AUSTRIAN INSTITUTE OF TECHNOLOGY

THE RISE OF AI-DRIVEN VISUAL INSPECTION: STREAMLINING PROCESSES AND ENHANCING QUALITY

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Complex Dynamical Systems
Dr. Glück

High-Performance Vision Systems
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Digitrans best answers for future transport
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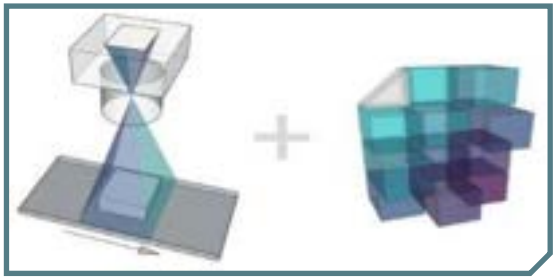
HIGH-PERFORMANCE VISION SYSTEMS

RESEARCH FIELDS

High-speed Sensing

- High-performance camera and illumination concepts and systems
- High-speed sensing concepts

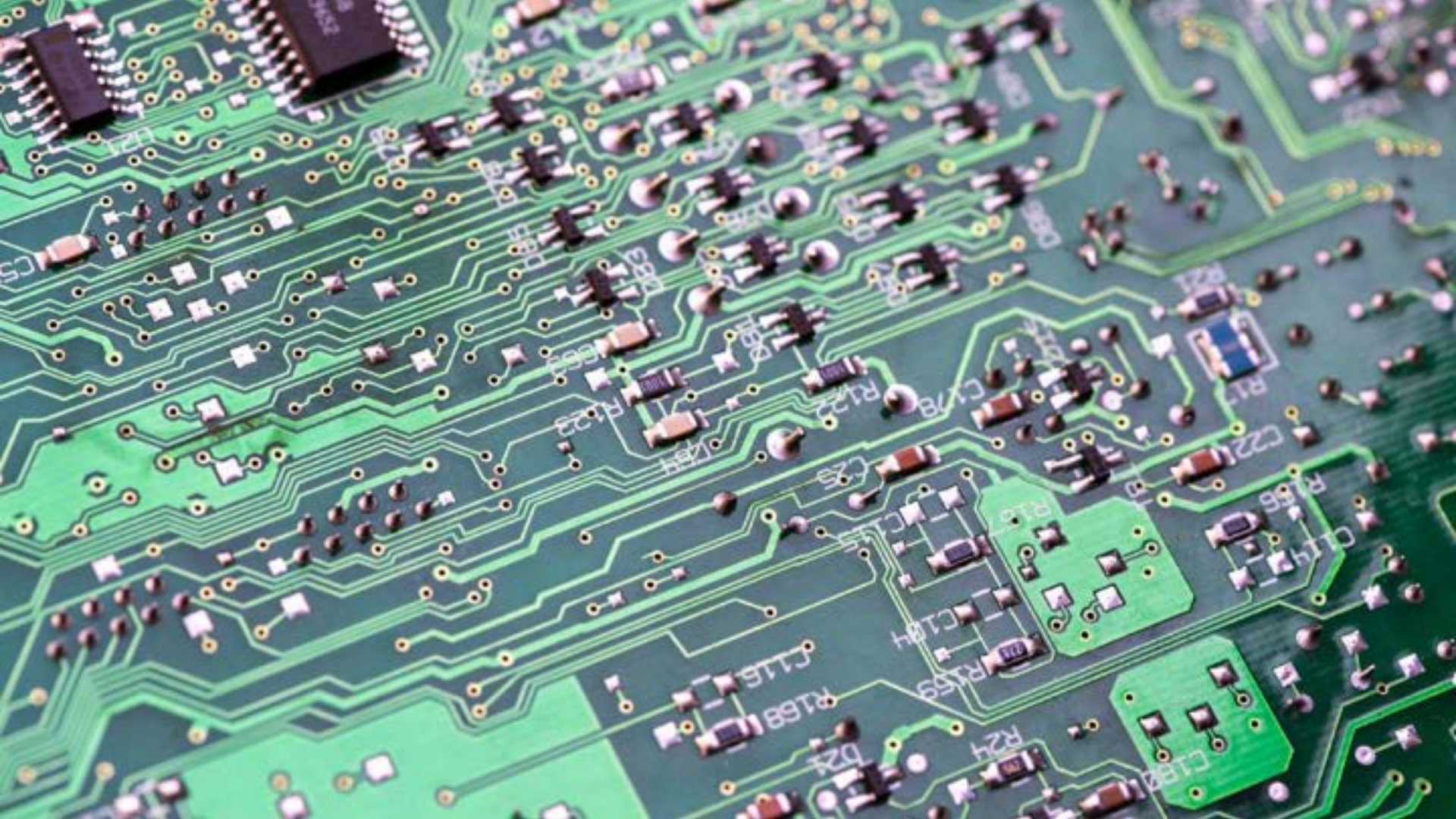


Inline Computational Imaging

- Simultaneous 2D & 3D Imaging
- High-performance algorithms for 3D reconstruction and image enhancements

AI-based Inspection

- Vision + Computation + AI Combination of model-based and data-driven learning
- Semantic segmentation



