Defect Localization Using Modulated-Thermal Laser Stimulation and Phase-Shift Imaging Method

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founded by Philips

Purpose

- **Defect localization : last step before destructive analysis (Physical characterization)**
  - **Additional informations on the defect localization could improve the localization efficiency**

- **Experimental studies show that TLS spots can be difficult to interpret**
  - **Could M-TLS be a solution to improve TLS signature interpretation?**
  - **Case study: Could M-TLS be a solution to distinguish artifacts from real signatures?**

Outline

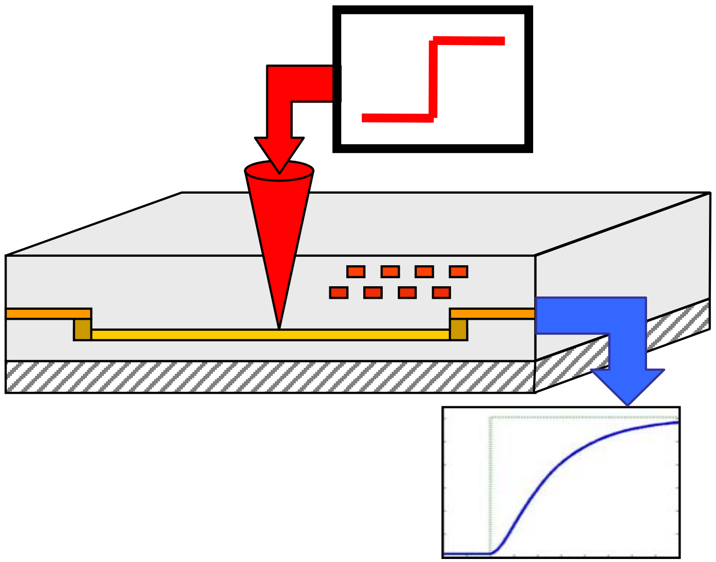
- **M-TLS acquisitions and phase-shift imaging**
- **A solution to access additional information: Application on a 65nm non defective test structure**
- **A solution for a better interpretation of TLS signature: Application on a 45nm defective structure**
- **Conclusions**

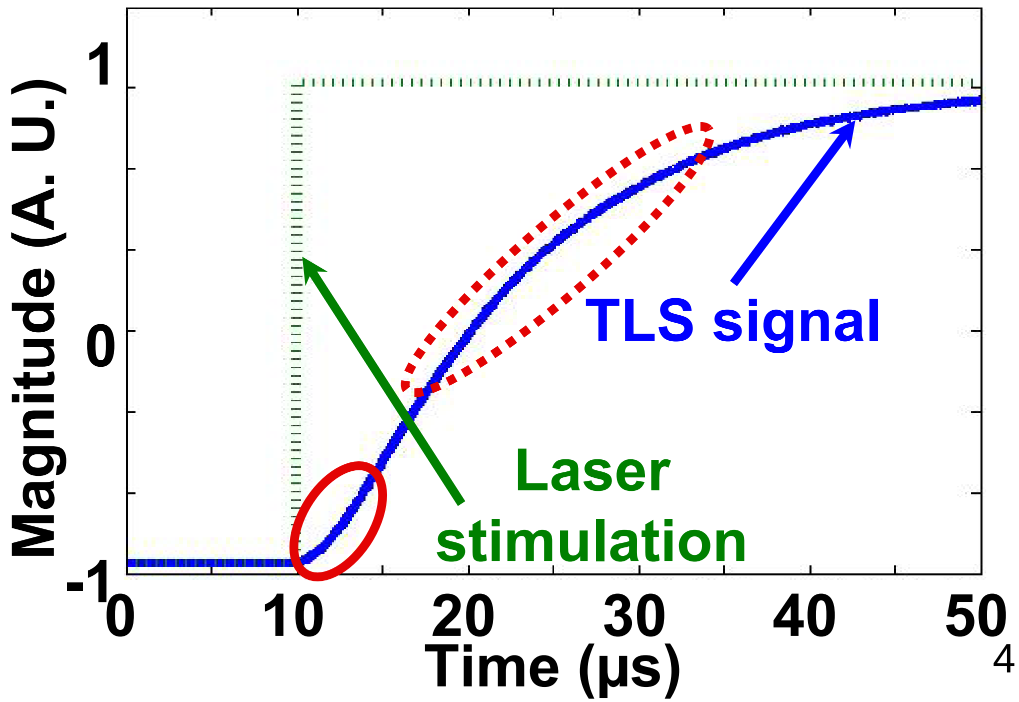
Modulated-TLS principle

- **Requirement:** **modulated laser source**

- **Study of the M-TLS signal time dependence**
  ⇔ Thermal Time Constant (TTC)

