#NewWays4Space

Implementation and validation of in-situ process monitoring and control for highly automated space solar generator manufacturing

SpaceTech GmbH

SpaceTech GmbH

SME Small System integrator

Facts

- Independent SME
- Founded in 2004
- 109 Employees
- 20 M€ Turnover

Customers

- Institutional Space
- New Space

In Orbit

1044 units…

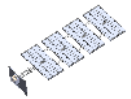
…on 442 satellites

Equipment

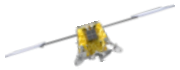
Solar Arrays

Structures & Mechanisms

Electronics



Solar Arrays
Oneweb, York, Copernicus,…
> 200 satellites
> 163 in orbit (on 79 satellites)



Mechanisms
> 600 Satellites
> 800 in Orbit (on > 400 satellites)

Structures
GRACE FO
Formosat 5

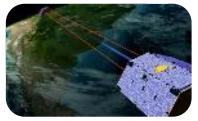
Electronics
Laser Electronics
Remote Terminal Units
Instrument control units

Instruments

Photonic & QT Instruments

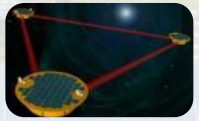
Structures & Mechanisms

Optical Components



GRACE Follow-On
2018
NGGM
2028

MERLIN
2024



LISA
2034

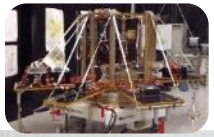
Systems

Mission Design

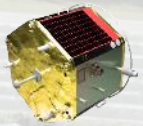
Small Satellites

End-to-End Systems

ICARUS
2018



Formosat 5
2017



DEOS
2012
M2Space
2019

Kolja.nicklaus@spacetech-i.com / www.spacetech-i.com

Facilities

Clean Rooms

- ISO 8 / class 100,000
- ISO 7 / class 10,000
- ISO 5 / class 100

Manufacturing

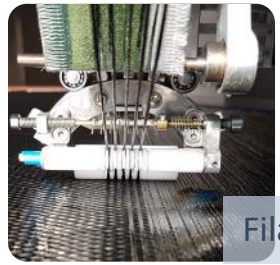
- Electronics Lab
- Laser-optics Lab
- Mechanical Workshops
- Mechanical Integration
- CFRP Production
- Solar arry factory

Testing

- Thermal Vacuum Chambers
- Thermal cycling chambers
- Shakers & Shock Tables
- Flasher


Hot press

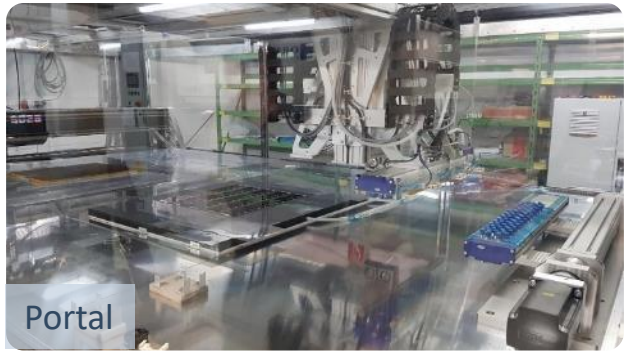
Cycling. chamber




Filament Winding


Optics Lab


TV Chamber


Portal


CNC Turning


CNC Milling

New Solar Array Facility G4

CFRP manufacturing area

Clean Rooms

- ISO 8 / class 100,000

Manufacturing

- Mechanical Integration
- CFRP Production
- PVA integration
- Solar array factory

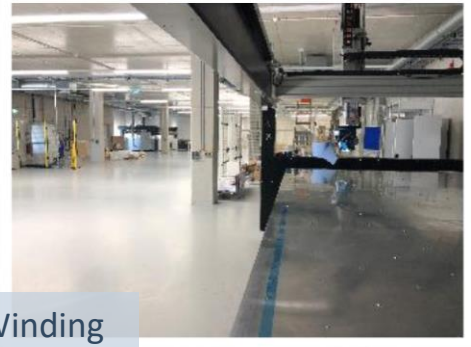
Testing

- Thermal Vacuum Chambers
- Thermal cycling chambers
- Shakers & Shock Tables
- Flasher and sun simulator


Hot press


CNC Milling


Filament Winding




Wing integration


TV & APTC Chamber


PVA integration

Selection of Space Projects Managed by ESA

Equipment

Solar Arrays (selection)

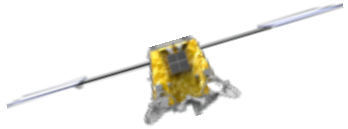
- Sentinel-5 Precursor, external PVA,
- JASON CS /S-6, external PVA,
- EUCLID, external PVA,
- **FLEX, ALTIUS, PLATO, Copernicus**, STI PVA,

Instruments

- NGGM
- LISA Laser

Electronics

- LISA Laser Head electronics
- Rose-L ICM
- Galileo LADU



Mechanism

- JUICE RIME, antenna, Multi hinge
- Jason-CS/Sentinel-6 deployement mechanism

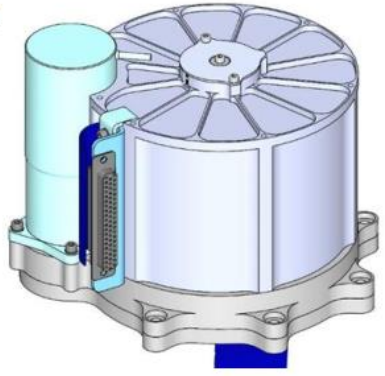
Solar Arrays

Equipment

STI offering

- PVA laydown
  on customer furnished panels
- Solar array panels (SAP)
  with CST substractes and STI PVA laydown
- Solar Array Wings (SAW)
  with CST substractes STI PVA laydown and STI deployment system
- STI SADA
  stand-alone or in combination with SAW

SADA



STI Solar Array Programmes

- GökTürk 2, deployable SA, external PVA, launched 2012
- Formosat-5, deployable SA, external PVA, launched 2017
- Sentinel-5 Precursor, deployable SA, external PVA, launched 2017
- C-Sat, deployable SA, external PVA, delivered 2017
- Space IL, body mounted SA, external PVA, launched 2019
- JASON CS /S-6, deployable SA, external PVA, 2 SA launched 2020
- NGSAR, body mounted SA, external PVA, delivered 2018
- EUCLID, body mounted SA, external PVA, delivered 2021
- Lapan A4(Indonesia), body mounted SA, STI PVA, delivered 2019
- York Space Systems, deployable SA, STI PVA, launched 2019
- Vigoride, deployable SA, STI PVA ,delivered 2020
- Imece, deployable SA, STI PVA , delivered 2021
- NAOS, deployable SA, STI PVA, delivery 2022
- FLEX, deployable SA, STI PVA , delivery 2022
- ALTIUS, deployable SA, STI PVA, delivery 2022
- PLATO, body mounted SA, STI PVA, delivers 2023
- 8 Solar arrays for Copernicus HPCM: CHIME, CO2M, CRISTAL, LSTM,
- Airbus Oneweb Satellites , >300 solar panels, STI PVA, > 100 launched
- YORK, 10 plus 80 (Transport layer) SA, STI PVA, delivery 2021/22

GSTP In-Situ Process Monitoring for Solar Generator Manufacturing

Since 2018 STI applies own laydown process with ongoing improvement towards automation