Predicted Text: 17313NH14215C21801

IMAGE PROCESSING

Contrast Enhancement

Noise Reduction

IMAGE PROCESSING

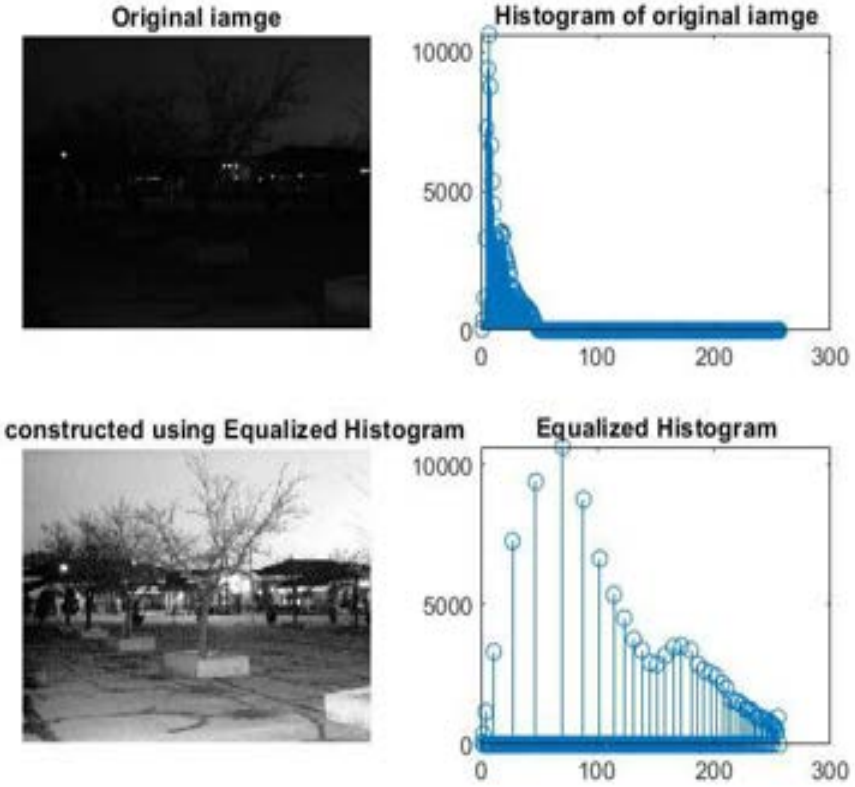
Blur

Sharpen

Lights and Shadows

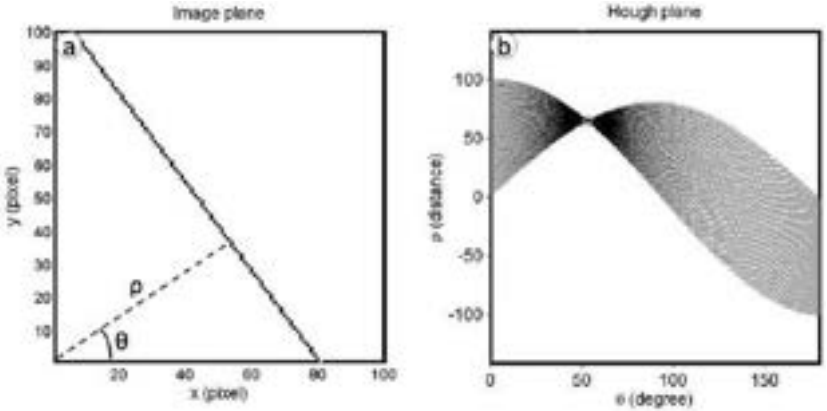
IMAGE PROCESSING

Histogram
Equalization

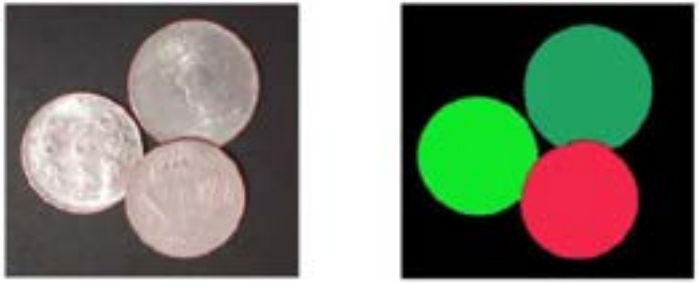


FEATURES DETECTION

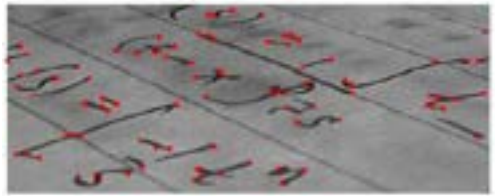
