Application of Lock-in Thermography for Defect Localisation at Opened and Fully Packaged Single- and Multi-chip Devices

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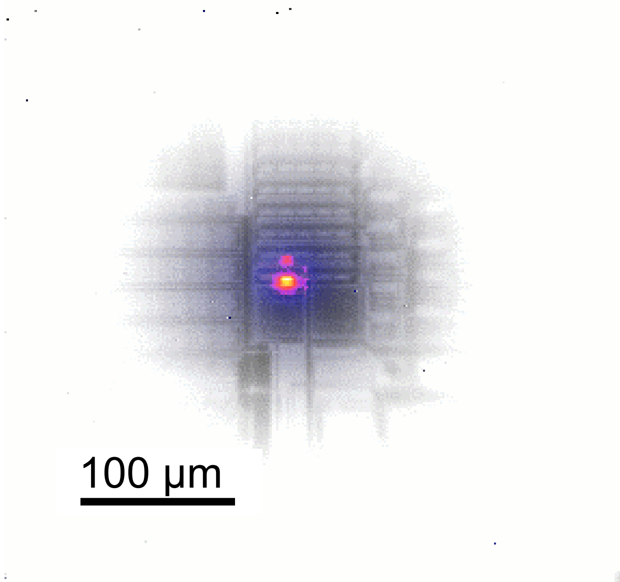
Overview

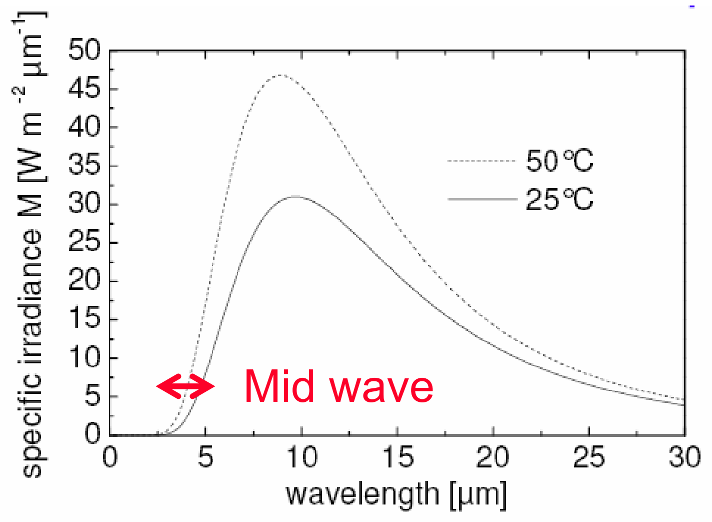


- The principle of Lock- in Thermography
- Defect localisation at open devices
- High resolution imaging
- Defect localisation at fully packaged devices
- Conclusion / Discussion

Infrared imaging

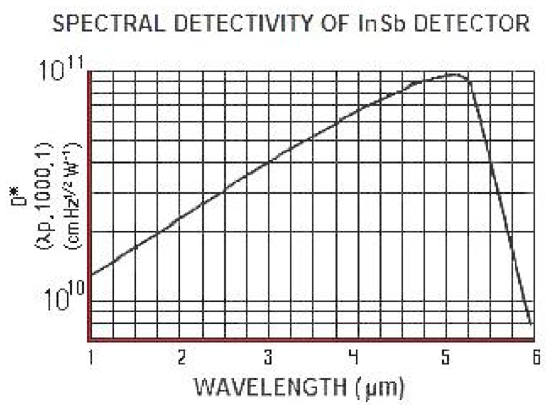
Detector wavelengths ranges
1-2 µm (short wave)
3 -5 µm (mid wave),
8-10 µm (long wave),

Optimal wavelength range for IR imaging near room temperture: Mid Wave



Spectral distribution of a black body

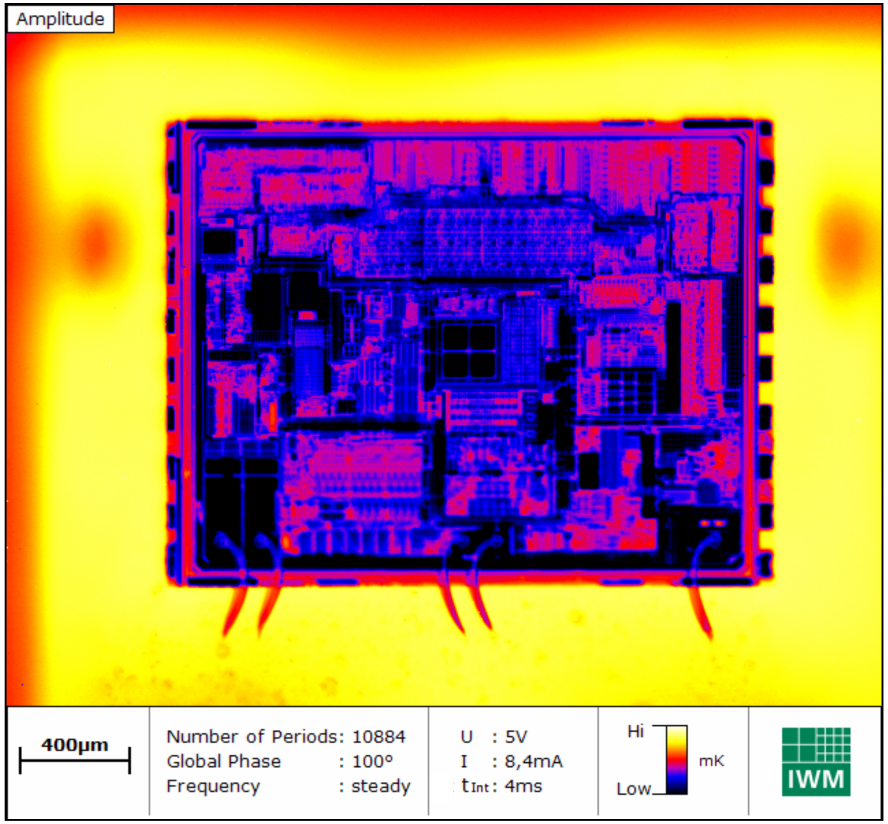
Detector types for MW:
focal plane arrays made from:
- cadmium mercury telluride (CMT)
- platinum silicide (PtSi)
- Indium antimonide (InSb)

