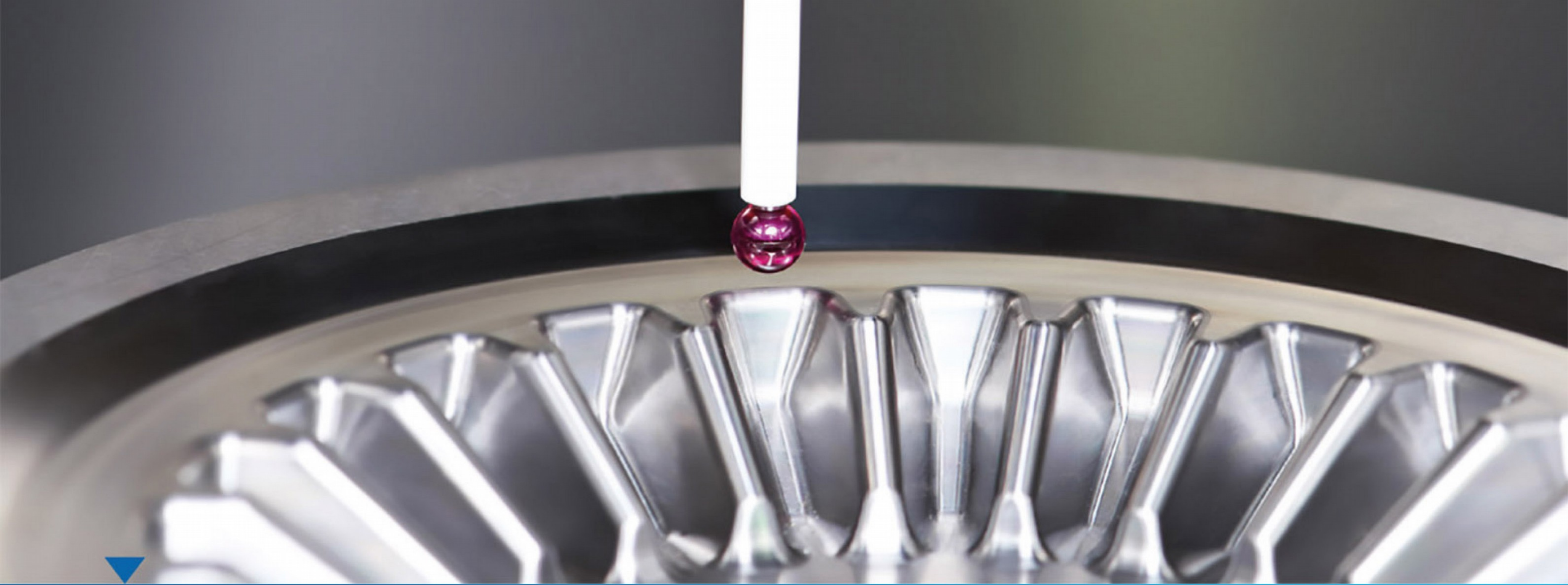

# Fast areal thermal imaging for nanowire solar cell samples

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EMPIR EURAMET

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# Motivation: goals and methods

**What we want to measure?**
Local temperature distribution on nanowire based devices, like solar cells, to map defects on them.

**Which techniques can we use?**

**Scanning Thermal Microscopy**
Spatial resolution ~100 nm
Temperature resolution ~0.01 K
Temperature accuracy ~1 K
Traceable, slow, contact based

