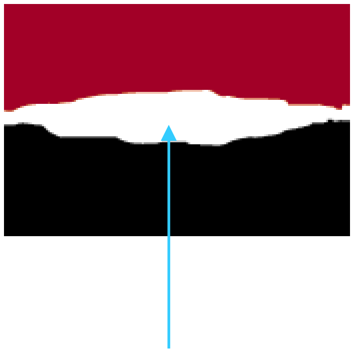
# ***Thermal Management Materials for PCBs used in LED Lighting Systems***

***Sandy Kumar, Ph.D.***
Director of Technology
American Standard Circuits, Inc.
3615 Wolf Road, Franklin Park, IL 60131

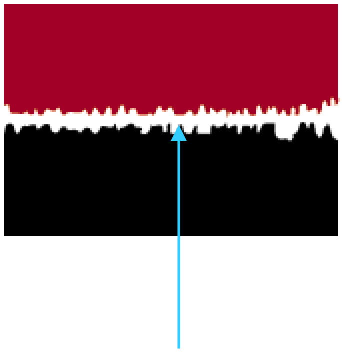
# Thermal management issues

- Solid-air interface represents the greatest barrier in thermal management
- Between two typical electronic components, as much as 99% of the surfaces are separated by a layer of interstitial air ***(Dr. Miksa de Sorgo, Electronics Cooling, 2000)***

# 95-99 % Air Resistance



Poor surface flatness

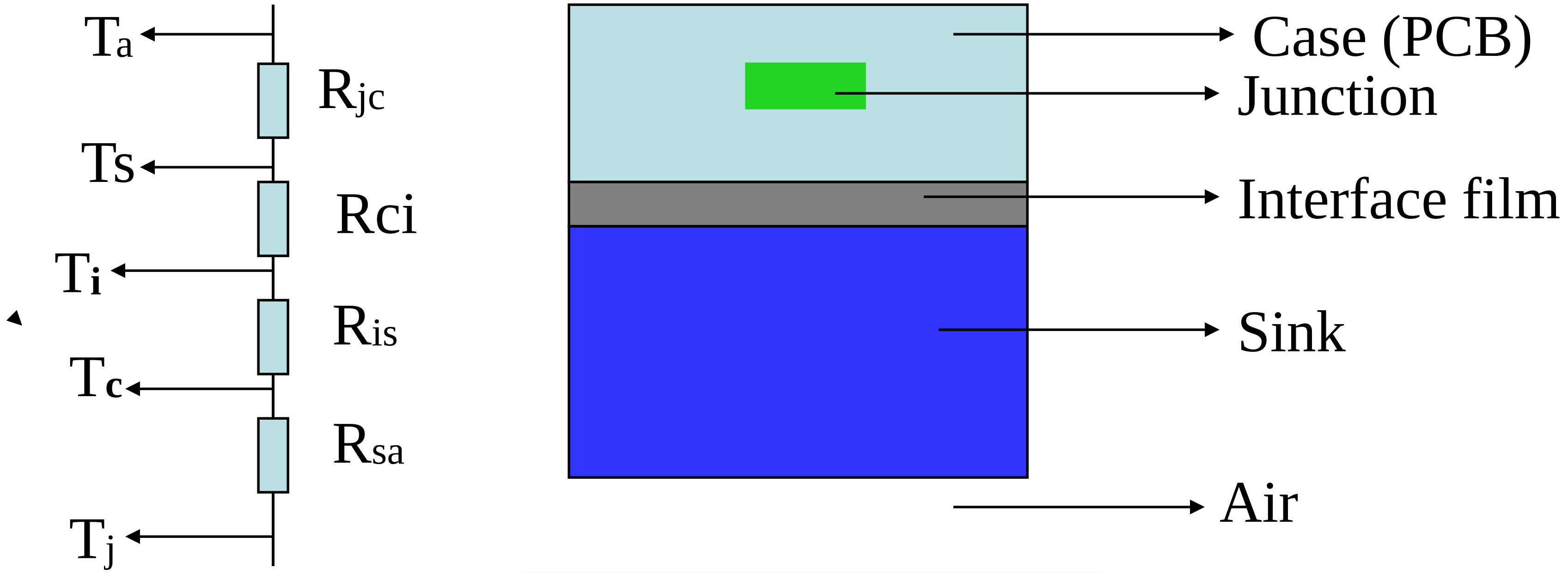


Surface roughness

*Total Thermal Resistance is given by*

$$R_{ja} = R_{jc} + R_{ci} + R_{is} + R_{sa} = (T_j - T_a)/Q$$

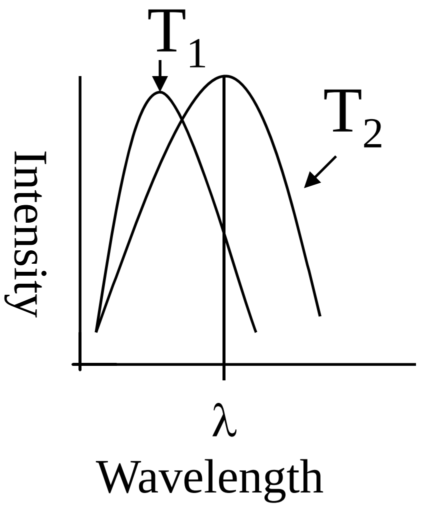
(Q = Heat generated in Watts / Time)