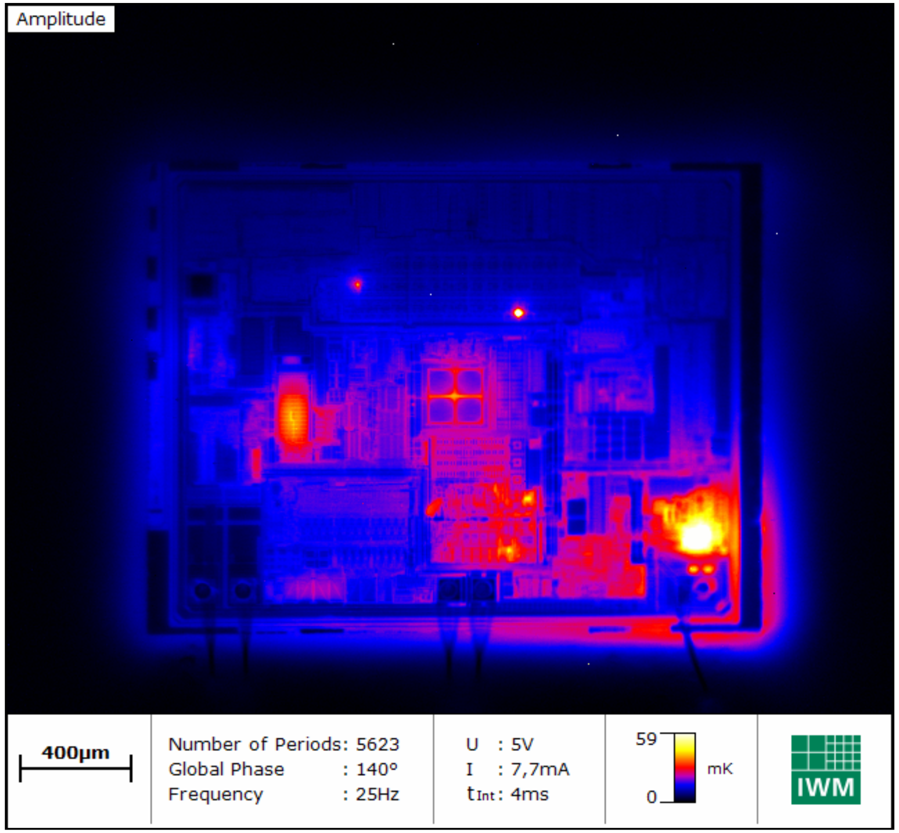


Spectral sensitivity

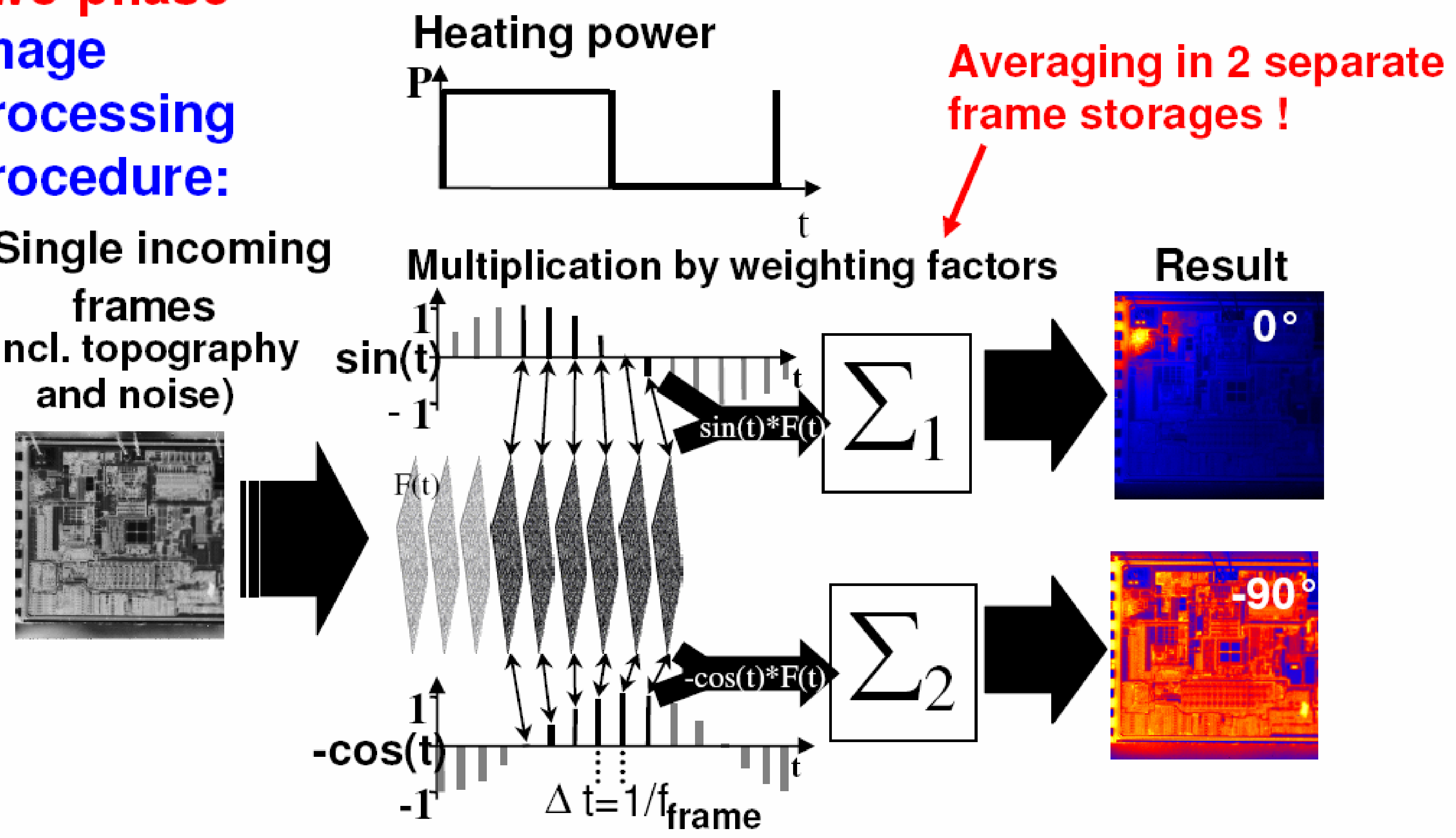
The principle of Lock-in Thermography (LIT)

What is the main difference between steady-state and Lock-in Thermography?





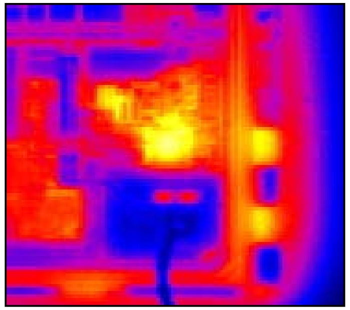
Two-phase image processing procedure:



- both resulting signals are influenced by emissivity → base for calculating Amplitude and Phase

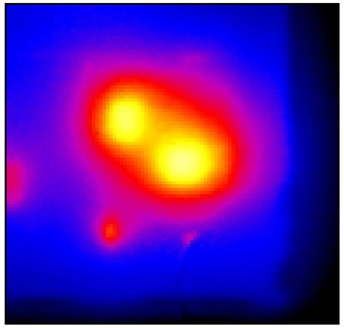
Amplitude:

$$A = \sqrt{\left(S^{0^\circ}\right)^2 + \left(S^{-90^\circ}\right)^2}$$



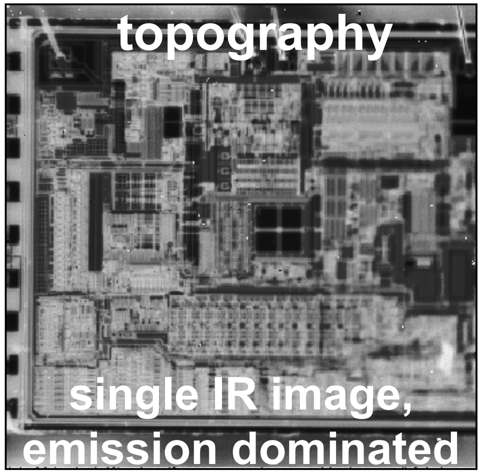
Phase:

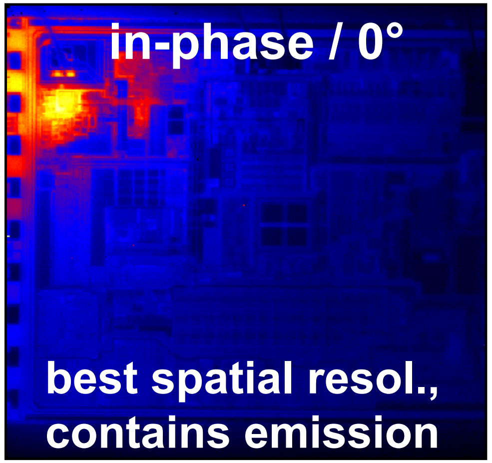
$$\Phi = \arctan\left(\frac{-S^{-90^\circ}}{S^{0^\circ}}\right)$$

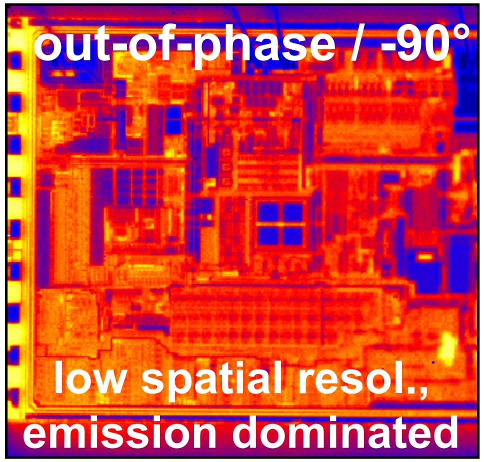


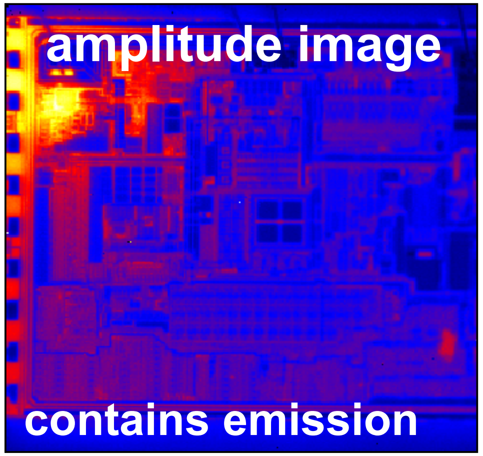
Advantages phase:

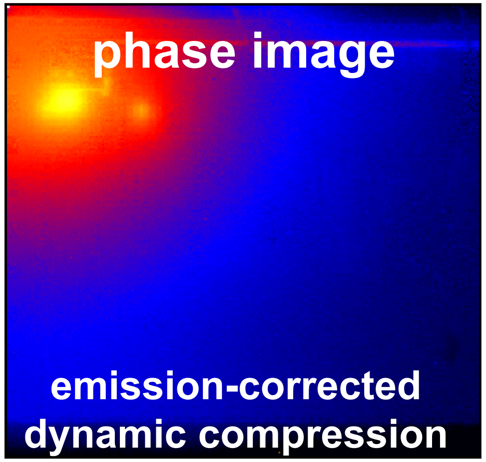
- no emissivity contrast
- “dynamic compression” in the phase image allows detection of weak hot spots even in the closer area to strong hot spots
- determining the phase shift allows a defect depth localization

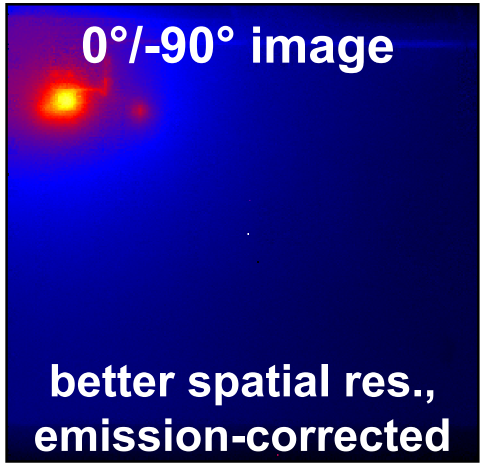

topography
single IR image,
emission dominated


in-phase / 0°
best spatial resol.,
contains emission


out-of-phase / -90°
low spatial resol.,
emission dominated


amplitude image
contains emission


phase image
emission-corrected
dynamic compression

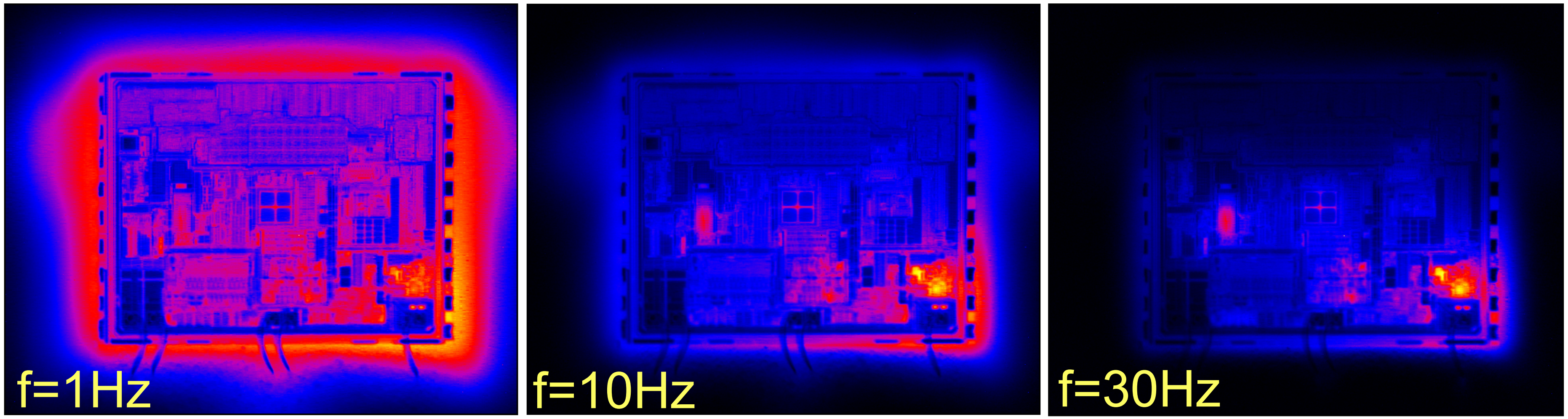

0°/-90° image
better spatial res.,
emission-corrected

Important factor of influence: the lock-in frequency $f_{Lock\text{-}In}$

• taking into account calculating the **thermal diffussion length**:

$$\Lambda \sim \frac{1}{\sqrt{f_{Lock-In}}}$$

→ Spatial resolution increases the higher the lock-in frequency is



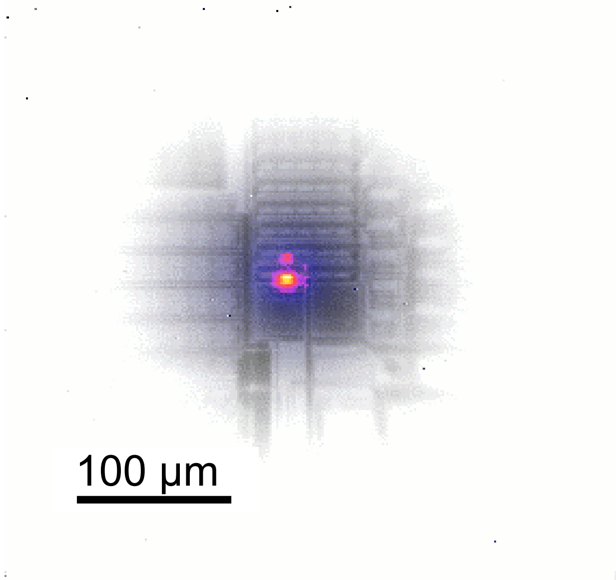
LiT- system used for measurements:

- „Thermosensorik“ InSb 640XL
- InSb – detector (spectral range: 1.5µm – 5 µm)
- 640x512 pixel, 15µm pixel pitch

  → high spatial resolution

- sample excitation voltage: 0 – 50V
- framerate: 100Hz (fullframe) up to 380Hz (subframes)

Overview



- The principle of Lock- in Thermography
- **Defect localisation at open devices**
- High resolution imaging
- Defect localisation at fully packaged devices
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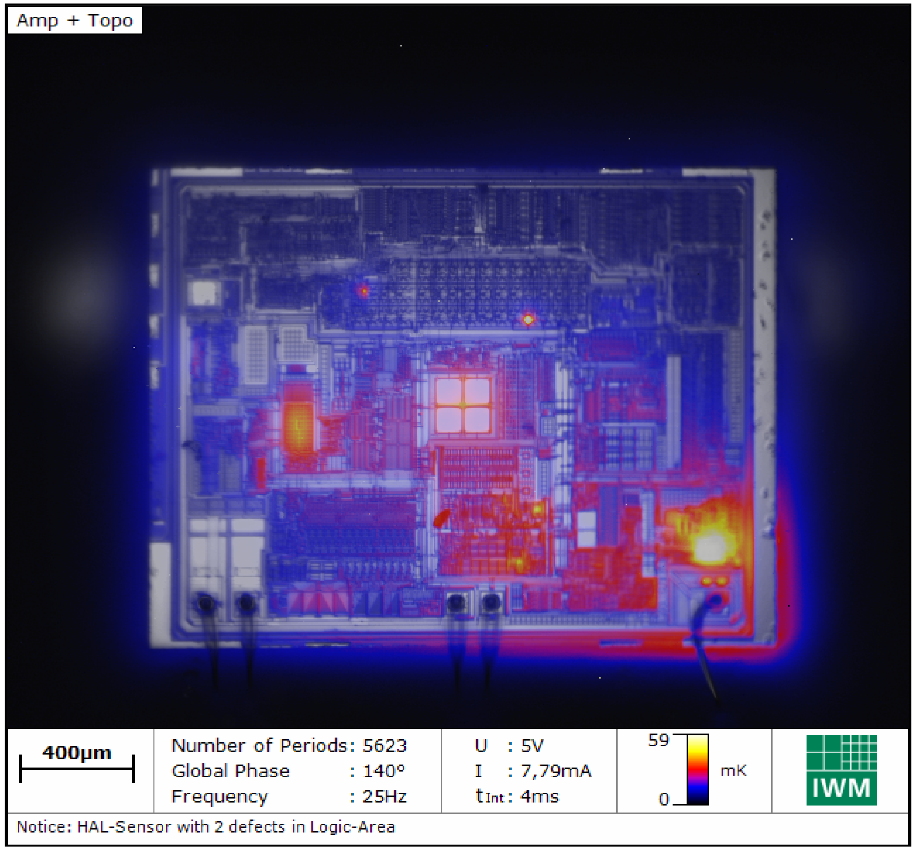
Standard: defect localisation at open devices

