Dimming InGaN LEDs

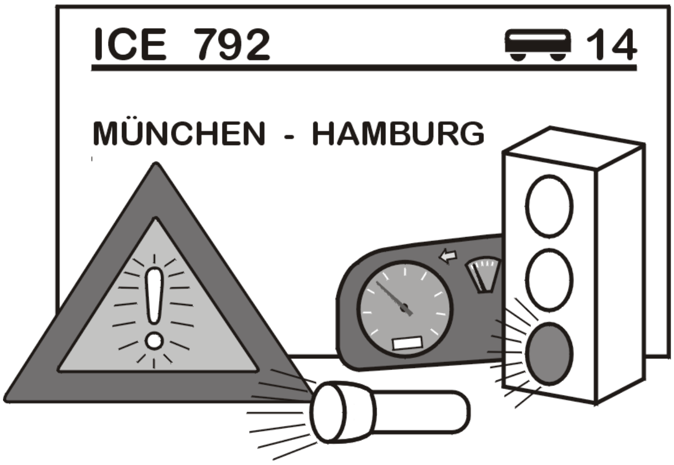
Application Note

Introduction

The first true ancestors to the Indium Gallium Nitride (InGaN) LED evolved last decade. These took the form of blue LEDs utilizing Silicon Carbide (SiC) as the active, light-emitting material. These early LEDs were characterized by very low light output, less than 2cd/m^2. The next generation of blue LEDs relied upon SiC as a base layer only and employed Gallium Nitride (GaN), grown directly on the SiC substrate, as the active, light-emitting epitaxial layer. This process initially increased light output by a factor of eight. The final iteration saw the introduction of Indium (In) to the epitaxial layer to form InGaN. This development further boosted light output by a factor of five—a full 1300% increase in intensity over the first SiC LEDs. Today, through advances in process, packaging and thermal transfer technologies, light output continues to evolve.

Besides increasing the intensity of blue, and by extension, white LEDs (since all white LEDs use a blue chip in conjunction with a light converter, or phosphor), the InGaN process has replicated two new colors: verde and true green. These unique colors, alongside InGaN's high intensity and inherent reliability, has greatly increased their proliferation into applications once reserved solely for incandescent lighting: traffic signals, real-color displays, message boards, moving signs, dashboard backlighting, battery flashlights and toys.

While the InGaN process produces the brightest light output across blue, verde, true green and white, it is important to understand that the wavelength of the light emitted is strongly dependent upon the forward current driven through the device, and that in order to avoid shifts in color, careful consideration must be paid to dimming strategies. This application note, then, will examine methods for dimming InGaN LEDs with little or no effect on wavelength.



InGaN LED applications

Technology Data

Parameter	Symbol	Values				Unit
		Blue	**Verde**	**True Green**	**White**	
Wavelength at peak emission I_F = 20mA	λ_{peak}	465	503	523	--	nm
Dominant wavelength I_F = 20mA	λ_{dom}	470 ±7	505 ±8	528 ±10	--	nm
Spectral bandwidth at 50% I_{relmax} I_F = 20mA	$\Delta\lambda$	25	30	33	--	nm
Chromaticity coordinate x acc. to CIE1931 I_F = 20mA	x	--	--	--	0.32	
Chromaticity coordinate y acc. to CIE1931 I_F = 20mA	y	--	--	--	0.31	
Forward voltage (typ.) I_F = 20mA (max.)	V_F	3.5 4.2	3.3 4.2	3.3 4.2	3.5 4.2	V
Reverse Current (typ.) V_R = 5V (max.)	I_R	0.01 10	0.01 10	0.01 10	0.01 10	µA µA
Temperature coefficient of λ_{peak} I_F = 20mA	TC_λ	0.04	0.03	0.04	--	nm/K
Temperature coefficient of λ_{dom} I_F = 20mA	TC_λ	0.02	0.02	0.03	--	nm/K
Temperature coefficient of x I_F = 20mA	TC_x	--	--	--	0.1	10^{-3}/K
Temperature coefficient of y I_F = 20mA	TC_y	--	--	--	0.3	10^{-3}/K
Temperature coefficient of V_F I_F = 20mA	TC_V	-2.9	-3.2	-3.6	-3.0	mV/K

Figure 1 – Typical characteristics of InGaN LEDs at an ambient temperature of 25°C.