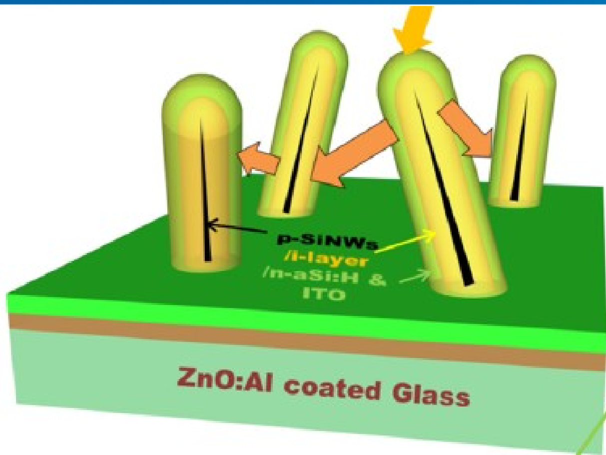
*going non-contact*
*speeding up*

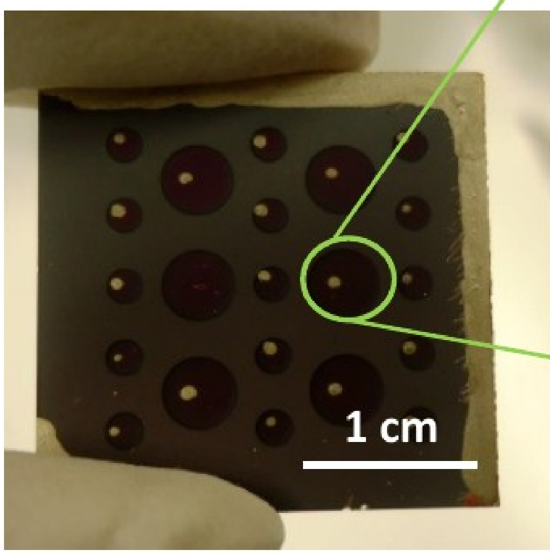
**IR microscopy**
Spatial resolution ~10 um
Temperature resolution ~0.1 K
Temperature accuracy ~2 K
Traceable, medium speed,

*increasing resolution*
*speeding up*

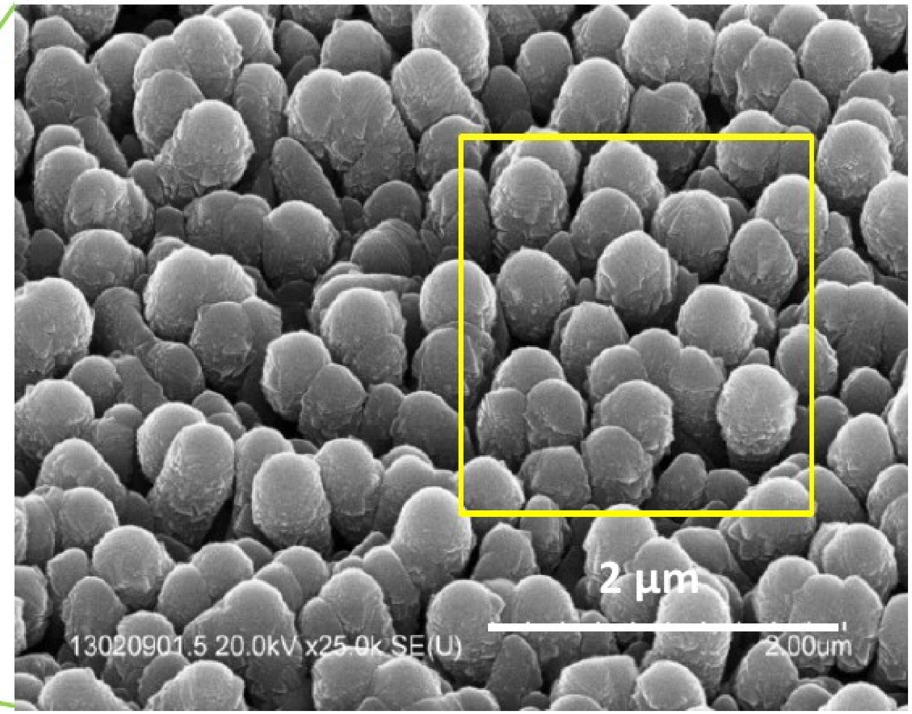
**Thermoreflectance**
Spatial resolution ~500 nm
Not yet traceable, very fast

# Motivation: samples




**Radial junction with ITO top contact**




- **The radial junction density is over $5x10^8/cm^2$.**

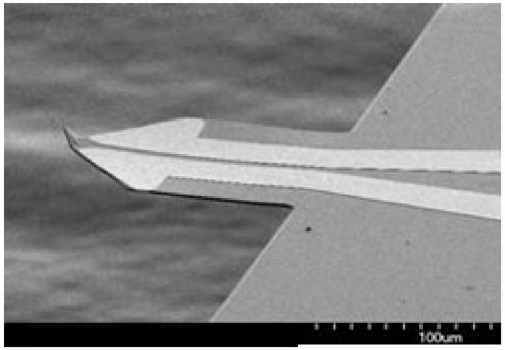
S. Misra, L. Yu, M. Foldyna, P. Roca i Cabarrocas, *Solar Energy Materials and Solar Cells*, **118**, 90-95 (2013)