$$\Delta R(t) = \frac{\rho_0 . L}{S} . \alpha_{TCR} . \Delta T(t)$$



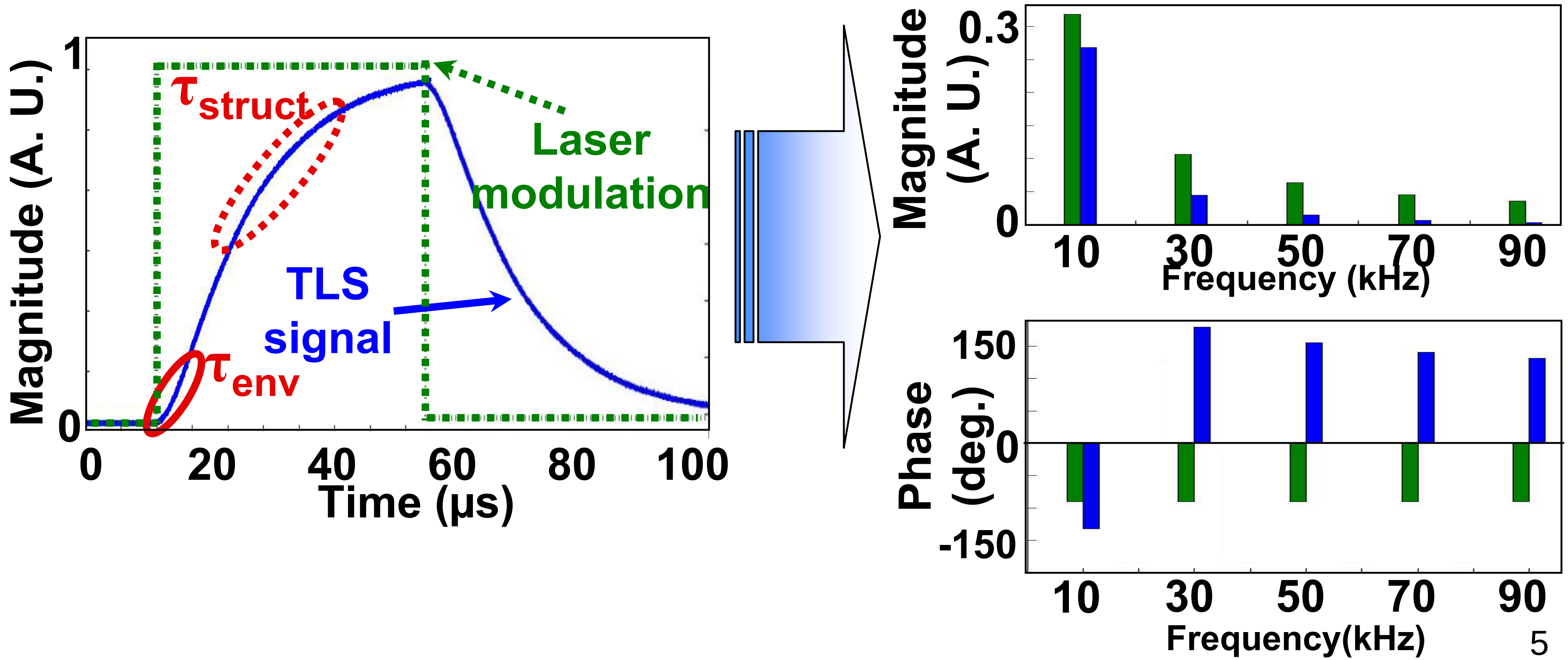


Practical access to the Time dependency

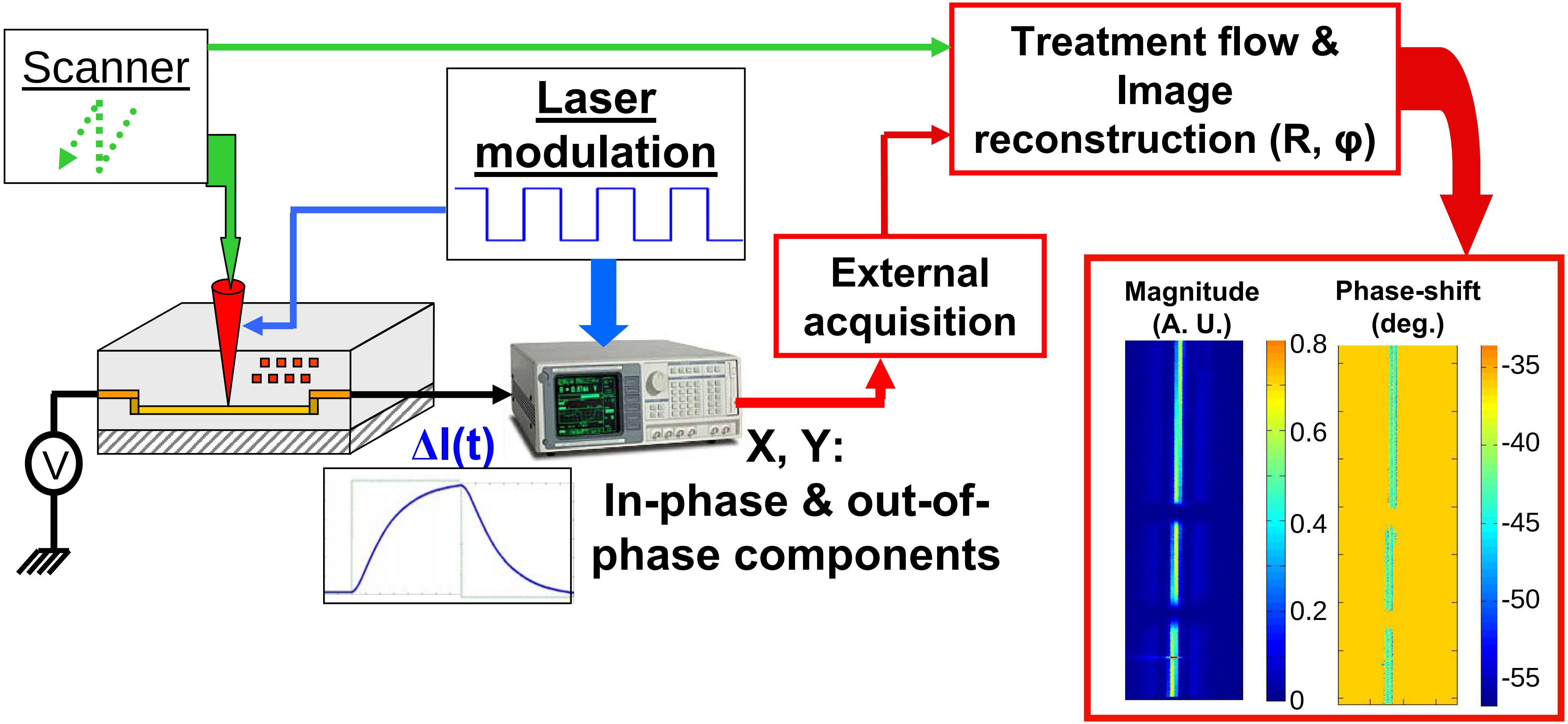
- **<u>Requirements:</u>**
  - **Compatible with TLS configuration (laser scan)**
  - **Access to magnitude and phase-shift (⇔ time dependency) information**