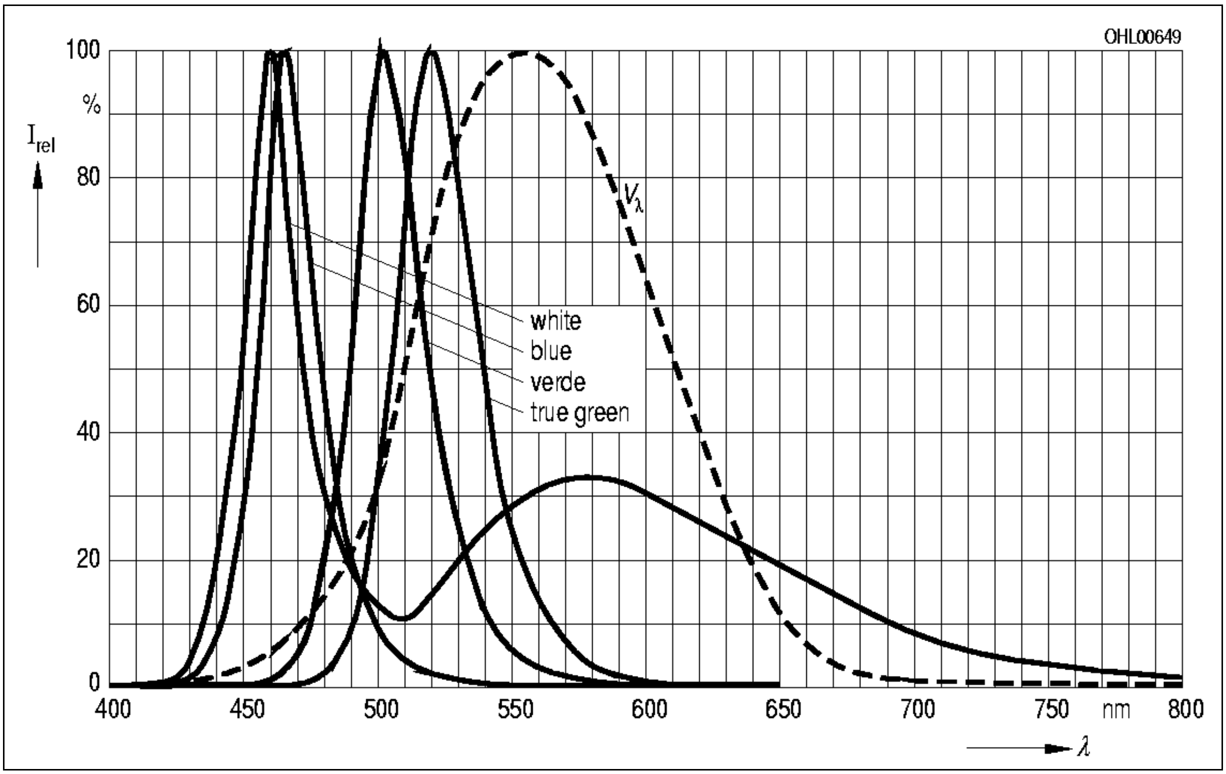


Figure 2 – Relative spectral emission; $I_{rel} = f(\lambda)$, $T_A = 25^oC$, $I_F = 20mA$

