# C-Parameters

*An Introduction to Color Parameters*

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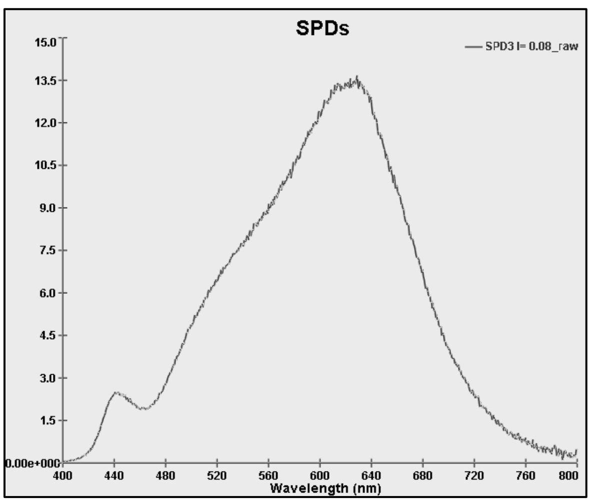
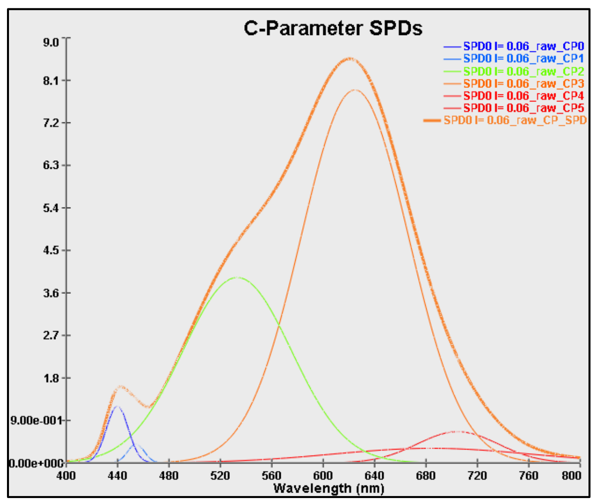
## WHAT ARE C-PARAMETERS?

C-Parameters (Color-Parameters) break down a spectral power distribution (SPD) and quantifies the spectrum by fitting a number of functions to it. A spectral power distribution is a measure of the intensity of each wavelength that makes up light. White light contains all of the colors of the rainbow.

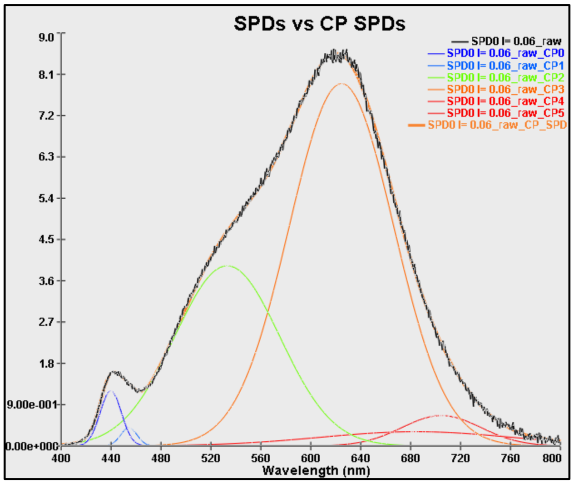
A white LED spectrum looks like this:




And it's C-Parameters look like this:




The C-Parameter algorithm takes the raw spectrum and deconvolves the spectrum into Gaussian components. C-Parameters describe the full SPD with a set of numbers that represent the amplitude, center wavelength, and width of each Gaussian component that makes up the spectrum. The sum of the Gaussian components matches the spectrum (SPD). C-Parameters works best with bounded spectrums like LED's and other solid state lighting.