⇨ **Transposition in the Frequency domain**

<u>Time domain</u> ***<u>Frequency domain</u>***



M-TLS acquisition flow



Acquisition of both magnitude and phase-shift information during a single scan

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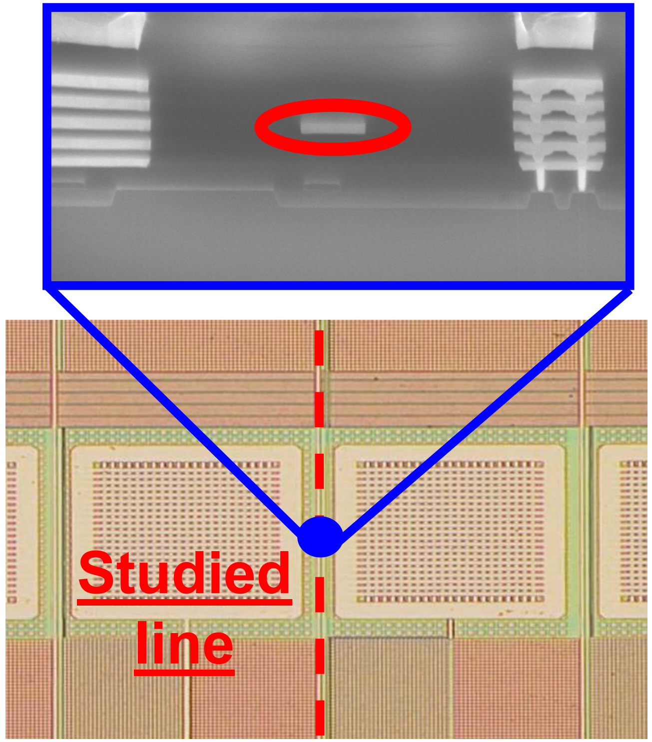
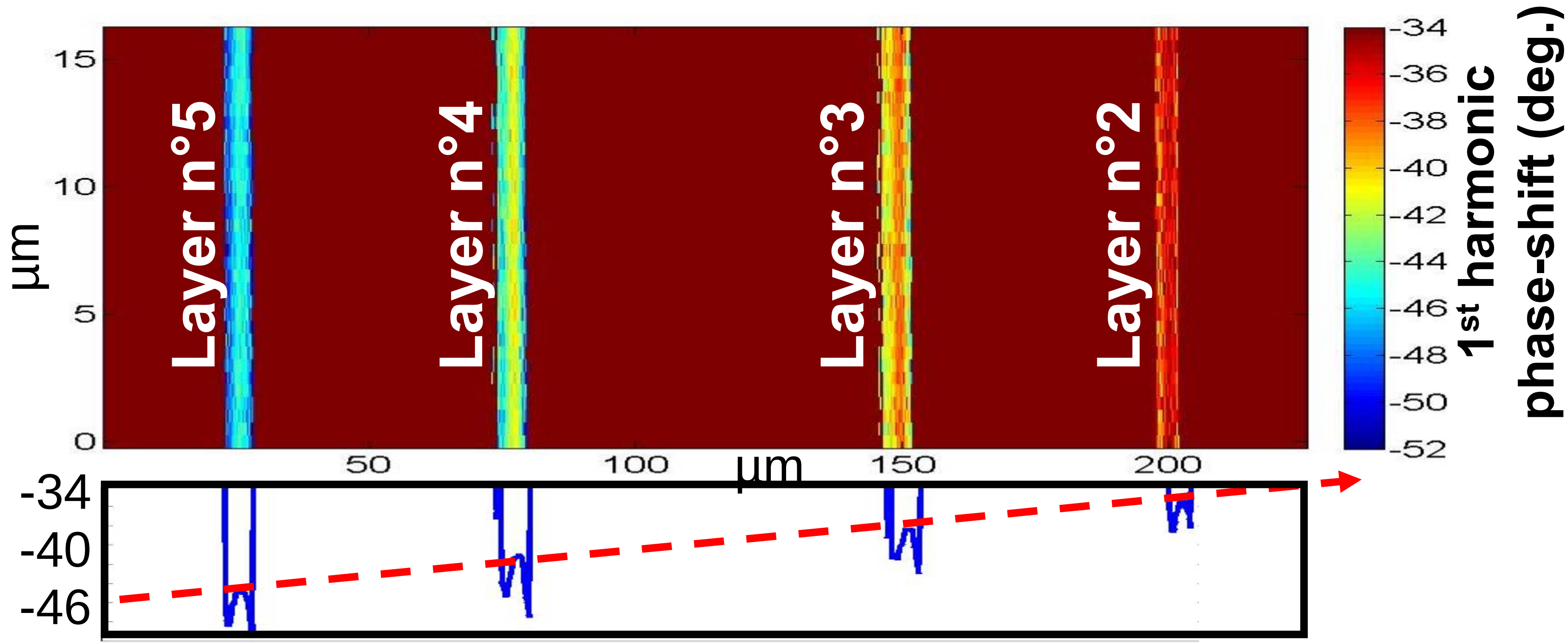
Application: structure description