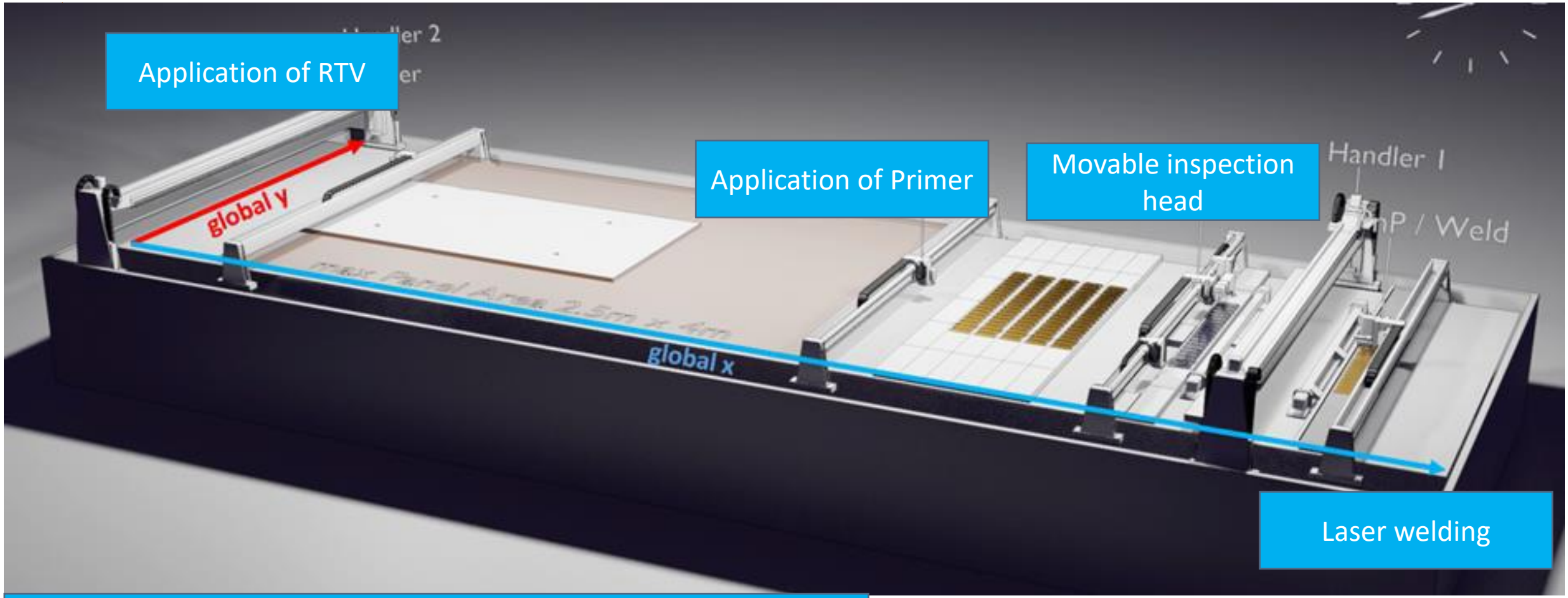
GSTP program linked to the PVA laydown (String of solar cell assembly to panel)

- to define and surveil process parameters
- build inspection head
- enable automated reporting
- verification of process with manufacturing and testing of a DVT - coupon

Goals of SpaceTech (STI)

- Innovative automated production line to provide competitive edge
- High quality/yield with tight control of process parameters
- Increase production capacity to serve large system integrator

PVA Assembly Line (PAL)



Fully automated stringing (28 Strings/day for 2.5 m x 4 m panels)