Edge



Blob



Line

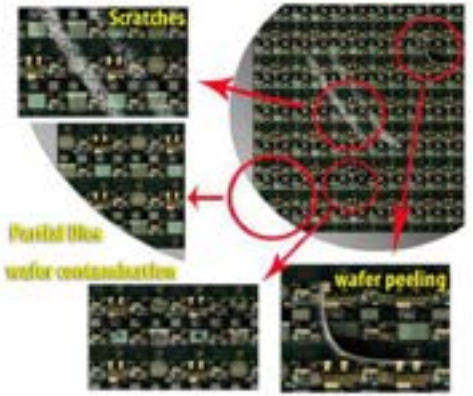


Corner

VISUAL INSPECTION

Identify defective products on your assembly line

Inspect automobile parts for defects

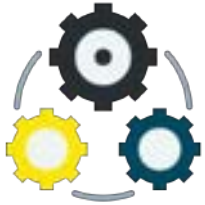


Detect defects on VLSI Wafers

MACHINE VISION

Accuracy and precision

Speed



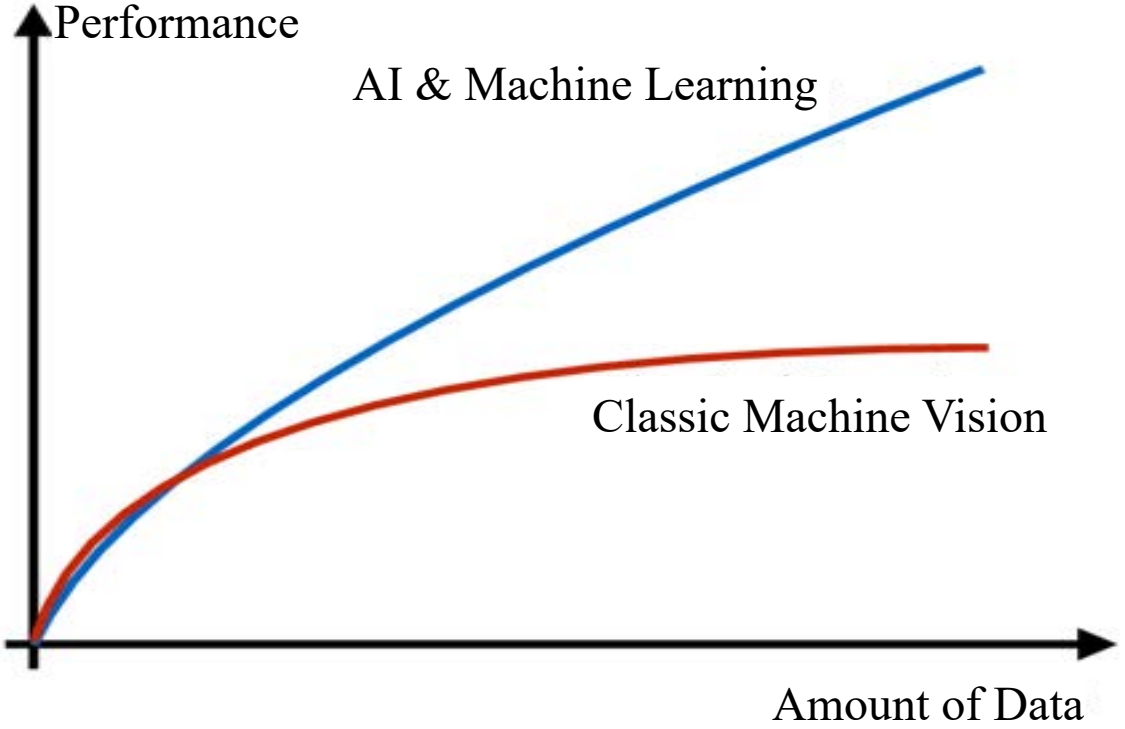
Efficiency

