

**MODELLING LIGHT EMITTING DIODE USING SPICE**Dattaprasad Madur<sup>1</sup>, Najib Ghatte<sup>2</sup>, Vinit Pereira<sup>3</sup>, Tushar Surwadkar<sup>4</sup><sup>1234</sup> Department of Electronics

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This paper presents the equivalent circuit models of the light-emitting-diode, including the DC model. In order to characterize the equivalent DC circuit model of the LEDs, a linear model is built by adopting the concept of the single series equivalent DC circuit model of LED with DC supply applied to it. Furthermore, in order to perform the DC analysis of the LEDs, the equivalent DC model is implemented using SPICE where the parameters are already defined, so that it becomes convenient to study the current and voltage variations with respect to variation in the emission factor of LED. Emission factor plays very important role in designing of LED's used for various applications and Research work.

**Keywords:** Equivalent DC circuit model; LED;

**1. INTRODUCTION**

LEDs, or Light emitting diodes are very widely used in today's electronics equipment. In fact, over 20 billion LEDs are manufactured every year and this its usage has tremendously increased. With new forms of light emitting diodes being developed that emits white light (white LEDs) and blue light (blue LEDs) they are likely to find even more uses, and the production of these diodes is likely to increase still further. LEDs are used in a wide variety of applications. One of their first applications was as small indicator lamps. They were also used in alphanumeric displays, although in this particular application they have now been superseded by other forms of display. With recent developments light emitting diodes are being used in lieu of incandescent lamps for illumination. Due to its, demand in long range of application areas, it is anticipated to have abundant development of such LEDs in future.

The LED is a specialized form of PN junction that uses a compound junction. The semiconductor material used for the junction must be a compound semiconductor. The commonly used semiconductor materials including silicon and germanium are simple elements and junction made from these materials does not emit light. Instead compound semiconductors including gallium arsenide, gallium phosphide and indium phosphide are compound semiconductors and junctions made from these materials results in emission of light. The diode emits light when it is forward biased. When a potential difference is applied across the junction, so as to make it forward biased, current flows as in the case of any PN junction. Holes from the p-type region and electrons from the n-type region enter the junction and recombine like a normal diode to enable the current to flow. When this occurs energy is released, some of which is in the form of light photons.

It is found that the majority of the light is produced from the area of the junction nearer to the P-type region. As a result the design of the diodes is made such that this area is kept as close to the surface of the device as possible to ensure that the minimum amount of light is absorbed in the structure. To produce light which can be seen the junction must be optimized and the correct materials must be chosen. Pure gallium arsenide releases energy in the infra red portion of the spectrum. To bring the light emission into

the visible red end of the spectrum aluminium is added to the semiconductor to give aluminium gallium arsenide (AlGaAs). Phosphorus can also be added to give red light. For other colours other materials are used. For example gallium phosphide gives green light and aluminium indium gallium phosphide is used for yellow and orange light. Most LEDs are based on gallium semiconductors. <sup>[1]</sup>

## 2. DESIGN

Design characteristics of LED include colours light/radiation wavelength, light intensity, and a variety of other LED characteristics. The different LED characteristics have been brought about by a variety of factors, in the manufacture of the LED. The semiconductor make-up is a factor, but fabrication technology and encapsulation also play major part of the determination of the LED characteristics. One of the major characteristics of an LED is its colour. Initially LED colours were very restricted. For the first years only red LEDs were available. However as semiconductor processes were improved and new research was undertaken to investigate new materials for LEDs, different colours became available. The Fig. 1 shows some typical approximate curves for the voltages that may be expected for different LED colours.

The voltage drop across an LED is different to that of a normal silicon LED. Typically the LED voltage drop is between around 2 and 4 volts. The actual LED voltage that appears across the two terminals is dependent mainly upon the type of LED in question - the materials used. As would be expected the LED voltage curve broadly follows that which would be expected for the forward characteristic for a diode.