(Rjc + Rci + Ris) < Rsa

**$R_{ci}$ and $R_{is}$ can be decreased significantly by surface finish and type of interface material**

# Maximizing Thermal Emmisivity of Heat Sink




$T_1 > T_2$

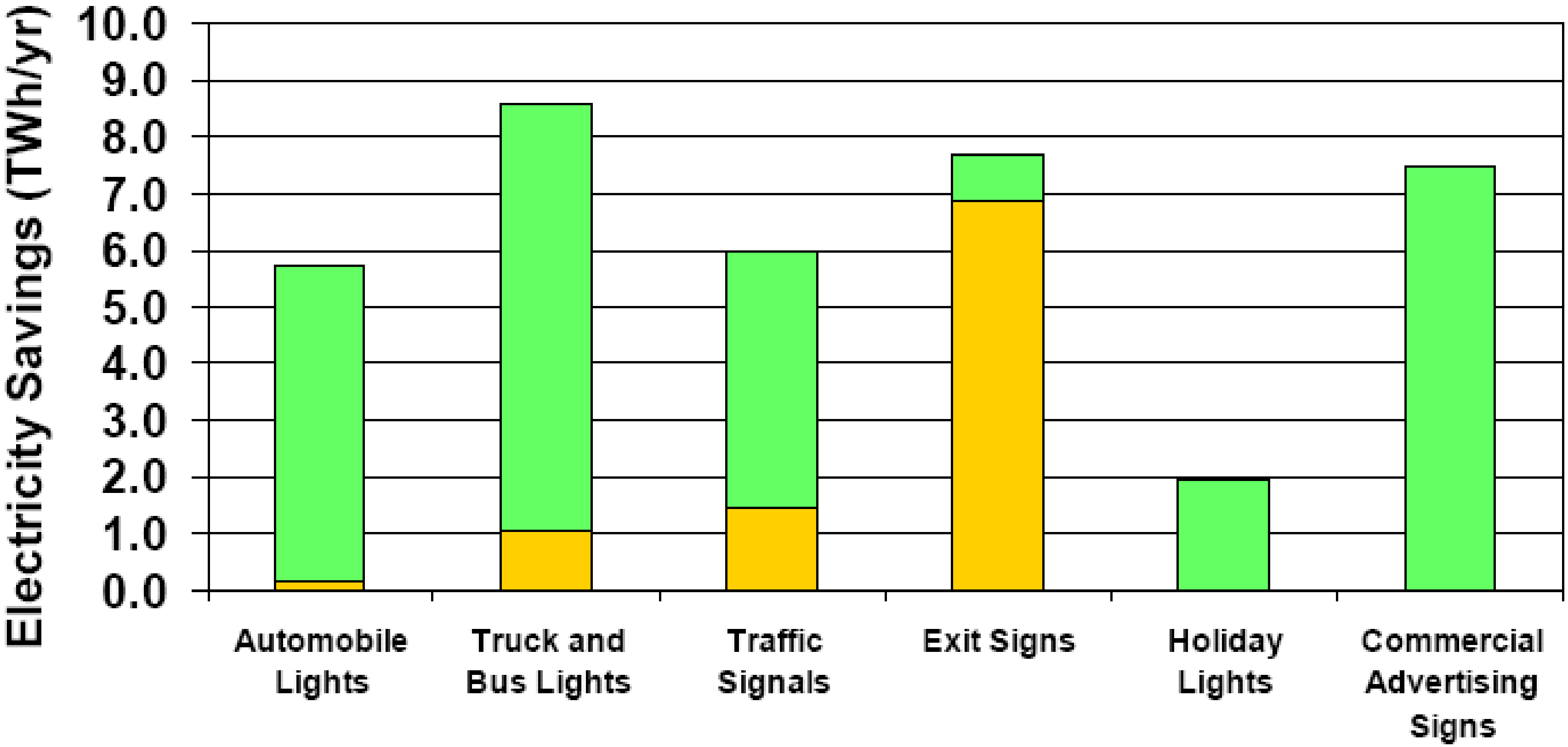
Heat Sink

$$\alpha_\lambda = \varepsilon_\lambda$$

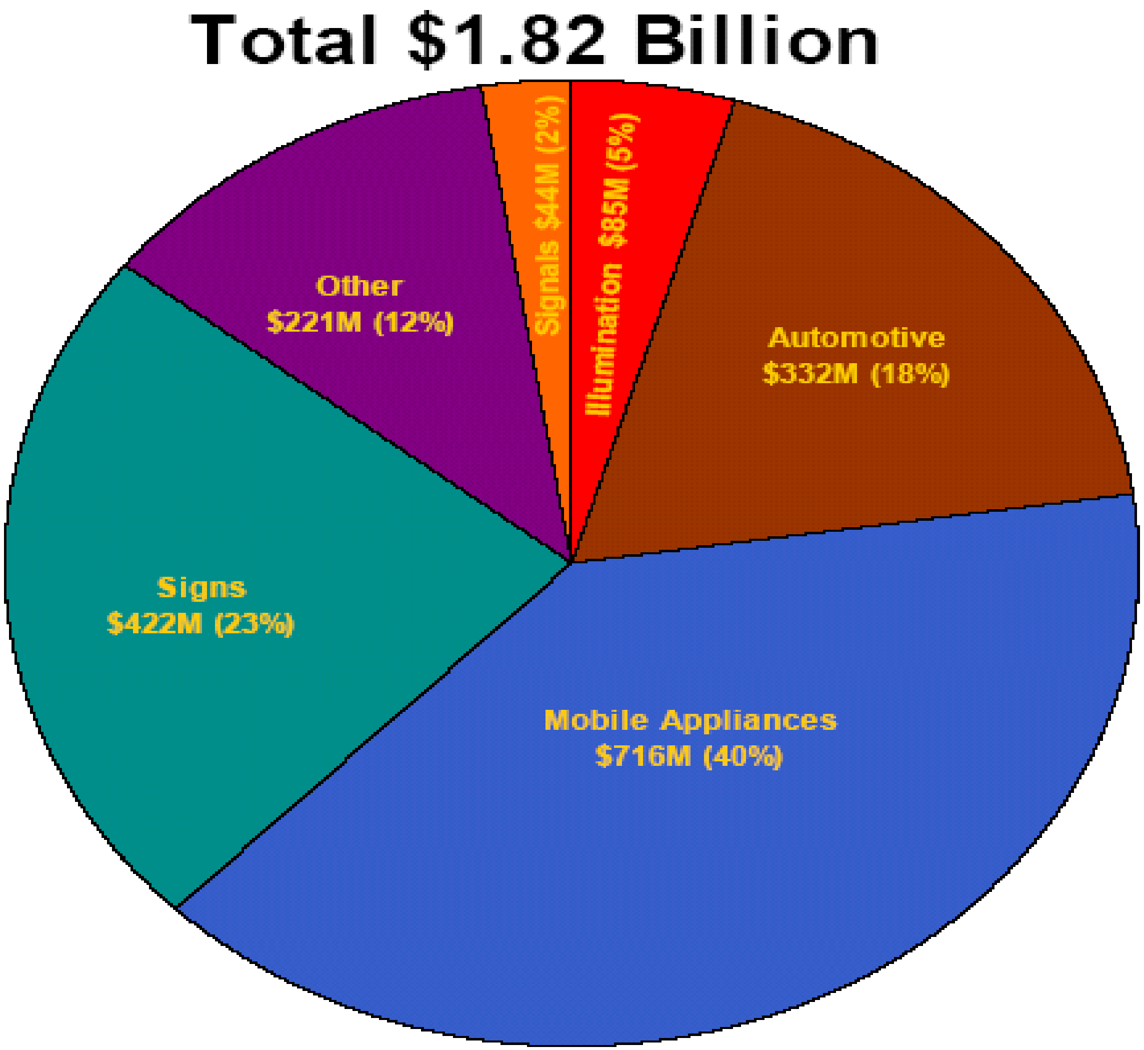
Texture the heat sink surface to tune with the operating temp. $\lambda_{Max}$