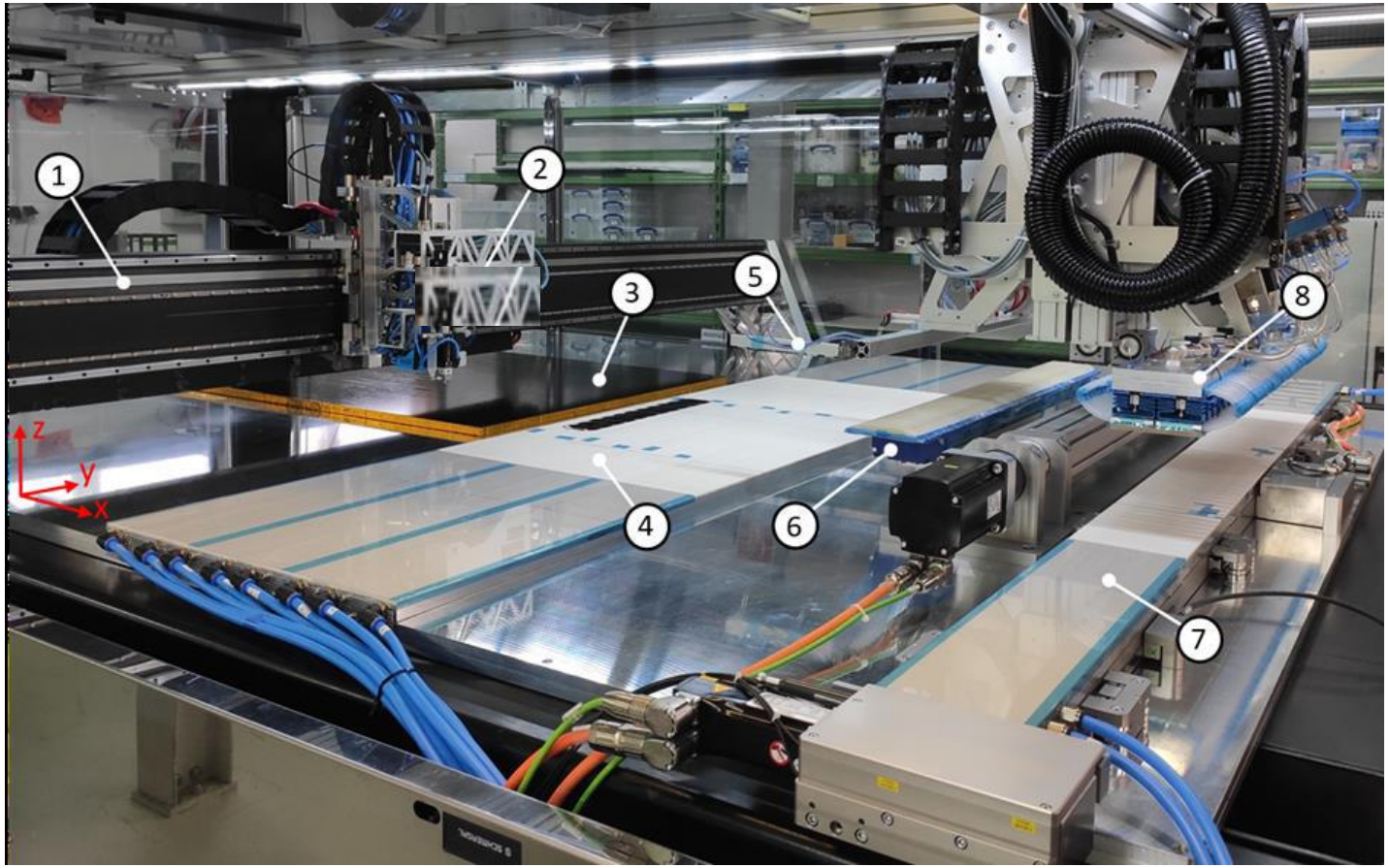
First laydown planned for July 2022

PVA Pilot Line

Currently main production line

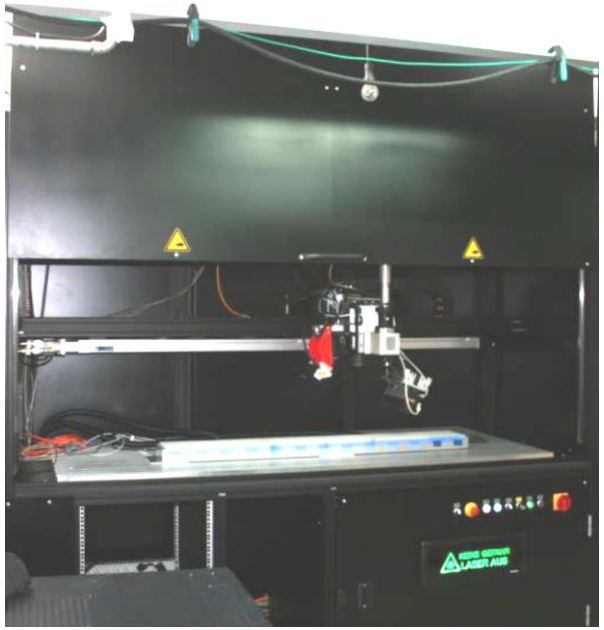
- **Max Panel Size: 2.5 x 4 m**

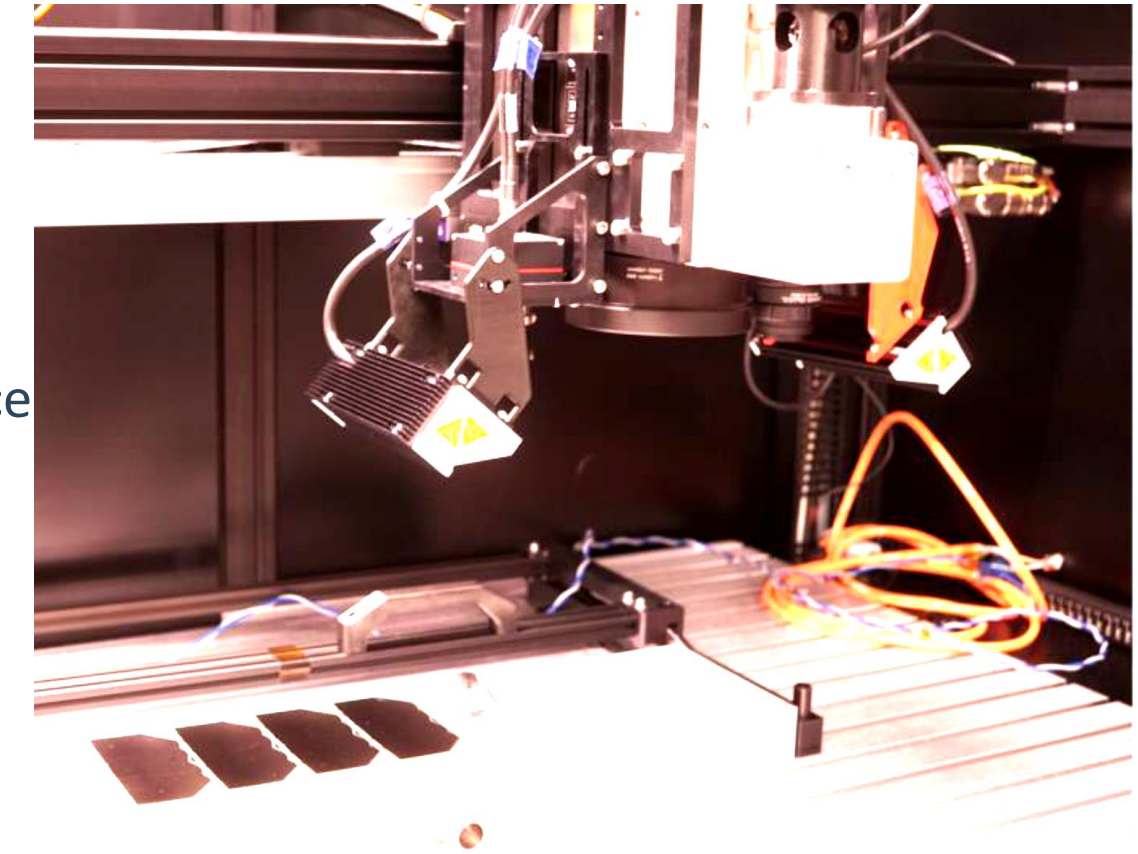
- **Portal (1)**
- **Inspection head (2)**
  - EL, 3D-Tasks, 2D Tasks
- **Solar panel (3)**
- **Buffer station (4)**
- **EL contacting unit (5)**
- **Flipper Unit (6)**
- **Input Station (7)**
- **Pick and Place Unit (8)**



Test Bench

- **Single Axis, travel range 1.5 m**
- **Incoming Inspection**
- **Testing of new methods**
  - All junction Electroluminescence/ Photoluminescence
- **Laser welding (not part of the activity)**





In Process Control Tasks

Processes	Analysis
▪ Incoming inspection of substrate	→ Check for defects/ flatness requirement within SCA-S
▪ Incoming inspection of (string of) solar cells	→ Rear-side inspection → Luminescence (ELM/ PL optional) → electrical integrity (ECD/ECC) → SCA-S alignment
▪ Applying of Adhesive	→ Volume/height of RTV – Dots → Location of Dots
▪ Gap between Cell and Substrate	→ Bonding of cell
▪ Alignment of SCA	→ Gap between adjacent cells (ESD risk)
▪ Final Defect detection	→ Photoluminescence

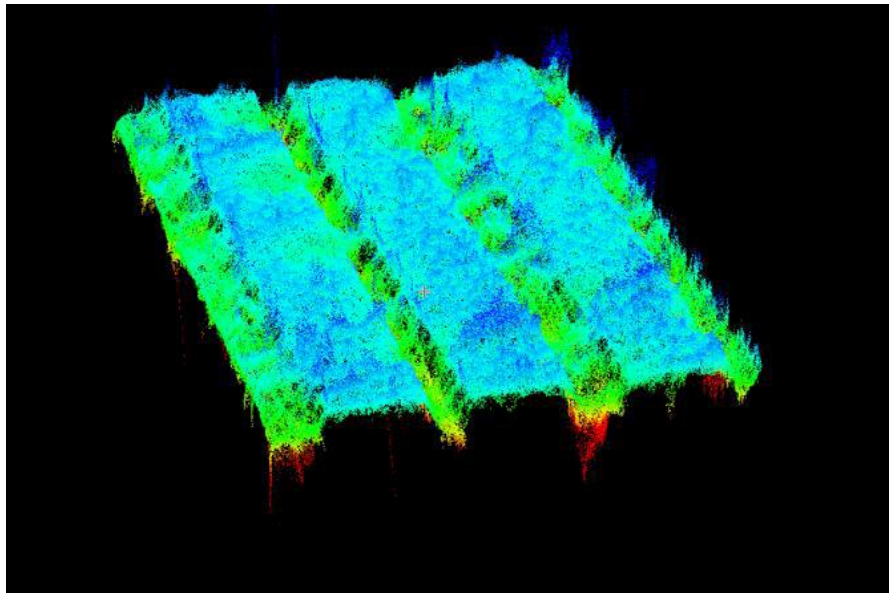
2D Analysis 3D Analysis

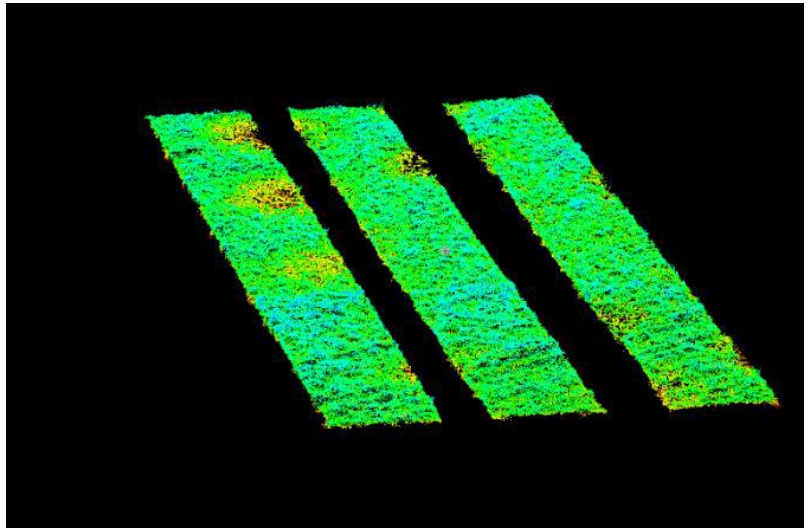
Sensors used in Inspection Head

- Two different sensor: 2D Senor & 3D Sensor
- Both of type line scan sensors
- Commercial sensor
- Home built analysis software
- Laser/LED Illumination
- Band pass filter
- Scanning speed approx. 10 m/min
- FOV adapted to largest cell dimensions
- Sub 100 µm resolution and accuracy (x,y,z)

Example of Computational Steps

- **Intrinsic and Extrinsic Camera Calibration**
  - →Results in „World Coordinate System”
- **Filtering of Data Points**
- **Image Stitching**
- **Analysis Tasks**
- **Speed Optimization**
  - **5s to 40s of 1m of SCA-S**





CFRP substrate image
Before/after filtering

Substrate Flatness (3D Task)

Goal:

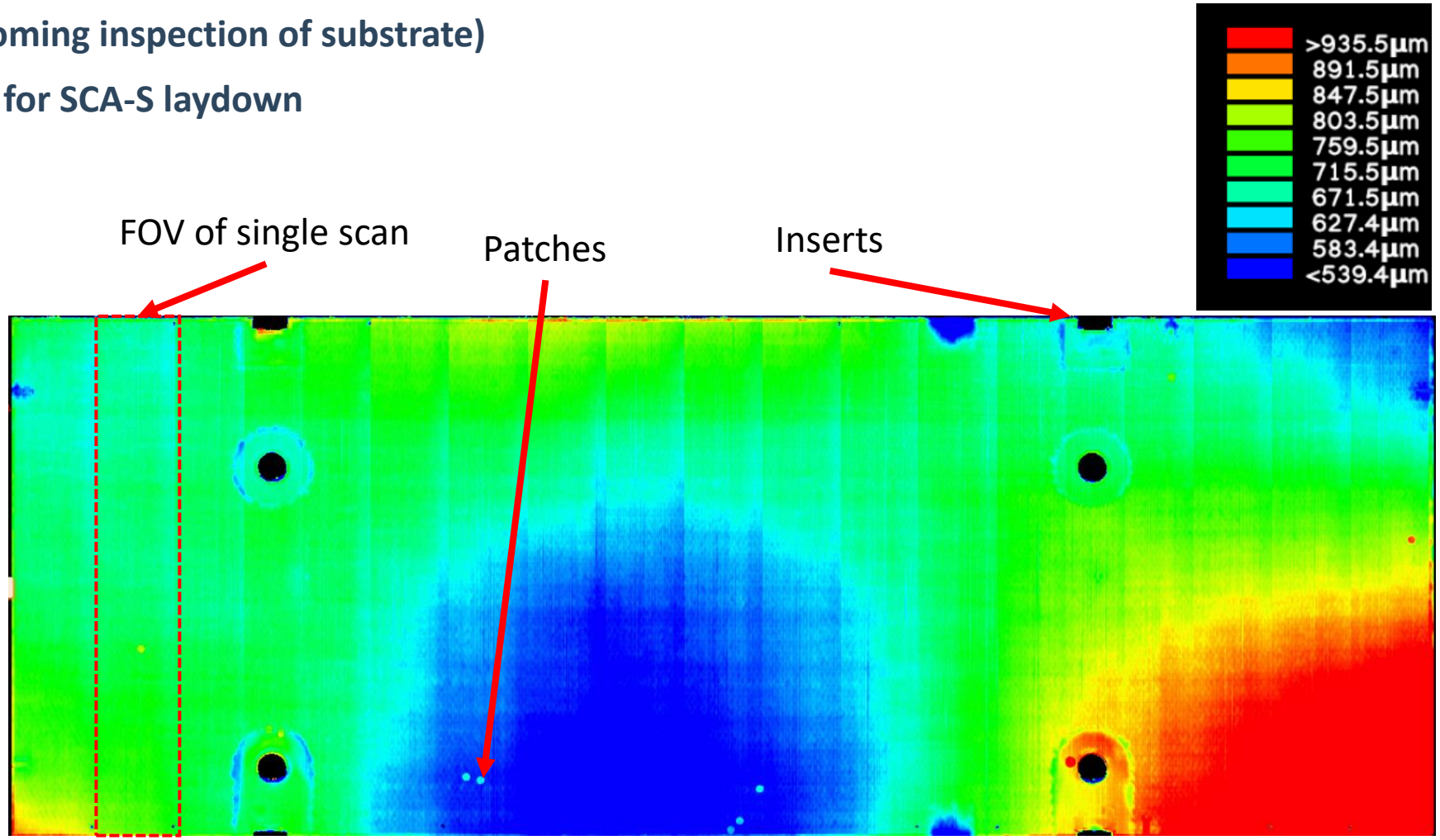
- Integrity of substrate (incoming inspection of substrate)
- Peak-Valley requirements for SCA-S laydown