C-Parameters can be used to quantify the spectral content into as few as 6 real numbers. For example, the C-Parameters of this white LED are:

| CP's | Amplitude (uW/nm) | Center Wavelength (nm) | Width (nm) |
|---|---|---|---|
| CP0 | 1.2 | 439.824 | 12.0243 |
| CP1 | 0.394727 | 454.303 | 9.30811 |
| CP2 | 3.92469 | 533.09 | 59.6388 |
| CP3 | 7.89573 | 624.62 | 59.163 |
| CP4 | 0.309919 | 684.251 | 108.777 |
| CP5 | 0.661505 | 704.664 | 44.7096 |
| Err $R^2$: 0.998842 | Total Area: 1387.1 (uWatts) | Floor offset: -0.235377 | Floor Slope: 0.000892848 |

This white LED needed 6 Gaussians in order to fit the whole shape, because of the various emission mechanisms in the white LED. This white LED is a blue LED with a yellow-emitting phosphor on top of the blue LED that combine to make white light out of blue and yellow light. Most single colored LEDs need 2 to 3 Gaussians and therefore only 6-9 real numbers to describe the full spectrum.

## WHY C-PARAMETERS?

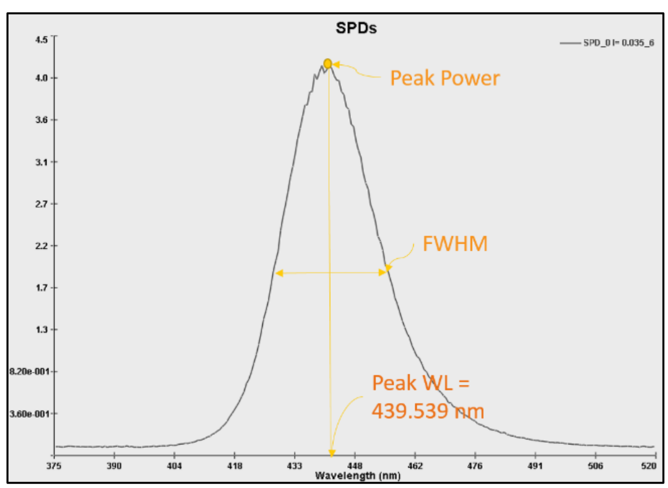
### QUANTIFIES PHYSICS NOT HUMAN PERCEPTION

Metrics like CRI, CCT quantify how a light source renders color or the perceived color temperature, meaning how it is perceived by a human observer. C-Parameters are not set out to measure human perception, but the actual physical phenomenon that is emitted from a light-emitting-diode, and that can be sensed by a photodetector. Therefore, wavelengths that cannot be seen by the human eye, like UV, and infrared are also quantified using C-Parameters.

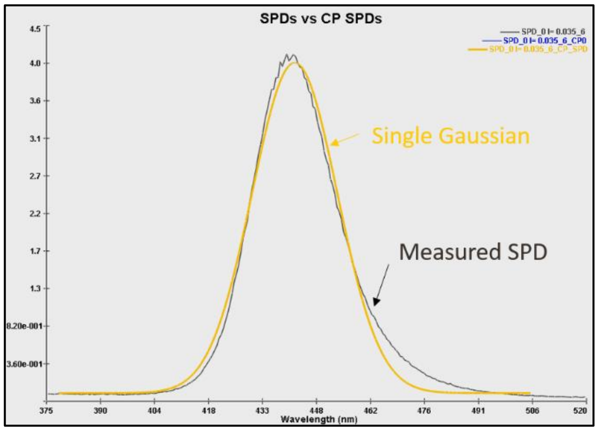
### PRESERVES THE WHOLE SPECTRUM SHAPE

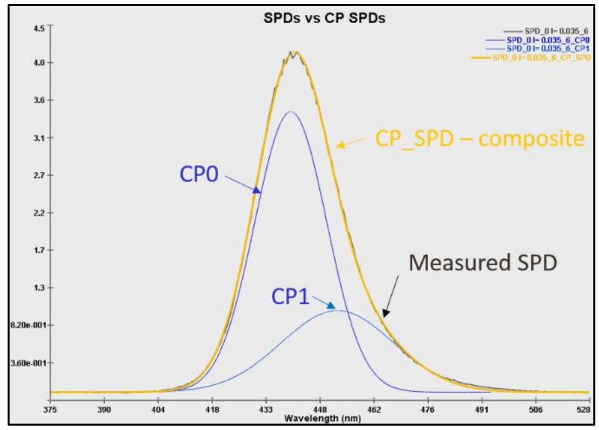
Single point metrics like peak power, peak wavelength, and full-width-half-max (FWHM) already try to characterize the shape of a SPD, and is being used for single color devices (*right*).