# Electricity Savings by LED

## *(US Dept of Energy, Nov 2003)*



# LED Market Potential (12/03)
# Excluding In-house Market!!

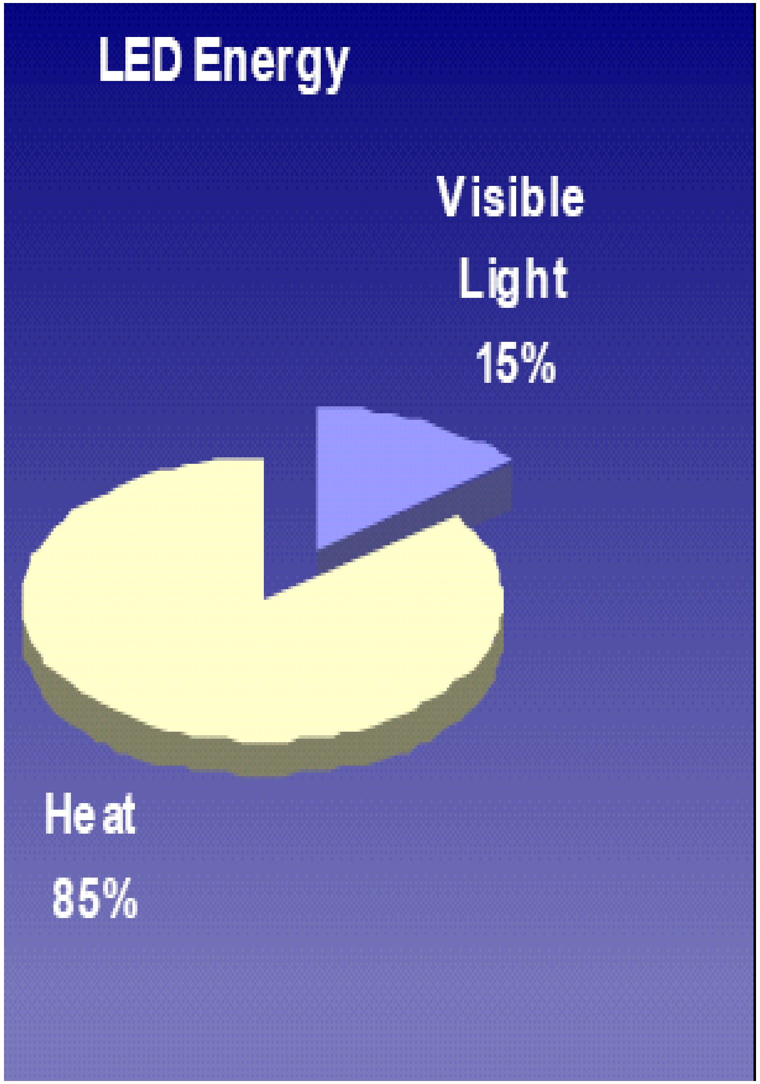


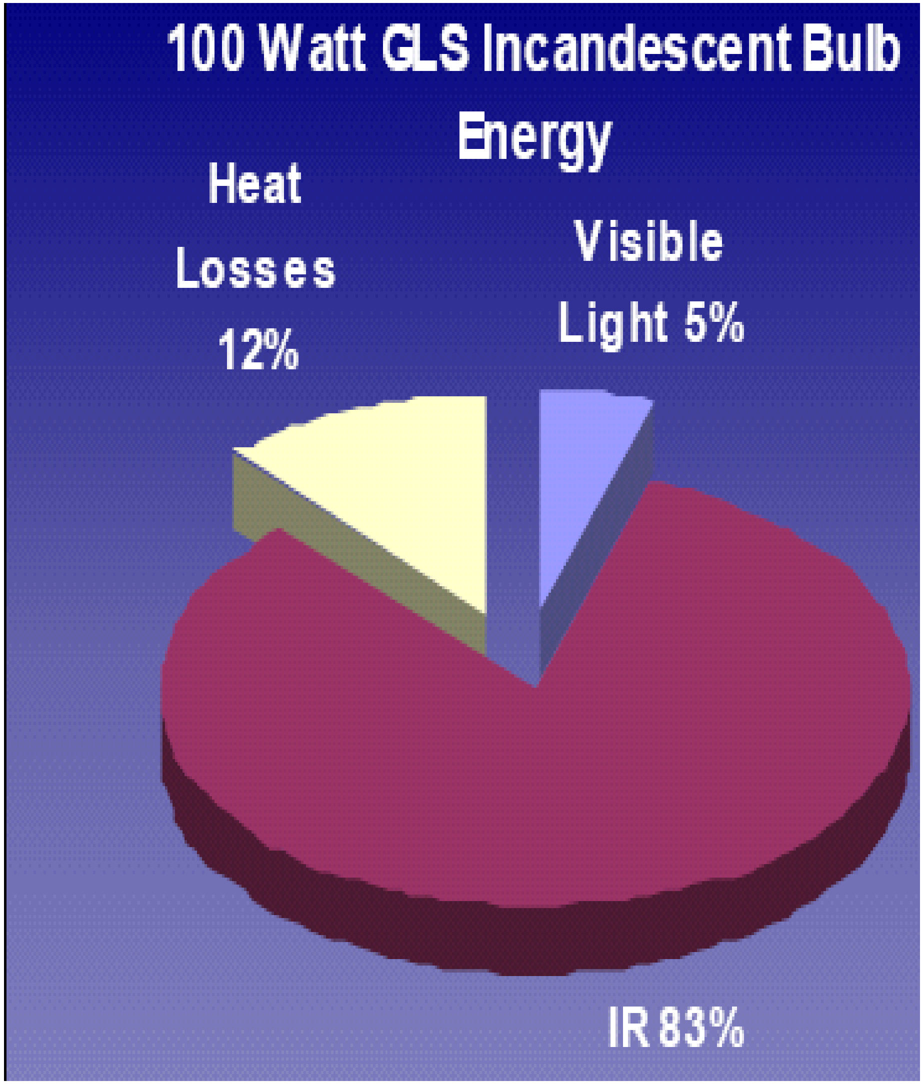

Source: Bob Steele “Strategies Unlimited” Published in “Compound Semiconductors” Dec 2003

# LED Package

- LED lighting consists of – optics, electronic control gear and PCB with thermal management system
- Installed into the fixture much like today's lamp and ballast fitting

