Application Note AN051608a:

In-Situ LED Junction Temperature and Thermal Resistance Measurement

Overview

LED manufacturers and solid state lighting developers are driving to increase power levels. As more energy is pushed through the LED diode junction, heat removal becomes a critical issue. To assure device lifetime, quantum efficiency, and LED color, the diode junction temperature (Tj) must be maintained within a specified band. Measuring this important parameter is difficult with direct methods, such as thermocouples and infrared cameras, due to the small size of the LED and its surrounding optics.

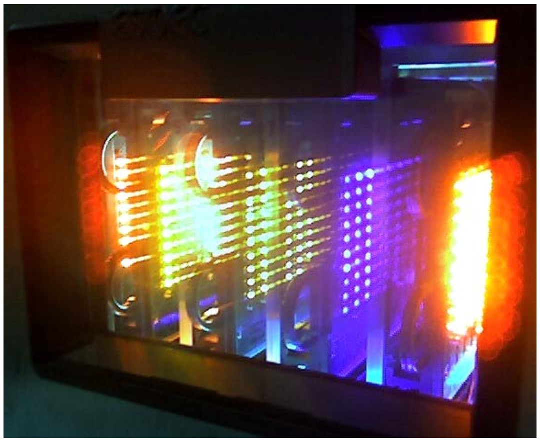

Figure 1, LED burn-in with in-situ Tj monitoring

Fortunately, Tj can be measured indirectly using the LED diode junction's inherent voltage/temperature dependency with a technique specified by JEDEC. However, this technique is difficult to implement in multi-LED series circuits because of high common mode voltages and the need to generate fast, high duty cycle current pulses. Nevertheless, by combining the SpikeSafe current source with a high-speed sampling Digital Multi Meter (DMM), lighting designers can reliably measure Tj in multi-LED circuits. The resulting measurements also allow designers to calculate the thermal resistance and make design changes to minimize it – key to perfecting efficient lighting products.

The JEDEC Electrical Test Method

The Electronic Industries Association EIA/JEDEC JESD51-1 specification describes the industry-standard Vf-based Tj measurement technique for diodes the Electrical Test Method. This method uses two current levels: a low-level measurement current and a high-level heating current. The measurement current's level is set high enough to drive the forward voltage above the diode's cut-in voltage, but low enough so as not to introduce significant self-heating, typically a few tens of milliamps. For LEDs, the heating current is usually chosen close to or equal to the operating current—hundreds of milliamps to amps.

In the test method, the Vf versus temperature relationship is first determined by driving the LED with the measurement current and adjusting temperature. The resulting points are graphed and the relationship is reduced to a single slope factor called the K-factor:

$$K = \Delta Vf/\Delta T$$

For LEDs, K is in the range of 1-3mV/degree C. Using this factor, a change in LED junction temperature can then be calculated by measuring the corresponding change in Vf and dividing by K.

$$\Delta T = \Delta Vf/K$$

The Electrical Test Method specifies a dynamic technique for measuring Tj under high current heating conditions. The LED is driven with the high heating current for a period of time and then quickly switched to the low measurement current. Vf is measured just after switching to the lower current, and it is then compared with a Vf measurement taken before the higher current was applied. Using the equation above, the ∆T is obtained. This ∆T is then added to the known case temperature of the LED to obtain the actual junction temperature.

$$Tj = Tcase + \Delta Vf/K$$

Challenges Found In High-Power LED Circuits

Though the ETM is a fairly straightforward “source measure” test, implementing it in high-power LED lighting circuits presents significant challenges for both the source and the measure instruments.

Source Requirements:

- Drive up to 10A for LEDs with internal parallel elements
- Pulse at duty cycles above 99%
- Shift quickly between two precise current levels 3-5 orders of magnitude apart
- Produce clean, fast transitions in highly inductive circuits
- Support high compliance voltages – over 100V in some designs

Measure Requirements:

- Measure with sub-millivolt resolution
- Reject common mode voltages as high as 200V
- Measure at a precise time a few microseconds after a current transition
- Integrate over a small aperture of a few tens of microseconds

To meet these requirements, custom approaches using data acquisition systems and pulsed sources are sometimes tried, but data acquisition devices have limited common mode voltage capability. These requirements are also beyond most source-meters, which are the traditional instruments used for this work.

Solution Example: Measuring Tj in a High Power Lighting Product

To measure Tj in high-power LED applications, it is best to separate the source and measure functions. This allows the optimal instrument to be selected for each function. Figure 2 shows an example Tj measurement in a high power solid-state lighting product. The product features a series circuit of several LEDs all mounted to a custom heat sink in order to remove waste heat. In this example, Tj is measured for one LED in the array and the thermal resistance (Rθ) from the junction to the case is calculated.

Figure 2 shows an example Tj measurement in a high power lighting product performed with separate source and measure instrumentation.

To achieve the precise pulsed current, the constant current regulator is replaced with a precision high-compliance pulsed source, in this case the SpikeSafe 200. This instrument uses digital power technology to yield very precise current pulses of any duty cycle at compliance voltages up to 200V with precise low-current control between pulses. The SpikeSafe is outfitted with an optional Tj module to produce the measurement current.

