convert the radiant intensity to (photometric) luminous intensity in units of millicandelas [mcd], where one candela is one lumen per steradian. You need to know the luminous efficacy at the center wavelength of the LED to do this conversion. Use a center wavelength of 475nm (79 lm/W), 525nm (537 lm/W) or 621nm (252 lm/W) for B, G or R, respectively. Does your maximum value of luminous intensity match the value in the spec sheet?

2. Measure the **relative** power as a function of viewing angle. Mount the LED holder on a rotation stage so that the radiation angle can be continuously varied with respect to the detector. To avoid interference from the room lights, you can modulate the LED at something like 600 Hz using the function generator, use the mechanical chopper, or turn out the room lights. **Beware: the LED doesn't like reverse voltages greater than about 5 Volts.** Use a small iris placed in front of the detector, and keep the iris size fixed.

   Plot the relative detected signal as a function of measurement angle, and use the on-axis radiant intensity to scale your plot to be $J(\theta)$ in units of [W/sr^{-1}]. Does the source look Lambertian, isotropic or something else? Does it look like the radiant intensity curve in the datasheet? Describe the geometry of the LED and package, and discuss your results.

3. Measure the polarization state of the output radiation. Comment on this result.

4. Use the grating spectrometer to measure the optical spectrum of the emitted light. Determine the center wavelength and bandwidth of the output spectrum. Repeat this for the white LED, and any other LED sources as desired … **you may bring your own LED for this part**.