Localisation of thermal active defects:

- line shorts
- oxide breakdowns
- transistor / diode defects
- latch-ups, ESD defects

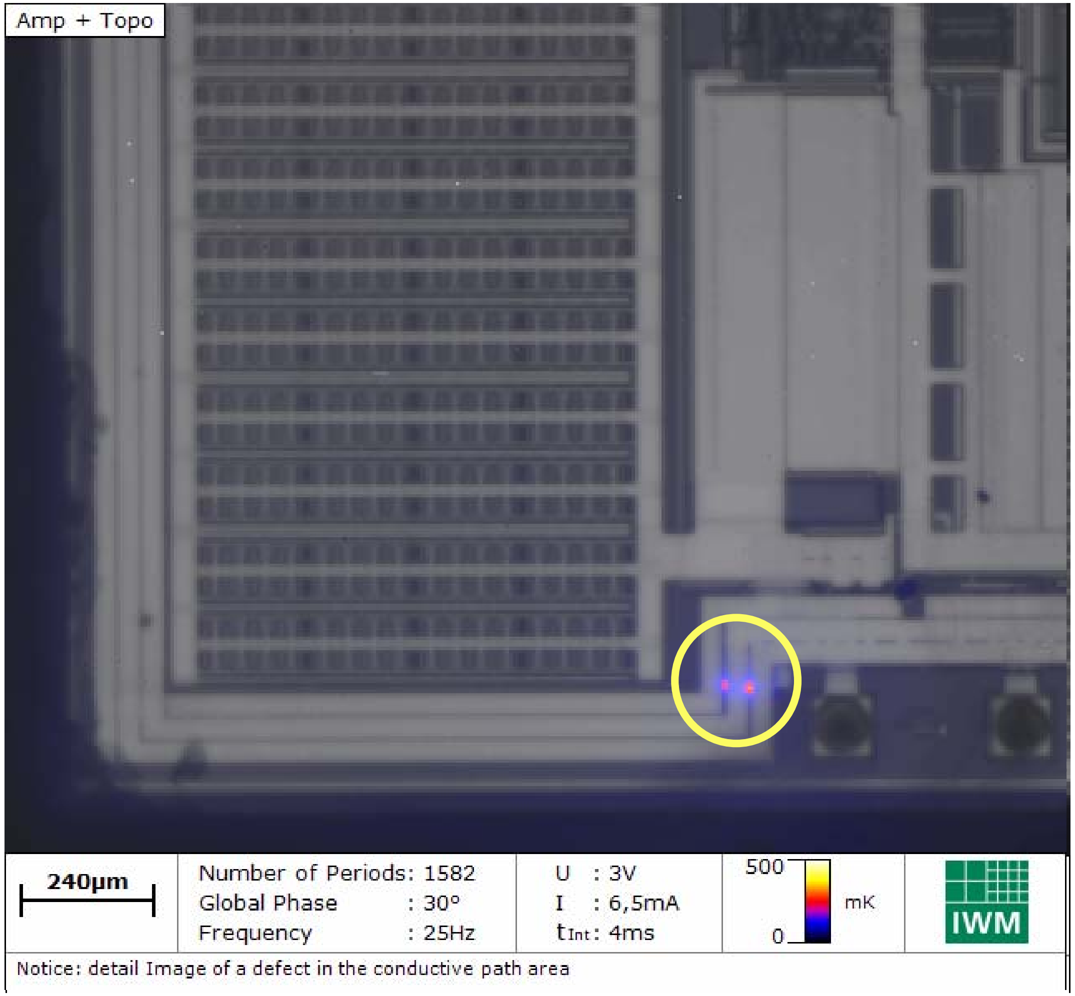
- IC is opened for optical access via removing the mould compound using e.g. chemical etching



Challenge:

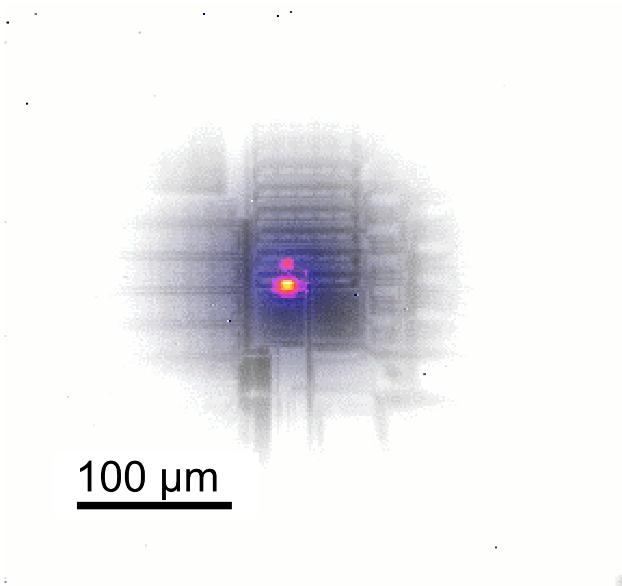
- root causes of defects can be influenced → e.g. metal splinter can be removed by chemical etching

Example I: failed device with short path



- temperature-resolution: **<100 µK**
- power dissipation detection limit : **several µW**
- **sensitivity about 3 orders better than for steady state mode!**
- lateral resolution: about **5 µm**

Overview



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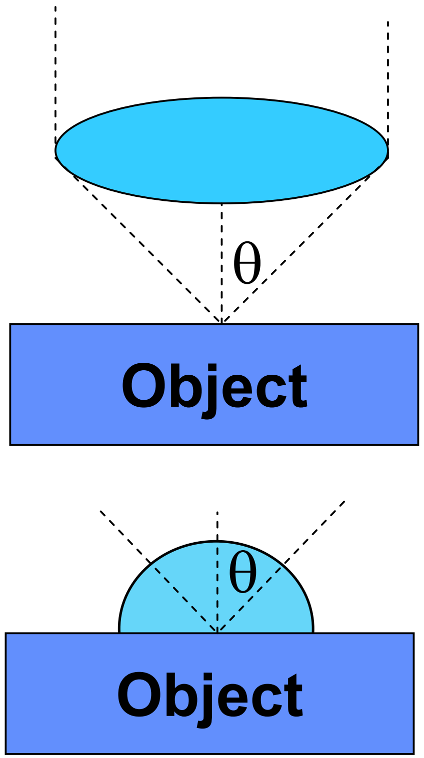
High resolution IR imaging

- **Aim:** Improving the optical resolution for a more accurate localisation of defects
- **Problem:** wavelength used: 5µm, diffraction limits the resolution
- **Solution:** Increasing **n** by using different materials above object