# Thermal Management in LEDs

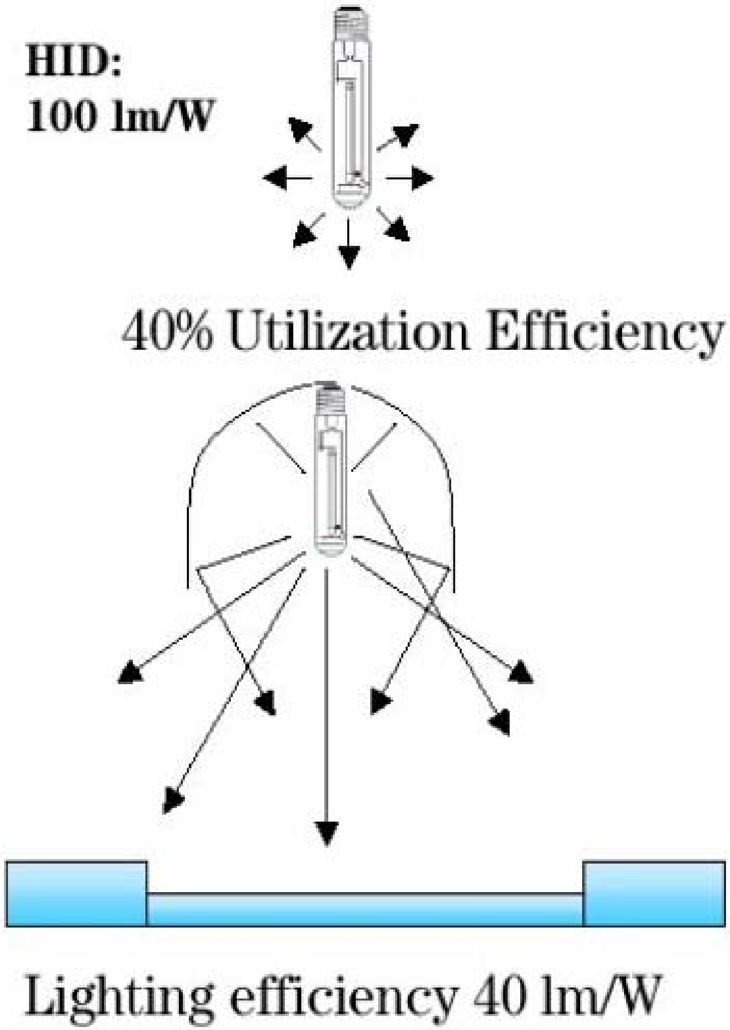


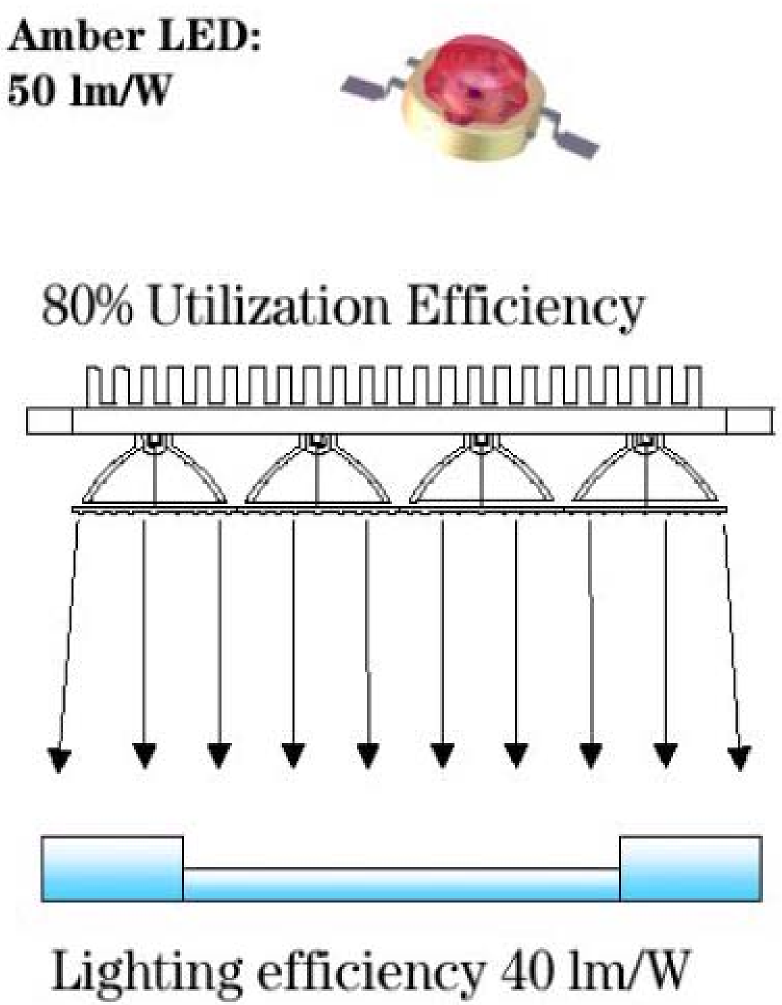



# LED Thermal Management

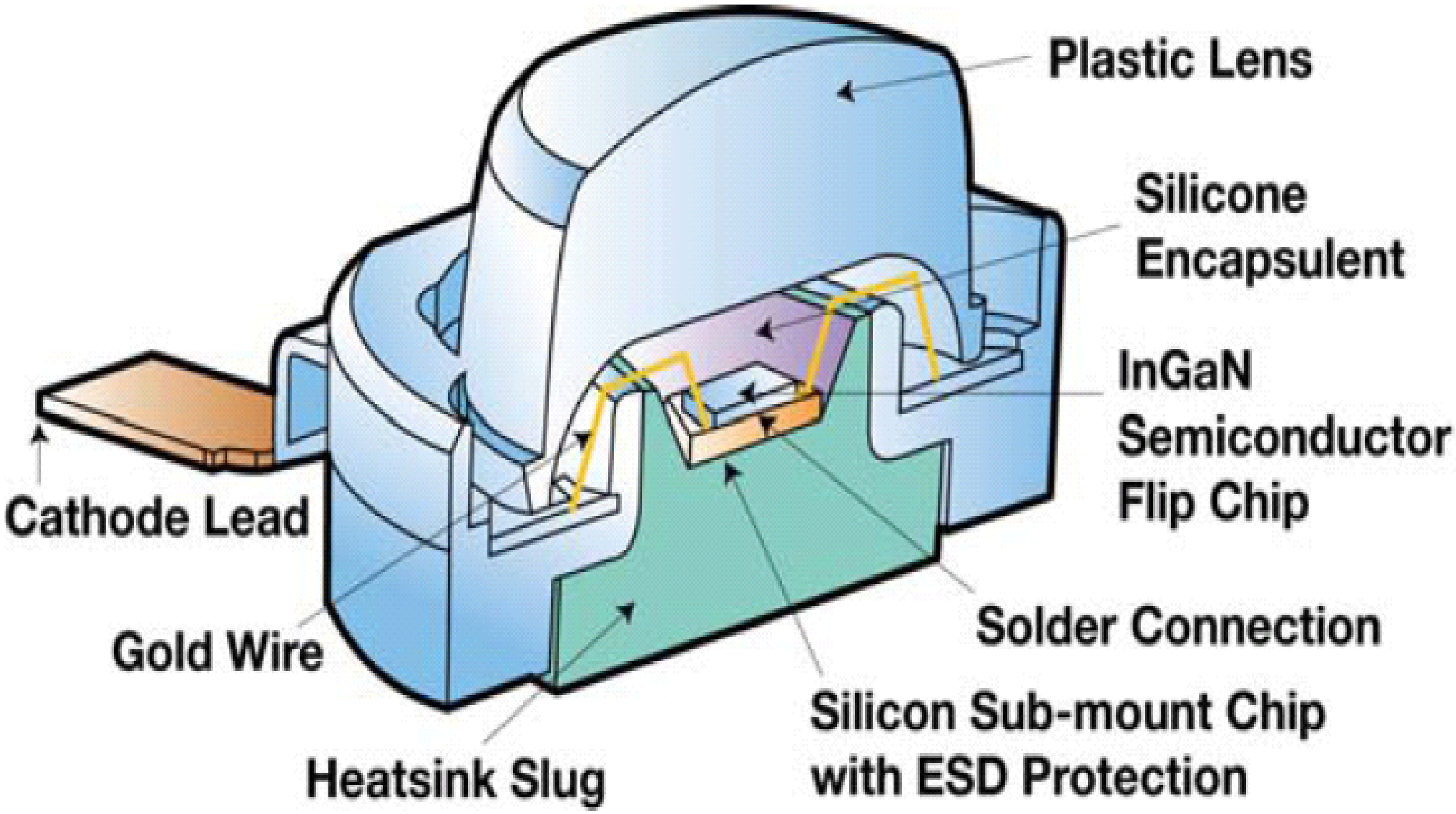
- Incandescent light: Most of the heat is radiated plus conduction and convection
- LED: Heat transferred only by conduction to heat sink  - under sizing the heat sink in LED would give color shift