- **Study of a matrix of embedded copper lines, 65 nm technology:**
  - ***Metal layers:***
    - **M5 => M1**
  - ***Widths:***
    - **1100nm**
    - **740 nm**
    - **480 nm**
    - **Min width (110 or 90 nm)**



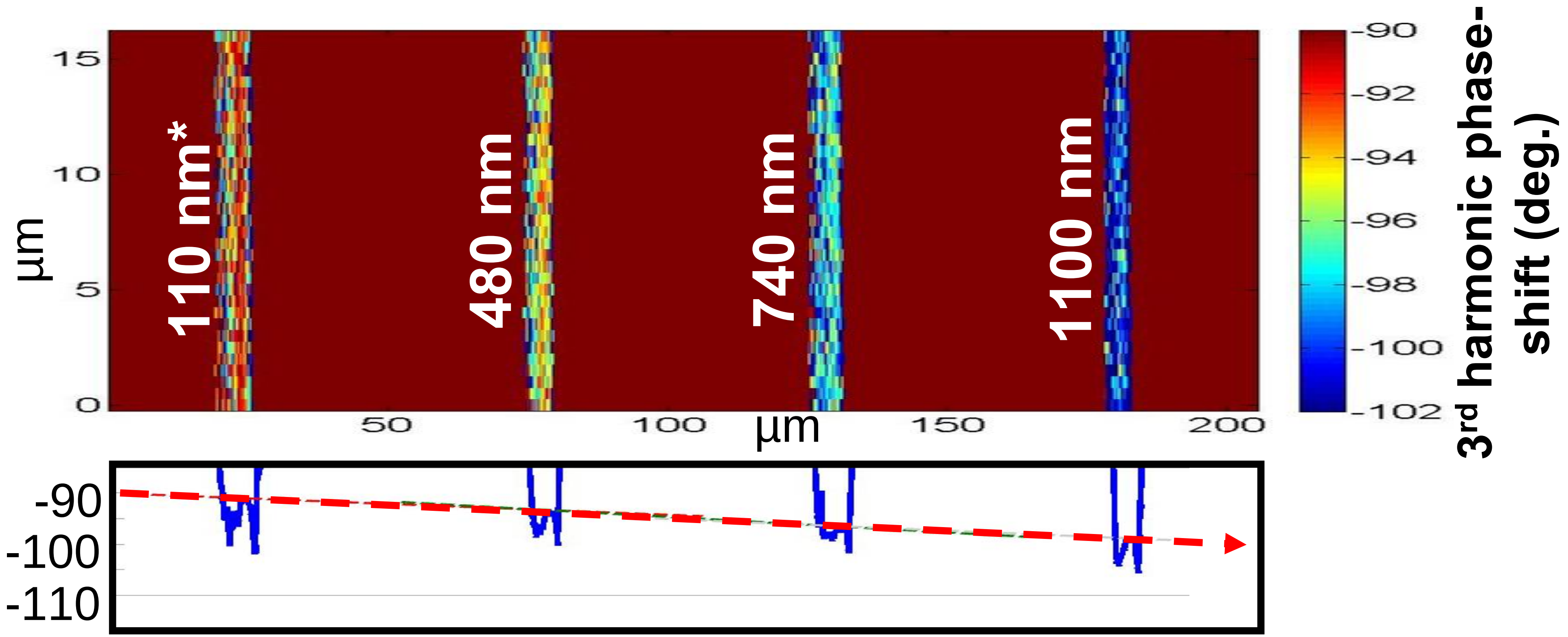
Objective: apply phase-shift detection analysis to discriminate each test structure

