Calculating an LED's Junction Temperature

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The LED junction temperature T_j is an important parameter for LED performance and life time. The junction temperature is calculated out of the thermal resistance of the LED $R_{th\ LED}$, the thermal power $P_{thermal}$ produced by the LED and the local temperature of the PCB T_{PCB}.

(1) $T_j = R_{th\ LED} * P_{thermal} + T_{PCB} = R_{th}\ LED * (P_{electrical} - P_{optical}) + T_{\ PCB}$

$P_{thermal}$ is the difference between the electrical power applied to the LED and the generated optical power. $P_{electrical}$ and $P_{optical}$ both change with temperature:

(2) $P_{optical} = P_{optical}\ (25°C)\ (1 + T_{C\ I}\ (T_j – 25°C))$
$T_{C\ I}$: Temperature coefficient of the LED flux (a negative value like -0.005 / K)
T_j: LED junction temperature

(3) $P_{electrical} = V_{f\ LED}\ I_{LED}$
$V_{f\ LED}$: LED forward voltage
I_{LED}: LED current

The LED forward voltage V_f changes with the LED junction temperature:

(4) $V_{f\ LED} = V_{f\ LED}\ (25°C) + T_{C\ V}\ (T_j – 25°C)$
$T_{C\ V}$: Thermal coefficient of the forward voltage (a negative value like -0.001 V / K).

Inserting Eq. 4 in Eq. 3 defines P electrical. Inserting Eq. 3 and 2 in Eq. 1 leads to the following expression:

(5) $T_j = R_{th\ LED}\ (\ (V_{f\ LED}\ (25°C) + T_{CV}\ (T_j – 25°C))\ I_{\ LED} - P_{optical}\ (25°C)\ (1 + T_{C\ I}\ (T_j – 25°C))) + T_{PCB}$

An LED data sheet provides the parameter values $R_{th\ LED}$, $V_{f\ LED}$ (25°C), $T_{C\ V}$, $P_{optical}$ (25°C) and $T_{C\ I.}$ As Eq. 5 is linear in T_j, T_j can be expressed as:

(6) $$T_j = \frac{R_{th\ LED}\ ((V_{f\ LED}\ (25°C) – T_{C\ V}\ 25°C)\ I_{LED} - P_{optical}\ (25°C)\ (1 – T_{C\ I}\ 25°C)) + T_{PCB}}{1 + R_{th\ LED}\ (P_{optical}\ (25°C)\ T_{C\ I} – T_{C\ V}\ I_{LED})}$$

The PCB temperature T_{PCB} might increase due to the heat from the LED. In this case you can replace $R_{th\ LED}$ with $R_{th\ LED} + R_{th\ PCB}$ and T_{PCB} with $T_{ambient}$.

Electronic components around the LED might add to the heat power and Eq. 6 can get more complicated. However, T_j can be calculated with Eq. 5 instead using iterations. In order to do so, we write the right side of Eq. 5 as f (T_j). To begin the iteration we assume a T_{j0} start value (like 25°C) and insert it in the function f (T_j).

(7) $T_{j1} = f(T_{j0})$

We can then calculate $T_{j2} = f\,(0.5\,(T_{j1} + T_{j0}))$ or in general $T_{jn+1} = f\,(0.5\,(T_{jn} + T_{jn-1}))$. When T_{jn+1} matches $0.5\,(T_{jn} + T_{jn-1})$ with suitable accuracy we can stop iterating. Typically, 15 iterations are sufficient, but it's worthwhile to check. Using a spread sheet, each line might calculate T_{jn+1} taking the T_{jn} and T_{jn-1} values from the line above.