Thermal Needs and Challenges in Next Generation Solid State Lighting Applications: Light Emitting Diodes

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This course consists of two main parts; solid-state lighting (SSL) technology and thermal requirements for SSL applications. Light emitting diodes, LEDs, historically have been used for indicators and produced low amounts of heat. The introduction of high brightness LEDs with white light and monochromatic colors have led to a movement towards general illumination. The luminous efficiency of LEDs is soon expected to reach over 80 lumens/Watt, about 6 times higher than an incandescent tungsten bulb. Thermal management of LEDs in both package and system levels are very challenging due to compact size, cost, and long-life. Air-cooling due to the availability and cost-effectiveness is the primary candidate for system level thermal management.

First practical visible LED was invented in 1962 by Nick Holonyak of the General Electric. The early red devices typically emitted 0.001 lumen. Due to their longevity, power requirements, and resistance to shock and vibration the LEDs found uses as indicator applications. Throughout the next two decades advances continued in material development and processing leading to improved efficiency, reliability and additional colors. New materials and techniques enabled high brightness LEDs from the yellow to red spectrum. In 1994, Hewlett-Packard developed a technique and produced red devices reached 25 lm/W, however a typical LED was still only producing 3 lumens. One approach uses an appropriate combination of red, green and blue LEDs to produce white light, while the second approach utilizes a blue or UV LED and a phosphor to create white light.

White LEDs can exhibit exceptional lifetimes, exceeding 50000 hrs, when operated under ideal conditions. Unlike an incandescent bulb filament operating at over 1000 °C, an LED device junction temperature should be kept under 120 °C. In order to meet this requirement the package and system materials and thermal design become crucial. Unlike traditional 5 mm devices with a package thermal resistance of ~400 K/W, a power LED package resistance needs to be less than 20 K/W. At elevated temperatures the lumen depreciation with time is enhanced and performance is degraded. The effects on all of the package components such as; chip, wire-bonds, encapsulation, lens, lead-frame over-mold, and submount material must be considered. A typical LED power-chip has a 1 mm^2 surface area, leading to heat fluxes of 100 W/cm^2 or higher. Increasing junction temperature lowers the overall efficiency of the device, causes the emission to shift to longer wavelengths, and reduces the device lifetime and reliability. Lifetime effects due to temperature conditions are irreversible. This course will focus on

- Historical development and economical benefits of solid state lighting
- Introduction to LED packaging technology and thermal trends
- Thermal management of SSL applications in package level (conduction based)
- System level thermal management requirements (Design and selection of heat sinks)
  - Discussion on the fundamentals of heat transfer in fin arrays
  - Least material thermal optimization
  - Design for manufacturability