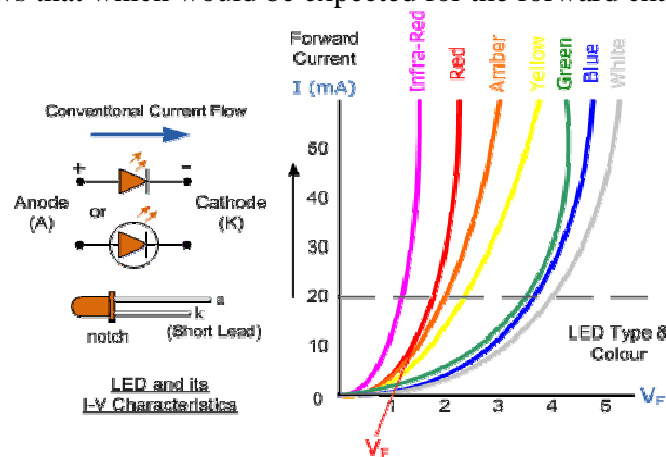


Fig. 1 V-I characteristics of LED for different wavelength of light

However once the diode has turned on, the voltage is relatively flat for a variety of forward current levels. This means that in some cases designers have used them as very rough voltage stabilizers - zener diodes do not operate at voltages as low as LEDs. However their performance is obviously nowhere near as good. LEDs operating in different wavelengths are shown in Table I given below. <sup>[2]</sup>

TABLE I  
FORWARD VOLTAGE CONSTRAINS FOR VARIOUS WAVELENGTH

Wavelength Range (nm)	Colour	$V_F$ @ 20 mA
<400	Ultraviolet	3.1 - 4.4
400 - 450	Violet	2.8 - 4.0
450 - 500	Blue	2.5 - 3.7
500 - 570	Green	1.9 - 4.0
570 - 590	Yellow	2.1 - 2.2
590 - 610	Orange/amber	2.0 - 2.1

310 – 760	Red	1.3 - 2.0
>760	Infrared	<1.9

The DC characteristics of the diode shown in Table II are determined by the parameters  $I_S$ ,  $N$ , and the ohmic resistance  $R_S$ . Charge storage effects are modeled by a transit time,  $TT$ , and a nonlinear depletion layer capacitance which is determined by the parameters  $CJO$ ,  $VJ$ , and  $M$ . The temperature dependence of the saturation current is defined by the parameters  $EG$ , the band gap energy and  $XTI$ , the saturation current temperature exponent. The nominal temperature at which these parameters were measured is  $TNOM$ , which defaults to the circuit-wide value specified on the .OPTIONS control line. Reverse breakdown is modeled by an exponential increase in the reverse diode current and is determined by the parameters  $BV$  and  $IBV$  (both of which are positive numbers).<sup>[3]</sup>

### 3. IMPLEMENTATION

The Shockley ideal diode equation or the diode law (named after transistor co-inventor William Bradford Shockley) gives the I-V characteristic of an ideal diode in either forward or reverse bias (or no bias). The equation is:

$$I = I_S \left( e^{\frac{V_D}{nV_T}} - 1 \right) \quad (1)$$

where,

$I$  is the diode current,

$I_S$  is the reverse bias saturation current (or scale current given by  $I_S = 10^{-14}$ ),

$V_D$  is the voltage across the diode (we take it as  $V_D = 0.7$  volts),

$V_T$  is the thermal voltage, and  $n$  is the ideality factor, also known as the quality factor or sometimes emission coefficient.

The ideality factor  $n$  varies from 1 to 2 depending on the fabrication process and semiconductor material and in many cases is assumed to be approximately equal to 1. While designing of LED the factor  $n$  varies from 1 to 2.

TABLE III  
DC CHARACTERISTICS

Name	Parameter	Default
IS	saturation current	1.0e-14 A
RS	ohmic resistance	0 Ohm
N	emission coefficient	1
TT	transit-time	0 Sec
CJO	zero-bias junction capacitance	0 F
VJ	junction potential	1 V
M	grading coefficient	0.5
EG	band-gap energy	1.11 eV
XTI	saturation-current temperature exponential	3
KF	flicker noise coefficient	0
AF	flicker noise exponent	1
FC	coefficient for forward-bias depletion capacitance	0.5

	formula	
BV	reverse breakdown voltage	Infinite V
IBV	current at breakdown voltage	1.0e-3 V
TNOM	Parameter measurement temperature	27 deg C

The thermal voltage  $V_T$  is approximately 25.85 mV at 300 K, a temperature close to "room temperature" commonly used in device simulation software. At any temperature it is a known constant defined by:

$$V_T = \frac{KT}{q} \quad (2)$$

Where,

$K$  is the Boltzmann constant,  $T$  is the absolute temperature of the p-n junction, and  $q$  is the magnitude of charge on an electron (the elementary charge).