Metal layer influence (LDE)



- **Good discrimination level between 2 consecutive metal layers**
  Deeper the line, quicker the TLS response
- **Resistance of the thermal path through the silicon substrate ↘**
  ⇨ **TTC ↘** ⇨ **Phase-shift ↘**

Line width influence (LDE)



- **Line width information available:**
  Wider the line, slower the TLS response

- **Line width ↗ ⇨ heat capacity ↗ ⇨ TTC ↗ ⇨ phase-shift ↗**

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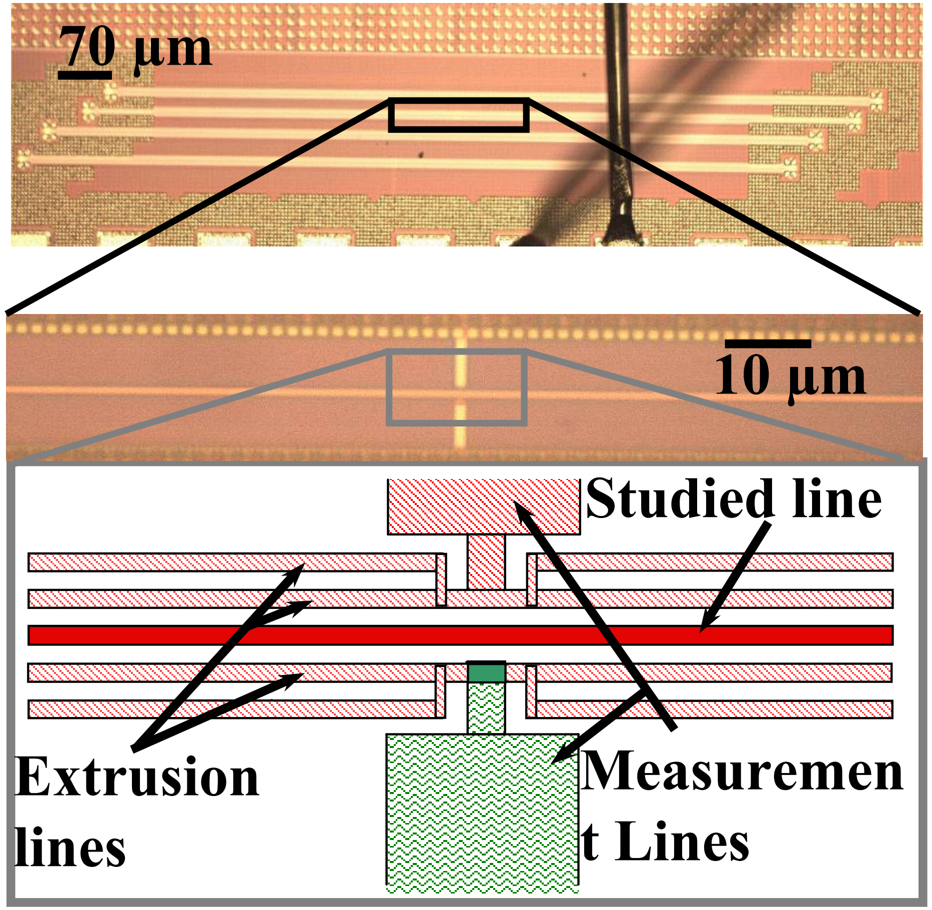
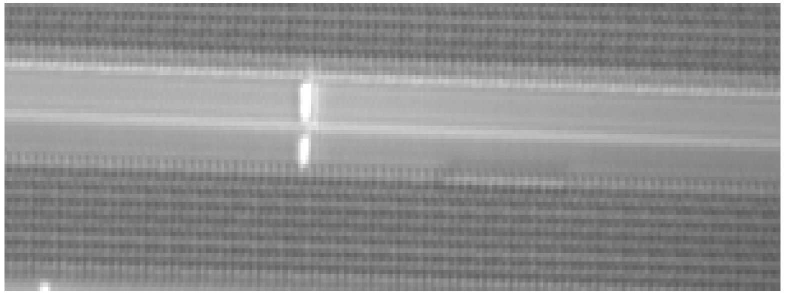
Electromigration case study

- **Structure description**
  - EM test structure, CMOS 45nm, V2M3 copper line
  - Specific design for copper migration detection:
    - Extrusion lines
    - Measurement lines
  - Line width: 70nm
  - Line pitch: 70nm
  - EM test:
    - 10mA/µm² at 300°C
    - Stop criteria 1% of resistance increase

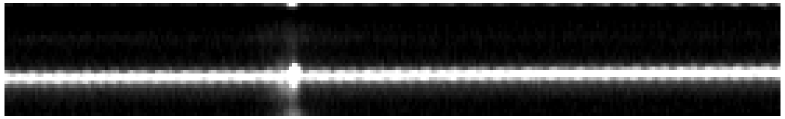


Standard TLS approach

- **Classical OBIRCH analysis**
  - OBIRCH spot located at center
  - Same result on several dies
  - No defect found