# Omni directional vs Unidirectional

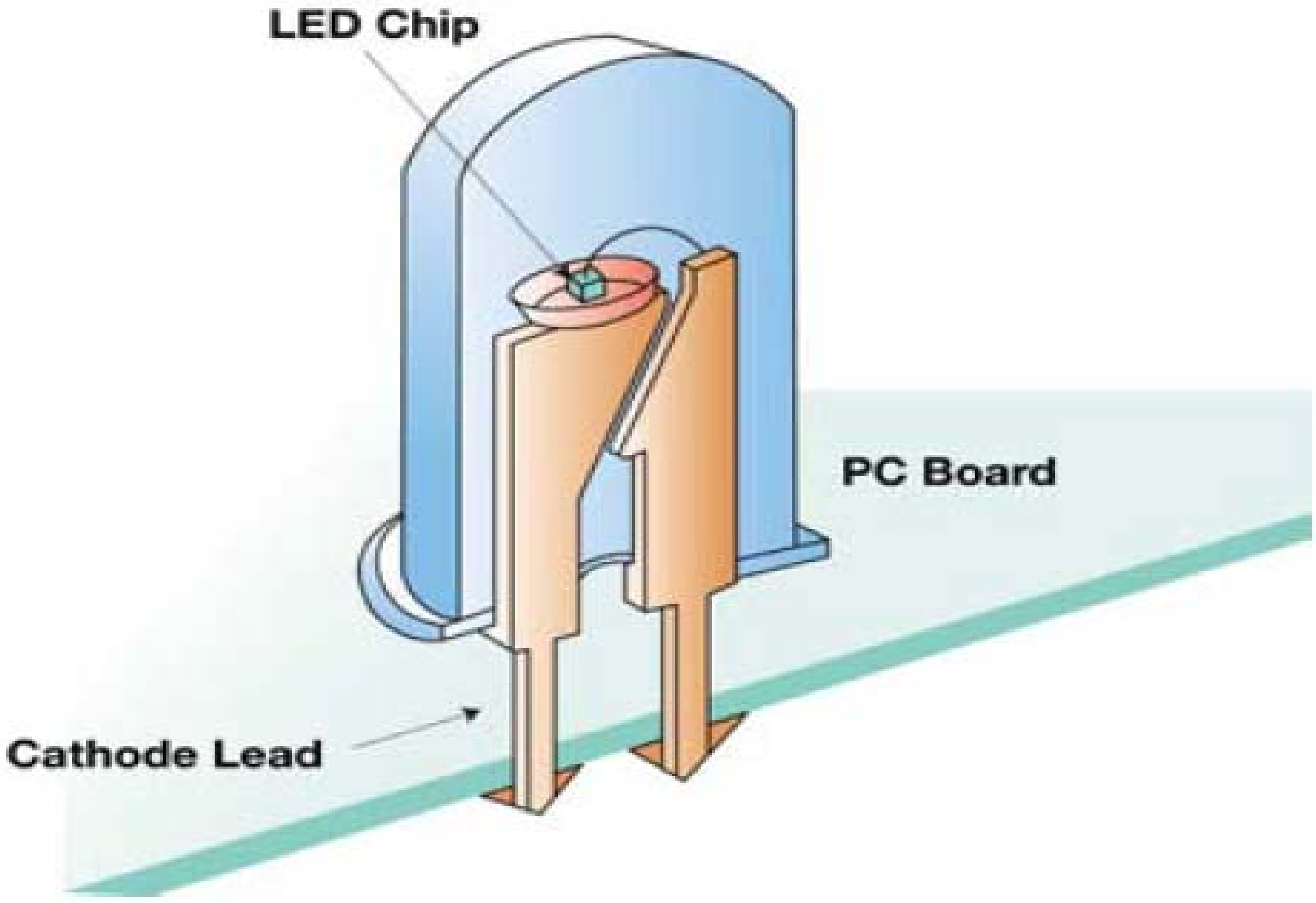


# Anatomy of High Power LED



# Anatomy of Low Power 5 mm LED



# Anatomy of High Power LED

- Large metal “slug” improves heat transfer
- High current, large light emitting surface, and proportionally higher light output
- Thermal resistance of the high power units is much lower than that of a conventional 5mm LED

***1 watt light source, 1sq mm area, operates at 350ma, and generates <u>25 lumens</u> (compared to 0.25mm square, <0.1 watt, 20-30ma, and <u>1-2 lumen</u> of a standard 5mm LED).***

# Anatomy of Low Power 5 mm LED

- The base pins serve as both electrical and thermal conduits, which limit how much light can be produced.
- Because of their low light output and heat transfer limitations, these small units have been main drivers for low power luminance applications.

# Tint Binning of White LEDs

wafer

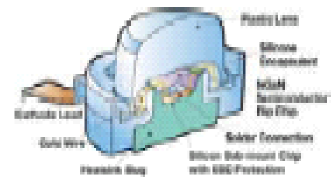
Reactor

- high pressure
- high temperature
- vapor density variations

Finished wafer

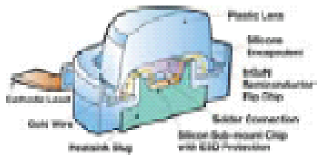
Sliced and diced into thousands of chips or die