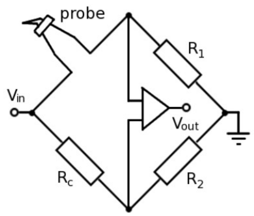
# SThM and Thermoreflectance

**Scanning Thermal Microscopy:**
Sharp resistive probe monitors local temperature or heats up the sample locally. With large area scanner we can make large maps.

**Traceability** is provided via special samples or using oven combined with numerical model of the heat distribution.

Main **uncertainties**: probe-sample junction, topography impact.

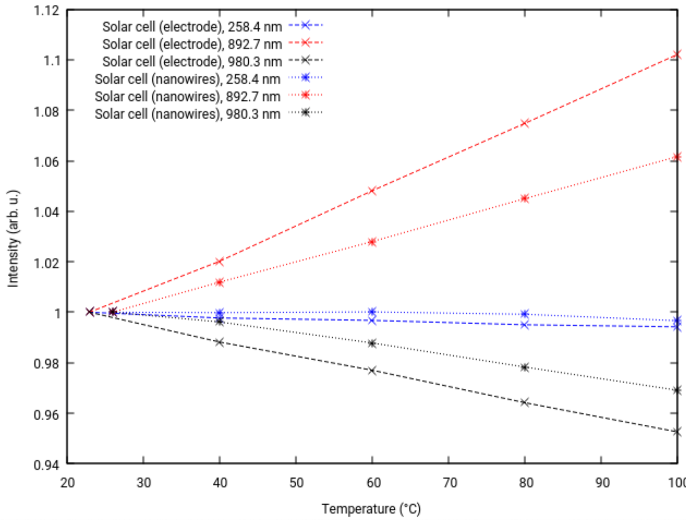





**Thermoreflectance imaging:**
Mapping the local reflectivity variations using a camera and lock-in technique.

**Traceability** is provided using passive/active measurement methodology.

Main **uncertainties** include impact of topography, thermal expansion, camera noise, non-linearity, reflectivity span.