Improved quality

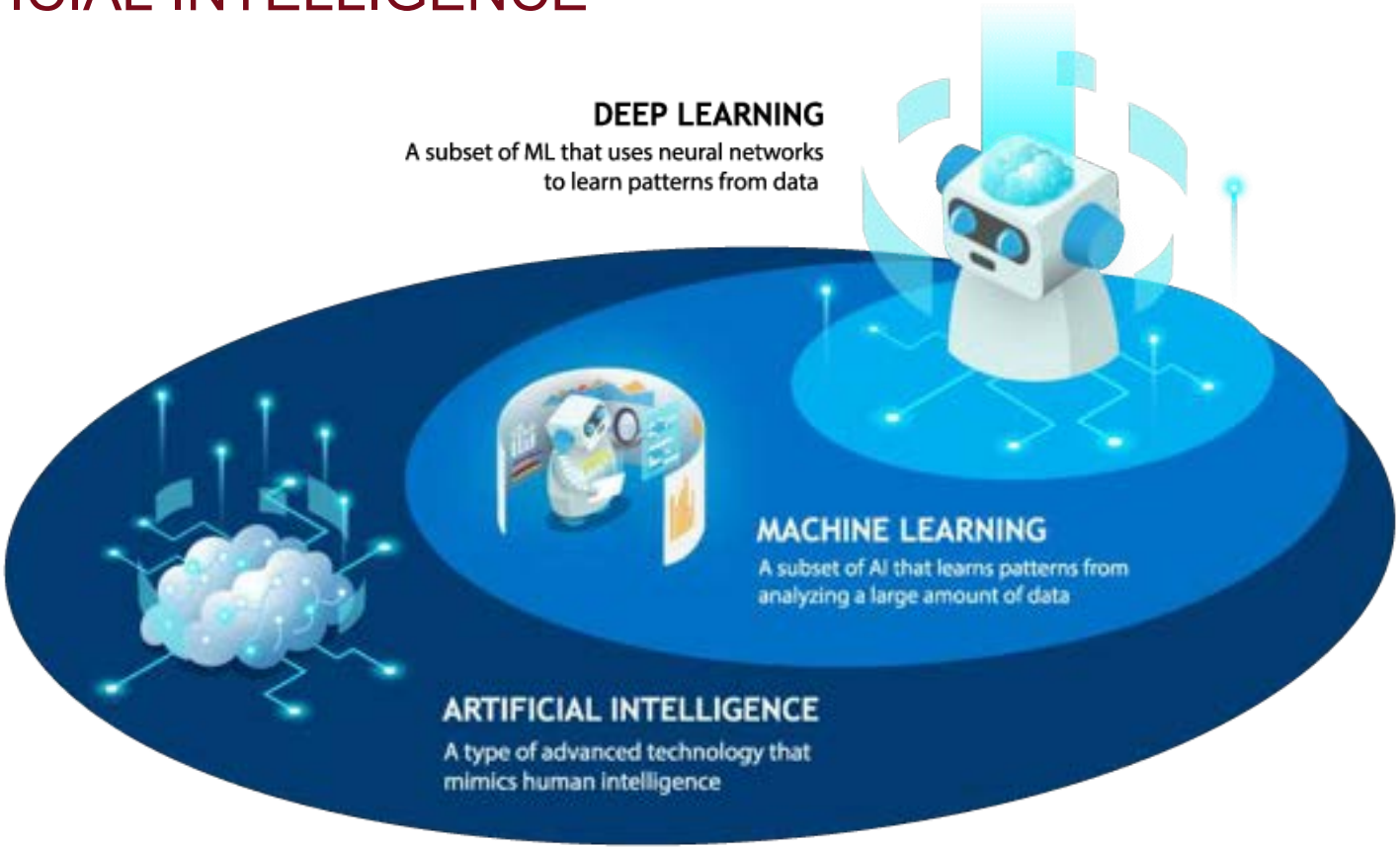
Safe and stable

Cost reduction

CLASSIC MACHINE VISION LIMITATIONS



ARTIFICIAL INTELLIGENCE



THE PIONEERS OF AI

Warren McCulloch and Walter Pitts

A Logical Calculus of Ideas Immanent in Nervous Activity (1943)

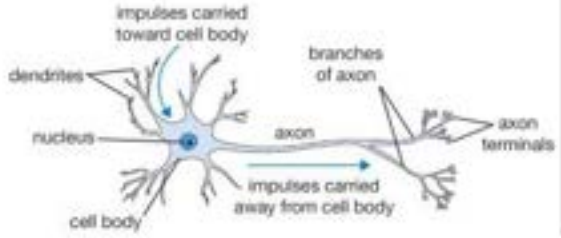
→ Describing the with a mathematical model the behavior of biological neurons