Packaging:
Die placement, wire bonds, encapsulation



Finished LED

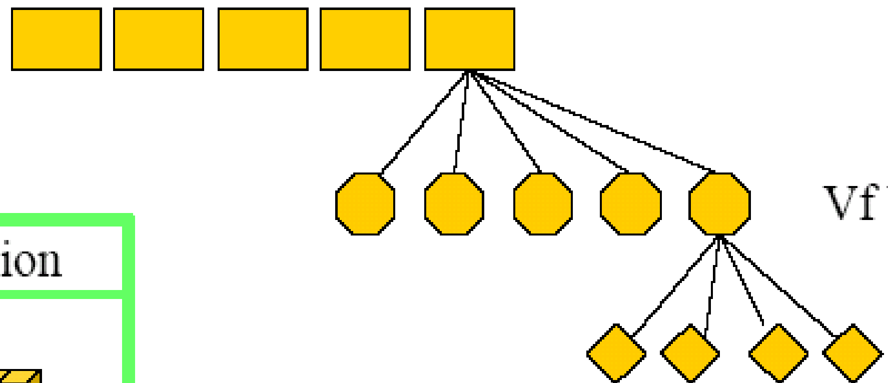
# Tint Binning



Finished LED → 100% test

- Functional
- Color, Flux, Vf
- Each LED Labeled by bin

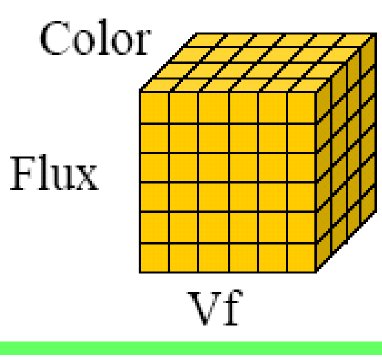
Wavelength bins, 2.5-20 nm wide



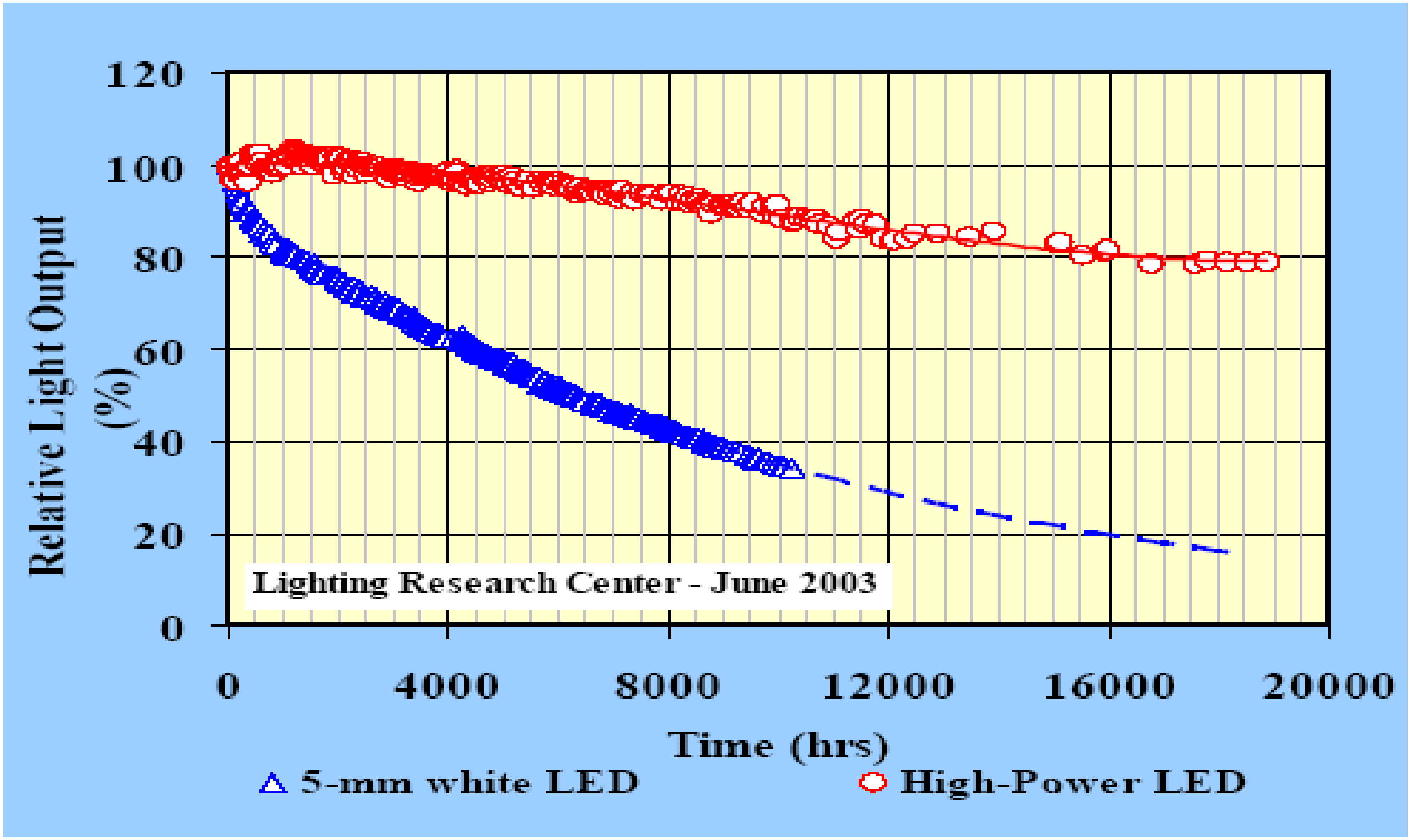
Vf bins, .20 -.50 mv wide

Flux bins: 30% + ranges

**Full Distribution**

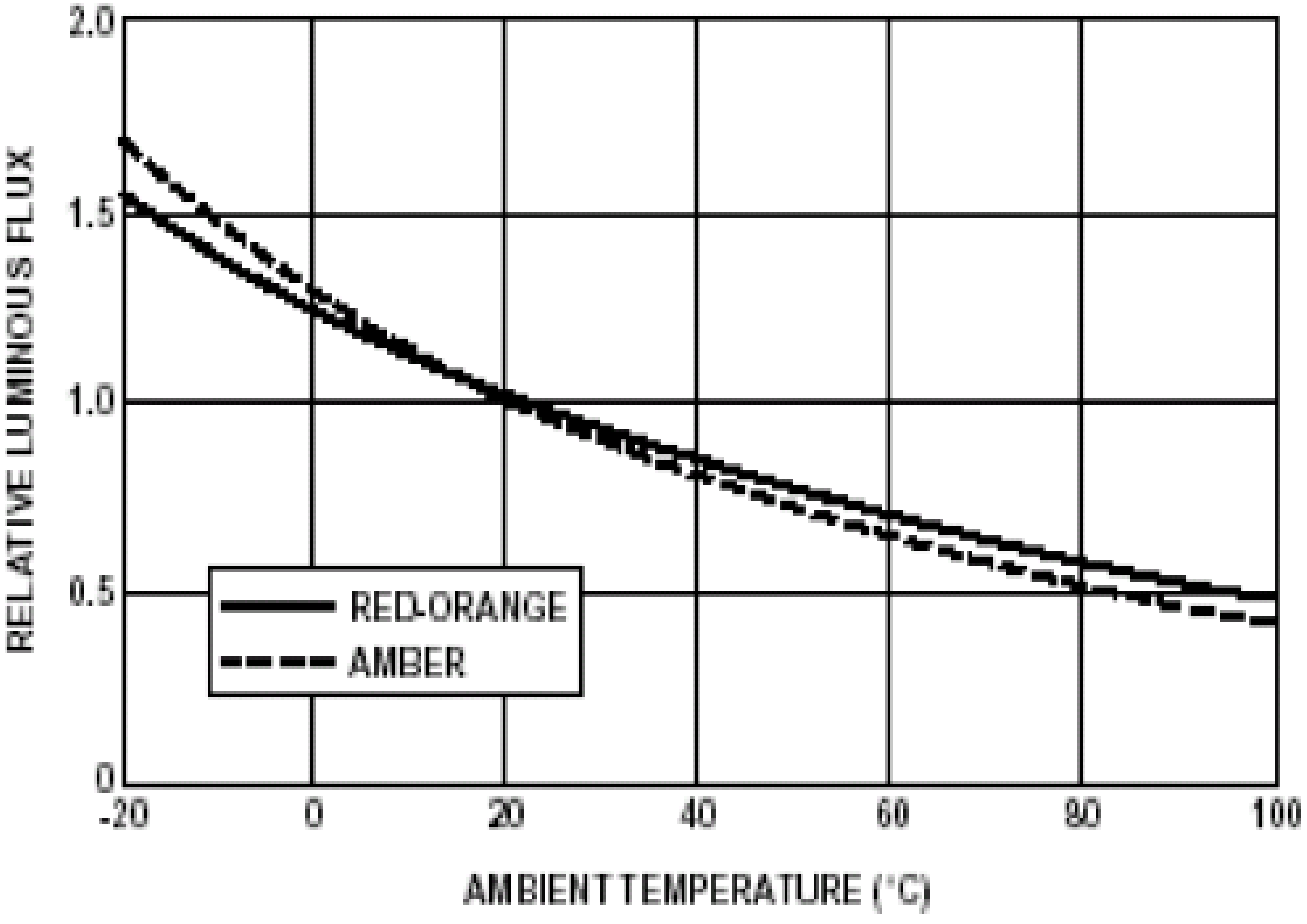



**Uniform White Light achieving depends on Proper Binning of individual LEDs**

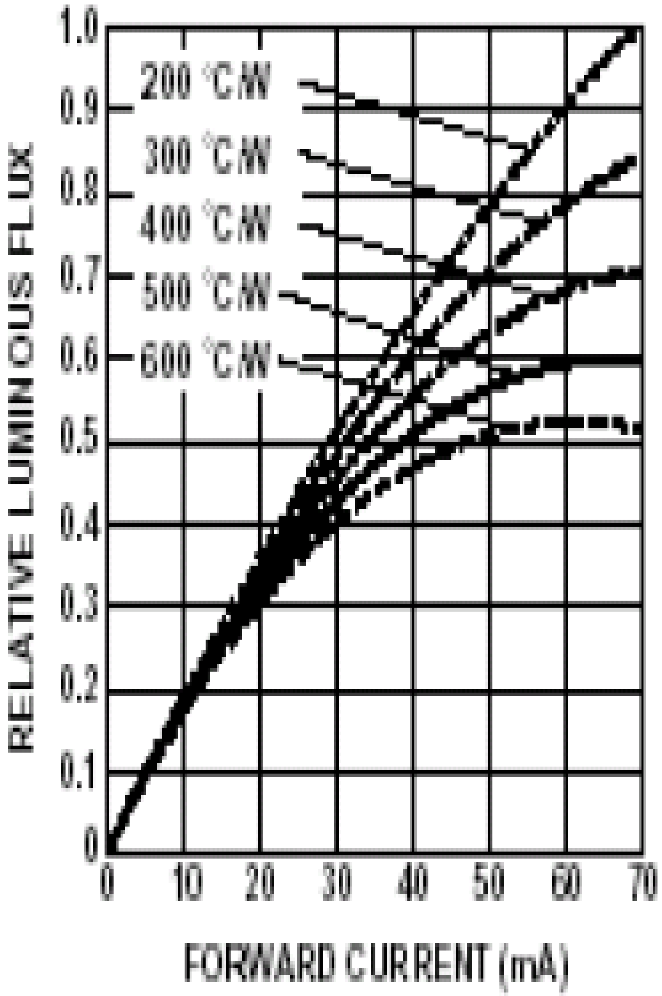


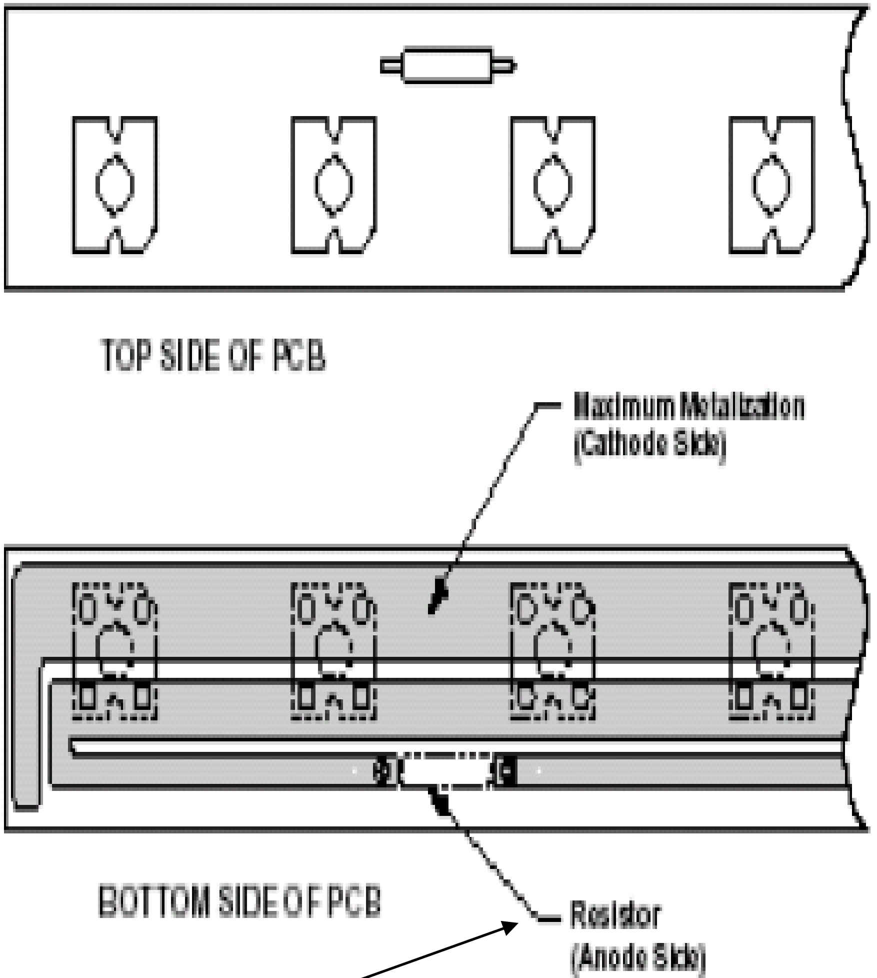

Comparison of high and low Power LEDs:
RPI Lighting Research Center -Troy, NY

# LED Temperature vs Intensity
# (at Constant Current)



# PCB Design: Thermal Resistance vs Lumen

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# Types of thermally conductive materials

- Greases
- Reactive compounds
- Elastomers
- Pressure sensitive adhesive films

All are designed to conform to surface irregularities, thereby eliminating air voids and improving heat flow

# Thermal Greases

(THERMALLY & ELECTRICALLY CONDUCTING)

- Dispersed thermally conductive ceramic fillers in silicone or hydrocarbon oils to form a paste
- Sufficient grease is applied to one of the mating surfaces
- Grease flows into all voids during pressing to eliminate the interstitial air. Excess grease flows out
- Joint integrity maintained with spring clips or mounting hardware
- No electrical insulation provided

# Thermally Conductive Epoxy Compounds

- Are compounds converted to a cured rubber film after heating at the thermal interface
- Before curing, flows freely as grease to eliminate the air voids and reduce the thermal resistance of the interface
- Does not require mechanical fasteners to maintain the integrity of the joint
- No migration or bleeding issues like in grease
- No electrical insulation provided

# Thermally and/or Electrically Conducting Elastomers

- Silicone elastomer pads filled with ceramic or metal particles
- Available in thickness from about 3 mil upward
- If required, elastomers pads can provide electrical insulation and can be used between surfaces that are at different electrical potential