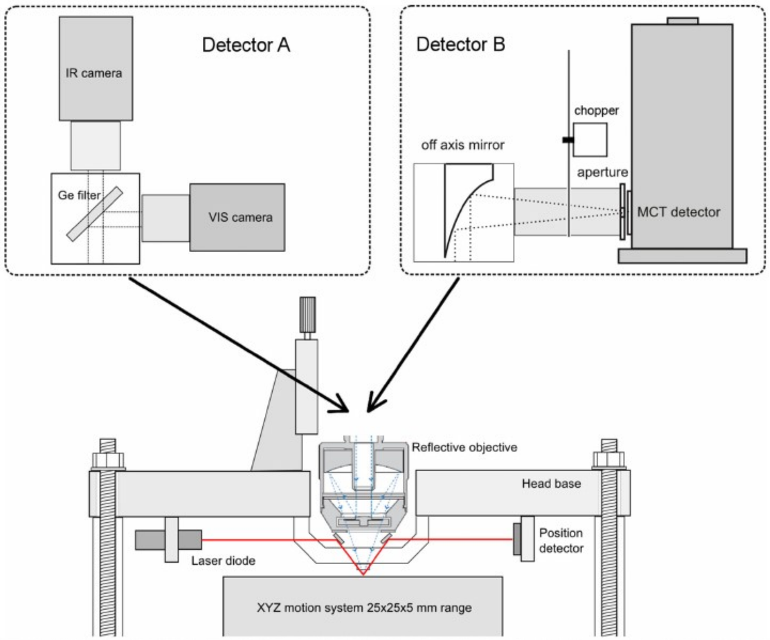


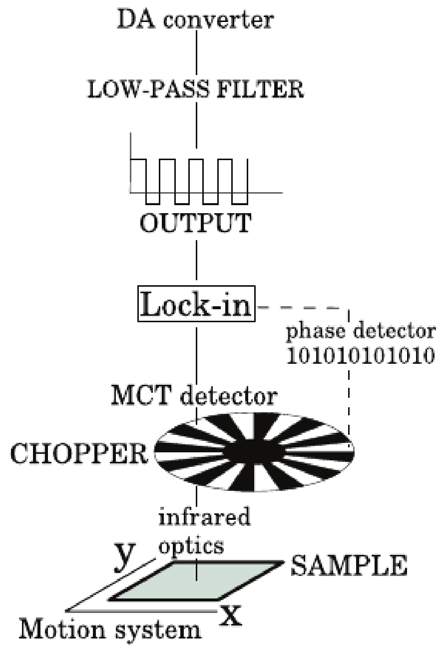
# Infrared microscopy

**IR microscopy:**
Mapping the blackbody radiation using either a cooled detector or an infrared camera.

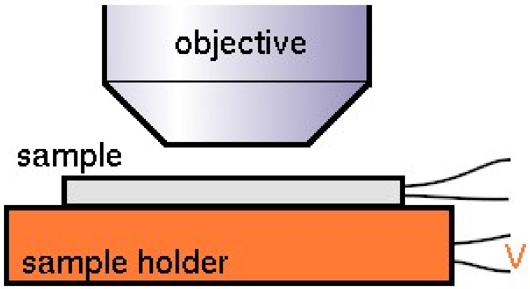
**Traceability** is provided using passive/active measurement methodology, determining the emissivity in each position of the sample.

Main **uncertainties** include impact of emissivity, topography, signal to noise ratio.

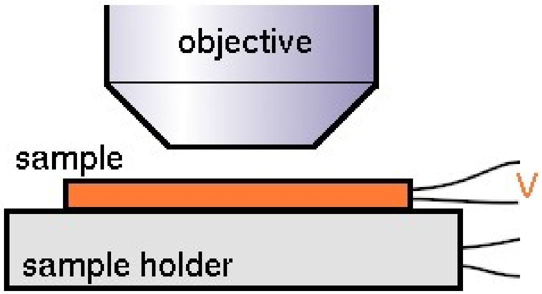



passive mode:

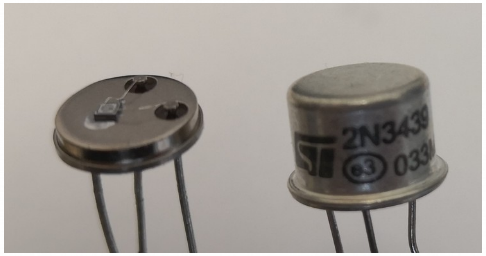


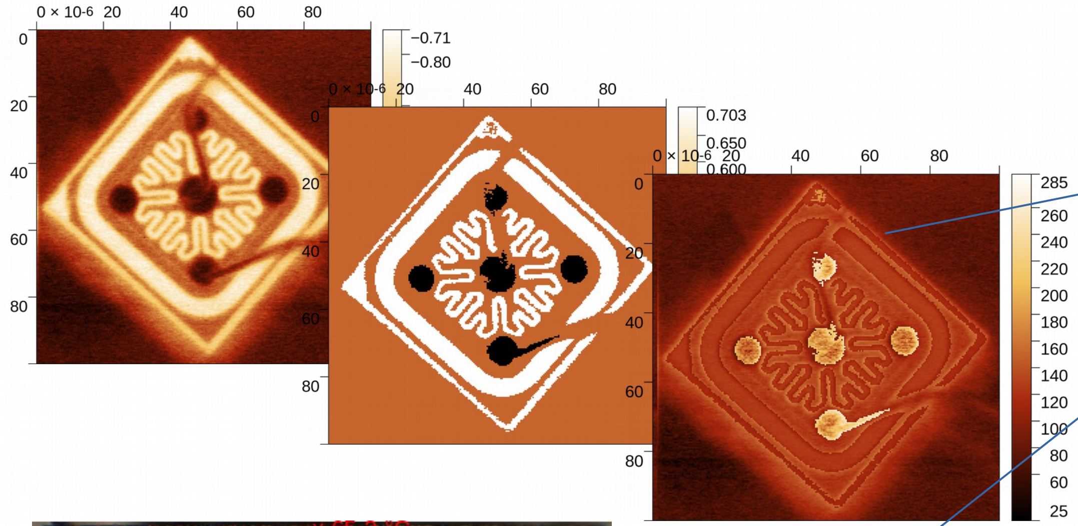

active mode:

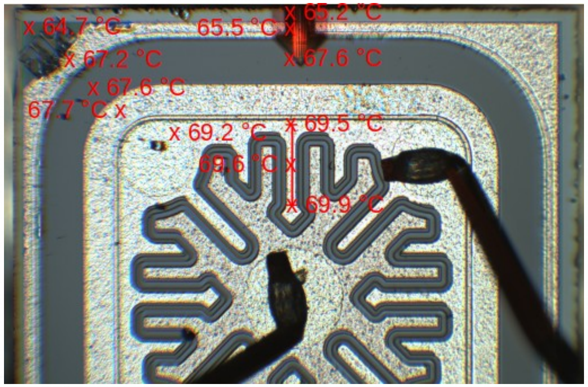


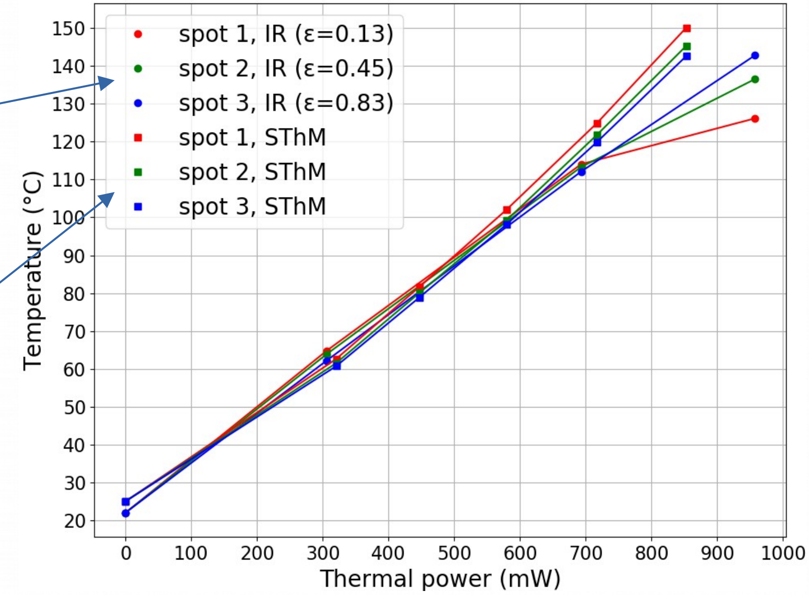
# Traceable methods can be compared!

Comparison between SThM and infrared microscopy on the same device (bipolar transistor) and same power, performed during the Advent EMPIR project.



