6.973 Lab 3: Organic Optoelectronic Device Growth 4/17, 4/18

1. Overview

In this lab we will perform the "More extensive and quantitative testing" that was alluded to in Lab 2. In fact, we will use the exact devices that you grew, packaged so that their performance will remain constant throughout the measurement time. The measurements will assess the optical and electrical properties of the devices, operated as both OLEDs (electrons in, and light out) and photovoltaics (PVs, light in and electrons out). The devices that we chose to grow in Lab 2 are appropriate for LEDs, and we expect good performance from them, but less than optimum for PVs, and so we expect poor response in this regime relative to the state-of-the-art. Nonetheless, this lab should familiarize you with the concepts of device testing, and the calculations necessary for accurate and complete reporting of optoelectronic device performance. This familiarity should in turn allow you to assess the techniques reported by others, and evaluate critically the pros and cons of the myriad of reported devices in the literature.

2. Measurements

a) OLEDs

i. Spectral response

Our first measurement will be to record the light output of the device, resolving intensity versus wavelength. The recording setup will be the same as in lab 1, making use of the visible spectrometer (monochrometer attached to a Silicon CCD camera), which we will fiber couple to our device. Of course, we need to apply voltage and current to the device in order to turn it on (a new concept in these labs), and so we must use an electrical probe setup as well. Each of the two probes (+/-) are on x,y,z translation stages, to make the positioning of the probe relative to our stationary device as simple as possible. The device must first be aligned over the fiber bundle that is coupled to the spectrometer. Then the probes may be brought into contact (+ voltage to ITO, ground to the metal cathode), and voltage applied. Our voltage source for this measurement will be a curve tracer, a useful piece of electronics for quickly display I-V curves, checking basic device performance, and then applying a fixed voltage (or current). When we test the spectral response of our devices, we may explore the different spectra of the three different devices created in lab 2, and also the dependence of the spectra on current density. The output of this measurement will be intensity numbers recorded at a range of wavelengths, similar to lab 1.

ii. Current-Voltage-Luminance

In this measurement, we want to record with high accuracy the voltage versus current dependence of our device. In addition, we can simultaneously record the light output of our device utilizing a calibrated Silicon photodiode. So, instead of coupling the light into the spectrometer, we will place the device on top of this detector, and then use the same probes to contact the device. Our voltage source in this case will be an HP 4156 parameter analyzer. This instrument allows us to source voltage and measure current (or vice versa) to extreme accuracy, capable of measuring 10fA current steps if we chose to. We will sweep voltage logarithmically, and record the current flowing through the device at each step. The HP will also read of the photodetector response in voltage (at the analog out of the detector amplifier) for each of these voltage steps. The output of this measurement will be 3 (useful) columns of data, V, I, L, and it will be your job to make this into meaningful plots, such as I-V, and external quantum efficiency versus current.

b) Photovoltaics

i. Spectral Response

To record the spectral response of our PVs (will use the simplest Alq/TPD device only in these measurements) we need to have the ability to continuously scan the INPUT light source to the device. To do this, we start with the same white light that we used for our absorption measurements in lab 1, and use a computer controlled monochromator to sweep the wavelength of light that it allows to pass. We shine this output beam of monochromatic light onto our device, and measure the output voltage (V_{OC}) that it produces.

However. we expect this voltage to be extremely small for these poor PVs, and so we must go to somewhat extreme lengths in order to make this voltage measureable. Our problem is separating signal voltage from device noise, and so the first step is to "chop" the input light, allows us to modulate between the noise "dark" signal and the actual response of the device to the light beam. A mechanical wheel chopper is used for this purpose, set to some frequency that will not be confused with 60Hz electrical noise, eg 400Hz.

Next we need to amplify the signal out of the device, but only at the frequency of the real signal (400Hz), and reject all of the other frequency signal, since it is now known to be noise. A lock-in amplifier is used for this task. The voltage out of the device is input to the lock-in, as is the modulation frequency signal, so that it knows at which frequency to look. Now we should see some measured signal in V that is the amplitude of the sine wave output that is the same frequency of the sine wave input. As we sweep the input wavelength we should see this amplitude change, telling us the wavelength response of our detector. Normalizing out the different lamp output intensity at different wavelengths is a subtler issue that may need to be dealt with as well, depending on the wavelength region to which this device responds.

ii. Magnitude of Response

While the previous measurement allowed us to see the response of our device to different colors of light, we didn't get any accurate information as to the magnitude of the response (or did we?). In addition, as discussed in class, it is important when reporting the performance of a solar cell, to report the efficiency of the response to a solar light source (in both spectrum and intensity). To this end, we will now remove the monochromator from the Xenon lamp beam, and allow bright white light to excite our device. We will measure the spectrum and the intensity of this light source, so that we will be able to match it to the solar spectrum later. Finally, we will record the current and voltage response of our PV under this illumination (and under dark conditions) so that we can calculate the device power efficiency. We will again use the HP parameter analyzer to do this, sweeping voltage from negative to positive voltage (+/- 1V) and record the current associated with each voltage. This will show us quadrant four of the I-V diode plot, and allow us to calculate the fill factor, I_{SC}, V_{OC}, and thus the maximum P_{OUT}.

3. Calculations

Using the above data, calculate, plot and include in your report:
1) The spectral response of each of the three OLEDs that the lab groups made in lab 2.
2) The CIE coordinates of each of these three devices, plotted over the horseshoe shaped graph that I will provide for you.
3) The current density (J) versus voltage for a device (log-log plot).
4) The external quantum efficiency versus current density for the same device (log-log plot).
5) The intensity versus wavelength response of the PV that we tested.
6) The quadrant four I-V plot for the PV.
7) Total power efficiency of our PV cell.

4. Discussion Questions

Pleas answer the following questions about the measurements that you performed and the results that you calculated:

1) Describe the electroluminescence mechanism involved in generating the observed light in each of the three devices that we measured (ie, electrons can go here, and why, holes can go there, and why, and excitons are created here, go there, and emit this color, and why).
2) Based on the CIE color diagram, are these three devices appropriate for display applications? Could they be made better, and how?
3) Describe the J-V plot that you made, and any major features that you observe. Tell me what physical effect is responsible for each of these features.
4) What is the maximum EQE of the devices? Describe the major features of the EQE vs J plot, and the physical causes of these features.
5) Why does the PV respond in the region of the wavelength spectrum that it does? What optical property of the device materials does this correspond to?
6) What is the fill factor, I_{SC}, V_{OC}, and power efficiency of our device? Is this measurement a fair comparison to the response that we would get if we made solar cells out of this device structure and operated it on our rooftops? What could have been done to improve upon the power efficiency?
7) What important measurements, if any, did we NOT perform in this lab, in order to fully characterize and compare our devices to others in the literature?