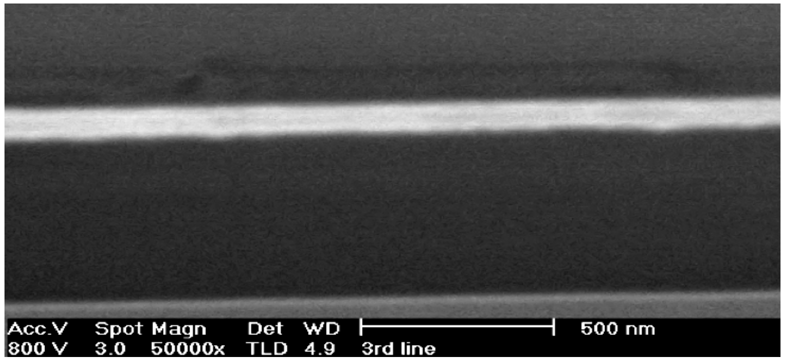
Reflected image



OBIRCH image, 150mV, 50x obj.

- **Conclusion:**
  - This specific signature results from surrounding changes

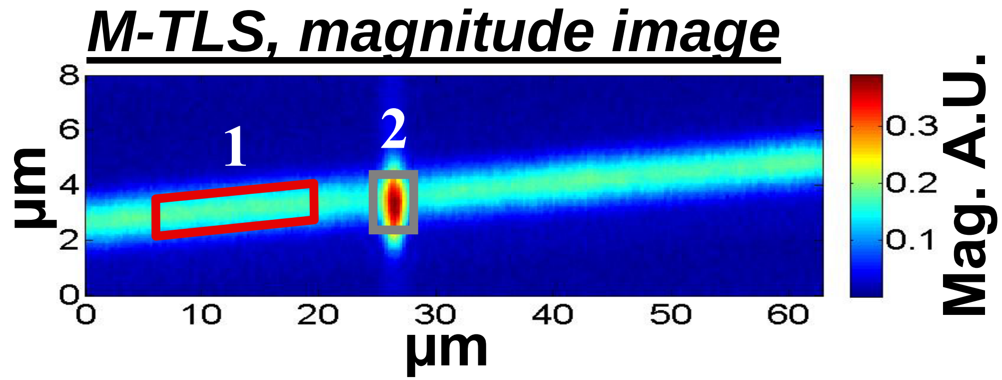
TLS ARTEFACT



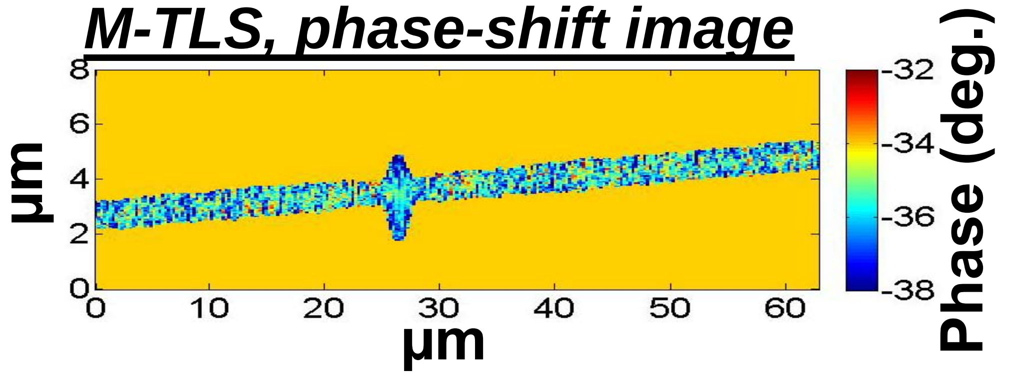
SEM image along the line (X-section)

M-TLS study (artifact area)

- **Magnitude image**
  Same artifact is present (as expected)
  Shape and value variation



- **Phase-shift image**
  Shape variation BUT same value along the line



- Convincing quantitative values

	Regular value (1)	Spot value (2)
Mag.	0.18	0.39
Phase	-35.8°	-35.9°

Phase-shift analysis interest

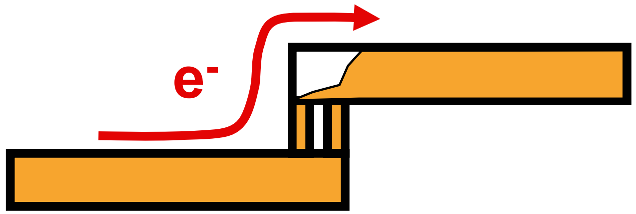
- The artefact (magnitude image) is not visible on the phase-shift image

M-TLS phase-shift analysis appears as a relevant and unique method to identify this kind of artifact resulting from surrounding interaction