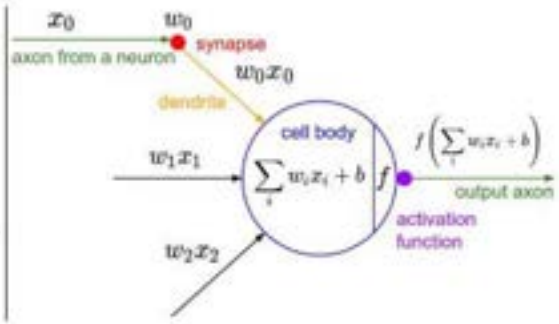
Frank Rosenblatt

The Perceptron - a perceiving and recognizing automaton (1957)

1st computational use of a Neuron (perceptron)

Neuron

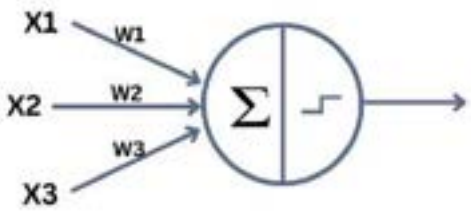




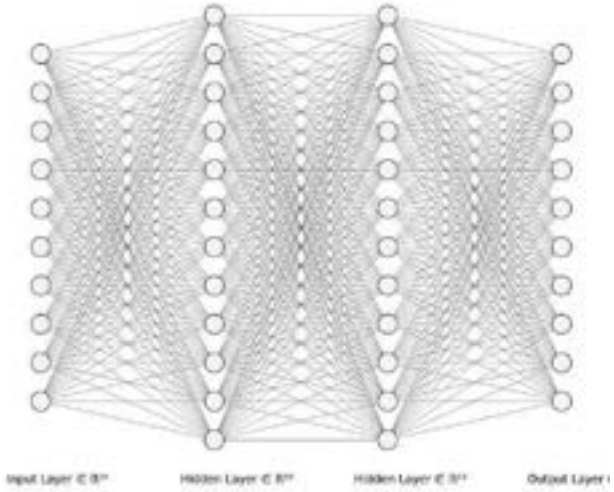
Perceptron

THE FATHER OF AI

- Geoffrey E. Hinton (1986)