The reverse saturation current,  $I_s$ , is not constant for a given device, but varies with temperature; usually more significantly than  $V_T$ , so that  $V_D$  typically decreases as  $T$  increases. The Shockley ideal diode equation or the diode law is derived with the assumption that the only processes giving rise to the current in the diode are drift (due to electrical field), diffusion, and thermal recombination-generation (R-G). It also assumes that the R-G current in the depletion region is insignificant. This means that the Shockley equation doesn't account for the processes involved in reverse breakdown and photon-assisted R-G. Additionally, it doesn't describe the "leveling off" of the I-V curve at high forward bias due to internal resistance. Under reverse bias voltages the exponential in the diode equation is negligible, and the current is a constant (negative) reverse current value of  $-I_s$ . The reverse breakdown region is not modeled by the Shockley diode equation. For even rather small forward bias voltages the exponential is very large because the thermal voltage is very small, so the subtracted '1' in the diode equation is negligible and the forward diode current is often approximated as

$$I = I_s e^{\frac{V_D}{nV_T}} \quad (3)$$

The use of the Shockley diode equation determines the emission factor for LED diode modeling [4].

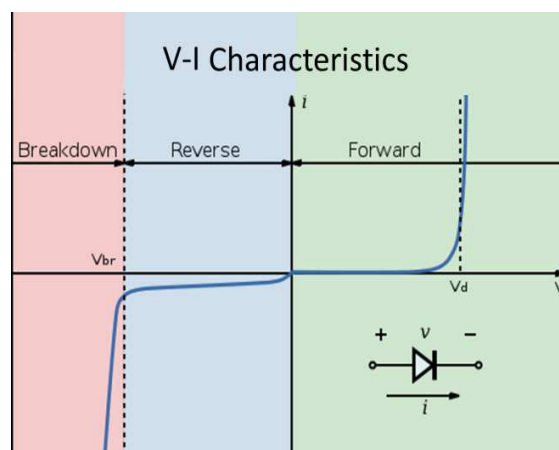


Fig. 2 V-I Characteristics

Shockley's diode equation can even be reduced further to remove the exponential term.<sup>[5]</sup> This is done by taking natural log on both sides of the Shockley's equation as represented below

$$\ln(i) = \ln(I_s) + \frac{V}{V_T} \quad (4)$$

#### 4. RESULT

The functional characteristics of LED were studied as the same is incorporated in SPICE Code with .cir extension. The code is then simulated using WinSpice and optimum results were obtained. The emission co-efficient was changed and corresponding results were obtained. Polarity of the applied voltage across the junction is also reversed to test the veraciousness of the functionality.

##### 4.1 Forward Bias ( $\eta=2$ )

The applied potential across the junction is such that the P-side is connected to the positive terminal of the battery whereas the N-side of the junction is connected to negative terminal of the battery. This aids the forward biasing across the junction and resultant current due to flow of majority carriers.

When the emission co-efficient ( $\eta$ ) is assigned to a value 2, as per the Shockley's equation, the current flowing is of the order  $10^{-3}$ .