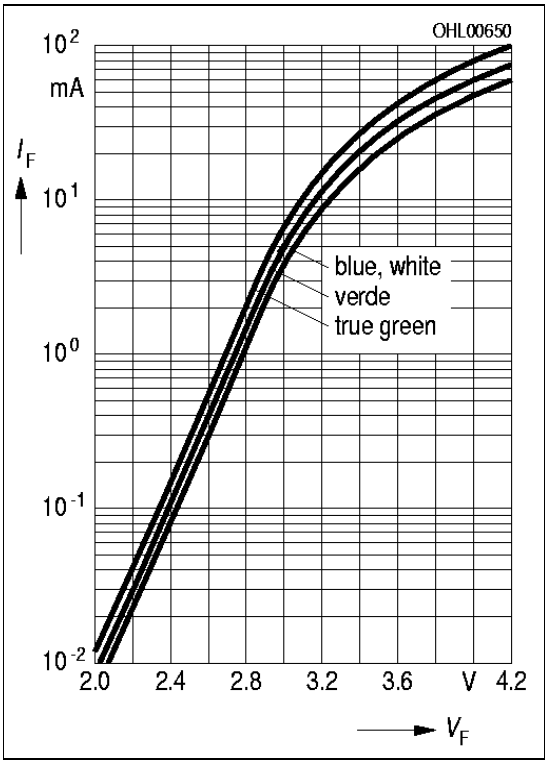


Figure – 3 Forward Current

$I_{rel} = f(\lambda)$, $T_A = 25^oC$, $I_F = 20mA$

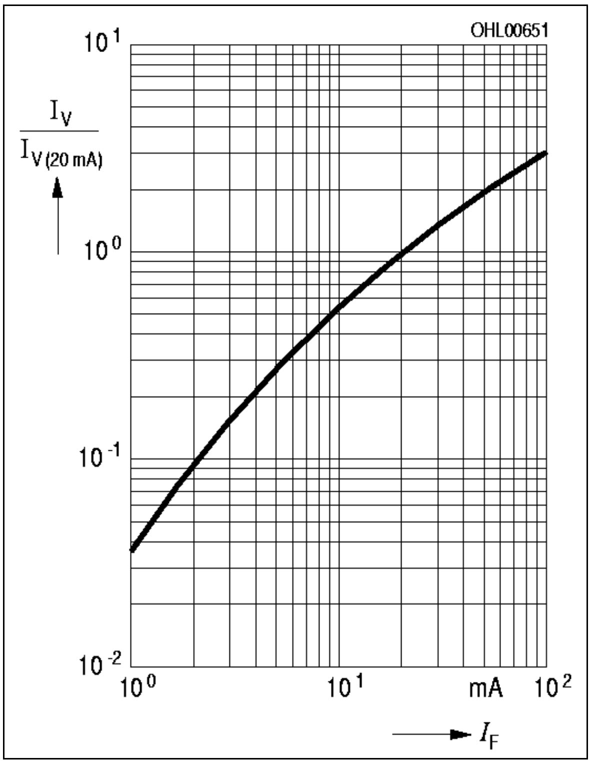


Figure 4 – Relative luminous intensity

$I_V / I_{V\,(20\,mA)} = f(I_F)$, $T_A = 25°C$

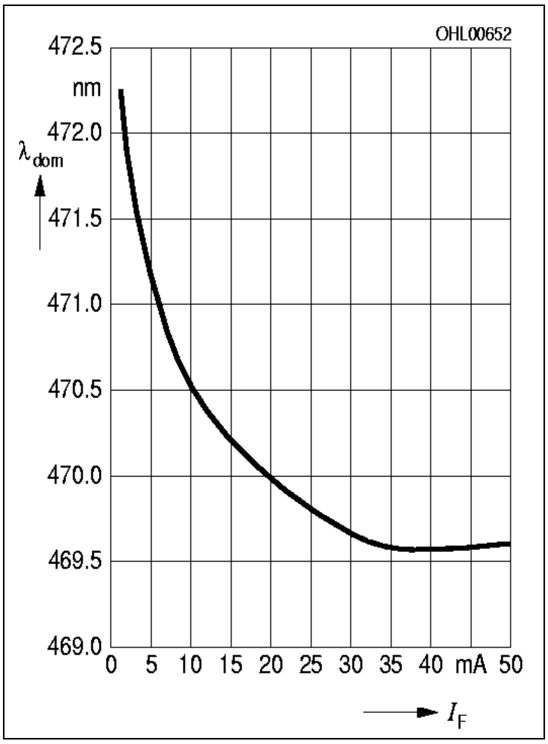


Figure 5 - Dominant wavelength for blue λ_{dom} = *f* (I_F), T_A = 25°C

