

# Entwärmung von Schaltungsträgern auf IMS und FR4 Basis; Konzepte, Prozesse und Grenzen

Gregor Langer

“Thermal Management in elektronischen Schaltkreisen  
und LED-Systemen”

18. März. 2010

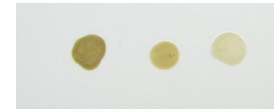
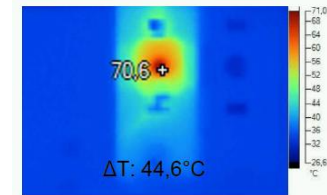
Hanau

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## Content

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- **AT&S facts**
- **Motivation for thermal management on PCBs**
- **Thermal management concepts for heat dissipation on PCBs**
- **First results: Project “PCB substrate evaluation”**
- **Thermal indicator**
- **Conclusion**

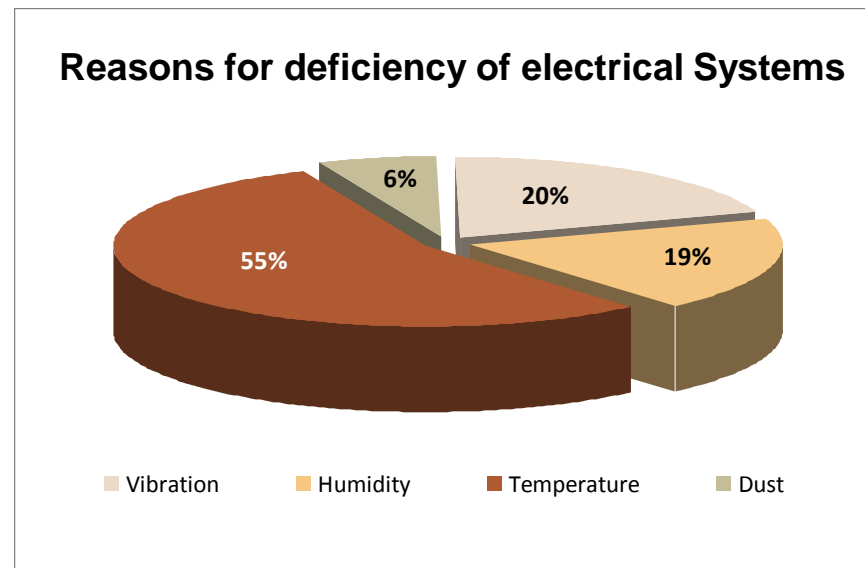


## AT&S at a Glance

- **Europe's largest supplier** of PWB's
- One of the world's **top 3** producer of **HDI PWB's**
- Production sites in Europe and Asia
- Supplier for **Automotive, Industrial** and **Mobile Devices**
- **110 Mio.** PWB's produced for Automotive Applications every year, **160 Mio.** PWB's for Industrial Applications and **11%** of the worldwide produced PWB's for **Mobile phones** are from AT&S
- **Worldwide** Sales, Service, Technology and Supplier-**Network**
- More than **6,000 employees** working in Austria, India, China and Korea

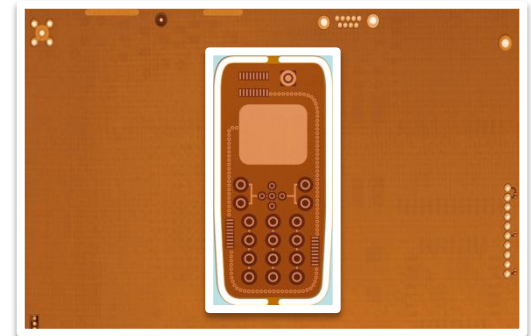
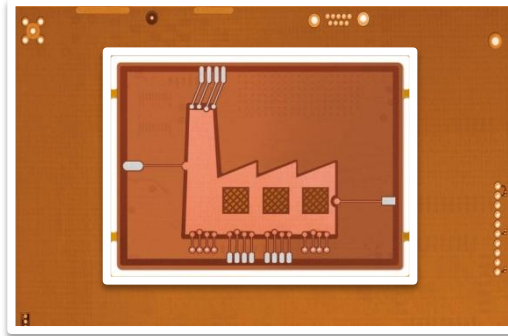
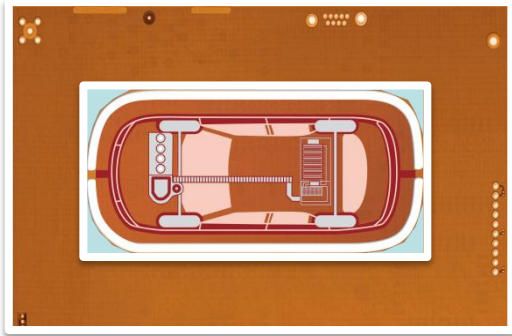


## ■ Motivation for thermal management on PCBs



Source: US Air Force Avionics Integrity Programm (AVIP)

# AT&S Business Units



**AUTOMOTIVE**

**INDUSTRIAL**

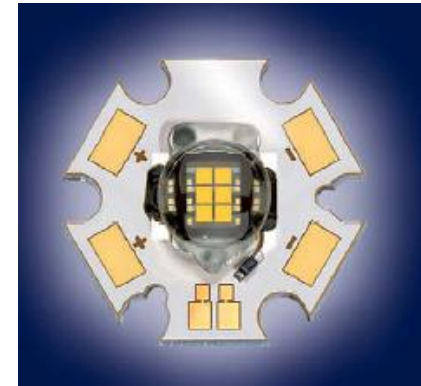
**MOBILE DEVICES**

## Applications: General

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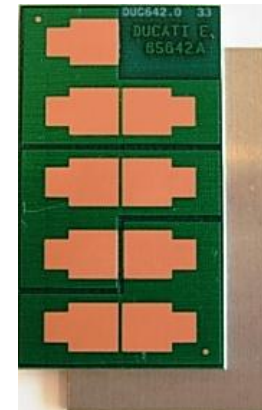


- LEDs



- Motor Drivers

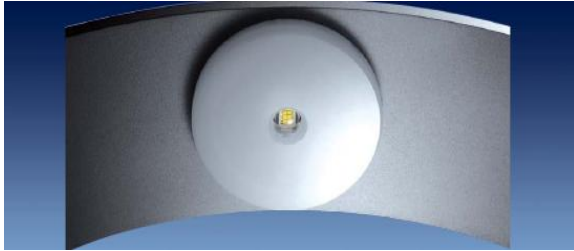
- Heat Sink



Source: Osram, Lumiled

## Applications: LED

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### ▪ General Lighting



### ▪ Automotive



### ▪ Others



Source: Osram, Lumiled, Tridonic/Optoelectronics

## Fundamentals

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### Incandescent lamp



[http://members.aon.at/uflink/kreative\\_methoden/gluehbirne.jpg](http://members.aon.at/uflink/kreative_methoden/gluehbirne.jpg)

$$T_{\text{tungsten filament}} > 2300^{\circ}\text{C}$$

$$\eta < 5\%$$

$$\dot{q} = \varepsilon \cdot \sigma \cdot T^4$$

$T_{\text{tungsten filament}}$  independent of ambience

### LED module



<http://www.led-tech.de/>  
[http://media.conrad.de/m/1000\\_1999/1700/1750/1759/175991\\_LB\\_00\\_FB.EPS.jpg/](http://media.conrad.de/m/1000_1999/1700/1750/1759/175991_LB_00_FB.EPS.jpg/)