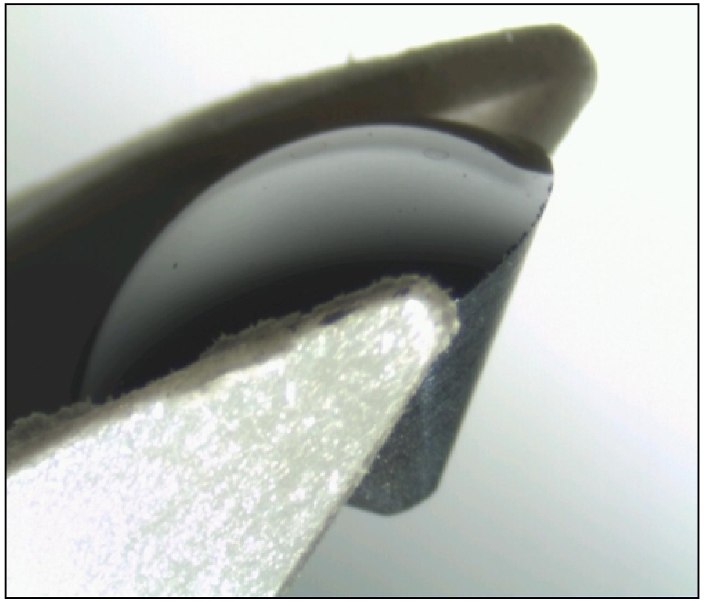
$$\Delta x = \frac{0.5\,\lambda}{NA}$$

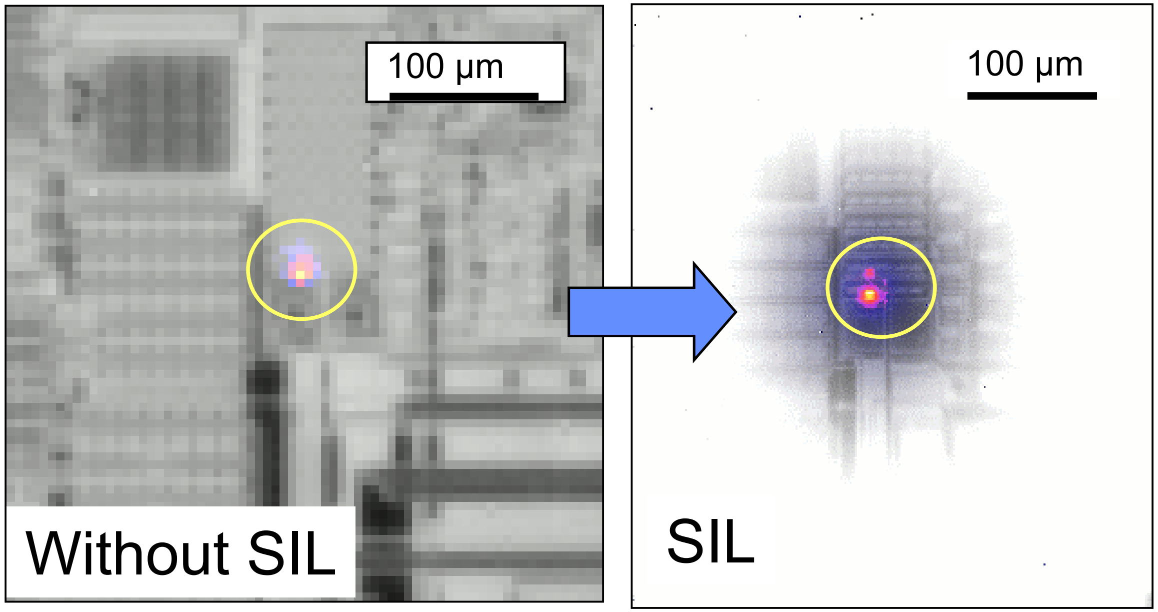
$$NA = \mathbf{n} \cdot \sin\theta$$

NA…Numeric Aperture
n…index of refraction

Material	Index of refraction **n**
Quartz	1.544
Diamond	2.417
Silicon (IR)	**3.43**
Germanium	**4.02**

