Solder-Point Temperature Measurement of XLamp® LEDs

Figure 1: Example solder-point temperature measurement

TABLE OF CONTENTS

INTRODUCTION

One of the most important factors of successful solid-state lighting (SSL) design is good thermal management of the lamp or luminaire. When the LED junction temperature (Tj) increases, the performance of the LED decreases, resulting in lower light output from the LED. The LED junction temperature cannot be measured directly, however it can be calculated from the solder-point temperature (Tsp). Therefore accurate Tsp measurements are imperative for proper thermal management and lumen maintenance. This document provides a guideline for measuring Tsp accurately.

There is no need to calculate the Tj inside a CX family LED package, as the thermal management design process, specifically from solder point (Tsp) to ambient (Ta), remains identical to any other LED component. For more information on LED thermal management, see the Thermal Management application note.

Cree LED / 4001 E. Hwy. 54, Suite 2000 / Durham, NC 27709 USA / +1.919.313.5330 / www.cree-led.com

IMPORTANCE OF T_{SP}

LEDs produce light when a current is passed across the junction of the chip. As efficient as LEDs currently are, a large percentage of the input power generates heat rather than light. Heat that is not dissipated will have not only an immediate negative impact on light output but also decrease the LED's light output over time and could cause premature catastrophic failure. Cree LED provides data characterizing how each of its XLamp LEDs performs versus T_j. The T_j of an LED cannot be measured directly; it must be calculated using Equation 1 below, based on the measured T_{sp}, the total power input to the LED and the thermal resistance of the LED as stated on its data sheet.

$$T_j = T_{sp} + \theta_{th} P_{total}$$

Equation 1: Junction temperature calculation

where:

T_j Junction temperature in degrees Celsius (°C)

T_{sp} Measured solder-point temperature (°C)

θ_{th} Thermal resistance of the LED in degrees Celsius per watt (°C/W)

Each XLamp LED's thermal resistance can be found in the LED's data sheet.

P_{total} Total power input to the LED (W)

P_{total} can be calculated by multiplying the input current (I_f) by the forward voltage (V_f)

USING THERMOCOUPLES FOR THERMAL MEASUREMENT

Thermocouples are the equipment most commonly used for temperature measurements. A thermocouple is made of two thin metal wires of two different types of metal. The ends of the wires are welded together, and the leads are separated with insulation, so that only the welded end is in contact with the device under test. When the welded end is heated or cooled, a DC voltage differential is created between the two metals, often referred to as the Seebeck effect. The DC voltage is interpreted by a thermometer to provide a temperature reading; the voltage generated is proportional to the temperature of the device under test.

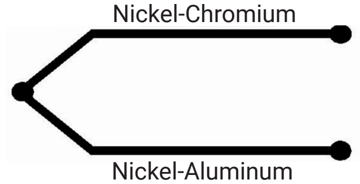

Figure 2: Typical type K thermocouple

Thermocouple types are determined according to the metals from which they are made. Each type is color coded according to American National Standards Institute (ANSI) and Illuminating Engineering Society (IES) standards, as shown in Table 1.[1]