$$T_{\text{Chip}} < 150^{\circ}\text{C}$$

$$15\% < \eta < 25\%$$

$$\dot{q} = \lambda \cdot \text{grad } T$$

$T_{\text{Chip}}$  is dependent on ambience

**>>> constructive action for heat removal  
is essential!!!**

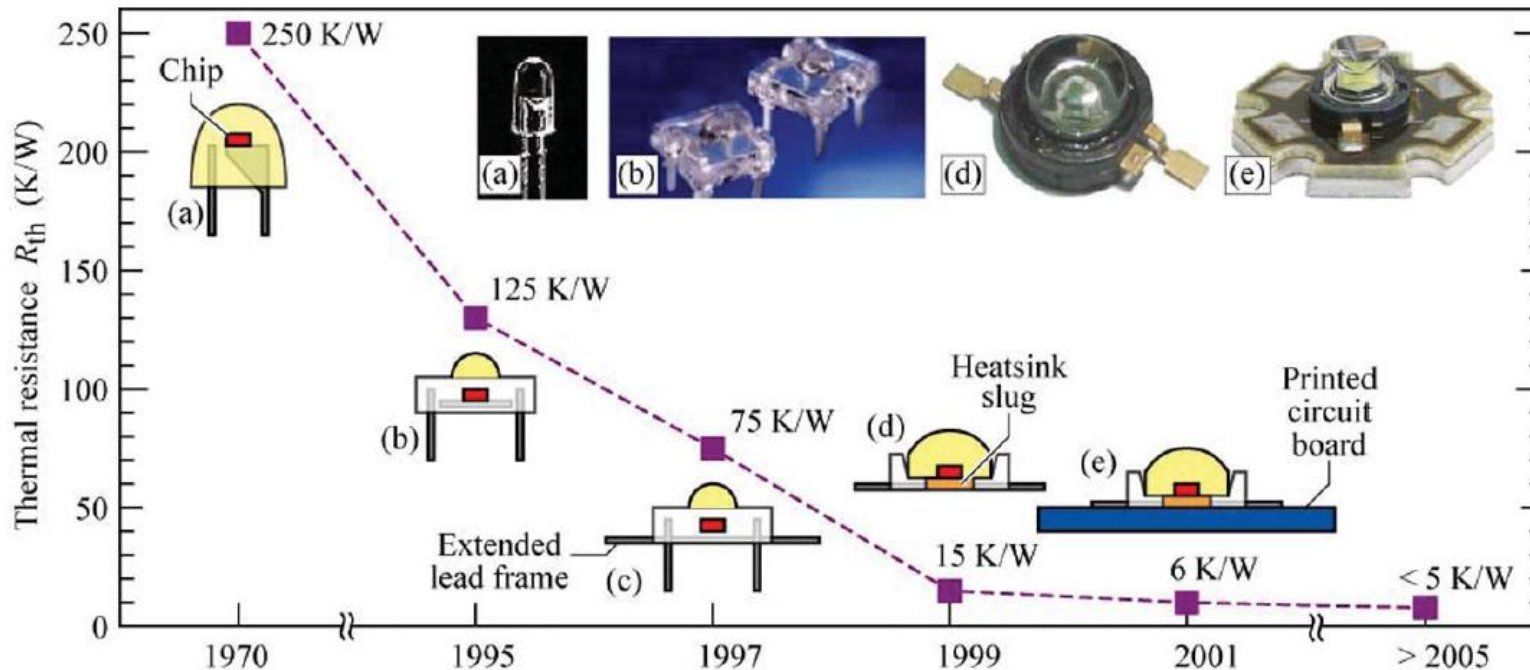


## LED-package evolution

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### Steady evolution of package enhancements to improve thermal resistance

THERMAL RESISTANCE OF LED PACKAGES

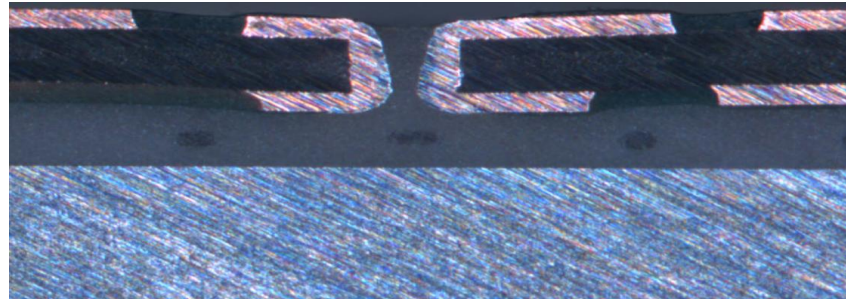


General lighting applications are always mounted in some form of thermal enhanced package to improve overall heat sinking efficiency.

## Content

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- **Thermal management concepts for heat dissipation on PCBs**



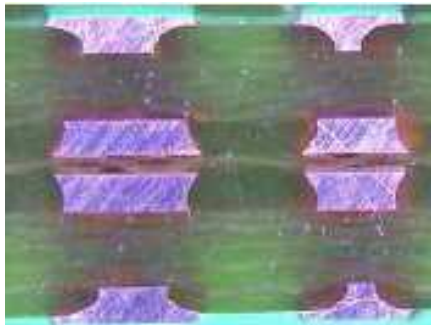
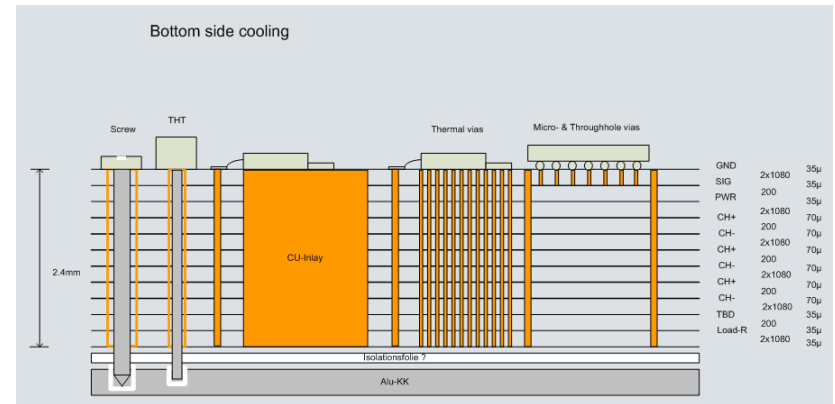
## Copper Inlays, thick Copper

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### ■ Copper Inlay:

Status: „In qualification“

Insertion of pure metal copper piece in a standard PCB-build up



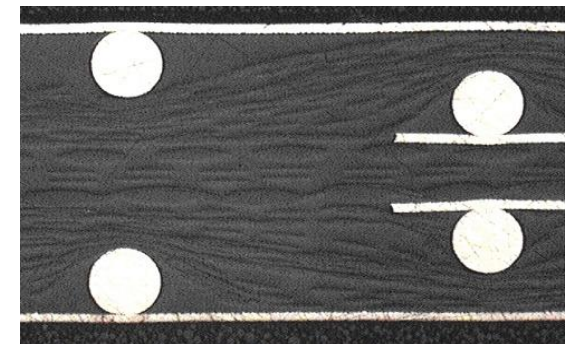
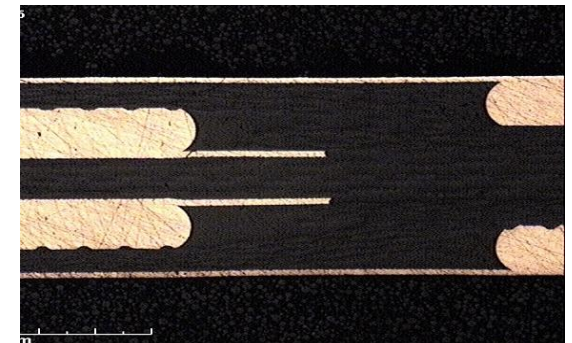
### ■ Thick copper:

- Realisation of 200 – 400 µm thick inner layer copper lines

- **Integration of Cu-wires and Cu-profiles** into PCBs for high current and thermal management issues
- Cooperation between Häusermann GmbH and AT&S AG since Sep.2009
- High current in extremely small spaces
  - Space can be saved
  - Weight can be saved
- Improved thermal management
- Integration in standard FR4 material => manufactured as standard PCB-production process
- Examined, approved technology