Input:

- Peak-Valley requirements

Output:

- Acceptance report



Adhesive Checking (3D Task)

Goal:

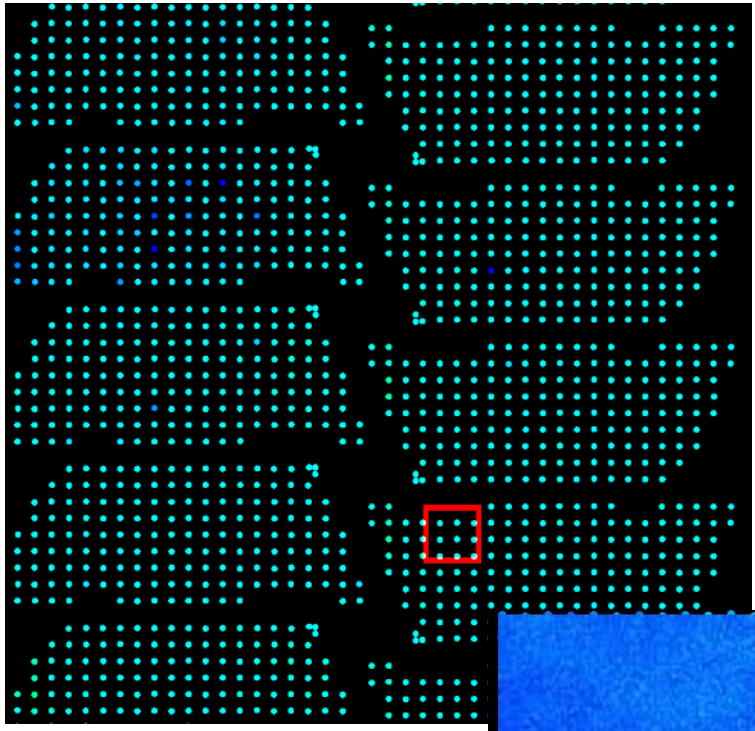
- Check position of RTV dots
- Verify height/volume of dots
- Particle alarm

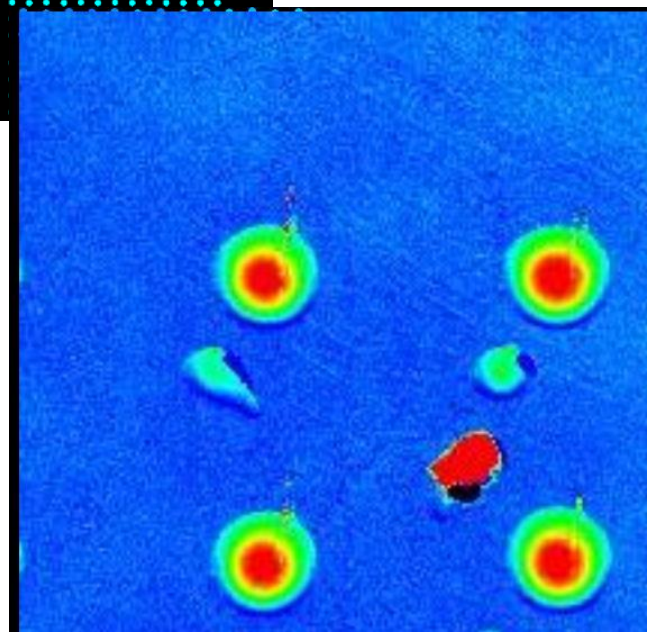
Input:

- Drawing of dot pattern

Output:

- Acceptance decision
- Statistic of Dots → used to counteract tool wear out





In Process Control Tasks

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▪ Alignment of SCA	→ Gap between adjacent cells (ESD risk)
▪ Final Defect detection	→ Photoluminescence

2D Analysis 3D Analysis

Adhesive Gap (2D Task)

Goal:

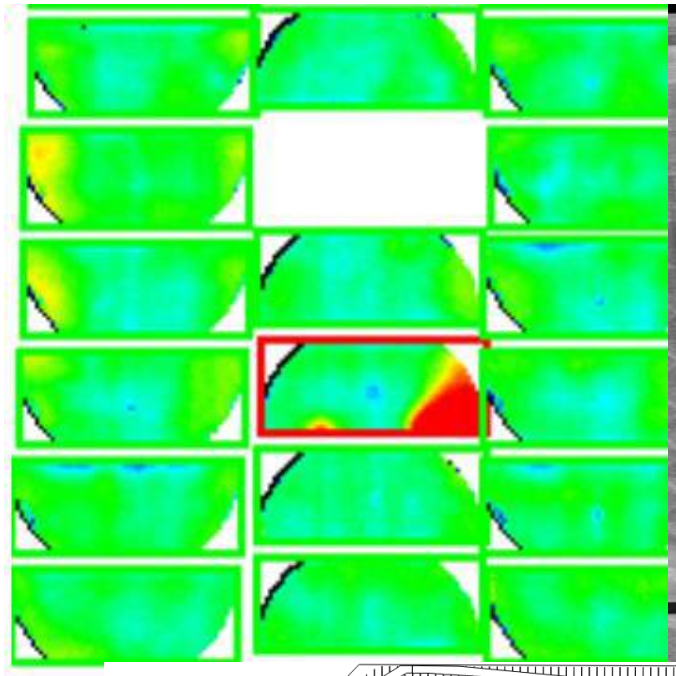
- Guarantee thermal and mechanical bonding
- Important in-line monitoring tool