# Advantages of elastomers

- Elastomers combine the advantages of not exhibiting melt or flow during solder flow, **and remain flexible after curing to accommodate stress due to CTE differences**
- Thermal conductivity: 0.5 – 5.0 W/M K
- Operating temp: 500 F (stability: -150 to +600 F)
- Stable: Si-O Bond Energy: 88-117 kcal/mol vs 83-85 kcal/mol for C-C
- Oxidative attack less for $1^0$ H of $CH_3$ in silicone than $2^0$ or $3^0$ H found in epoxy

# Elastomeric ASC Materials

- **Thermasil®:** Flexible thermal bonding film to bond copper circuit layer with aluminum/brass/copper heat sink body

- **Thermorig:** Rigid thermal bonding film to bond copper foil with copper foil to construct a *rigid* thermally conducting insulator board

- **Conformal Thermasil:** Thermally conductive, electrically insulating conformal pad (putty type material) as interface between PCB and complex machined parts. The bonding can be permanent or temporary

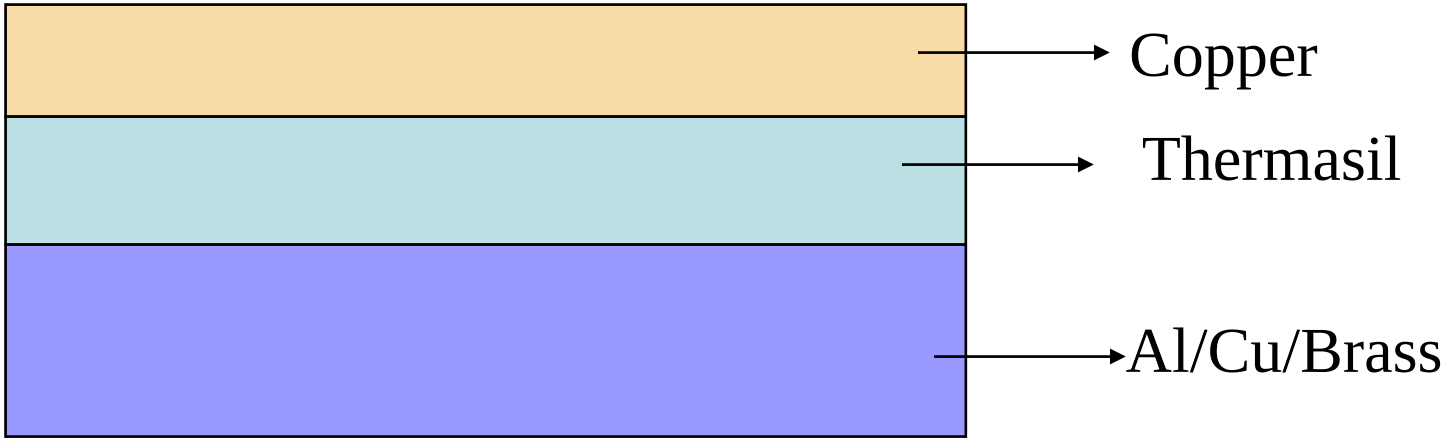
# Elastomeric ASC Materials

- **Silver filled silicone:** Thermally and electrically conducting bonding film for bonding PCBs with heat sinks
- **Silver coated aluminum filled silicone:** Thermally and electrically conducting bonding film for bonding PCBs with heat sinks
- **Conformal gap pad for pressure sensitive applications (PSAs)**: Thermally conductive, electrically insulating gap pad as interface between PCB and a flat heat sink. The assembly can be easily disassembled and reassembled.

# Thermasil$^{R}$ Bonding film

- Thermasil$^{R}$ is a patented elastomeric thermal interface dielectric adhesive material
- Can be tailored for various thickness and thermal conductivity

# *Anatomy of Thermasil bonded laminate*




Cu = ¼ Oz to 5 Oz
Thermasil: 3 mil or more
Heat Sink: Al, Cu, Brass

# **Thermasil**$^{R}$ Thermally Conductive Silicone

| Cure Condition | Sp. Gr. | Durometer Shore A | Tensile Strength PSI | % Elongation |
|---|---|---|---|---|
| 330 F | 1.4 | 80-90 | 1220 | 400 |
| Tear Strength PPI | Resistivity, Ohm meters | Thermal Conductivity, W/mK | Flame test | Shelf life months |
| 190 | $10^{12}$ | 0.5 – 5.0 | Pass | 6 |

***ASC Products***

# Material Specs & Finish

- Thermal Conductivity: 0.5 to 5.0 W/mK
- Cu Finish: HASL, Immersion Ag, Immersion Sn, ENIG, OSP, Electrolytic Ni/Au
- Al Finish: Bare, Ni, Au, Ag, Chromate