HÄUSERMANN

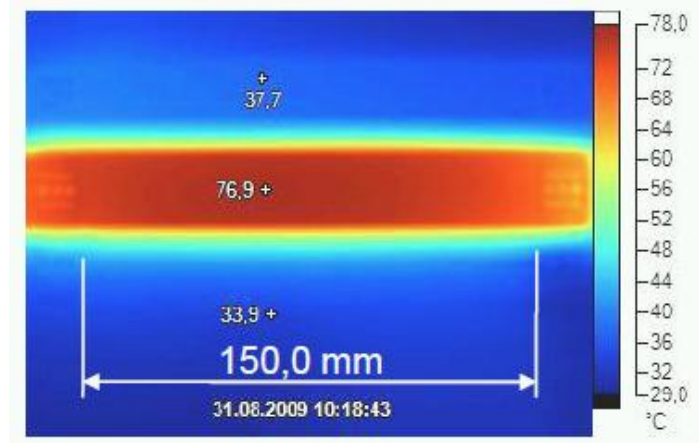
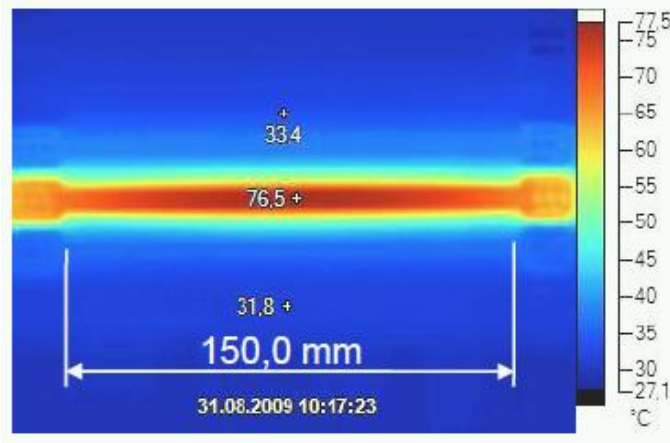
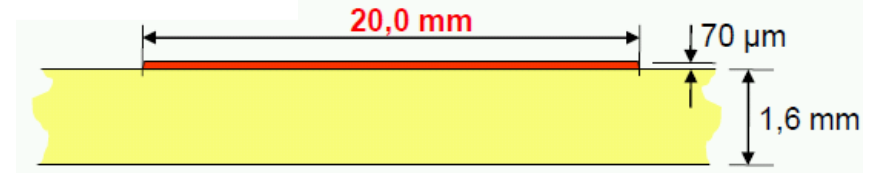
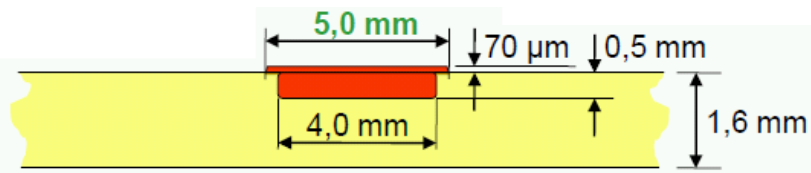


### High current on small areas

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Space saving factor: 4



Test current: 50 A; ambient temperature: 26°C;  $\Delta T$ : ~ 50K

## Improved thermal management

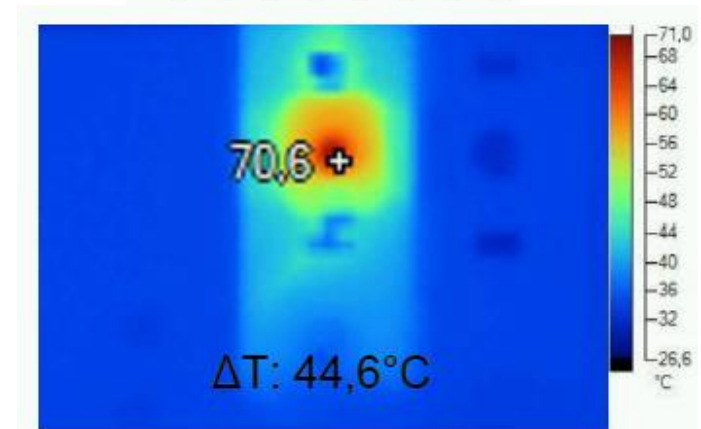
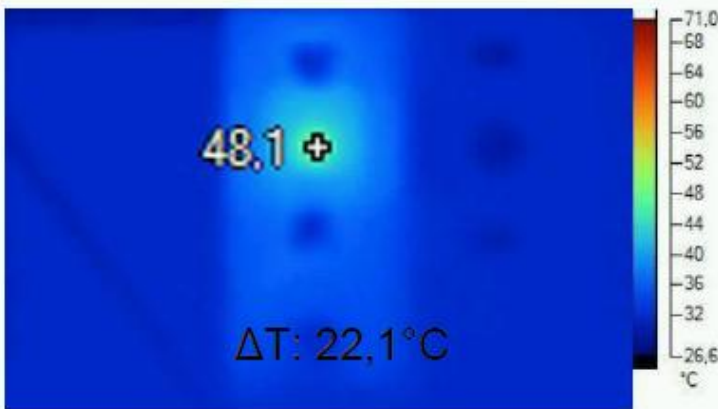
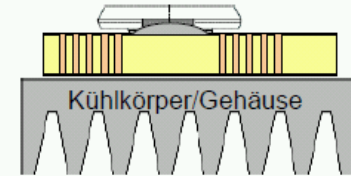
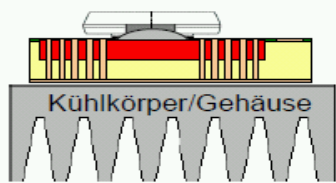
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- Reduction of PCB-heating due to increased copper cross sections
- Improved heat spreading

PCB with „HSMtec“

-16 K/W

Standard PCB technology



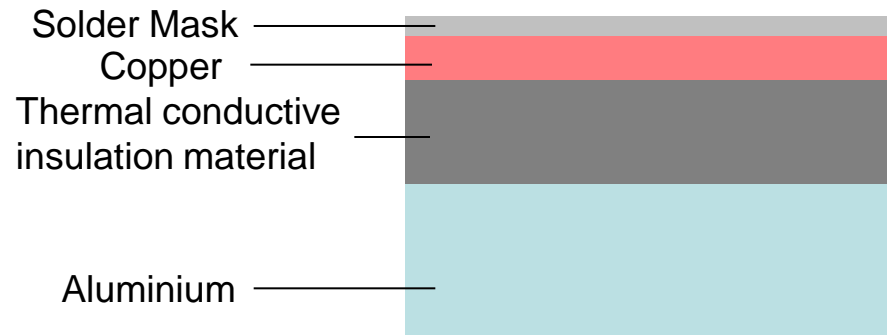
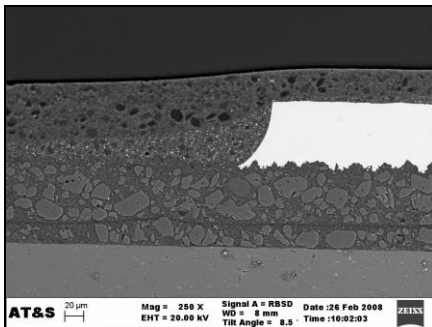
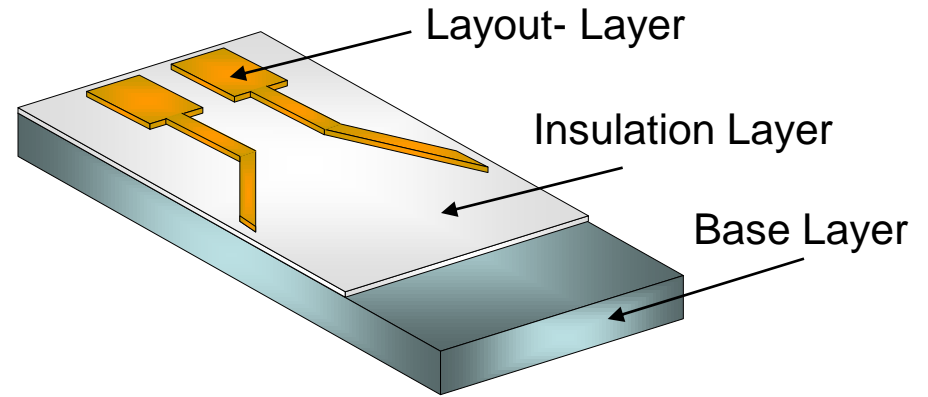
Power loss of the LED: 1.4 W; ambience temperature: 26°C