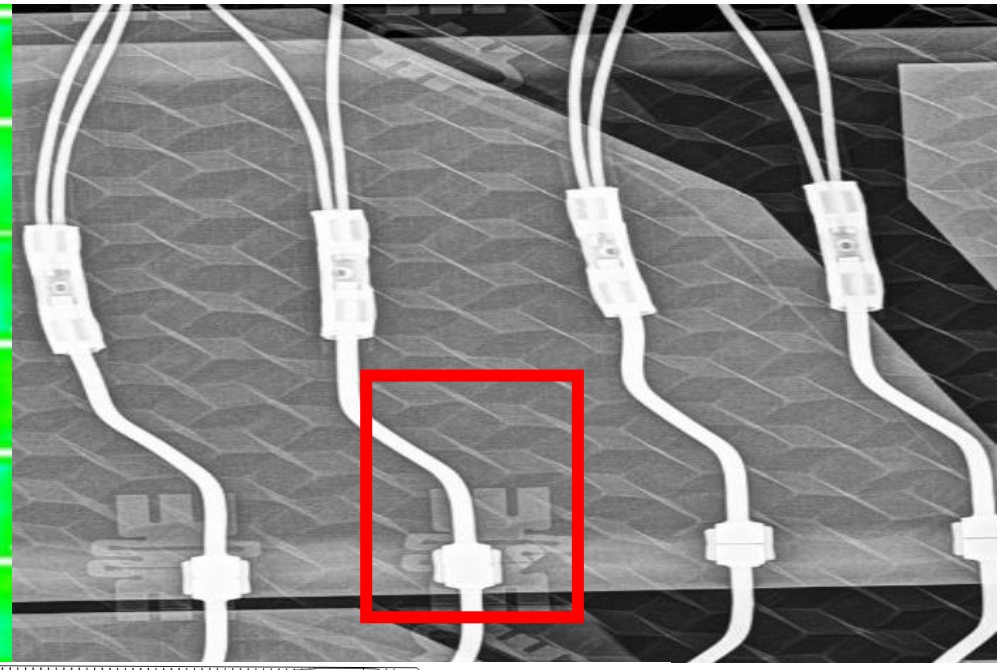
Input

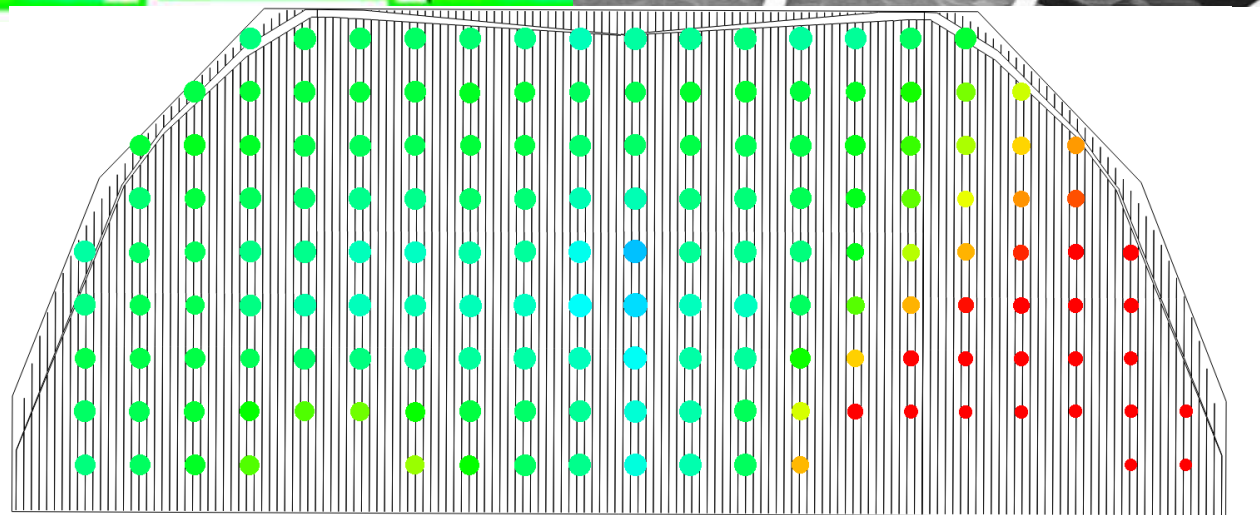
- 3D Image

Output

- Adhesive Gap map for PVA KIP







Alignment Monitoring (2D Task)

Alignment monitored twice:

- Before laydown → movement commands
- After laydown → ESD-risk

GOAL:

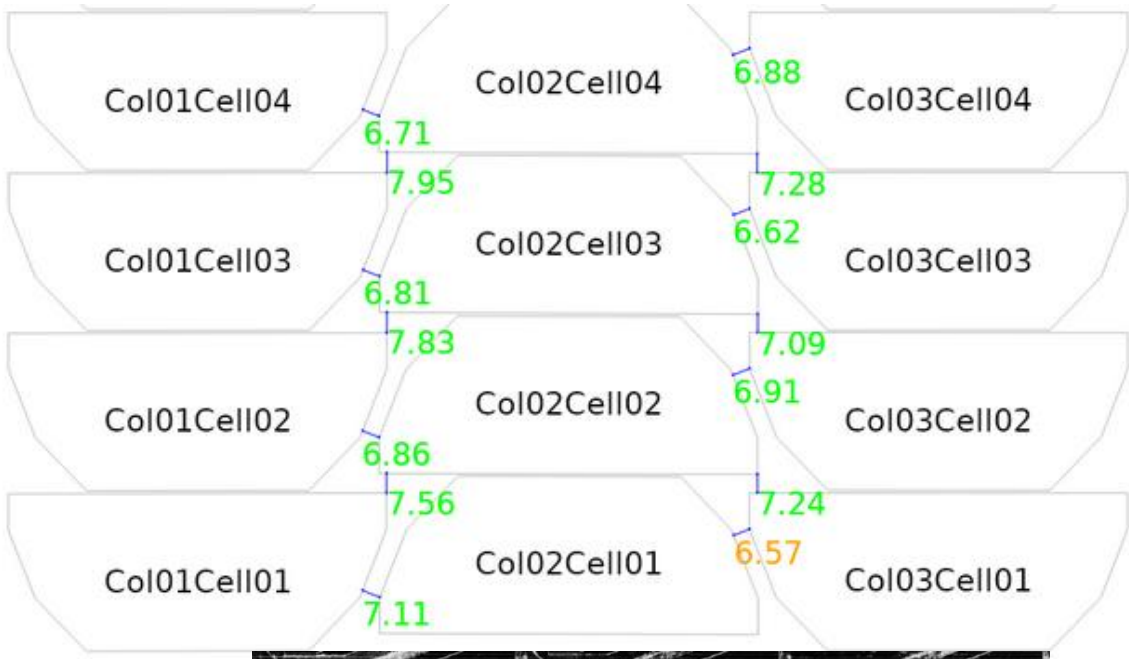
- Allow automated positioning
- Verify Requirements

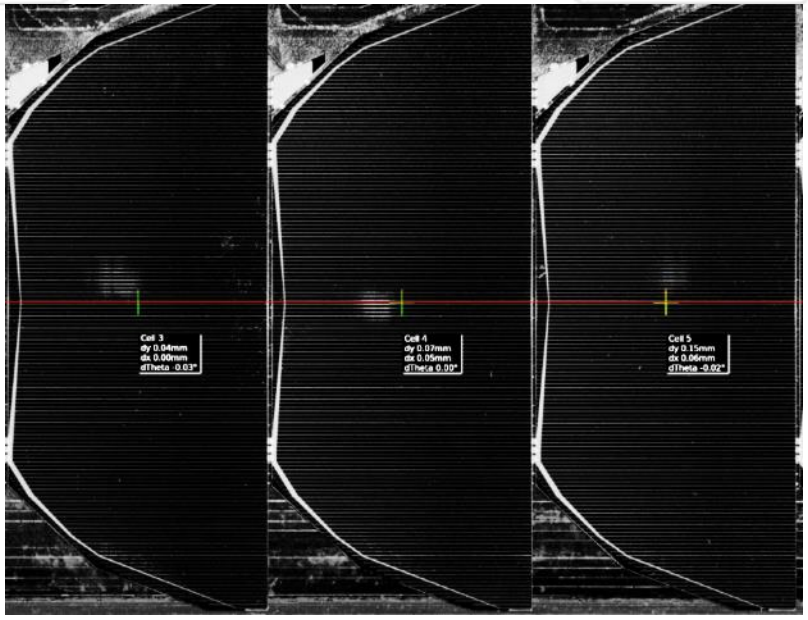
Input needed:

- Configuration of nominal SCA positions
- Drawing of the SCA
- High-resolution 2D image

Output:

- Location and angle of cell
- Distance to next neighbors (all directions)





Rear-side Inspection (2D Task)

GOAL:

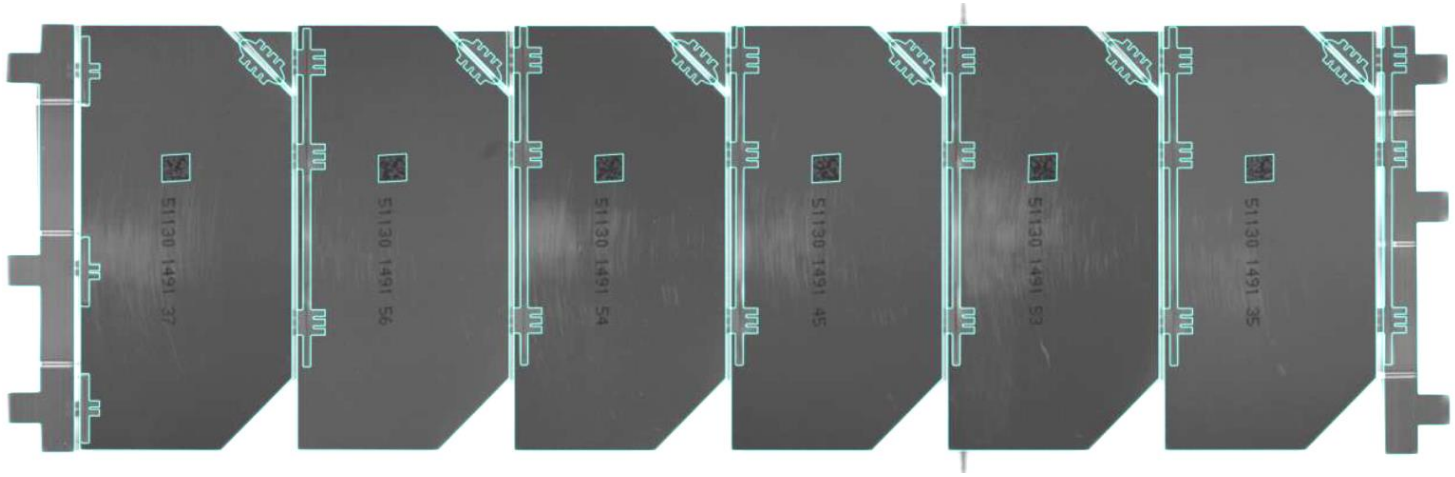
- Check for presence/positioning

Input needed:

- CAD – Drawings of Assembly
- High-resolution image

Output:

- Presence of component
- Delta position compared to nominal
- Score for shapematching
  → indicator of damage



```
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Cells  ID-06, 51130 1491 35

Presence inspection
  Component        |                Diode |   Diode_Interconnect |         Interconnect |
  Result           |                  1.0 |                  1.0 |                  1.0 |
  Score            |                 0.84 |                 0.90 |                 0.88 |
  Delta Position   |                0.417 |                0.178 |                0.208 |

----------
Presence inspection for bottom and top of string

  Component      |        Busbar_Bottom |           Busbar_Top | Universal_Inplane_Interconnect |
  Result         |                  1.0 |                  1.0 |                  1.0 |
  Score          |                 0.96 |                 0.95 |                 0.91 |
  Delta Position |                0.522 |                0.606 |                0.695 |

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String summary:

Overall string result: 1.0
```

In Process Control Tasks

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▪ Applying of Adhesive	→ Volume/height of RTV – Dots → Location of Dots
▪ Gap between Cell and Substrate	→ Bonding of cell
▪ Alignment of SCA	→ Gap between adjacent cells (ESD risk)
▪ Final Defect detection	→ Photoluminescence

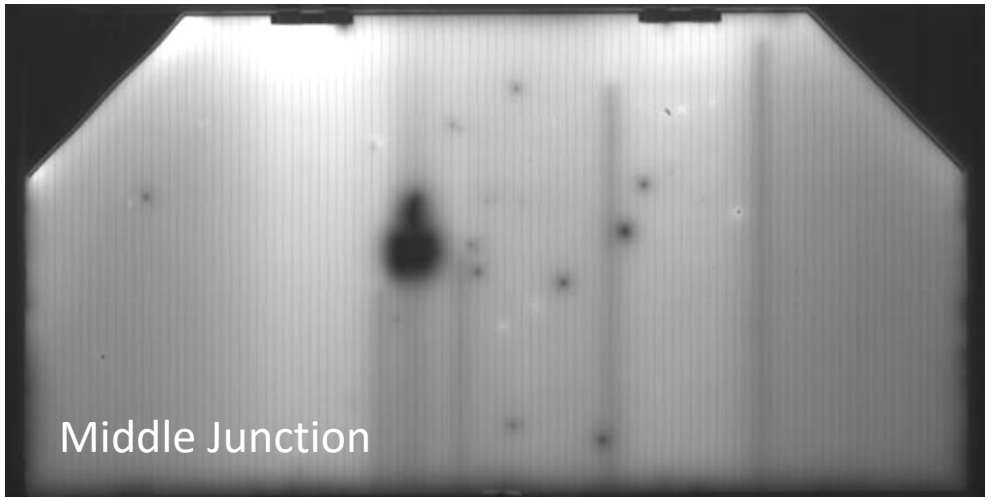
2D Analysis

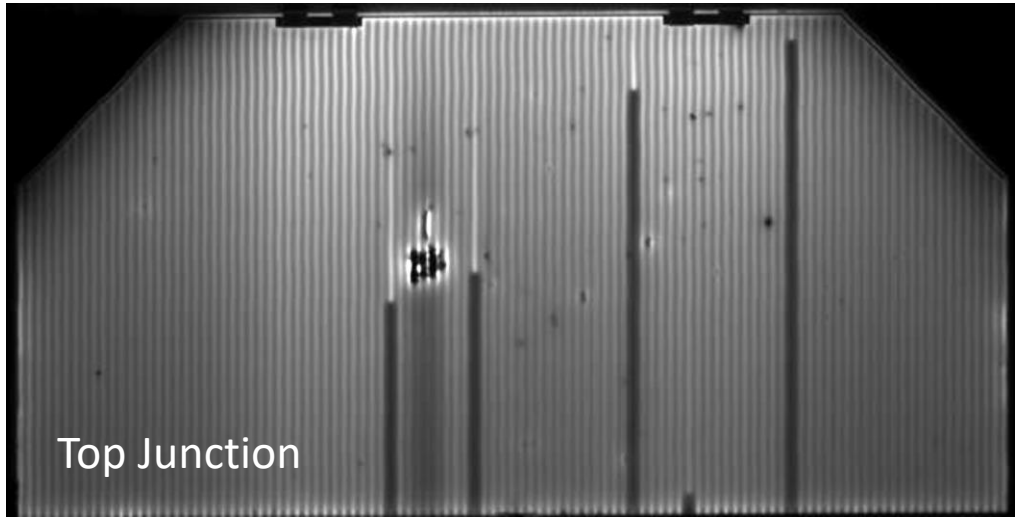
3D Analysis

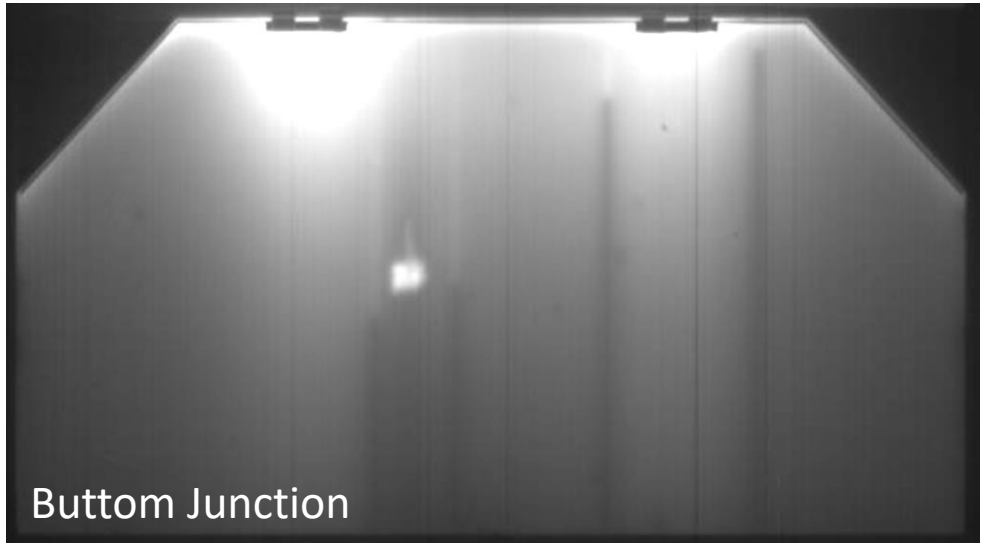
Luminescence (2D Task)

Developed Electro- and Photoluminescence on all 3 Junctions

- **Top + Middle Junction with silicon photonics**
  - High resolution
  - High speed
  - Baseline in Production Environment
- **Bottom junction with InGaAs photonics**
  - High resolution
  - Low speed
  - Implemented in Test bench