1 www.omega.com/temperature/pdf/tc_colorcodes.pdf

Table 1: ANSI and IES thermocouple color codes

Connectors Connectors

ANSI Code	ANSI MC 96.1 Colour Coding Thermocouple Grade	ANSI MC 96.1 Colour Coding Extension Grade	Alloy Combination + Lead	Alloy Combination – Lead	Comments Environment Bare Wire	Maximum T/C Grade Temp. Range	EMF (mV) Over Max. Temp. Range	IEC 584-3 Colour Coding Thermocouple Grade	IEC 584-3 Colour Coding Intrinsically Safe	IEC Code
J			IRON Fe (magnetic)	CONSTANTAN COPPER-NICKEL Cu-Ni	Reducing, Vacuum, Inert. Limited Use in Oxidising at High Temperatures. Not Recommended for Low Temperatures.	–210 to 1200°C –346 to 2193°F	–8.095 to 69.553			J
K			CHROME NICKEL-CHROMIUM Ni-Cr	NICKEL-ALUMINUM Ni-Al (magnetic)	Clean Oxidising and Inert. Limited Use in Vacuum or Reducing. Wide Temperature Range, Most Popular Calibration	–270 to 1372°C –454 to 2501°F	–6.458 to 54.886			K
T			COPPER Cu	CONSTANTAN COPPER-NICKEL Cu–Ni	Mild Oxidising, Reducing Vacuum or Inert. Good Where Moisture Is Present. Low Temperature & Cryogenic Applications	–270 to 400°C –454 to 752°F	–6.258 to 20.872			T
E			CHROME NICKEL-CHROMIUM Ni-Cr	CONSTANTAN COPPER-NICKEL Cu-Ni	Oxidising or Inert. Limited Use in Vacuum or Reducing. Highest EMF Change Per Degree	–270 to 1000°C –454 to 1832°F	–9.835 to 76.373			E
N			NICROSIL Ni-Cr-Si	NISIL Ni-Si-Mg	Alternative to Type K. More Stable at High Temps	–270 to 1300°C –450 to 2372°F	–4.345 to 47.513			N
R	NONE ESTABLISHED		PLATINUM-13% RHODIUM Pt-13% Rh	PLATINUM Pt	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.226 to 21.101			R
S	NONE ESTABLISHED		PLATINUM-10% RHODIUM Pt-10% Rh	PLATINUM Pt	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temperature	–50 to 1768°C –58 to 3214°F	–0.236 to 18.693			S
U	NONE ESTABLISHED		COPPER Cu	COPPER-LOW NICKEL Cu-Ni	Extension Grade Connecting Wire for R & S Thermocouples, Also Known as RX & SX Extension Wire.					U
B	NONE ESTABLISHED		PLATINUM-30% RHODIUM Pt-30% Rh	PLATINUM-6% RHODIUM Pt-6% Rh	Oxidising or Inert. Do Not Insert in Metal Tubes. Beware of Contamination. High Temp. Common Use in Glass Industry	0 to 1820°C 32 to 3308°F	0 to 13.820			B
G* (W)	NONE ESTABLISHED		TUNGSTEN W	TUNGSTEN-26% RHENIUM W-26% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F). Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 38.564	NO STANDARD USE ANSI COLOUR CODE		G (W)
C* (W5)	NONE ESTABLISHED		TUNGSTEN-5% RHENIUM W-5% Re	TUNGSTEN-26% RHENIUM W-26% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F) Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 37.066	NO STANDARD USE ANSI COLOUR CODE		C (W5)
D* (W3)	NONE ESTABLISHED		TUNGSTEN-3% RHENIUM W-3% Re	TUNGSTEN-25% RHENIUM W-25% Re	Vacuum, Inert, Hydrogen. Beware of Embrittlement. Not Practical Below 399°C (750°F)–Not for Oxidising Atmosphere	0 to 2320°C 32 to 4208°F	0 to 39.506	NO STANDARD USE ANSI COLOUR CODE		D (W3)

Organizations such as the Alliance for Solid-State Illumination Systems and Technologies (ASSIST)[2] recommend that thermocouples be shielded from direct light and other forms of optical radiation. Arrange the thermocouple wires to minimize the amount of direct light exposure to them. Cree LED recommends using type T thermocouples to take measurements on CX family LEDs. The CX Family Design Guide provides information on attaching a thermocouple and temperature measurement for CX family LEDs. For other XLamp® LEDs,

2 Alliance for Solid-State Illumination Systems and Technologies (ASSIST). 2014. *ASSIST recommends… Recommendations for measuring high-power LED primary lens surface temperature with thermocouples*. Vol. 13, Iss. 1. Troy, N.Y.: Lighting Research Center. Internet: http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/lensTemp.asp

Cree LED recommends using type K thermocouples that are insulated with Teflon® (FEP) or wrapping the thermocouple leads that are on the printed-circuit board (PCB) with three layers of white Teflon tape.[3] Doing so blocks any direct light on the thermocouple during testing.

MOUNTING A THERMOCOUPLE

A thermocouple junction should be mounted so that it makes direct physical contact with the surface of the LED to be measured, as close as possible to the LED's thermal pad. Refer to the XLamp LED's Soldering and Handling document on Cree LED's website to find the specific T_{sp} location. Thermocouples can be mounted several different ways, but the two most common ways are solder mount and adhesive mount.

1. Solder Mount

The solder mount method guarantees secure contact with the thermocouple and good thermal contact with the LED measurement point. This method offers reliable temperature measurement, however soldering requires a considerable amount of skill and experience to perform properly, and a compatible surface to which to solder. This method cannot be used to attach a thermocouple to surfaces with which solder cannot bond, such as plastic, solder mask, and FR4 boards, on which LEDs are commonly mounted. However, a thermocouple can be connected to an exposed contact pad as shown in the applicable Soldering and Handling document for each XLamp LED.

2. Adhesive Mount

Adhesive products are easier to use than solder, though they can pose other challenges such as short work life, requiring a post-attach cure, or simply causing a mess. This method can be performed with adhesive tape such as Kapton or a two-part thermal adhesive such as Arctic Silver™. Cree LED has found that using Arctic Silver thermal adhesive to secure the thermocouple provides accurate thermal measurements and is the recommended method for attaching thermocouples.

Figure 3: Arctic Silver thermal adhesive

After mixing, the Arctic Silver adhesive takes about ten minutes to cure at room temperature. Therefore, Cree LED recommends that, prior to mixing Arctic Silver, the thermocouple junction be placed at the desired T_{sp} location and the lead taped down so that the thermocouple junction does not move. With the thermocouple junction flat against the T_{sp} location, cover the thermocouple junction with a small dab of Arctic Silver. As shown in Figure 4, there should be just enough Arctic Silver to completely cover the thermocouple junction and attach it securely to the T_{sp} location.