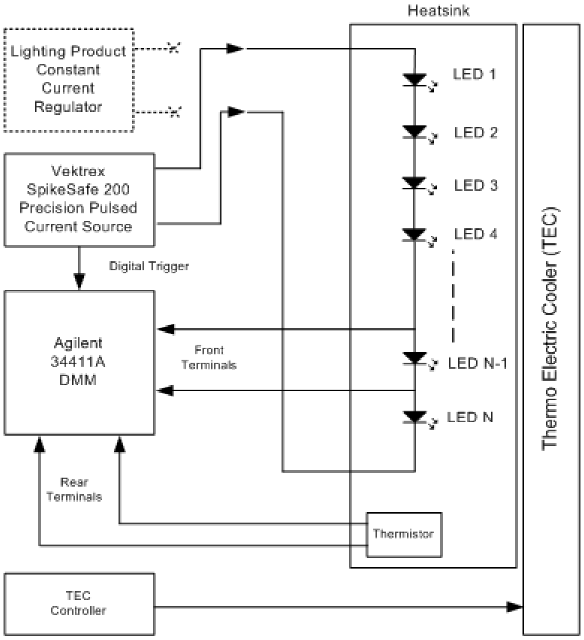

Figure 2, Solid-state light configured for Tj measurement

The LED’s Vf must be measured with sub-millivolt accuracy after the high-current pulse, which is difficult when the overall circuit voltage can approach 200V. The 34411A Digital Multimeter from Agilent Technologies of Loveland, Colorado was used because it is a high-speed sampling voltmeter with fast settling time and can make 20uS aperture triggered measurements. It also has high common-mode voltage rejection allowing it to make a differential voltage measurement on a single LED with high offset voltage.

To make the specified measurement, first the K-factor for the test LED is calculated. This is achieved by driving the LED string with the (low) measuring current, while controlling the heat-sink temperature with a thermoelectric cooler. Because there is little self-heating with the measurement current, the junction temperature is assumed to be the same as the heat sink temperature. Precise temperature readings are obtained using the digital multimeter and a precision thermistor mounted to the heat sink near the test LED.

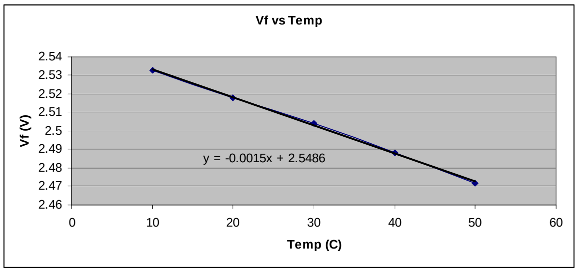

Figure 3, K-factor calibration example

A typical curve obtained is shown in Figure 3; in this example, a K-factor of 1.5mV/degree C is observed. Similar devices will often have a similar K-factor.

Once the K-factor is calculated, Tj is next determined using the dynamic method's pulsed current. Having the (high) heating current set to the lighting product's nominal operating current simulates nominal operating conditions. A reference temperature and Vf measurement are first taken with the measurement current to establish the starting temperature and voltage. Next, the LED string is driven with the two-level pulsed current. The measurement level is the same as the level used to obtain the K-factor. In this example, the current source is programmed to pulse down to the measurement level once per second, and remain at the measurement level for 200uS. The digital multimeter is configured to read a series of 20uS samples and is triggered externally by a digital trigger.

The voltage sample used to calculate ΔV is taken 140uS after the trigger allowing the circuit and the digital multimeter input time to settle after the high current pulse. This voltage and the K-Factor are then used to complete the calculation for Tj. For the tested LED, Tj was found to be 39 degrees C—20 degrees above the case temperature.

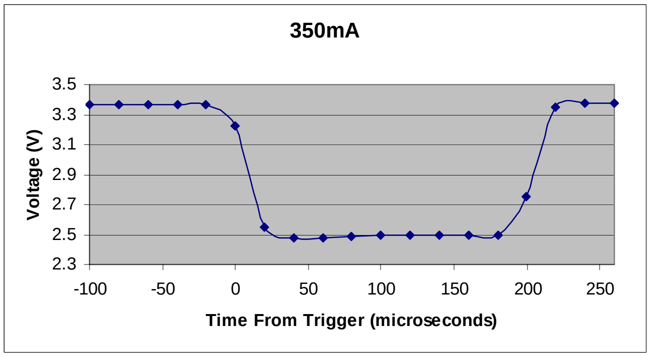

Figure 4, LED Vf Samples Taken With DMM

Once Tj is known, another important parameter, thermal resistance (Rθ), can also be calculated. Thermal resistance is a value that quantifies an LED's ability to transfer heat to its surrounding mount:

$$R\theta = \Delta T/(Vf_{heating}*If_{heating})^{1}$$

The measurements and calculated values for this example are shown in Table 1.

Tcase	$Vf_{measurement}$	Tj	ΔT	Rθ
19.5	2.492	39.1	19.6	16.6

Table 1 – LED Tj and Rθ

Conclusion – The Right Instrumentation Makes Tj Measurements Possible In High Power LED Applications

With the right instrumentation, it is possible to accurately monitor the Tj of an LED in challenging situations like high-voltage lighting circuits. In addition to the thermal design of lighting devices, this technique can be used in other series-circuit applications, such as LED burn-in. Using a circuit similar to the example above, along with signal switching, a large-scale burn-in system can be constructed with in-situ Tj monitoring of every LED. In such a system, devices with improper thermal mounts can be identified and replaced before they overheat and fail.

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[1] This equation does not take into account the duty cycle or energy lost from optical output.