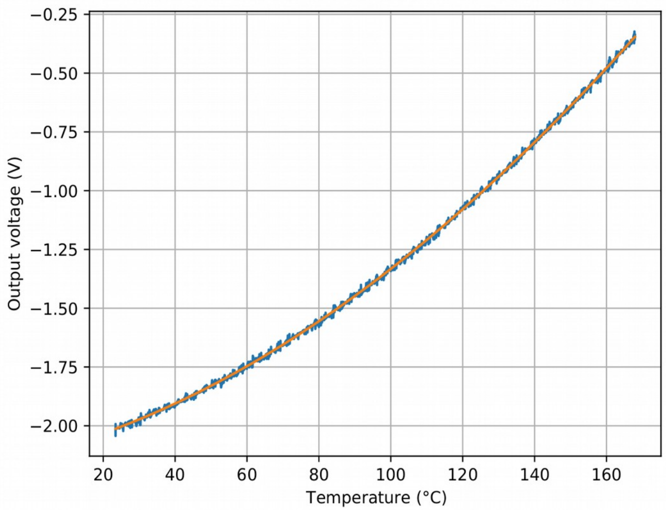


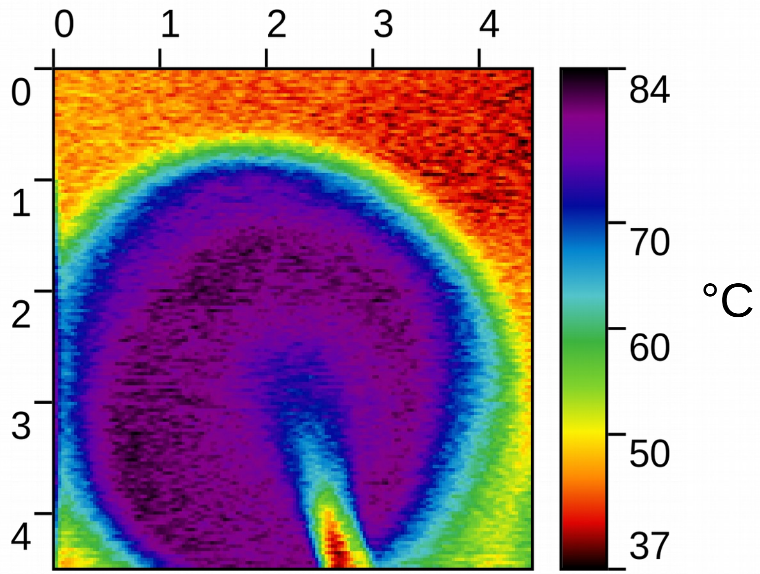

Comparison is fine up to about 120 °C
Uncertainty is about 2 Kelvin.

# IR measurements on NW solar cells

Generally, the emissivity of each pixel must be determined to calculate the temperature. In this case, however, the surface is black (ε=1) and homogeneous. Much simpler approach based on single calibration curve can be used.

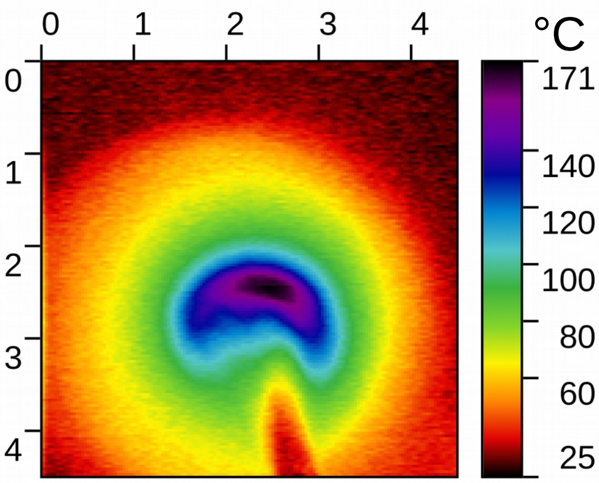



Calibration curve: the output voltage measured at rising temperature in passive mode. The objective was aimed at a single point.No scanning is necessary.

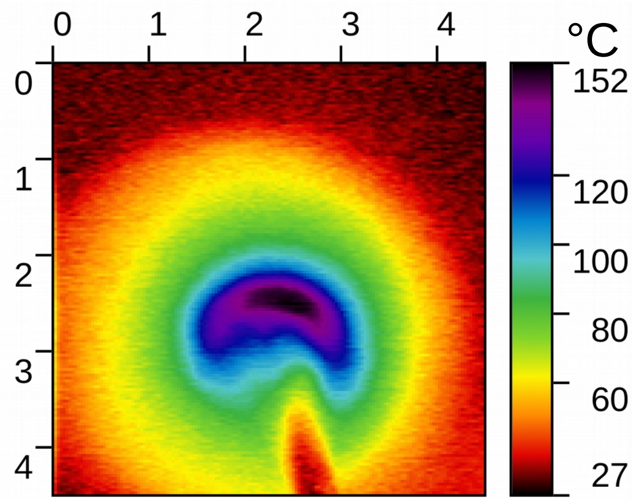



Only the purple area was the surface of interest. The image is a test if the surface is really homogeneous.