# *Anatomy of Rigid Thermorig bonded laminate*

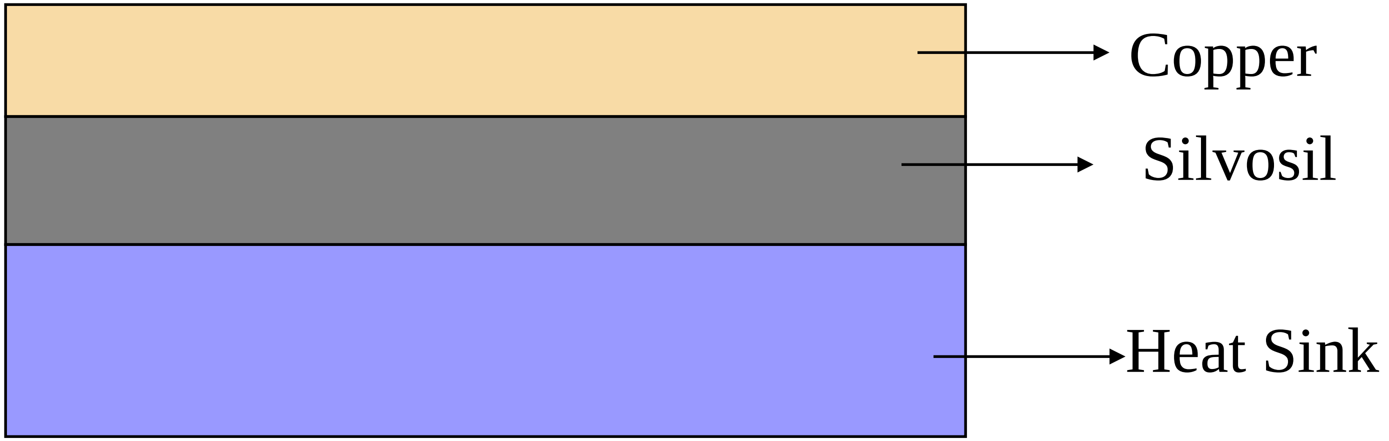

Cu = ¼ Oz to 5 Oz
Thermorig: 3 mil or more
Heat Sink: Al, Cu, Brass

# Hi Rigidity Thermorig Conductive Silicone

| Cure Condition | Sp. Gr. | Durometer Shore A | Tensile Strength PSI | % Elongation |
|---|---|---|---|---|
| 330 F | 1.6 | 85-95 | 1020 | 150 |
| Tear Strength PPI | Resistivity, Ohm meters | Thermal Conductivity, W/mK | Flame test | Shelf life months |
| 50 | $10^{12}$ | 0.9 | Pass | 6 |

***ASC Products***

# *Anatomy of Silvosil bonded laminate*




Cu = ¼ Oz to 5 Oz

Silvosil: 3 mil or more

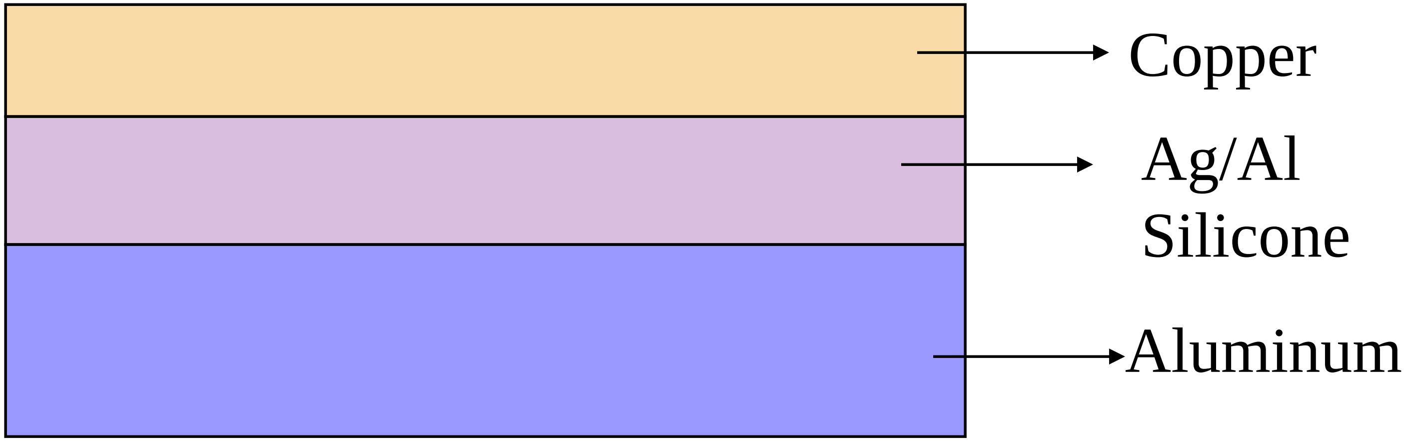
Heat Sink: Al, Cu, Brass

# Electrically & Thermally Conductive Silver Silicone (Silvosil)

| Cure Condition | Sp. Gr. | Durometer Shore A | Tensile Strength PSI | % Elongation |
|---|---|---|---|---|
| 330 F | 1.4 | 80-90 | 1220 | 400 |
| Tear Strength PPI | Resistivity, Ohm meter | Thermal Conductivity, W/mK | Flame test | Shelf life months |
| 190 | 0.0007 | 1.8 | Pass | 6 |

***ASC Products***

# *Anatomy of Metasil bonded laminate*




Cu = ¼ Oz to 5 Oz
Metasil: 3 mil or more
Heat Sink: Al, Cu, Brass

# Electrically & Thermally Conductive Metasil

| | | | | |
|---|---|---|---|---|
| Cure Condition | Sp. Gr. | Durometer Shore A | Tensile Strength PSI | % Elongation |
| 330 F | 2.1 | 68-82 | 200 | 200 |
| Tear Strength PPI | Resistivity, Ohm meter | Thermal Conductivity, W/mK | Flame test | Shelf life months |
| 50 | 0.002 | 1.6 | Pass | 6 |

***ASC Products***

# Conformal Thermally Conductive Putty Material

| Cure Condition | Sp. Gr. | Durometer Shore A | Tensile Strength PSI | % Elongation |
|---|---|---|---|---|
| 200 F or less | 1.3 | 50-60 | 625 | 315 |
| Tear Strength PPI | Resistivity, Ohm meters | Thermal Conductivity, W/mK | Flame test | Shelf life months |
| 62 | $10^{12}$ | 0.8 | Pass | 6 |

***ASC Products***

# Typical Configurations

- Cu circuit layer / Thermasil / Al heat sink
- Cu circuit layer / Thermorig prepreg / Cu ground plane / ***Thermasil*** / Al heat sink: Heat sink is electrically isolated from ground plane Cu
- Cu circuit layer / Thermorig prepreg / Cu ground plane / ***Silvosil or Metasil*** / Al heat sink: Heat sink is electrically connected to ground plane Cu

# *Advanced Materials with Ultrahigh Thermal Conductivities*

| Matl. | Sp.Gr. (SG) | CTE | ITC | TTTC | SITC (ITC/SG) |
|---|---|---|---|---|---|
| CVD Diamond | 3.52 | 1-2 | 1100-1800 | 1100-1800 | 310-510 |
| HOPG | 2.3 | -1.0 | 1300-1700 | 10-25 | 565-740 |
| Diamond-SiC | 3.3 | 1.8 | 600 | 600 | 182 |

ITC: Inplane thermal conductivity, TTTC: Through thickness TC, SITC: Specific inplane TC in W/mK. HOTG: Highly oriented pyrolytic graphite

# Summary

- ASC has developed several thermal interface materials and thermal management solutions for various power electronics PCBs
- Thermal management of electronic packaging has reached a crucial stage calling for immediate cooling solutions
- New materials technology advances hold great promise in creating novel thermal management solutions in tailoring interfaces and heat sinks