## IMS: Single layer

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### IMS @ AT&S

- Base Layer: Aluminum  
(1, 1.5, 2, 3 mm)
- Insulation Layer: Thermally conductive insulation material  
(0.5 – 8.0 W/mK)
- Layout Layer: Copper  
(35, 70, 105  $\mu$ m)



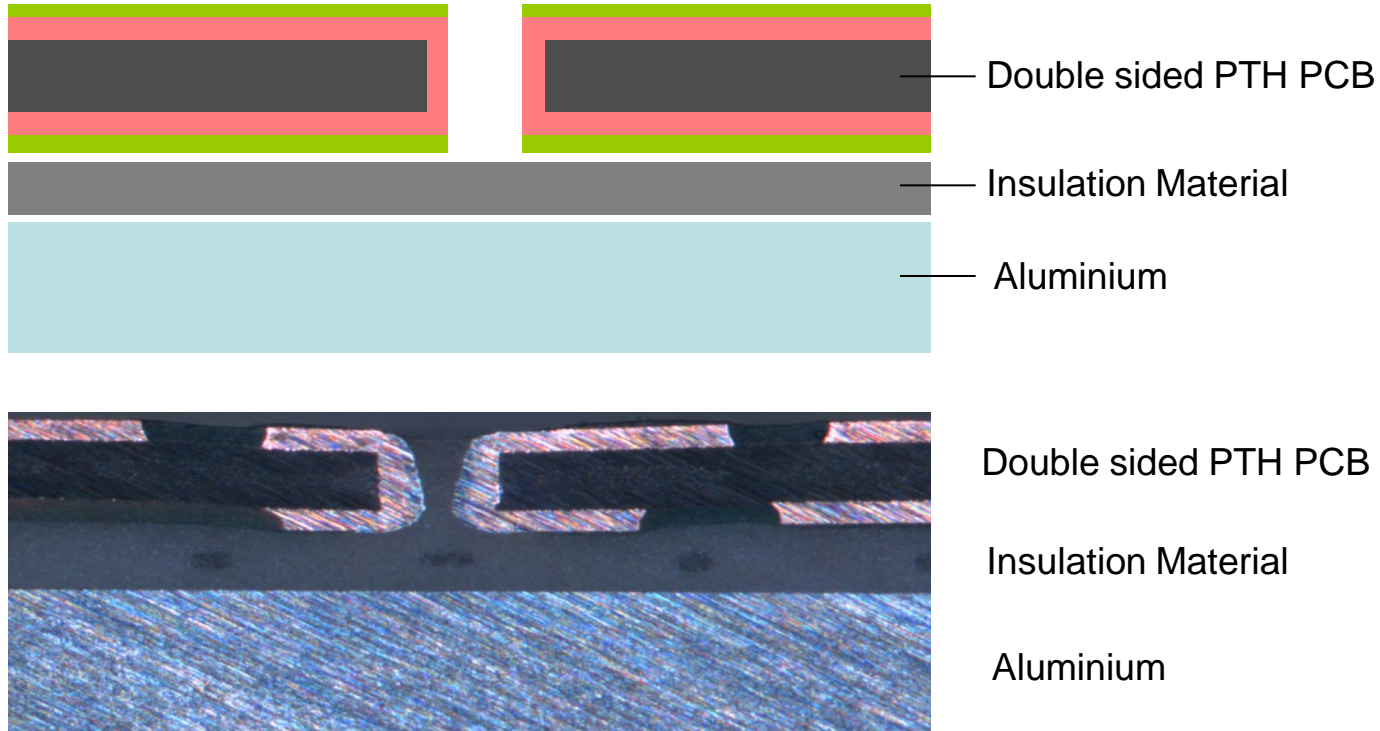
## IMS: Single sided / two layers

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### ▪ Single sided Aluminum / single sided two layout layers

Double sided plated through hole FR4 pressed on Aluminum

Insulated material: FR4-prepreg or thermal conductive prepregs



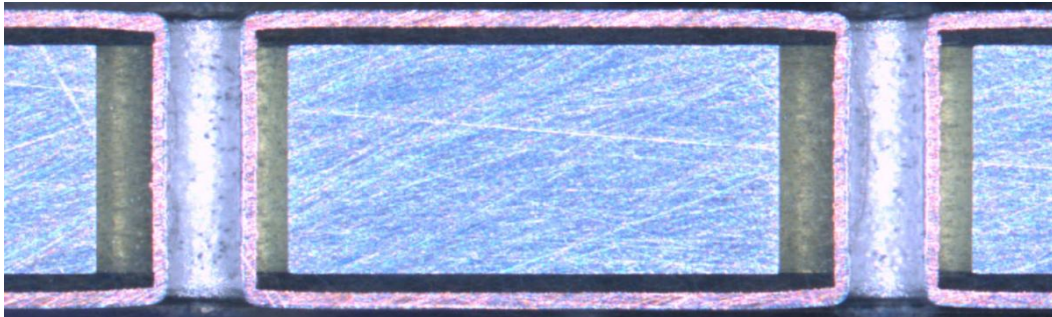
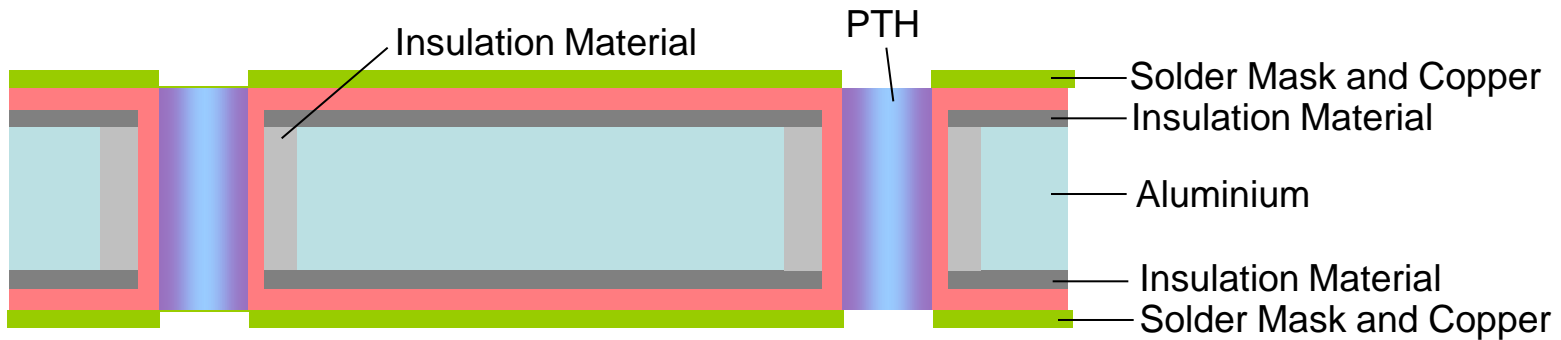


## IMS: Single layer / double sided

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### ■ Construction – single layer Aluminum / double sided two layout layers

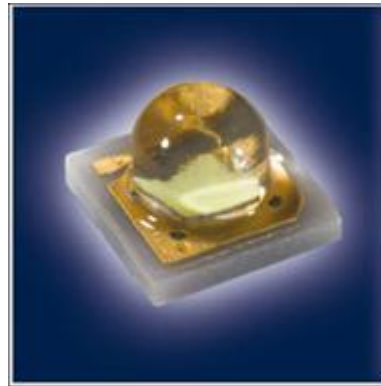
- Drilling of through holes into Aluminum core
- Aluminum Core laminated with insulation material (plugging of holes) and copper foils
- Drilling through plugged holes (smaller diameter) and plating of holes to connect the two copper layers



## Content

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- **First results: Project “PCB substrate evaluation”**



## Cooperation: Thermal Substrate Evaluation

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### ▪ Aim

- PCB material, design and built-up comparison concerning thermal and mechanical performance used as substrates for different high power LEDs

### ▪ Cooperation Partners

- AT&S
- OSRAM OS
- Institute of Sensor and Actuator Systems (TU Vienna)