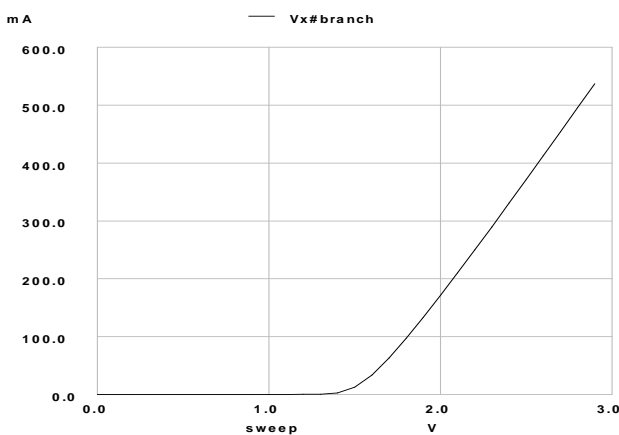


Fig. 3 V-I Characteristics for LED with  $\eta=2$

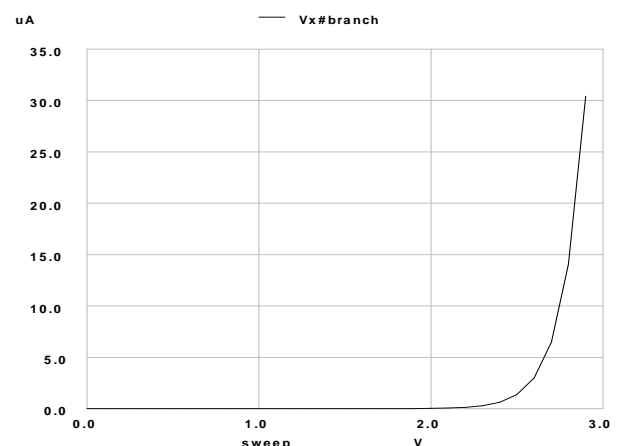


Fig. 4 V-I Characteristics for LED with  $\eta=5$

##### 4.2 Forward Bias ( $\eta=5$ )

The applied potential across the junction is such that the P-side is connected to the positive terminal of the battery whereas the N-side of the junction is connected to negative terminal of the battery. This aids the forward biasing across the junction and resultant current due to flow of majority carriers.

When the emission co-efficient ( $\eta$ ) is assigned to a value 5, as per the Shockley's equation, the current flowing is of the order  $10^{-6}$ .

##### 4.3 Forward Bias ( $\eta=8$ )

The applied potential across the junction is such that the P-side is connected to the positive terminal of the battery whereas the N-side of the junction is connected to negative terminal of the battery. This aids the forward biasing across the junction and resultant current due to flow of majority carriers. When the

emission co-efficient ( $\eta$ ) is assigned to a value 8, as per the Shockley's equation, the current flowing is of the order  $10^{-9}$ .

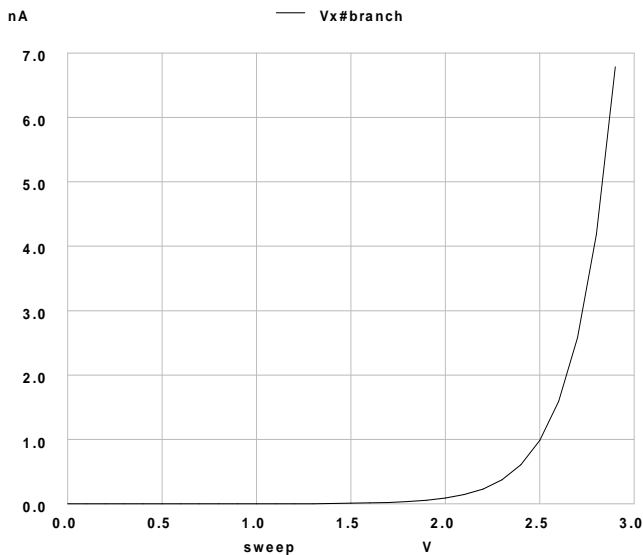


Fig. 5 V-I Characteristics for LED with  $\eta = 8$

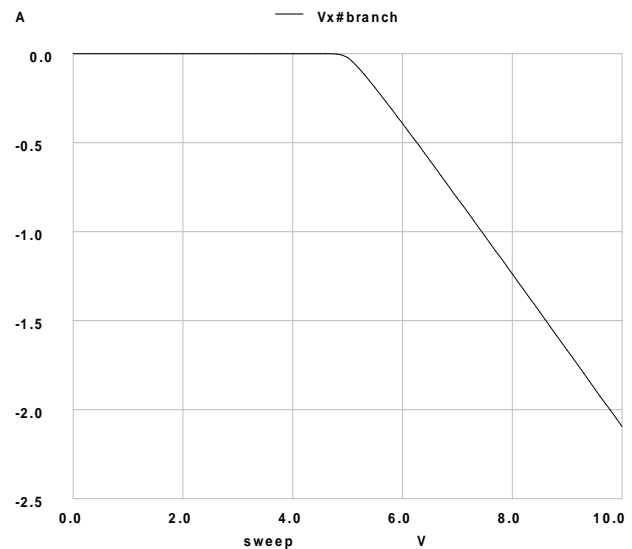


Fig. 6 Reverse Bias

### Conclusion

LED is modelled by varying intensity with respect to emission factor  $n$ . Current across diode varies proportionally with the Input voltage but it varies inversely with the increase in emission factor  $n$ .

### References

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