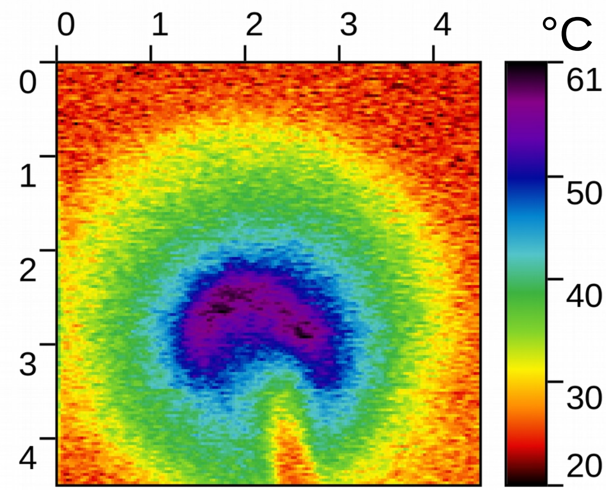
# IR measurements on NW solar cells




Forward direction.




Reverse direction.



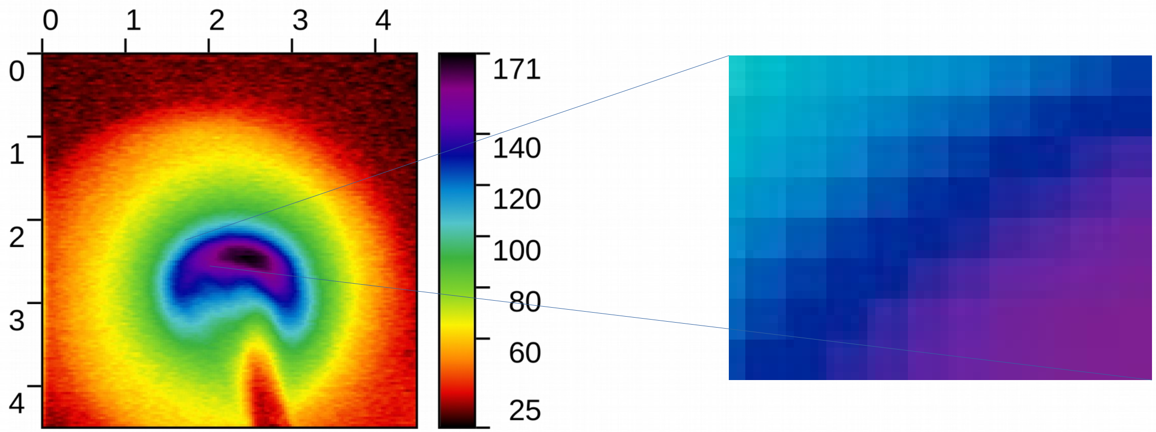

Reverse direction, damaged cell. Low current leads to low ohmic heating and worse image quality.

The temperature was calculated using the calibration curve. In this simple case no physics in the model was involved.

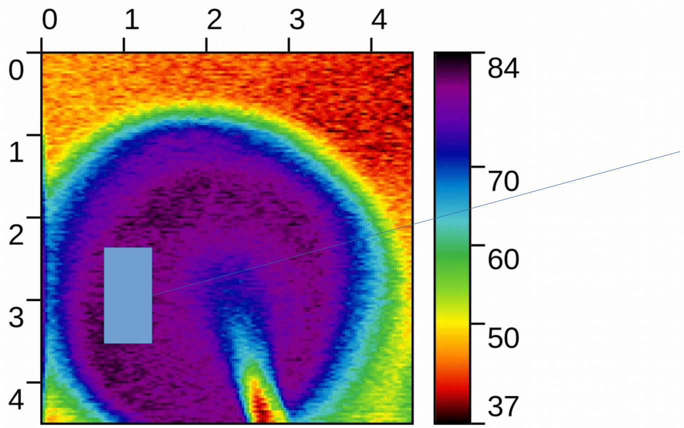
The solar cells were heated (and subsequently damaged) by electrical current in forward and reverse direction.

# IR measurements on NW solar cells

The measurement is a big struggle with noise.  Attempts to increase spatial resolution lead to smaller pixel size, and worse temperature resolution. Much work has been done in this tradeoff. Also, low temperature means low signal and worse images.




Spatial resolution:
At high temperatures, one pixel is 30x30 µm, still not burried in noise.