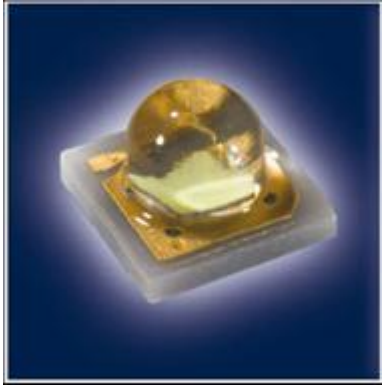


### ▪ Status

- Ongoing

## LEDs (OSRAM OS)

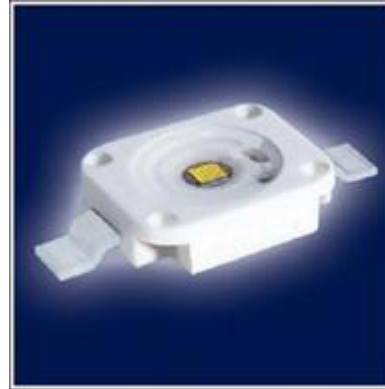
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**OSLON SSL**  
1x1 mm<sup>2</sup> chip  
Ceramic substrate  
Footprint: 3x3 mm

Applications:

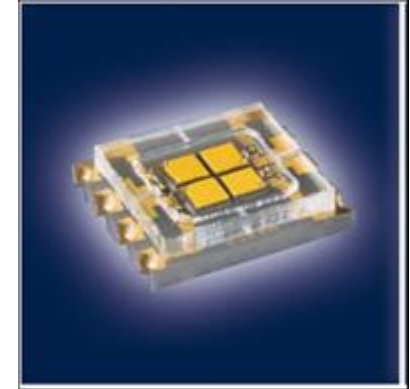
- Retail/shop lighting
- Spots and downlight
- Task and indirect lighting
- Retrofit



**Golden Dragon**  
1x1 mm<sup>2</sup> chip  
Pre moulded leadframe  
Footprint: ~ 3x14,5 mm

Applications:

- Illumination & signs (e.g. traffic lights)
- Automotive (e.g. daytime running, interior light)
- Communication: mobile phones, digital cameras (e.g. strobe lighting)



**OSTAR SMT**  
4x1 mm<sup>2</sup> chip  
Ceramic substrate  
Footprint: ~ 5x6 mm

Applications:

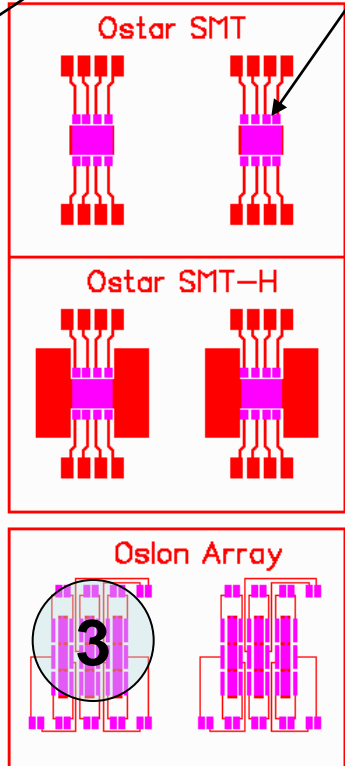
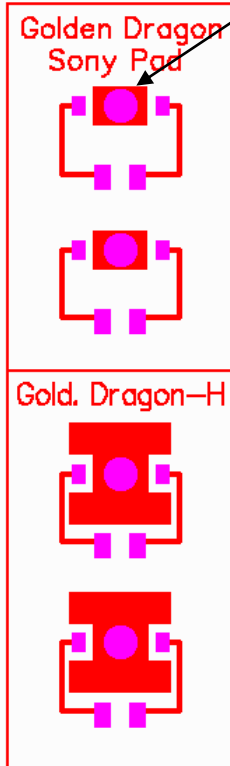
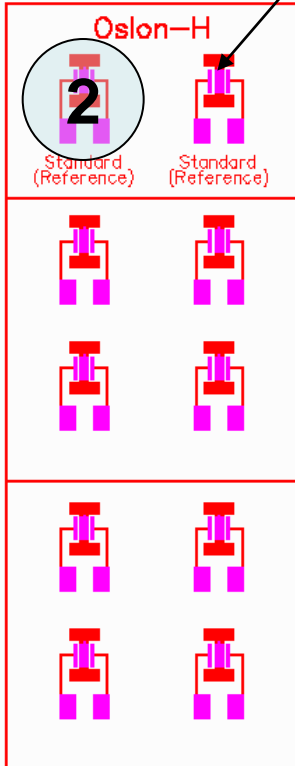
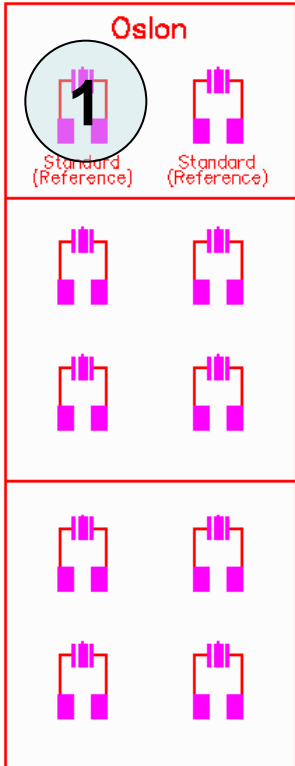
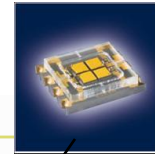
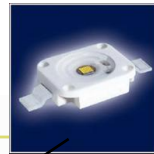
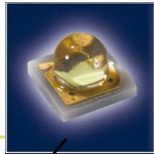
- Architectural lighting,
- General and mood lighting
- Projection
- High power flashlights

# Board-Design

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## Substrate

### Data IMS



**AT&S**

**OSRAM**  
Opto Semiconductors

## Substrates

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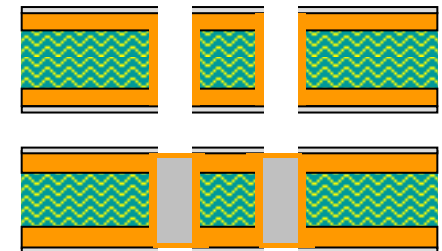
- **IMS Substrates (10 variations):**

- 0.5 – 8.0 W/mK
- Cu and Aluminum thickness



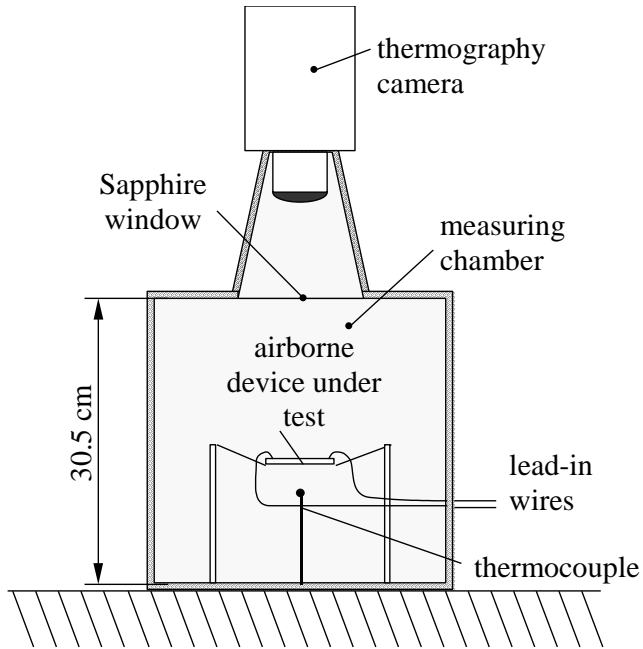
- **FR4- Boards with Plated Through Holes (7 variations)**