Results using hemispheric SIL made of Silicon

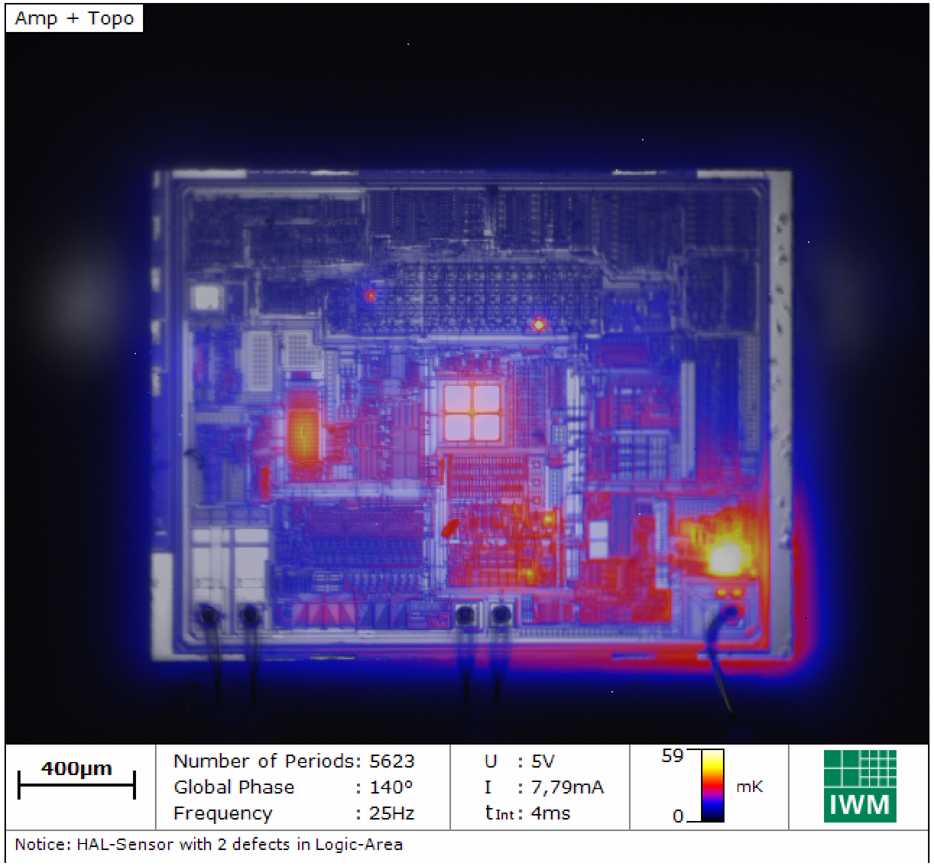


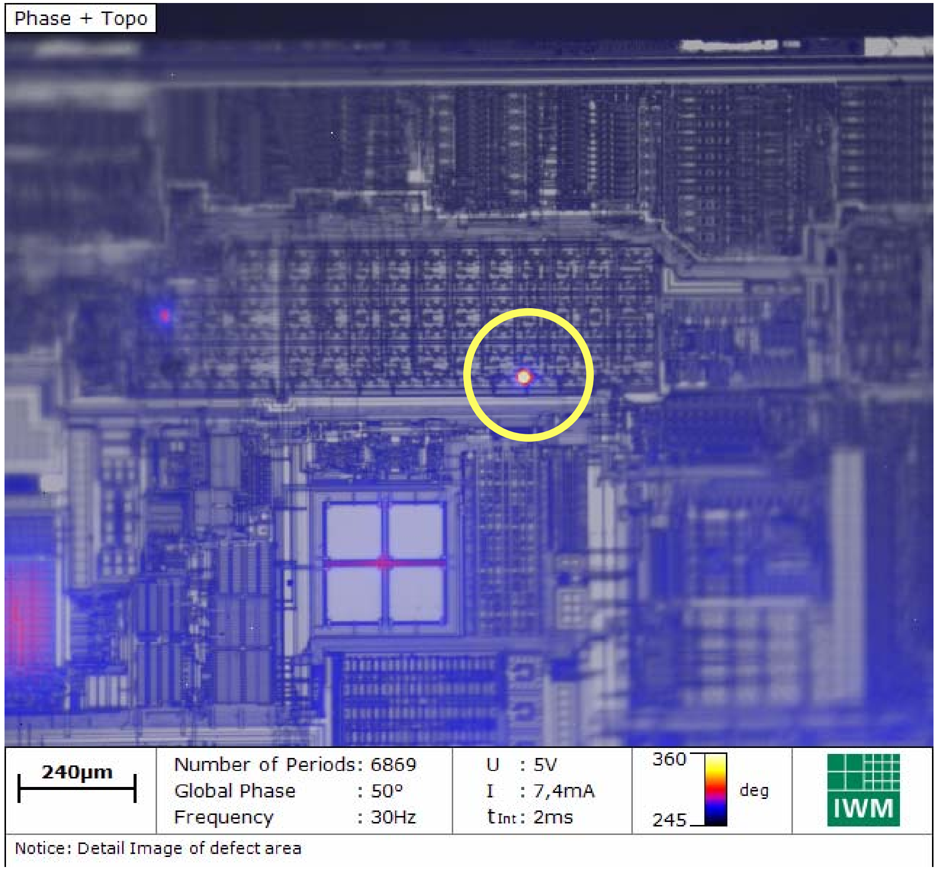


Left: Silicon - SIL in a tweezers: Dimension is around 3mm

Right: SIL in application detecting a heat spot with high spatial resolution

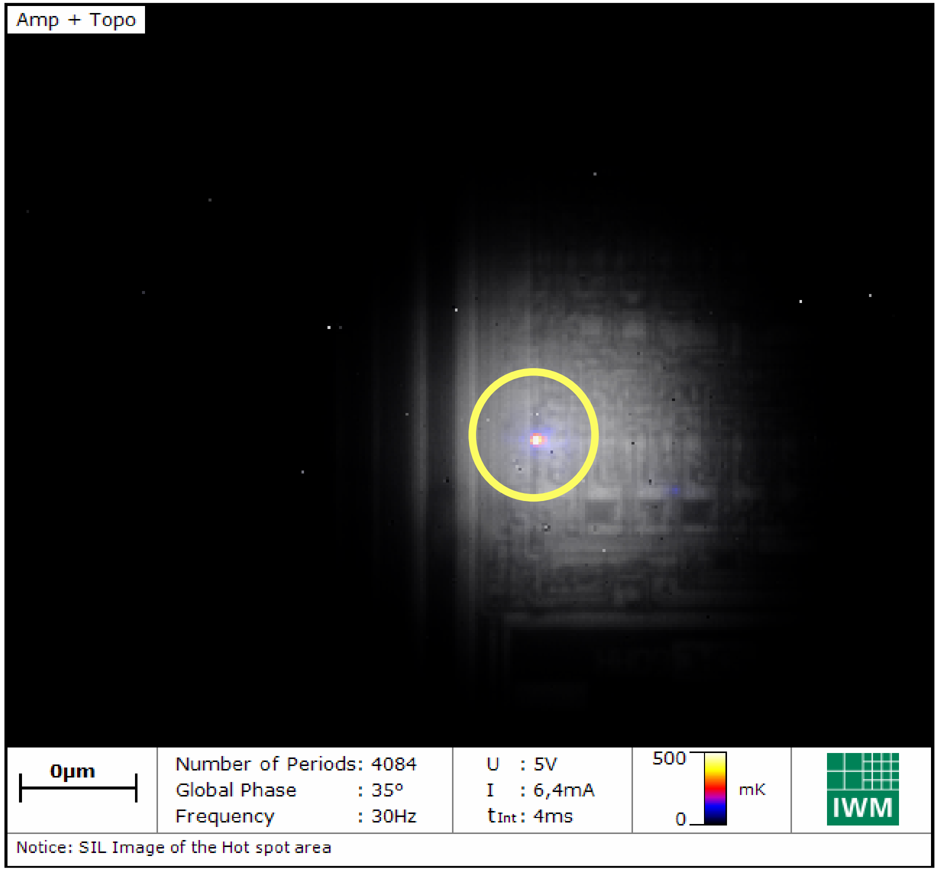
Example II: Lock-in thermography for defect localisation with following cross-section

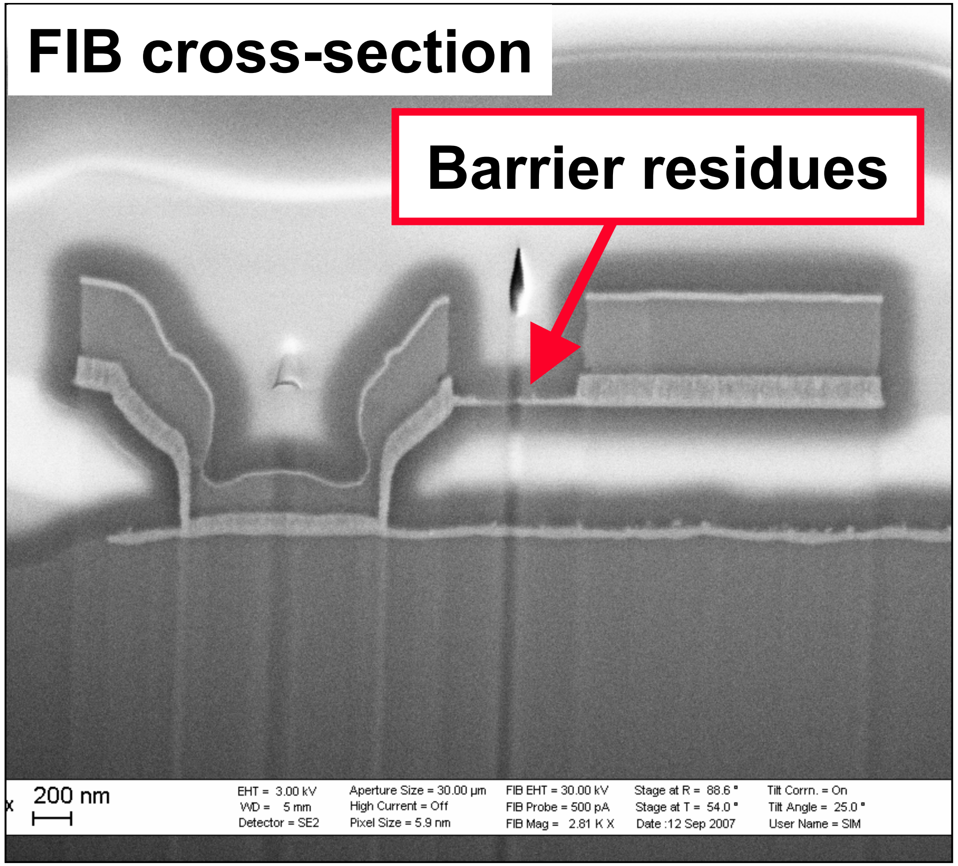




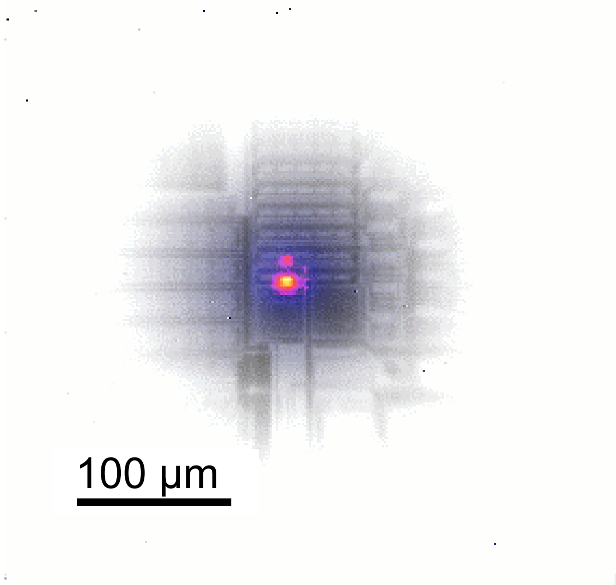
Application of SIL imaging for better spatial resolution → smaller cross-section area

Example II: Lock-in Thermography for defect localisation with following cross-section