3 Dupont™ Teflon®

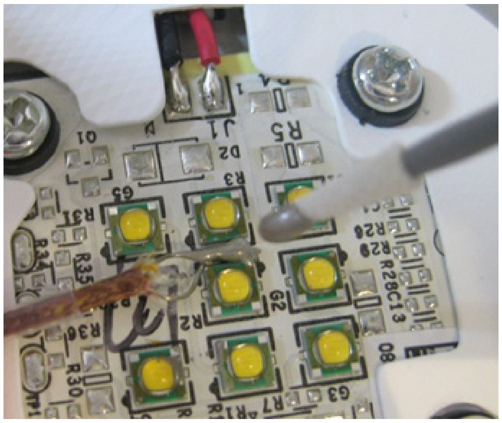

Figure 4: Applying Arctic Silver thermal adhesive

Figure 5 shows an example of a properly mounted thermocouple.

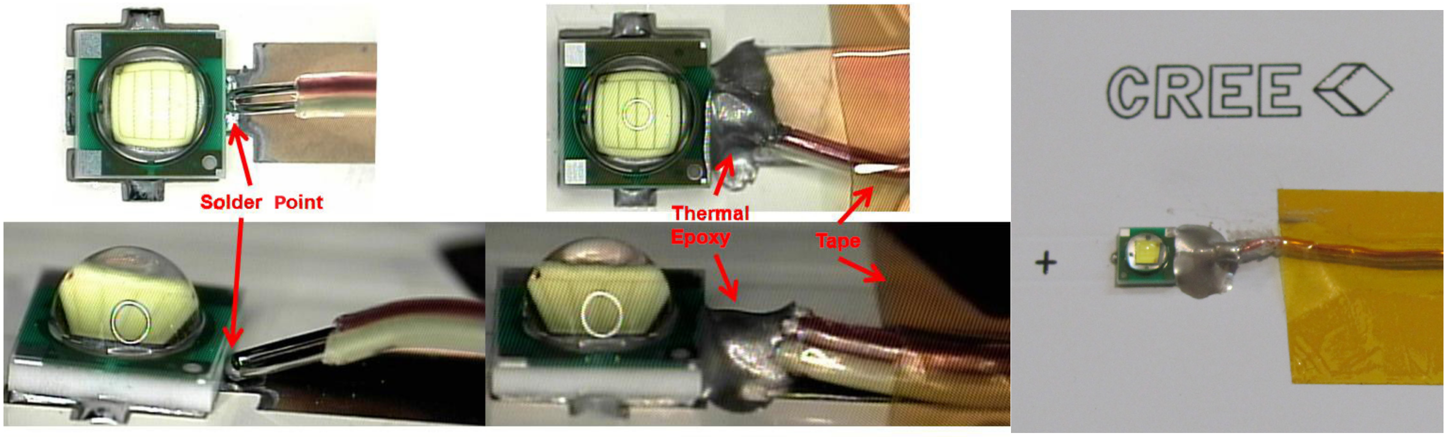

Figure 5: Left and center: properly mounting a thermocouple, right: the finished result

MEASURING THE SOLDER-POINT TEMPERATURE

After the thermocouple junction is securely attached and shielded from direct light, which can affect the temperature measurement, use a calibrated thermometer to measure the temperature. Cree LED recommends using a thermometer with data logging capabilities such as an OMEGA HH147U or Fluke 54-II to graph the temperature over time and monitor the temperature stabilization. Set the thermometer to record the temperature at one-minute intervals and apply power to the LED until the temperature stabilizes, which can take up to two hours or more. The temperature is stable when the temperature reading does not change more than 1% for five minutes. See Figure 6 for an example measurement of stabilized T_{sp}. Make sure to place the LED under test in a location with a constant ambient temperature.

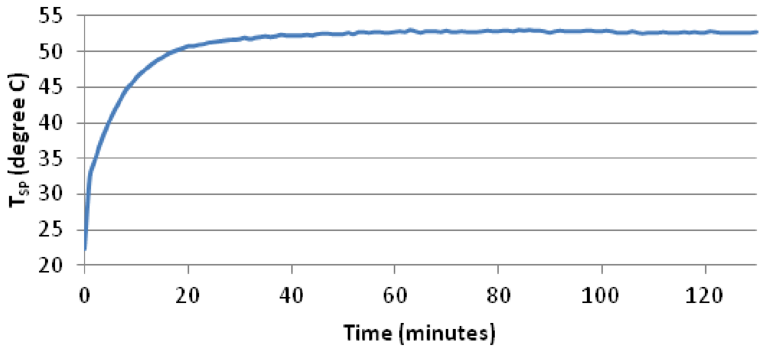

Figure 6: T_{sp} stabilizing time

CONCLUSION

Observe the following practices to accurately measure LED T_{sp}.

- Use an insulated thermocouple whenever possible.
- Minimize the amount of direct light exposure on the thermocouple junction. Photons of light contacting the thermocouple junction will affect the measurement.
- Ensure that the thermocouple junction is in good mechanical contact with the specified LED T_{sp} measurement location.
- Use tape to hold the thermocouple lead in place and relieve stress on the thermocouple junction.
- Attach the thermocouple junction directly to the T_{sp} location using thermally conductive epoxy or by soldering.
- Log the temperature measurement from turn-on until stable, i.e., the temperature not changing by more than 1% for five minutes, which can take several hours.