- Via Diameter (300 µm and 500 µm)
- FR4 thickness
- Holes plugged and unplugged

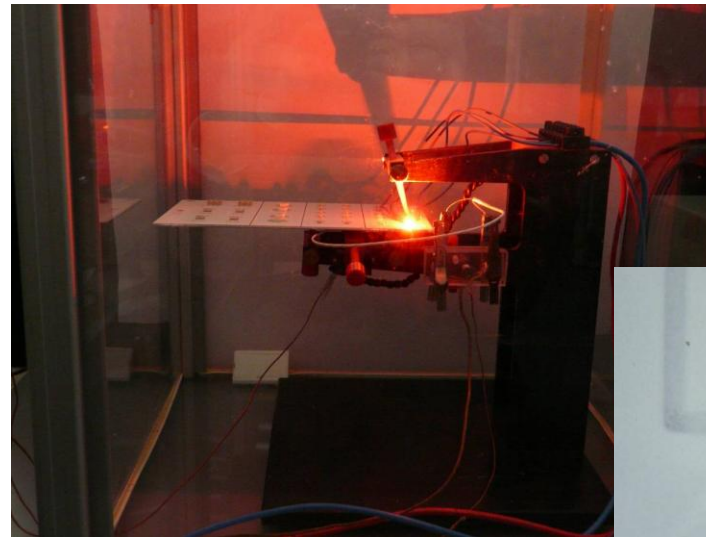


## Thermal Characterisation of Power LED assemblies

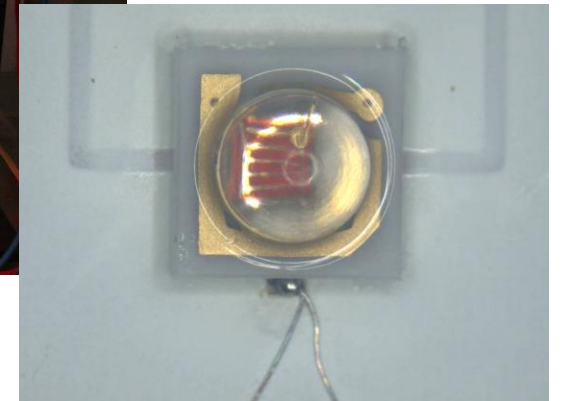
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Thermographic measurement



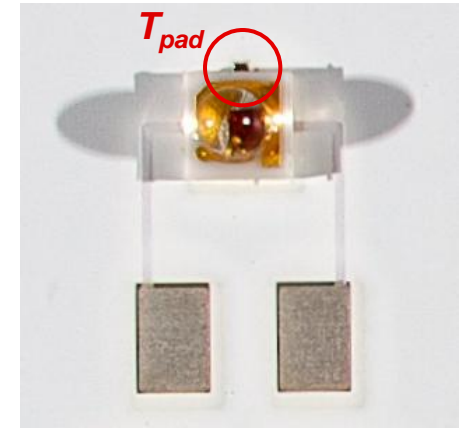
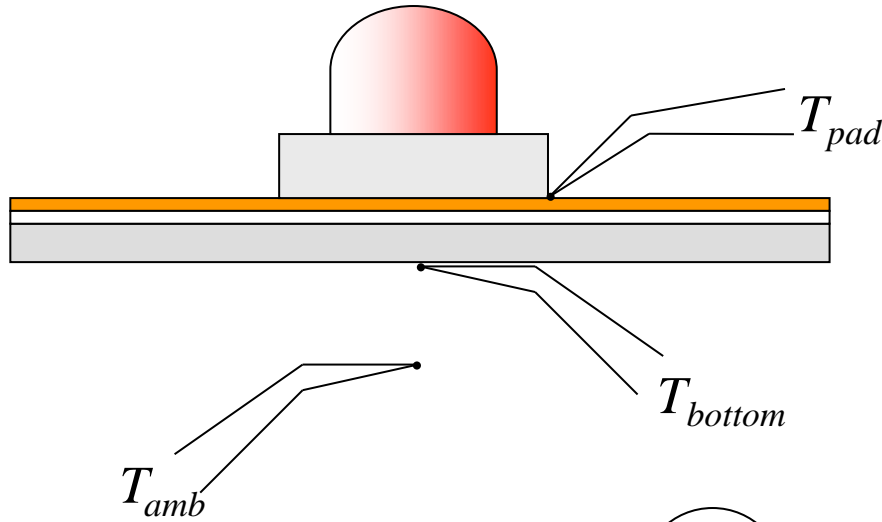
Experimental Setup



Thermocouple on OSLO chip

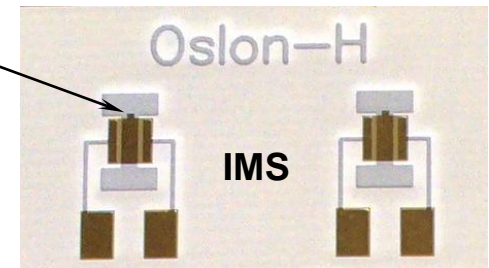
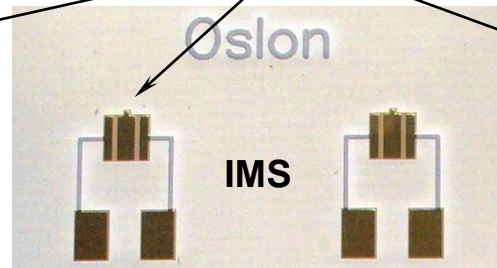
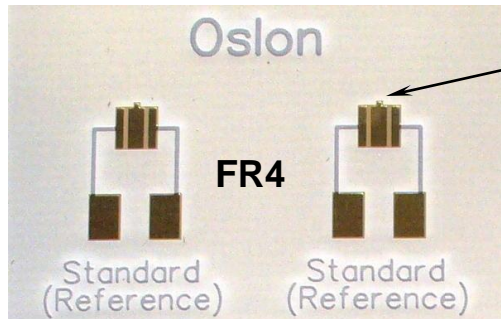
## Steady-state thermocouple measurement

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soldered OSLO chip

Measuring location of  $T_{pad}$





Steady-state thermocouple measurement

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**Substrate: FR4 (reference)**

LED Position	$I_{LED}$ mA	$U_{LED}$ V	$P_{EL}$ mW	$T_{pad}$ °C	$T_{bottom}$ °C	$T_{amb}$ °C	$R_{th,pad-bot}$ K/W	$R_{th,pad-amb}$ K/W
Oslon 1	140	2,013	282	85,3	55,8	21	130,8	285,0

**Substrate: IMS1 (0,5 W/mK)**

LED Position	$I_{LED}$ mA	$U_{LED}$ V	$P_{EL}$ mW	$T_{pad}$ °C	$T_{bottom}$ °C	$T_{amb}$ °C	$R_{th,pad-bot}$ K/W	$R_{th,pad-amb}$ K/W
Oslon 1	140	2,089	292	34,1	29,3	27	20,5	30,3
Oslon-H 2	140	2,096	293	29,9	27,5	26	10,2	16,6

**Substrate: IMS3: (4 W/mK)**

LED Position	$I_{LED}$ mA	$U_{LED}$ V	$P_{EL}$ mW	$T_{pad}$ °C	$T_{bottom}$ °C	$T_{amb}$ °C	$R_{th,pad-bot}$ K/W	$R_{th,pad-amb}$ K/W
Oslon 1	140	2,106	295	29,0	26,0	24	12,7	21,2
Oslon-H 2	140	2,125	298	27,9	26,9	25	4,2	12,2