However, with the various layers and light transforming and light emitting processes in a solid state devices, more than one Gaussian is needed to actually fit and characterize the shape of the spectrum.



When using a single Gaussian (*below left*), which is much like using the peak power (height), peak wavelength (center) and FWHM (width), we see that it does not actually fit the emission spectrum of an LED. There is a whole region of the spectrum from 462nm to 491nm that is not fit by the single Gaussian. However, when we use C-Parameters and fit at least two Gaussians to the spectrum (*below right*), we see that the composite, called the CP SPD, fits the full shape of the spectrum.

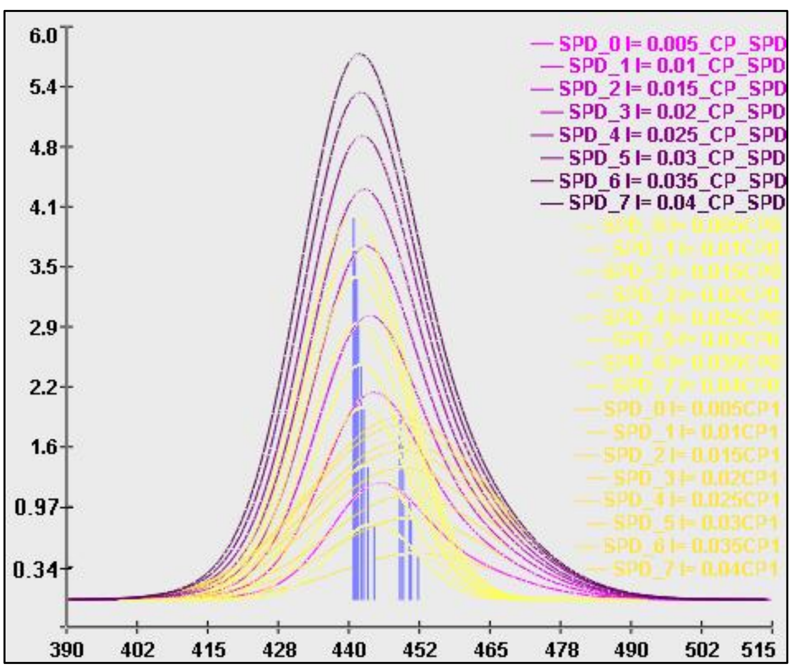



## APPLICATIONS OF C-PARAMETERS

### C-PARAMETERS IS A SPECTRUM ANALYSIS TOOL

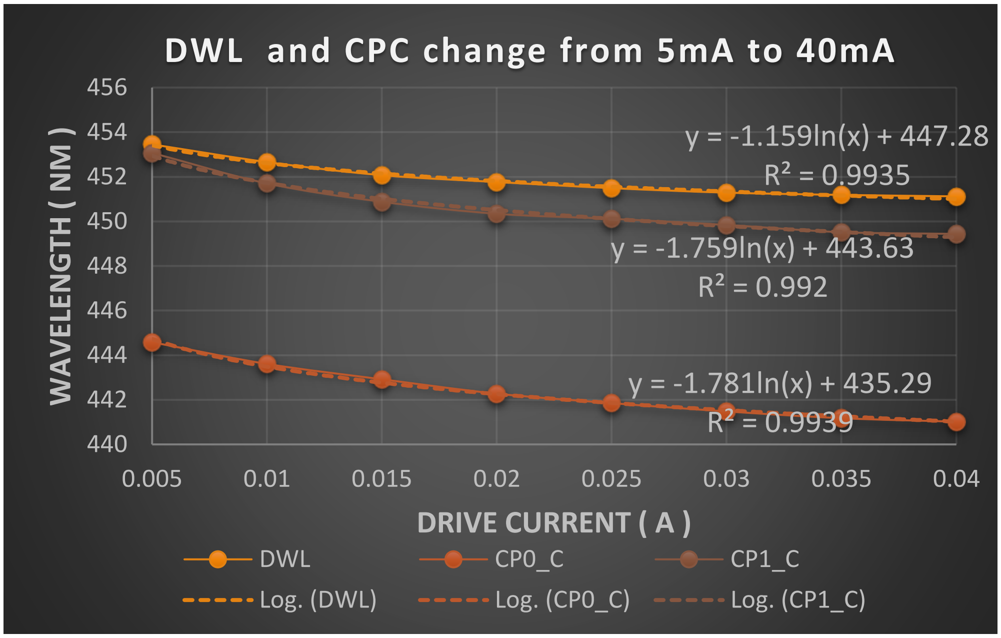
Since C-Parameters tracks in detail the change in shape in the spectrum, new things can be quantified in a spectrum. For instance, a blue LED is being driven by increasing current from 5mA to 40mA and with C-Parameters you can quantify a blue shift as more current is going through the LED.




Blue Shift could be due to wide barriers in the MQW (multiple quantum well) structure which shows bias-induced profile transformation of the QW (quantum well) adjacent to p-side which dominates the emission spectrum (Karpov S., Proc. Of SPIE Vol 9768 97680C, pg. 4).