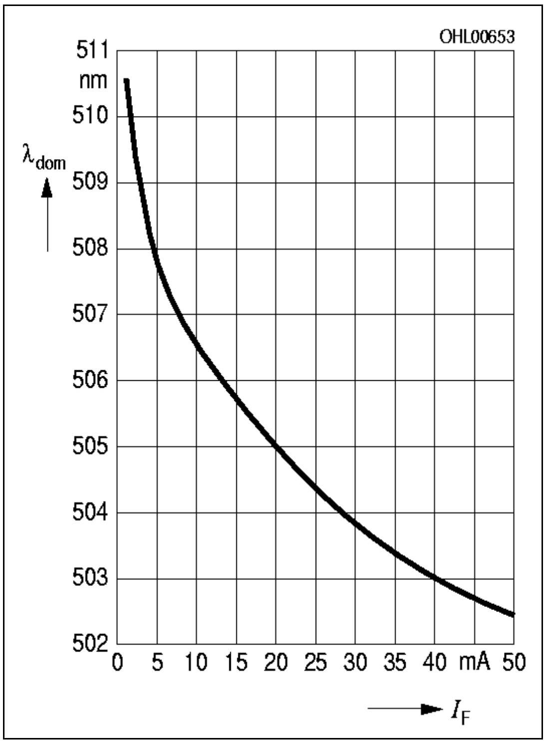


Figure 6 - Dominant wavelength for verde λ_{dom} = *f* (I_F), T_A = 25°C

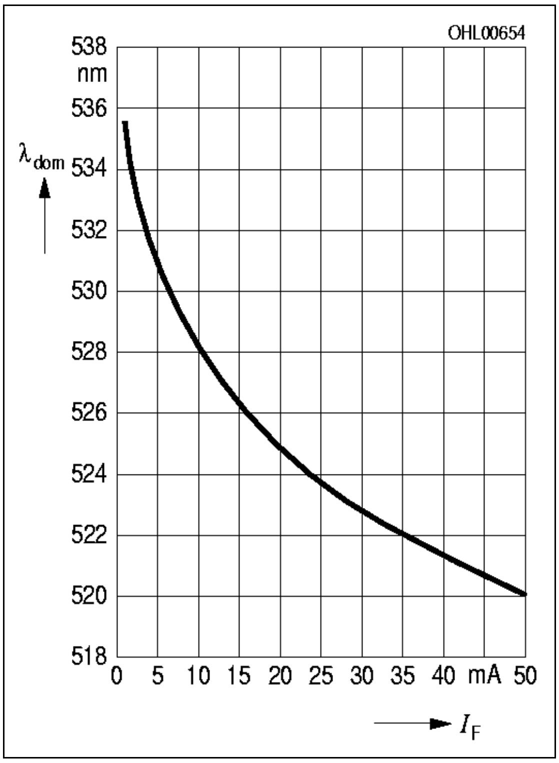


Figure 7 - Dominant wavelength for true green; λ_{dom} = *f* (I_F), T_A = 25°C

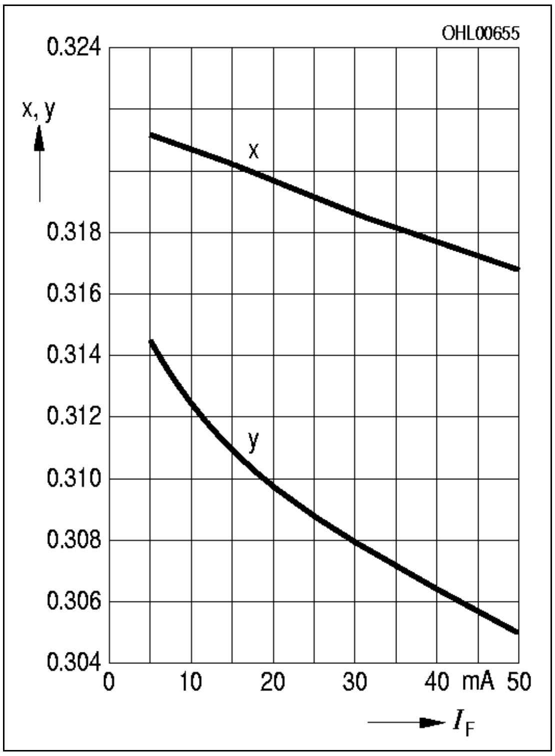


Figure 8 - Chromaticity coordinates for white; x = *f* (I_F), y = *f* (I_F), T_A = 25°C