**Remarks:**

Operation condition: free air floating in JEDEC chamber  
 Assumed power loss factor  $(\eta-1) = 80\%$   
 = Assumed photonic efficiency:  $\eta = 20\%$

$$R_{th,pad-bot} = \frac{T_{pad} - T_{bottom}}{P_{EL} \cdot (1 - \eta)}$$

$$R_{th,pad-amb} = \frac{T_{pad} - T_{amb}}{P_{EL} \cdot (1 - \eta)}$$

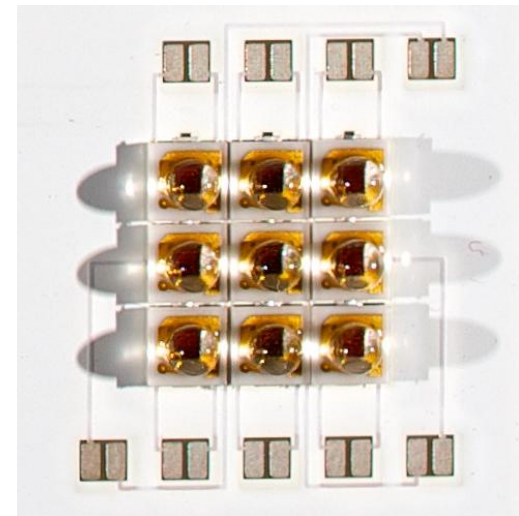
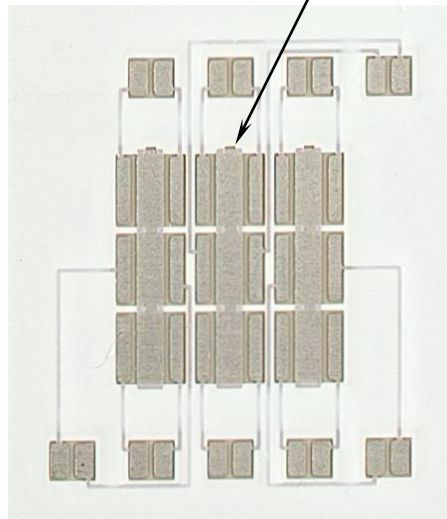
Steady-state thermocouple measurement

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**Substrate: IMS3: (4 W/mK): OSOLON 3x3 array**

LED Position	$I_{LED}$ mA	$U_{LED}$ V	$P_{EL}$ mW	$T_{pad}$ °C	$T_{bottom}$ °C	$T_{amb}$ °C	$R_{th,pad-bot}$ K/W	$R_{th,pad-amb}$ K/W
Osolon Array 7	140	19	2660	41,6	37,8	25	1,8	7,8

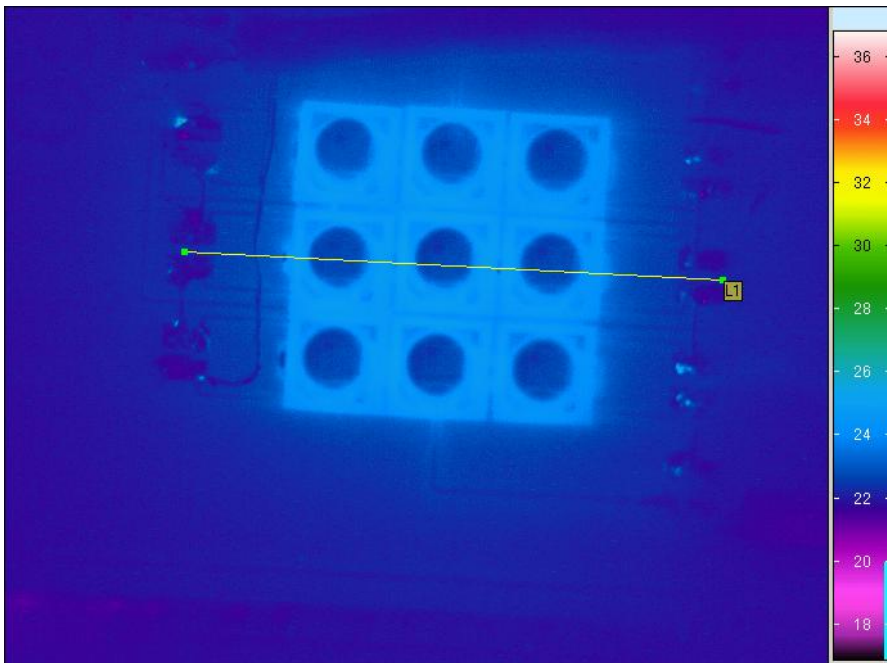
Remark: measuring position of  $T_{pad}$  upper middle LED!



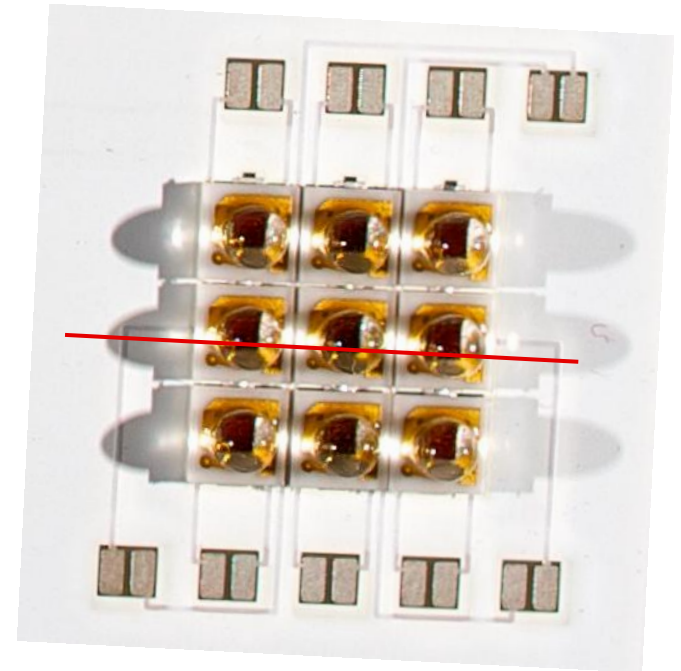
## Thermography measurement

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- Results: IMS 3 (4 W/mK): OSOLON 3x3 array



Surface temperature after 1.5 sec



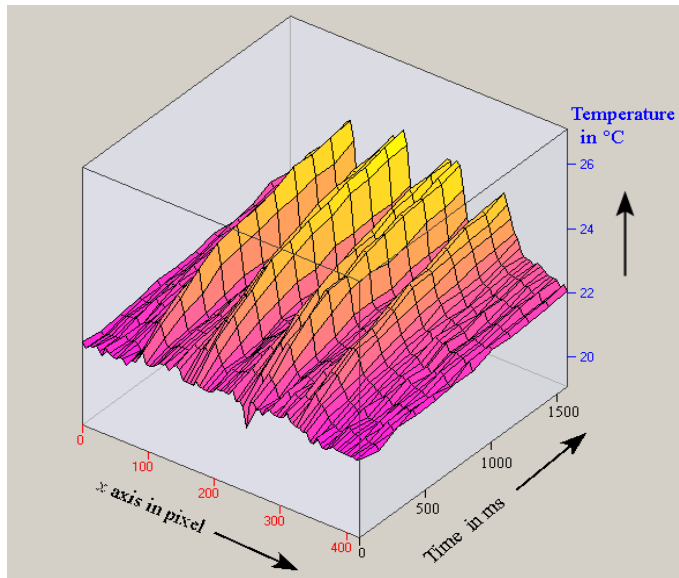
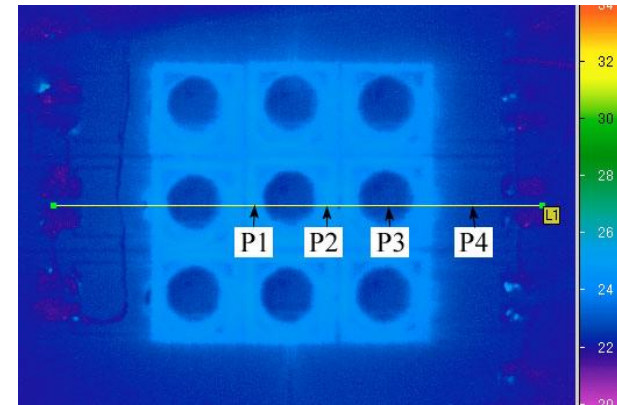
OSOLON 3x3 array