With C-Parameters you can see more than just a change in peak wavelength or dominant wavelength (DWL). In the chart below, the CP0C and CP1C (center wavelength of the C-Parameters) is graphed compared to the DWL and we see that the two

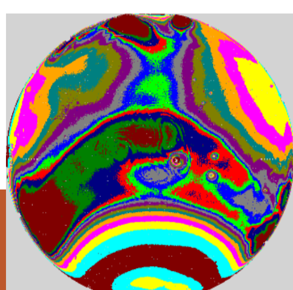
Gaussians actually shift at different rates from each other, which cannot be seen in detail from looking at the dominant wavelength.



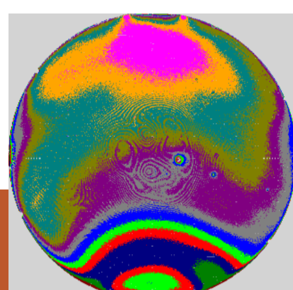

Just looking at one or more components of the spectrum using C-Parameters can tell you so much more about the spectrum and what is going on.

## USE C-PARAMETERS TO TRACK PROCESS SHIFTS

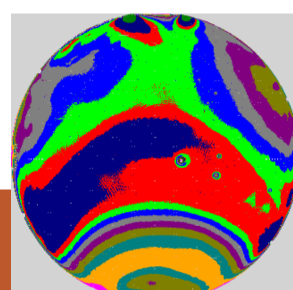
Now each stage in the LED manufacturing process can be quantified in detail of the optical properties using C-Parameters. It can be seen now how tweaking certain process parameters will affect the emission spectrum. Also previous layers or process steps can be correlated to the next step. Additionally, because C-Parameters breaks down the spectrum, more can be seen in wafer maps also. Below we see that some of the patterns in the wafer are due to the center wavelength of the first Gaussian component (CP0) but the amplitude and the width are not affected. However, the amplitude and width of the first Gaussian component show a rippling pattern that in does affect the dominant wavelength.



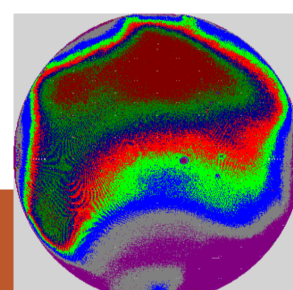
Dominant Wavelength



CP0A



CP0C



CP0W