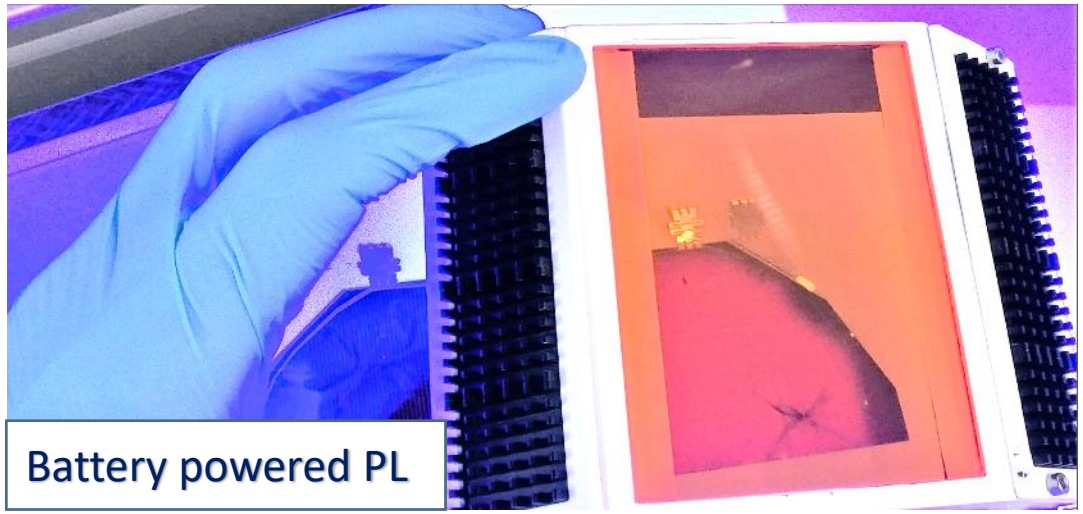




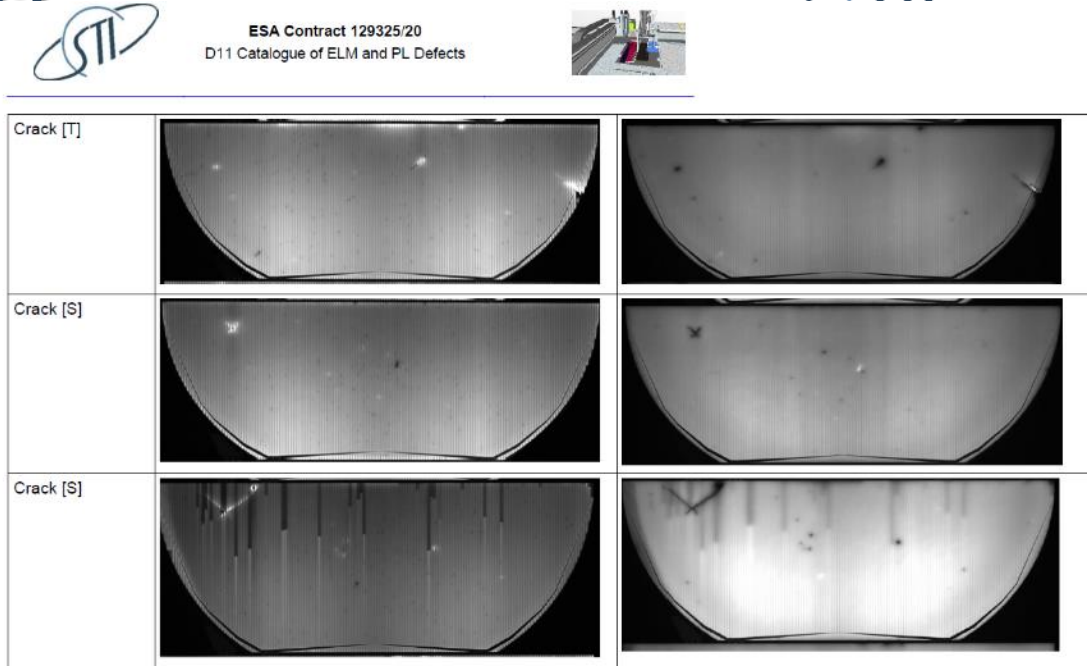


Electroluminescence vs Photoluminescence (i)

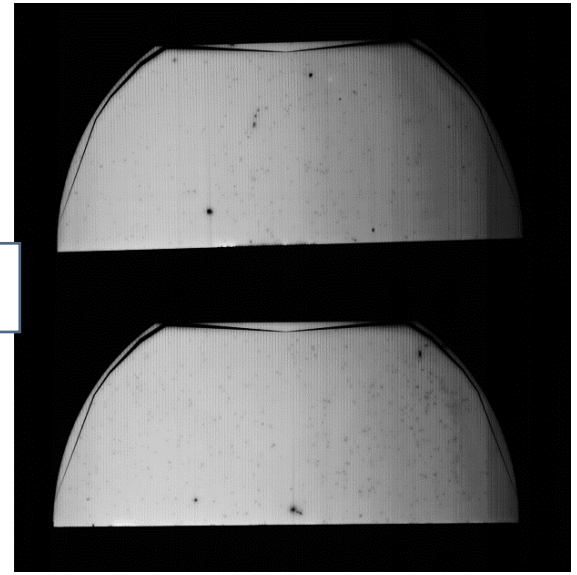
- **STI prefer Photoluminescence**
  - Contactless
  - Portable
  - Tendency to higher contrast
- **Issues related to manufacturing**
  - In particular cracks / shunts visible in both EL and PL
- **Verification on-going**
  - Defect catalogue
  - Ongoing implementation in series manufacturing



Battery powered PL

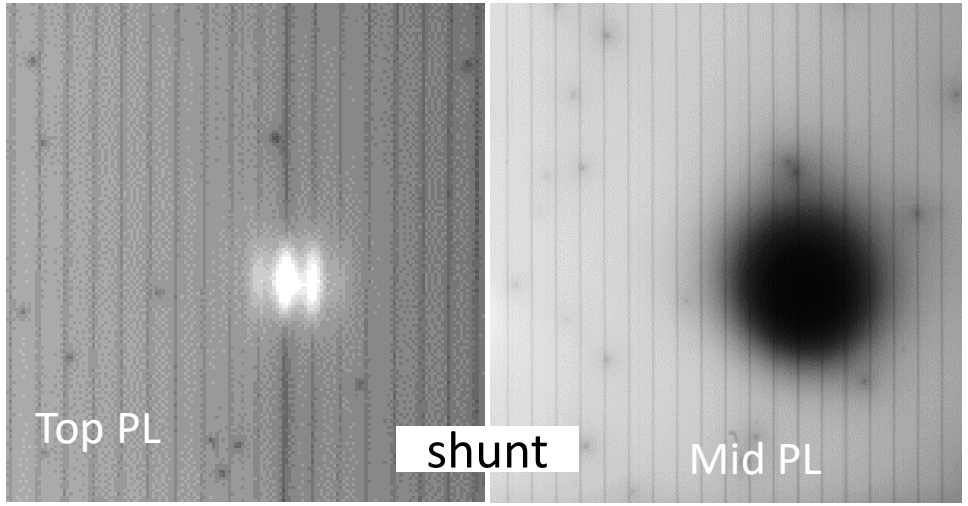


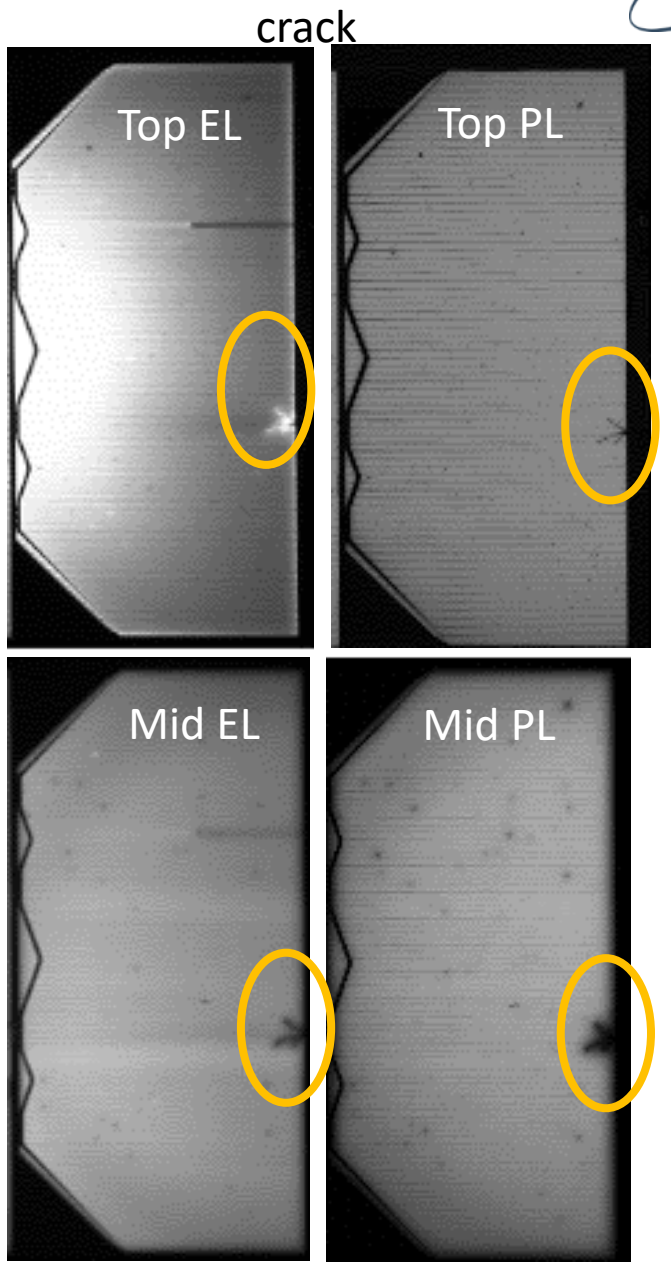
SCA Incoming



Electroluminescence vs Photoluminescence (ii)