## Transient thermography

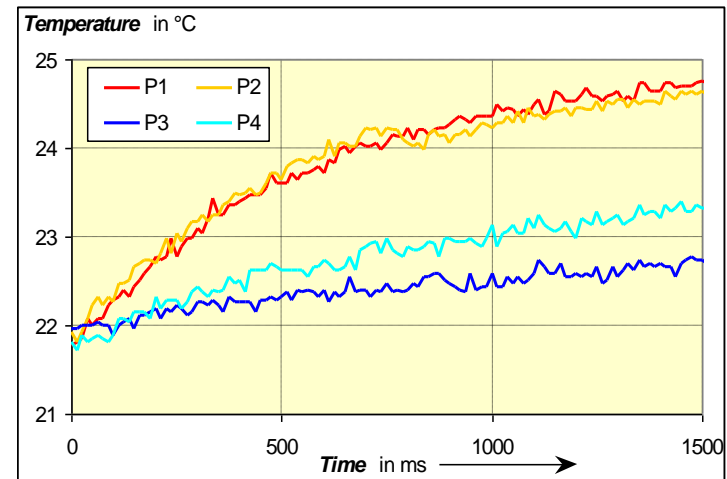
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### Results: IMS 3 (4 W/mK): OSLON 3x3 array

Surface temperature  $T_{\text{surface}}$   
after 1.5 sec



$T_{\text{Surface}}$ : First 1.5 sec of heating-up phase



T vs. t functions

- **Thermocouple steady state measurements of the different substrate variations**
- **Thermocouple steady state measurements of most of the LEDs and positions**
- **Further transient thermography measurements**
- **Set-up of a simulation model and varification of the thermocouple measurements**
  
- **Publication of results:**  
**ESTC 2010; Berlin; 13.-16.September 2010**  
*“Impact of Printed Circuit Board Technology on Thermal Performance of High-Power LED Assembly – Experimental Results”*

## Content

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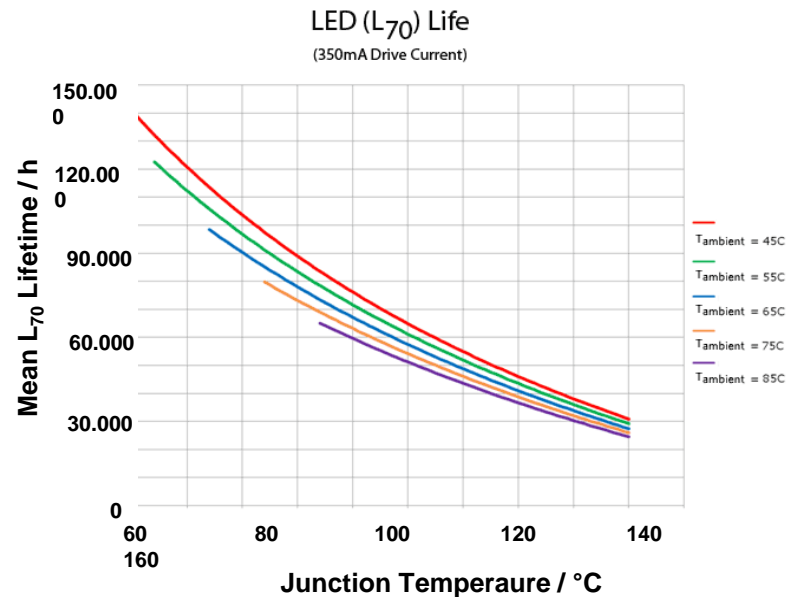
- **Thermal indicator**



## Thermal Indicator

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- **Problem:** Indication of Temperature impact of LEDs
  - **Solution:** Temperature-Time indicating substance
- >>> **Temperature sensitive color indicator** (Cooperation: OnPoint GmbH)



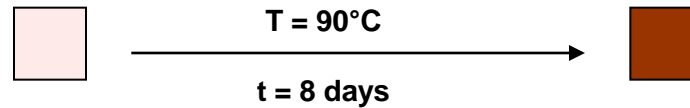
Lifetime of a LED-Chip vs. Junction Temperature

## Thermal Indicator

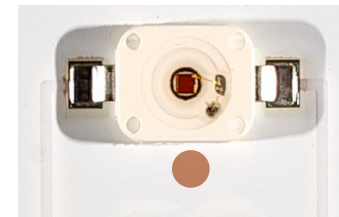
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### ▪ Application:

- Control of LED operation parameter
- Control of heat sink installation



Status of LED: no degradation



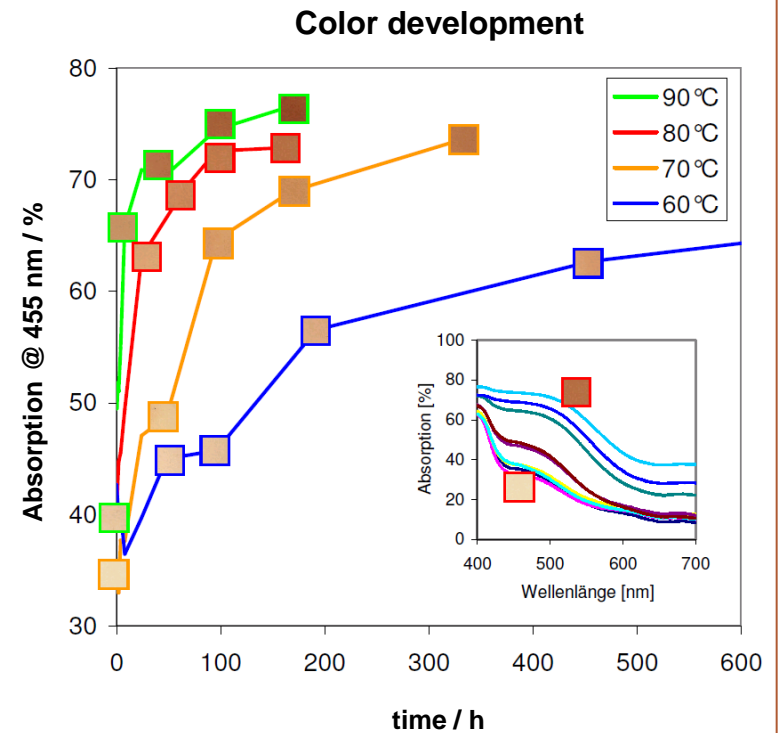
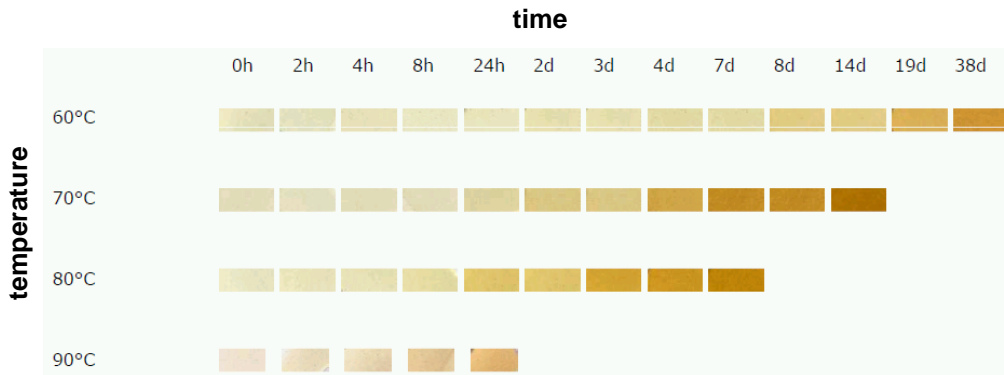
thermal degradation



## Thermal Indicator

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### Example: Temperature Indicator „brown“



## Thermal Indicator

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### ▪ Advantages

- Irreversible indication of cumulative T-impact
- Low amount of indicator substances needed
- Good adhesion to different PCB surfaces
- Fast check with color legend
- Objective check with intensity measurement



### ▪ Specifications

- Application of indicator: Dispensing
- Amount of indicator point:  $\sim 5 \cdot 10^{-6}$  litre
- Area of indicator point:  $< 1 \text{ mm}^2$



## Conclusion

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- **Thermal management is an increasing issue in electric systems**
- **There are many different thermal management concepts on PCBs**
- **Steady state thermocouple measurements on LED assembled FR4 and IMS boards**
- **Steady state and transient thermography measurements**
- **Usage of temperature sensitive color indicators to indicate the temperature impact to LEDs**



Thank you  
for your attention !!!