Overview



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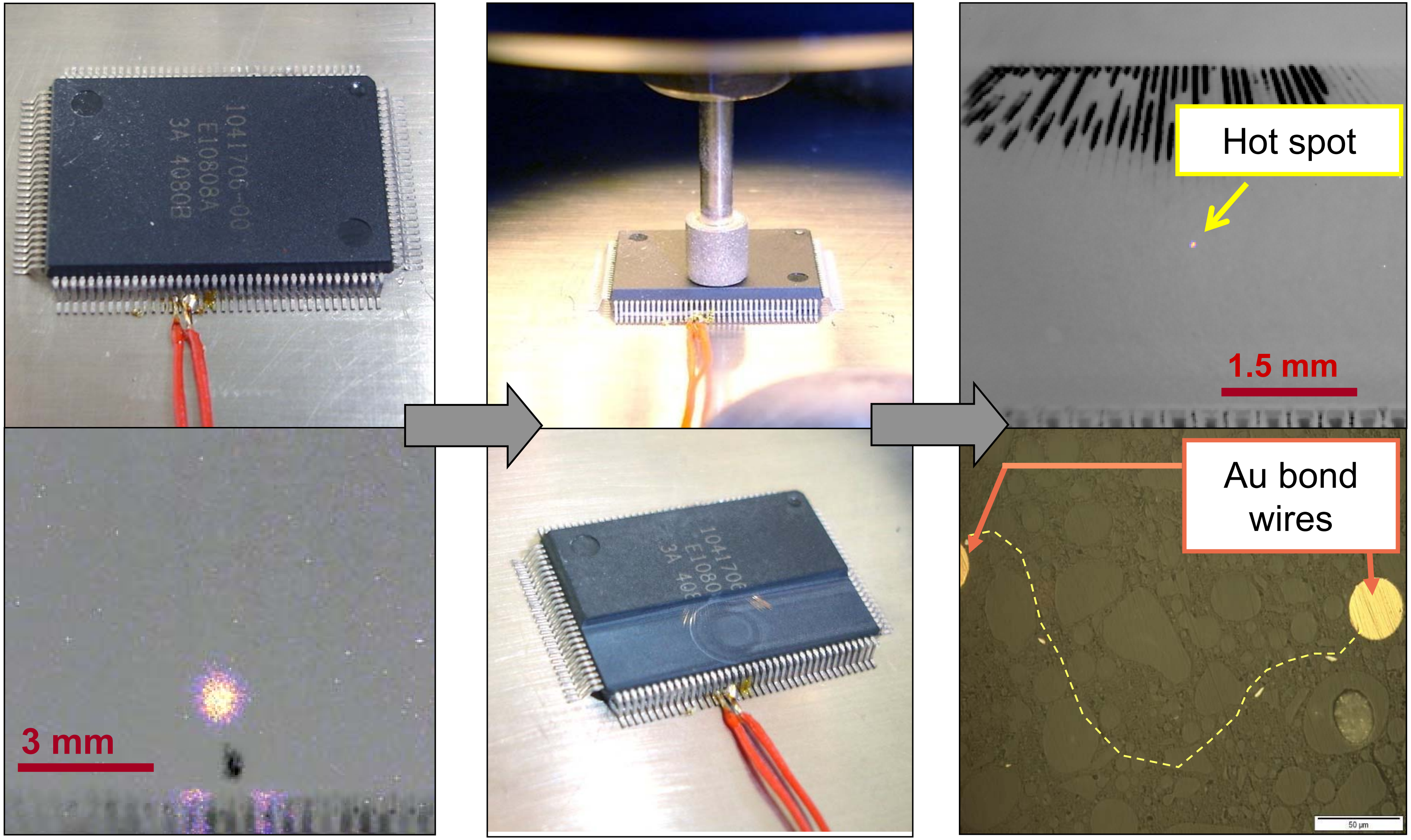
Example III: Short localization at a fully packaged single chip device



Example IV: Defect localization at a stacked die device

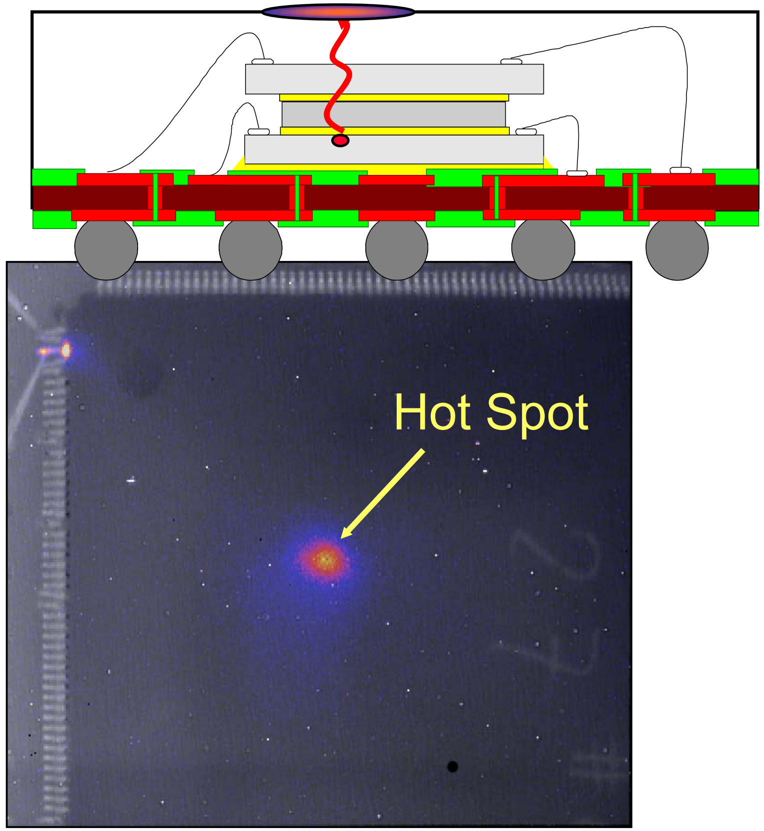
- first LIT- measurement was done at fully package stacked die

Result:
hot spot was obtained in the chip area

Challenge:
poor spatial resolution, unknown defect depth

Next step:
device opening, removal of Mold compound above the upper chip by chemical etching

→ additional LIT measurement



Thermogramm of the fully packaged device
(Amplitude-picture overlaid with topography)

Example IV: Defect localization at a stacked die device

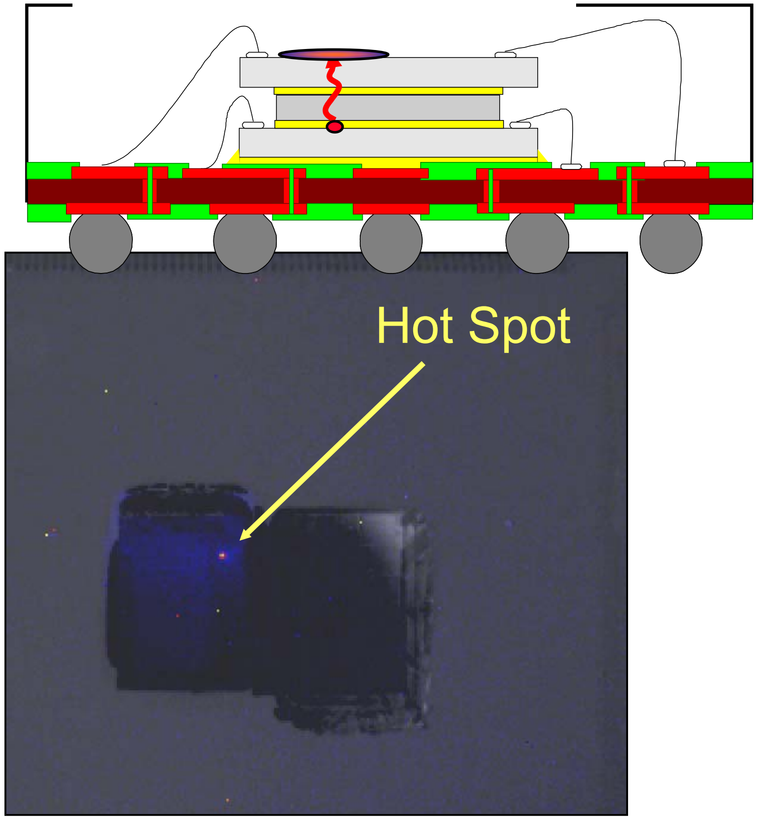
- second LIT-measurement

Result:
hot spot was obtained in the chip area again,
spatial resolution was significantly increased

Challenge: silicon is IR-transparent
→defect depth is still unknown

Next step:
→ disconnection of the upper chip layer via removing the bondwires

→ Third electrical / LIT-measurement



Thermogramm after opening the device
(Amplitude-picture overlaid with topography)

Example IV: Defect localization at a stacked die device

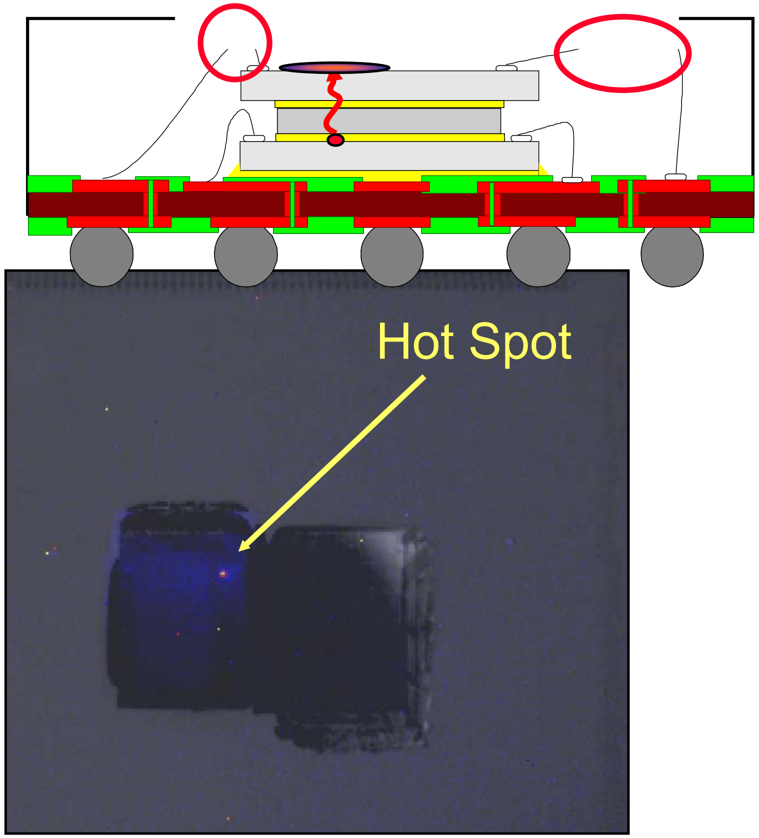
- third LIT – measurement

Result:
similar to second LIT, Short defect at the lower chip due to the fact that upper chip layer is inactive