The temperature resolution can be improved by increasing integration time or taking larger area into account.
Example: 2000 pixels with standard deviation 1.058 °C.
**Result with uncertainty: T = (80.670 ± 0.024) °C.**

# Conclusions

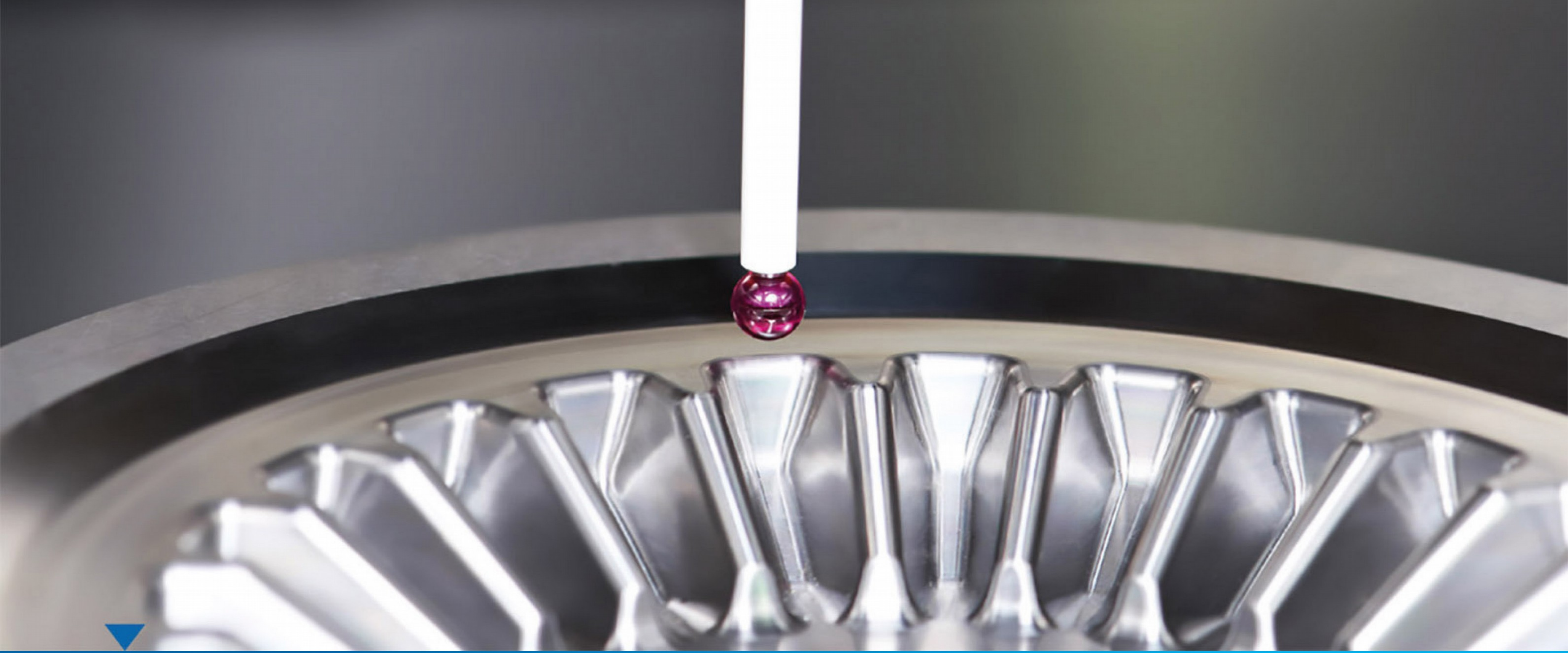
We focus on making the fast areal thermal imaging methods available and on applying them to nanowire based solar cell samples.

Goal is to detect local defects at different spatial scales, going up to the wavelength limited resolution (using non-contact methods) or even higher (using SThM).

Methodology for the non-contact methods is based on calibrating the system response using an externally heated samples.  It is necessary to minimize various systematic errors that are connected to this two-stage sample measurement procedure (sample drift, temperature gradients, signal to noise ratio). This was done for IR imaging and methodology is now being adapted to thermoreflectance.

Using combination of different methods is useful for testing reliability of the developed methods – methods having different systematic errors can be directly compared.

This work was performed within the EMPIR Nanowires project jointly supported by EU and Euramet participating countries.



# Thank you for your attention

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**Reference**
J. Martinek et al, Measurement Science and Technology 30 (2019) 035010

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