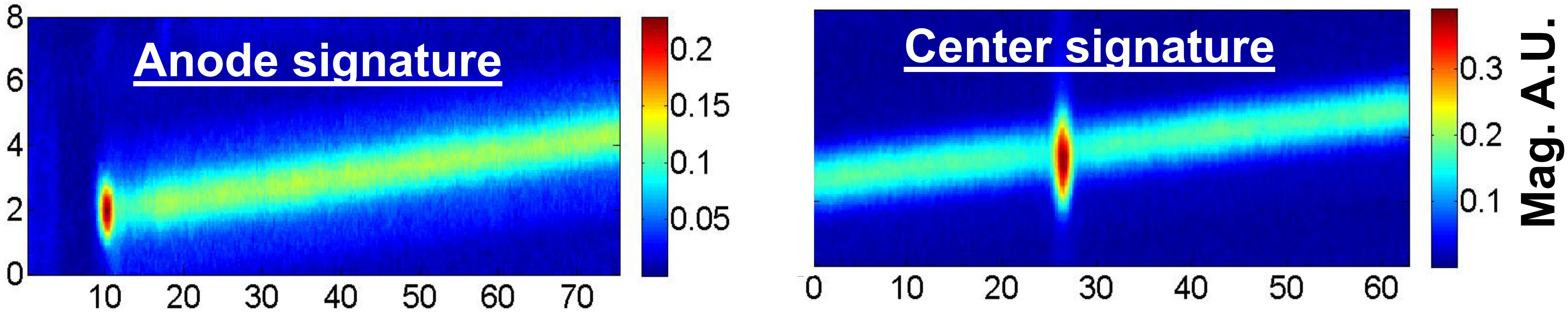
- What is the phase shift signature on a real defective area?

M-TLS study (defective area) Magnitude

- Resistance increase ⇔ voiding formation
- Via areas are preferential locations for voiding



- **<u>Comparison of M-TLS magnitude acquisitions</u>**

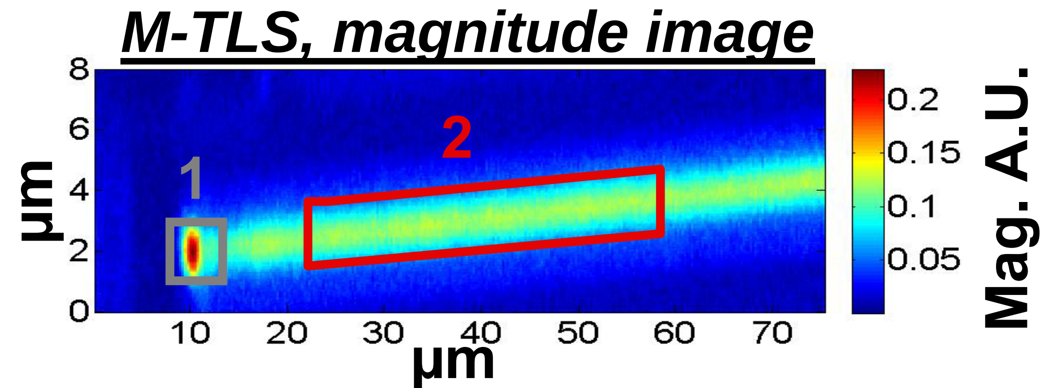


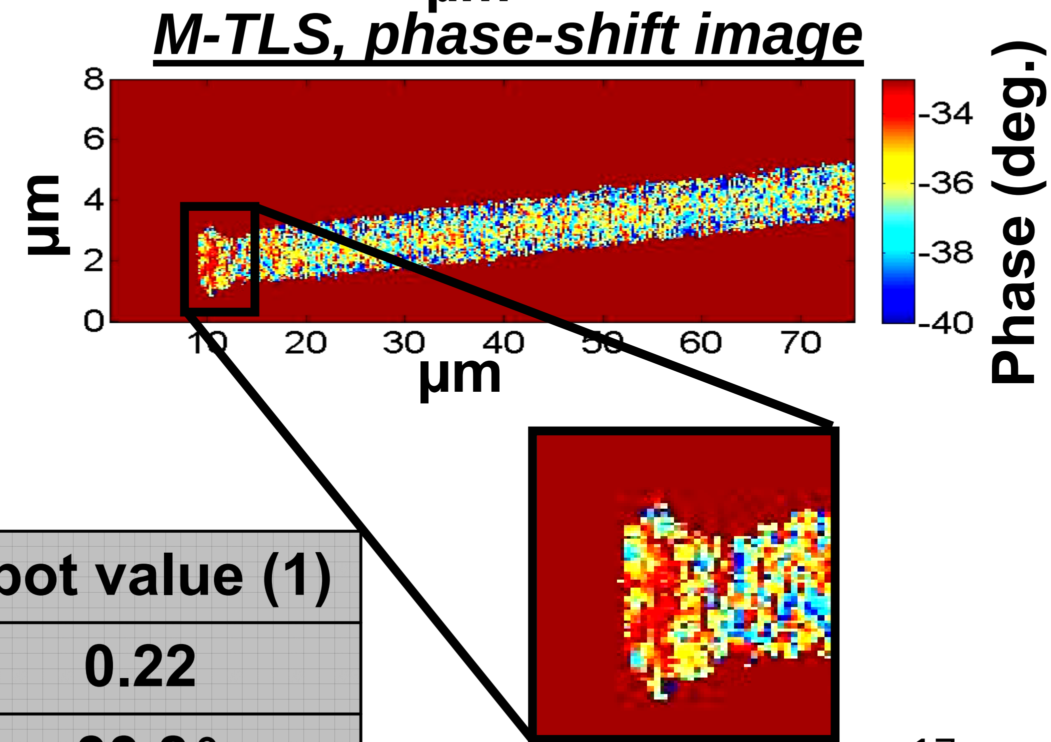
The two M-TLS signatures are similar

Do they come from the same interaction?