Challenge:
procedure is time-consuming

→ defect localization using the **phase information** of the LIT-measurement

→ **only one measurement necessary to detect defect**

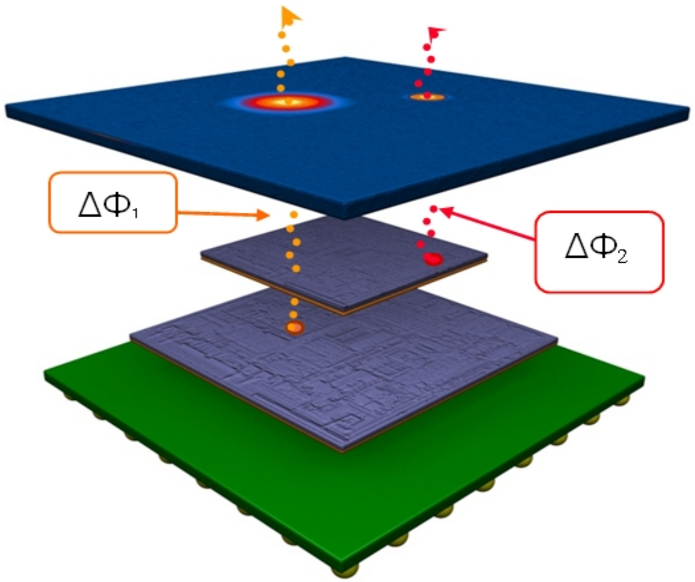


Thermogramm after disconnecting the upper chip layer (Amplitude picture overlaid with topography)

Aim:

non-destructive defect localization at

fully packaged complex devices



Solution: “Heat flow takes time”

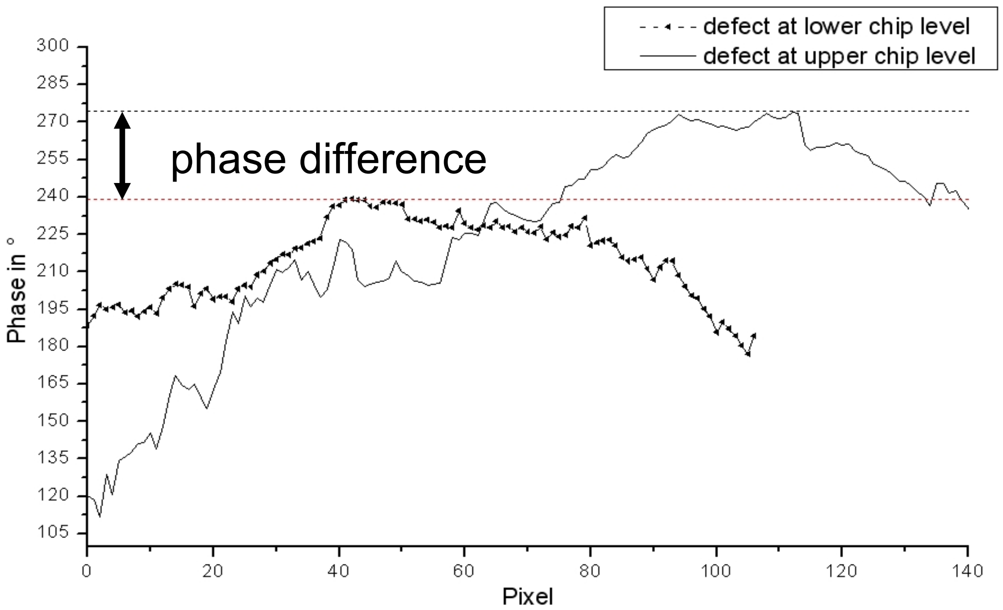
→ phase information give the opportunity

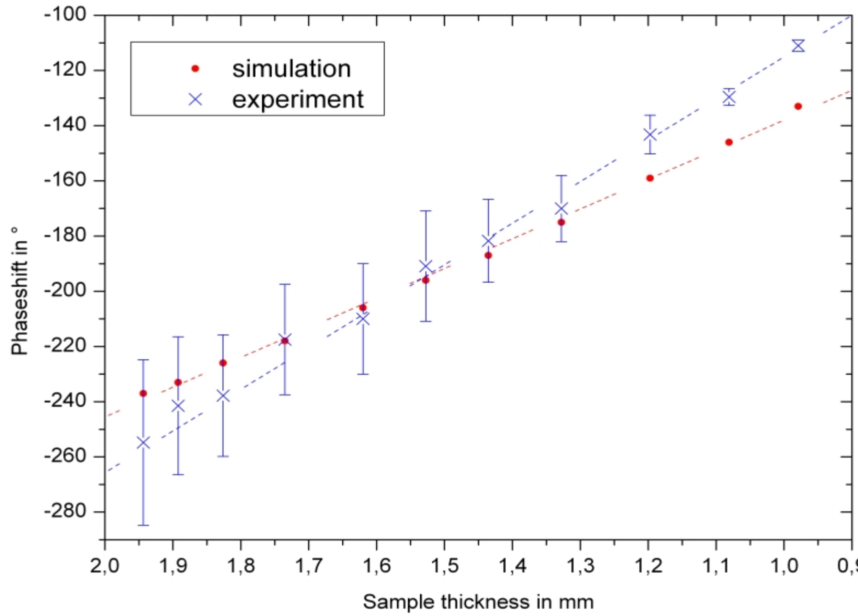
determining the defect depth

Challenge:

→heat occuring from the defect has to pass the mould compound before it can be observed by IR-detector → thermal spreading reduces spatial resolution

3D defect localisation using the phase information (Pidea Full Control)





former experiments at **stacked die devices** investigated the relationship between phase shift and defect depth (**ESTC 2008, ISTFA 2008**)

phase difference is base calculating a depth difference: 34° → 237µm

real difference: 195µm → **3D localisation is possible** (Part of research)

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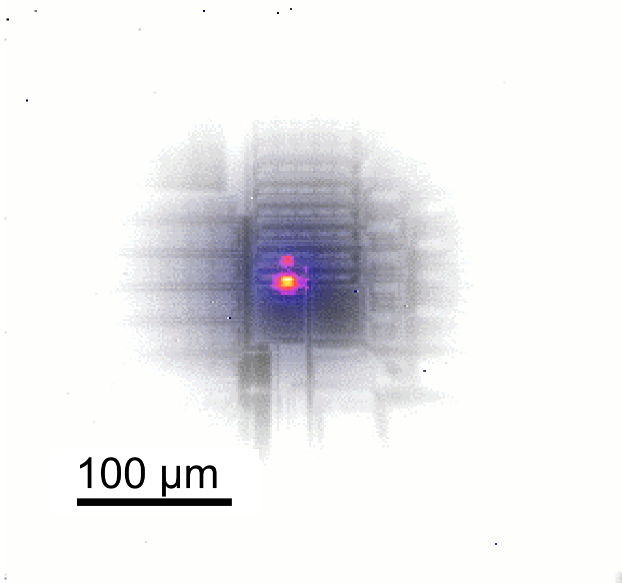

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Conclusion:

Lock-in Thermography:

- is a powerful method for failure localisation
- Easy sample preparation and works from the front or back side of the chip
- generally works at any temperatures (range is depending to the detector material)
- is more sensitive in comparison to steady state methods (<100µK, µW range)
- Satisfying spatial resolution for failure localisation on microelectrical devices: 5 µm (standard optics), 1.2µm (SIL)
- is also usable for non-destructive failure localization in packaged devices

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Thank you for your attention!

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