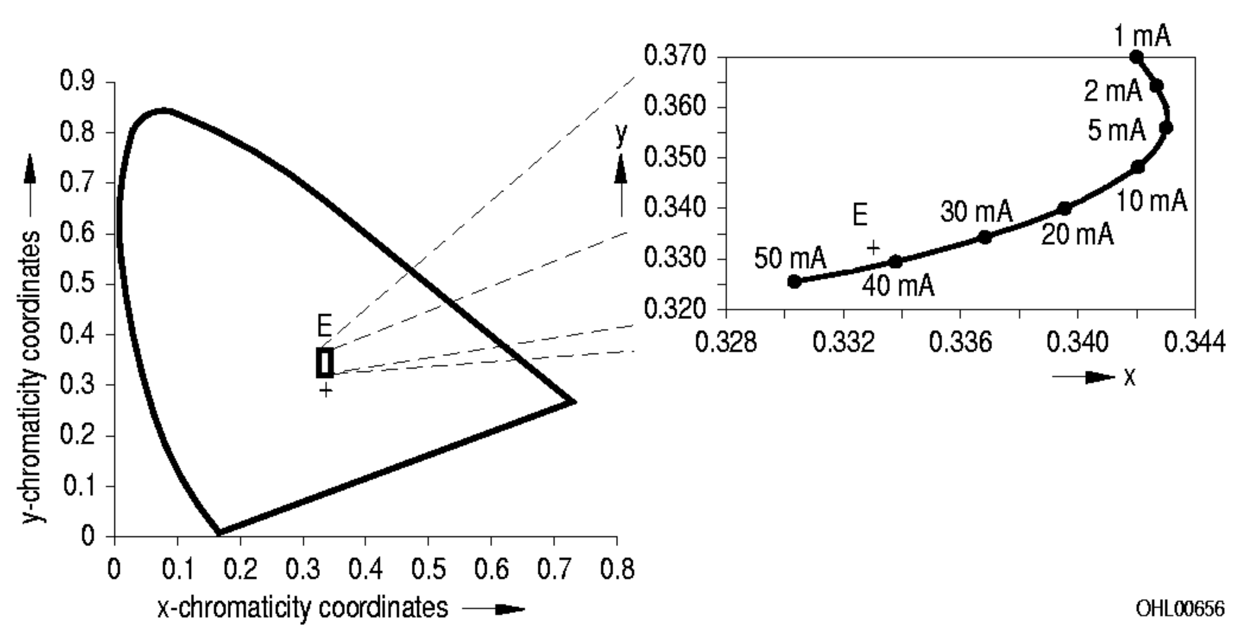


Figure 9 – Chromaticity coordinates for white at CIE1931; x = *f* (I_F), y = *f* (I_F), T_A = 25°C