M-TLS study (defective area) Phase-shift

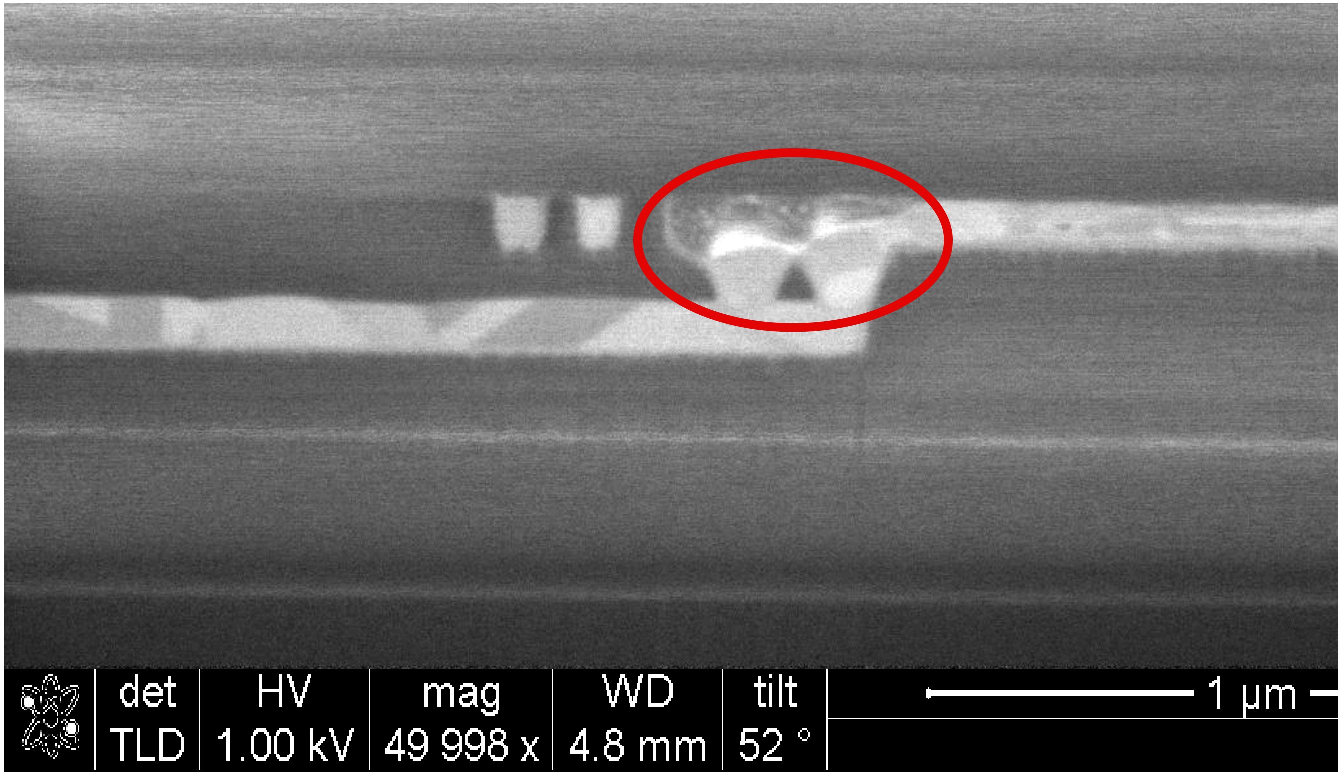
- **Specific phase-shift signature in the via location (shape & value)**
- **Small variation but visible in image mode with an appropriate treatment**
- **More significant mean values extraction**





	Regular value (2)	Spot value (1)
Mag.	0.12	0.22
Phase	-35.7°	-33.8°

Physical Characterization



SEM image of the anode side

Conclusions

- **Phase-shift detection associated with M-TLS acquisition allows to:**
  - **Access additional information on the excited structure, like depth and structure dimensions**
  - **Improve the TLS signature interpretation**

Design + Additional information => Indirect improvement of the localization accuracy

More information on the defect ⇔ More confidence on the defect localization step

Better interpretation of complex TLS signature (ARTEFACT)

Physical interpretation

- **2 possible explanations:**
  - Multiple reflection on copper surroundings
  - Heat conduction in copper surroundings then heat transfer to the studied line

- **2 consequences:**
  - Increase of energy transferred to the copper line
  - Indirect heating => Spatial expansion

- **1 result:**
  - Deeper and larger OBIRCH spot signature in the "measurement lines" implementation area