(For personal reference). General discussion of LED. There are two “bands”, conduction and valence with a band gap in the middle. The conduction band is comprised of free electrons, while the valence band is holes, which are the absence of electrons in the bond (crystal) formations of the material. The valence band always has the lower energy state. The band gap size/ material used can affect the emission of light from the LED. The emission occurs when a free electron is paired with a hole, the resulting loss of energy is released as a photon of a specific frequency. Band gap is usually a type of potential well for both holes and free electrons in order to trap them together, and thus increase probably of recombination. A p-n junction allows current to flow only one way, so they are used to run current through the crystals and fill electron holes. (still working on more for electroluminescence)

**Paper 3:**

White light emitting diodes with super-high luminous efficacy

Yukio Narukawa, Masatsugu Ichikawa, Daisuke Sanga, Masahiko Sano and Takashi Mukai

This article looks at the white LED structure/ efficiency. It defines the luminous efficacy (ηL) and As the luminous flux (phi), which may be useful in models I can make for LED’s. White LED’s can be described by the following equations.

Equation (1)

Equation (2)

Equation (3)

Equation (4)

Equation (5)

Where Vf and If are the LED operating voltage and current, ηphos is the wavelength conversion efficiency of a phosphor, phie is the output power of a blue LED, hbarv is the photon energy of blue emission, ηex and ηint are the external and internal quantum efficiency, and ηpkg is the extraction efficiency of light from an LED package to air. Granted, these equations describe the more complex scenario of a white LED (it has the blue LED emission built into it as you can see), these equations could be a good starting point for a model. A white LED is created simply by mixing the light emission from a blue LED, with the yellow fluorescence with phosphor (which is created by excitations from blue light emissions). For this setup, YAG phosphor was used as it is the most common, although others are being developed.

The paper reports 3 types of white LED’s, two super-high power ones and one ultra-high powered one. They then compared results to blue LEDs. Their conclusion was that white LEDs can soon be sued for more industrial purposes, such as car lights or home lighting. The ultimate goal of the work is to provided LED lighting for all cases, fully replacing traditional light sources.

**The characteristics of blue LEDs**

|  | *I*f(mA) | e(mW) | *V*f(V) | ηex(%) | WPE(%) |
| --- | --- | --- | --- | --- | --- |
| SHE-blue | 20 | 47.1 | 2.89 | 84.3 | 81.3 |
| SHP-blue | 350 | 756 | 3.10 | 76.7 | 71.0 |

**The characteristics of white LEDs**

|  | *I*f(mA) | v(mW) | *V*f(V) | ηL (lm W−1) | WPE (%) |
| --- | --- | --- | --- | --- | --- |
| SHE-white | 20 | 14.4 | 2.89 | 249 | 58.5 |
| SHP-white | 350 | 203 | 3.18 | 183 | 48.3 |
| UHP-white | 1000 | 1913 | 14.16 | 135 | 37.1 |

**Paper 4:**

The role of ITO resistivity on current spreading and leakage in InGaN/GaN light emitting diodes

V.Sheremet M.Genç M.Elçi N.Sheremet A.Aydınlı I.Altuntaş K.Ding V.Avrutin Ü.Özgür H.Morkoç

This article discusses ITO (indium-tin oxide) resistivity and their effects on LEDs. In current LEDs the low current spreading/ high ressitivty of GaN LEDs are a major hurdle to overcome. The major portions of the paper are trying to increase current distribution/ reduce reseitvity, and thus increase the total output of the LED. Again, for the purpose of my project there are a few equations that can be used as a starting point for a model. The paper states that,

Current transfer length can be described as  *Lt*=√(*ρc*⋅*t /ρcsl)*

Then the current distribution becomes

I = I0 e^(-x/Lt )

Where I0 is current through contact pad and x is distance from contact pad.

They also describe the efficiency of an LED,

N = Pq/(I\*h\*v\*A)

Where P is optical power, I is injected current, A is area of LED die, q is charge of electron, H is planck constant and v is frequency of emitted light. From this we also can get the emitted power

P = nhv(I/q)A

These equations (once edited for simpler purposes) could be very beneficial in modeling an LED for the project, as they give us a way to describe current, efficiency, and power. The rest of the paper goes on to model the resistance, however found it did not affect the LED brightness. The conclusions they draw are that the current transfer length is the principle factor that defines current spreading, and that subsequently current spreading of layers affects the efficient of LEDs.