Dimming by current or voltage variation

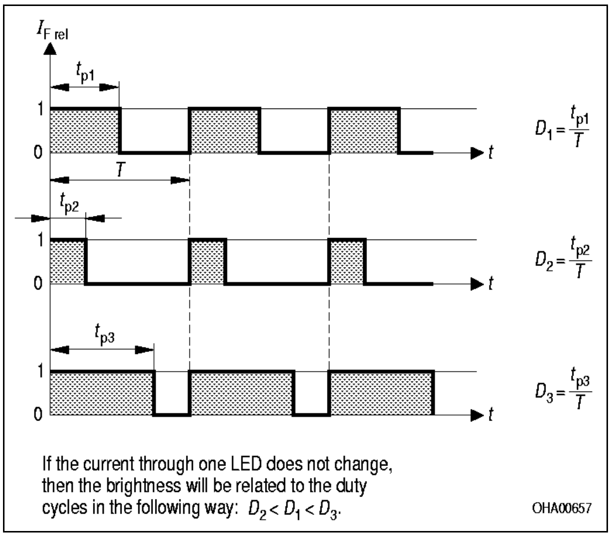
The most common method of dimming an LED is by varying either the forward current or voltage according to a function of chip technology (Figures 1–4). However, due to the unique characteristics of InGaN, varying current or voltage will shift the wavelength (Figures 5–9). This effect is proportional to wavelength, with the longer wavelengths undergoing the strongest shift/variation versus current. True green and verde experience the sharpest shift, followed by blue/white. No LED material other than InGaN has this dependency. Conversely, no material other than InGaN emits light in green, blue and white as brightly. It should be noted here as well, that when compared to competitors' products, OSRAM Opto Semiconductors' products experience the lowest wavelength shift versus current.

Besides current, temperature also has an effect on wavelength. The relationship is direct, whereby an increase in temperature results in an increase in wavelength (Figure 1). Yet by comparison, the influence of current on wavelength is much stronger than the influence of temperature. Subsequently, the effect of temperature can, by comparison, be ignored.

In the end, dimming an InGaN LED by current or voltage variation will shift the wavelength. In certain circumstances, and over small ranges, this can be acceptable. In many more cases though, a shift can not be tolerated. There, by employing Pulse Width Modulation (PWM), an InGaN LED may be dimmed without a wavelength shift.

Dimming by PWM

PWM works in the following manner: the forward current (I_F) is kept at a constant value and only the duty cycle (D) is changed. The duty cycle ($D = t_P / T$) expresses the ratio between pulse duration (t_P) and signal period (T). This means the LED is rapidly switched off and on. If the frequency is greater than 200 Hz, the human eye cannot perceive the individual light pulses, even in motion. The eye integrates and interprets the light pulses in terms of brightness that can be changed by varying the duty cycle (Figure 10).



If the current through one LED does not change, then the brightness will be related to the duty cycles in the following way: $D_2 < D_1 < D_3$.

Figure 10 – PWM

PWM with InGaN LEDs

So long as the forward current through an InGaN LEDs remains constant, no wavelength or color shift occur with PWM. Figure 11 illustrates that the brightness of the LED can be changed linearly by varying the duty cycle linearly. This is valid for all available InGaN colors. The maximum attainable brightness of an InGaN LED is limited by the adjusted forward current (at D). Maximum brightness can be adjusted by varying the forward current within the range shown on the data sheet, but this will, as indicated earlier, affect the wavelength emitted.

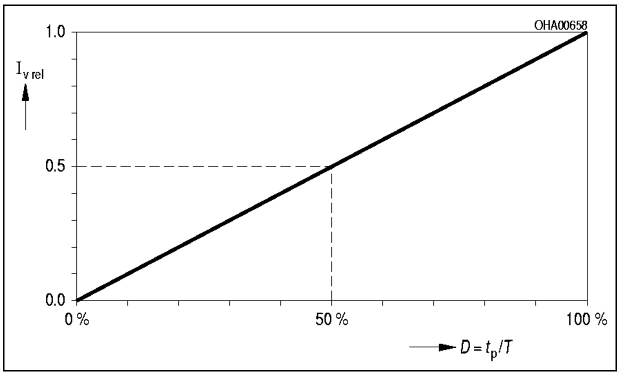


Figure 11 – Linearity of brightness versus duty cycle; I_F = 20 mA, $f > 200$ Hz, T_A = 25°C

Conclusion

InGaN epitaxial material emits the brightest light across the colors of blue, verde, true green and white. However the dominant wavelengths for the colors, as well as the chromaticity coordinates for white, depend on the forward current driven through the LED. Attempting to dim an InGaN LED by the established method of varying either current or voltage will result in a shift in wavelength. InGaN LEDs must be dimmed via pulse width modulation to avoid a color shift for blue, verde and true green and a hue shift for white.

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ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. Osram Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. Osram Opto Semiconductors also has sales offices throughout the world.
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