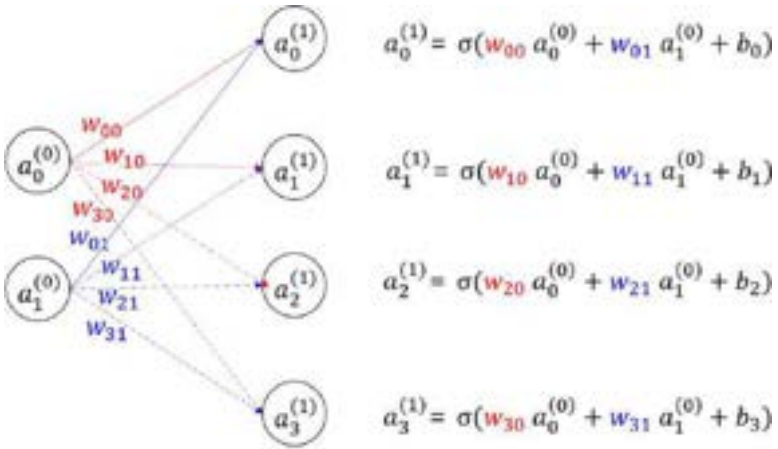
Single-layer perceptron



Multi-layer perceptron

ARTIFICIAL NEURAL NETWORK

Connection



$$a_0^{(1)} = \sigma(w_{00}\, a_0^{(0)} + w_{01}\, a_1^{(0)} + b_0)$$

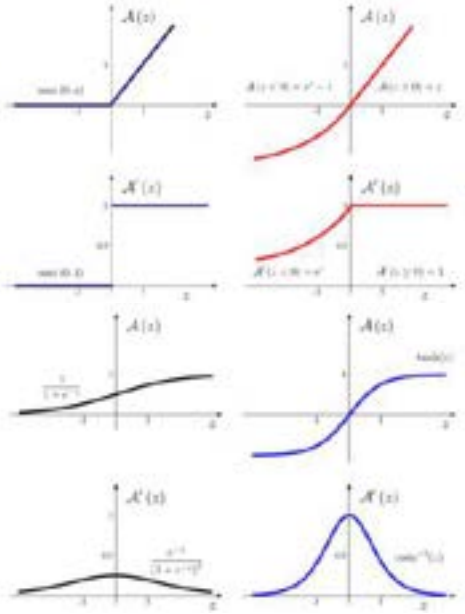
$$a_1^{(1)} = \sigma(w_{10}\, a_0^{(0)} + w_{11}\, a_1^{(0)} + b_1)$$