- **STI prefer Photoluminescence**
  - Contactless
  - Portable
  - Tendency to higher contrast
- **Issues related to manufacturing**
  - In particular cracks / shunts visible in both EL and PL
- **Verification on-going**
  - Defect catalogue
  - Ongoing implementation in series manufacturing





Machine Vision Defect Detection

GSTP2 compare cell images

Result comparison path: /home/sysgen/NSSA/Projects/2021_OneWeb_Tes

Log created on 2021-03-29 17:36:41,181 by LumiCompareImages 0.2

ref:03_PreLaydown	05_PostLaydown
TDBC9999_0000 0000 01_EL-BP650	OK
TDBC9999_0000 0000 01_PL-BP650	OK
TDBC9999_0000 0000 02_EL-BP650	OK
TDBC9999_0000 0000 02_PL-BP650	OK
TDBC9999_0000 0000 03_EL-BP650	OK
TDBC9999_0000 0000 03_PL-BP650	DEFECT
TDBC9999_0000 0000 04_EL-BP650	DEFECT
TDBC9999_0000 0000 04_PL-BP650	DEFECT

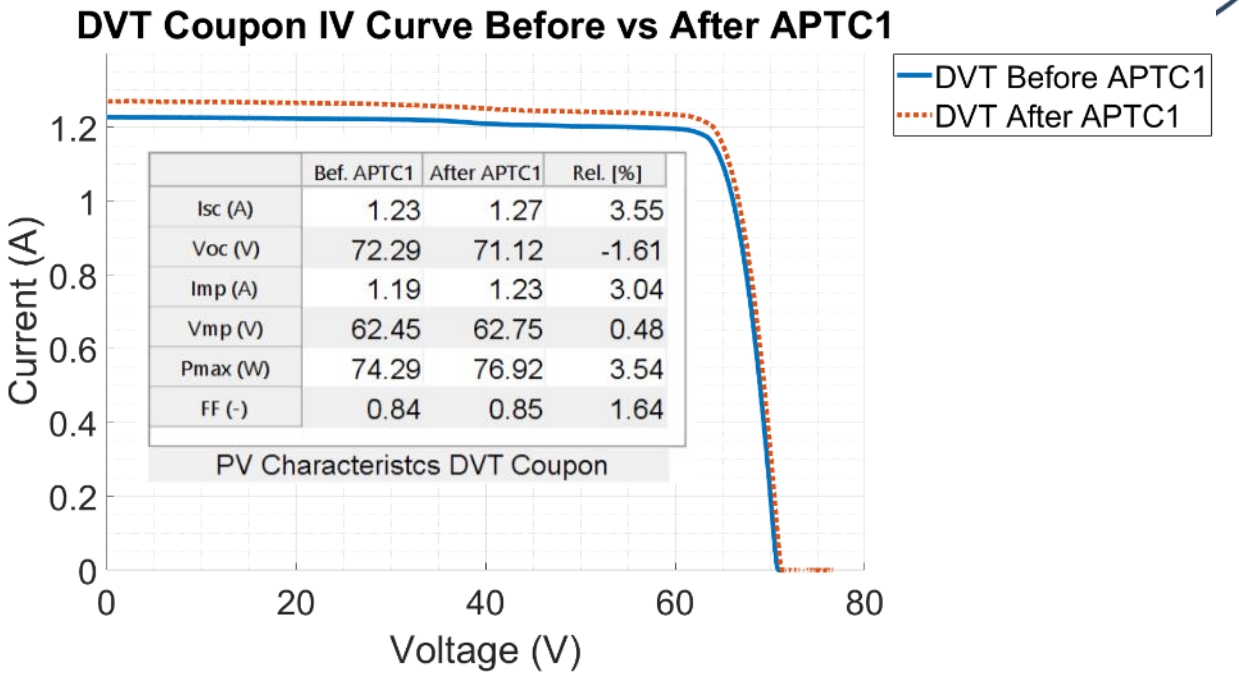
- Segmentation of images with px accuracy
- Machine vision based defect detection

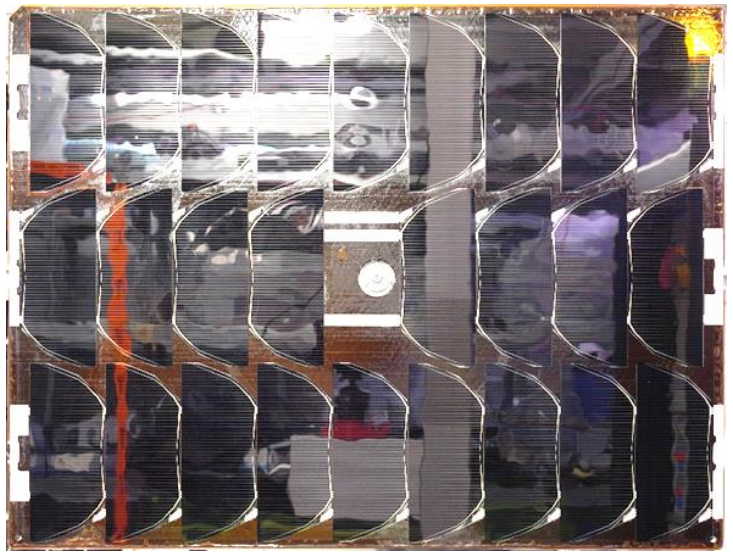
DVT Coupon

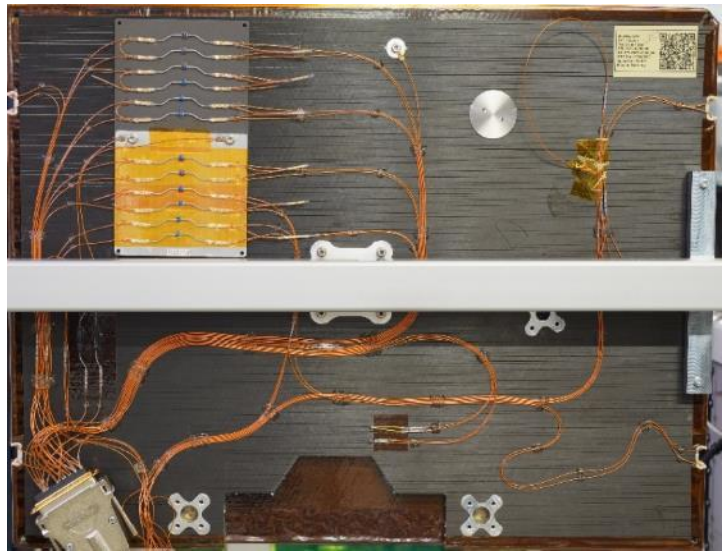
Built with automated process

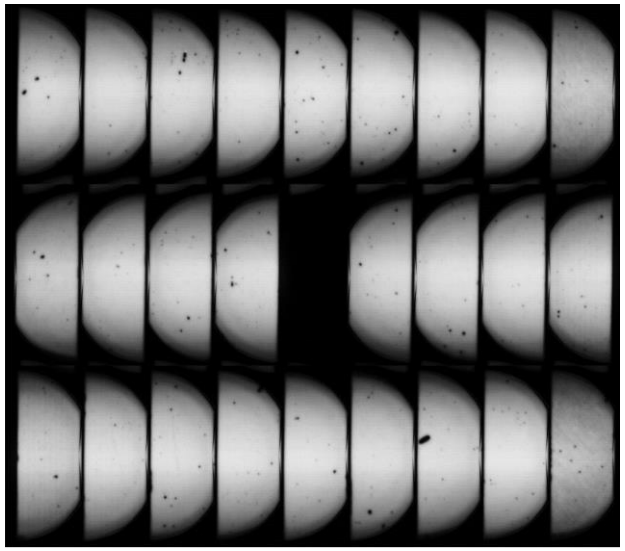
- TV Cycling
- APTC
- Electrical performance

→ Coupon is fine and healthy









Conclusion & Outlook

- **Implementation innovative in-line monitoring process**
  - →High Yield, high quality
- **Dedicated Software development**
  - Analysis
  - Reporting
  - Configuration management
- **Verification with DVT Coupon**
- **Since then series production of >200 m^2 manufactured SAPs**

Outlook

- PAL to be put into operation, increase max throughput by 4
- Laser welding (2022, supported by ARTES 4.0 activity, DVT)

Fin

Thanks to colleagues of ESA for the support

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Questions?

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Thank you very much for your attention!

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