$$a_2^{(1)} = \sigma(w_{20}\, a_0^{(0)} + w_{21}\, a_1^{(0)} + b_2)$$

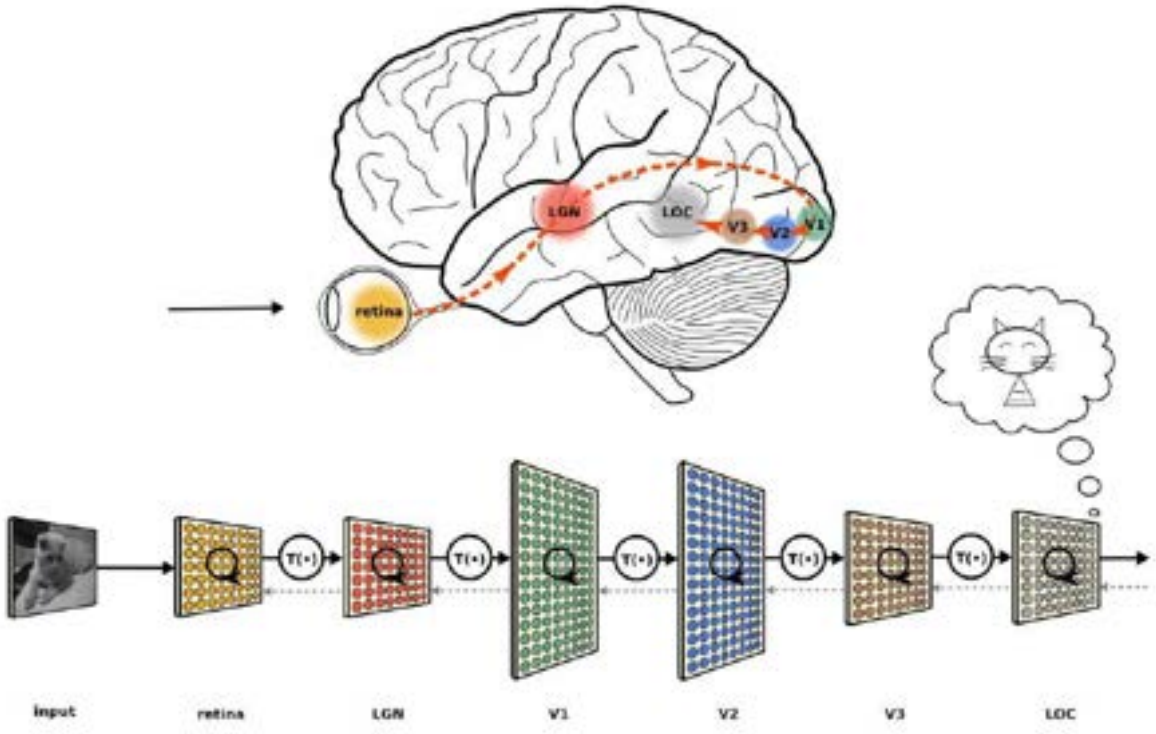
$$a_3^{(1)} = \sigma(w_{30}\, a_0^{(0)} + w_{31}\, a_1^{(0)} + b_3)$$

$$a_j^{(l)} = \sigma\left(\sum_{i=1}^{N_{l-1}} w_{ji}\, a_i^{(l-1)} + b_j\right)$$

Activation

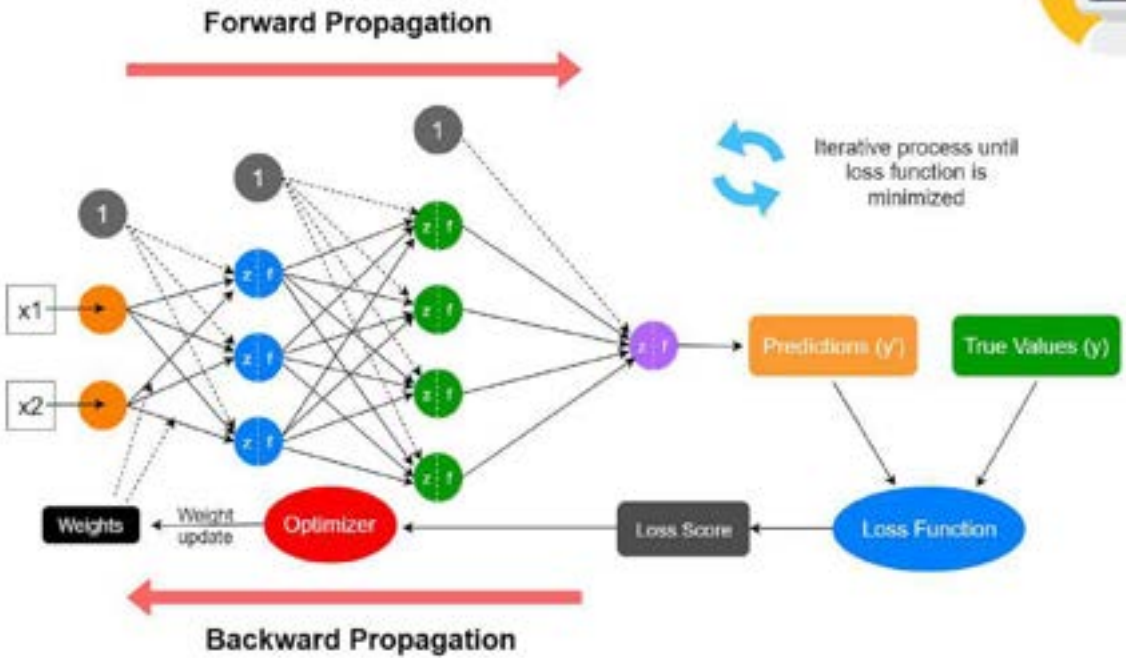


ARTIFICIAL NEURAL NETWORK

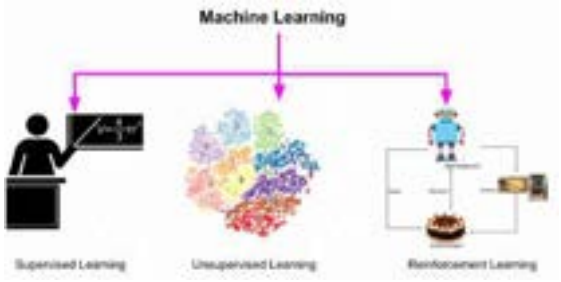


Lateral geniculate nucleus

HOW DOES IT LEARN?

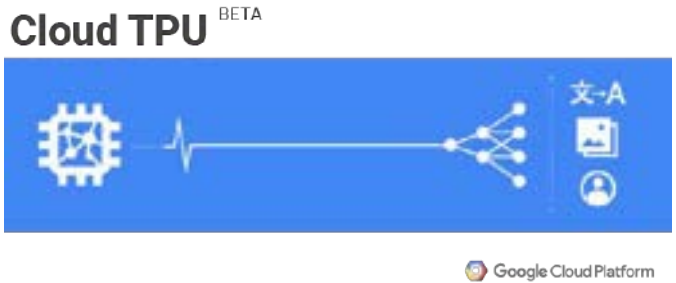


TYPES OF LEARNING



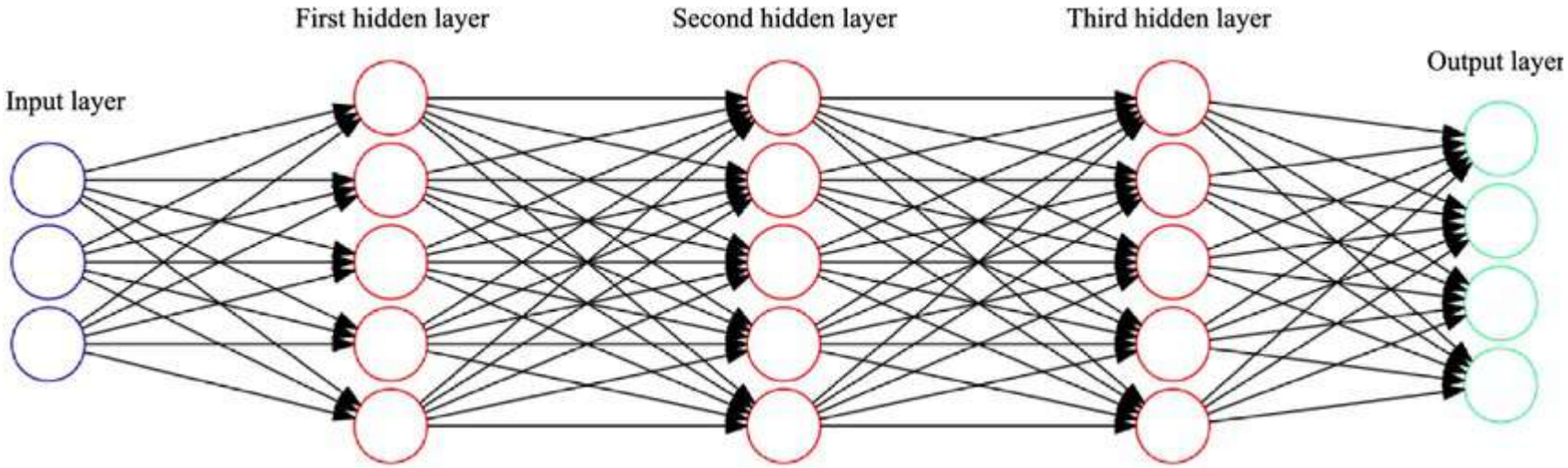
HARDWARE ACCELERATION

- CPU
- GPU
- TPU
- Outsourcing clusters



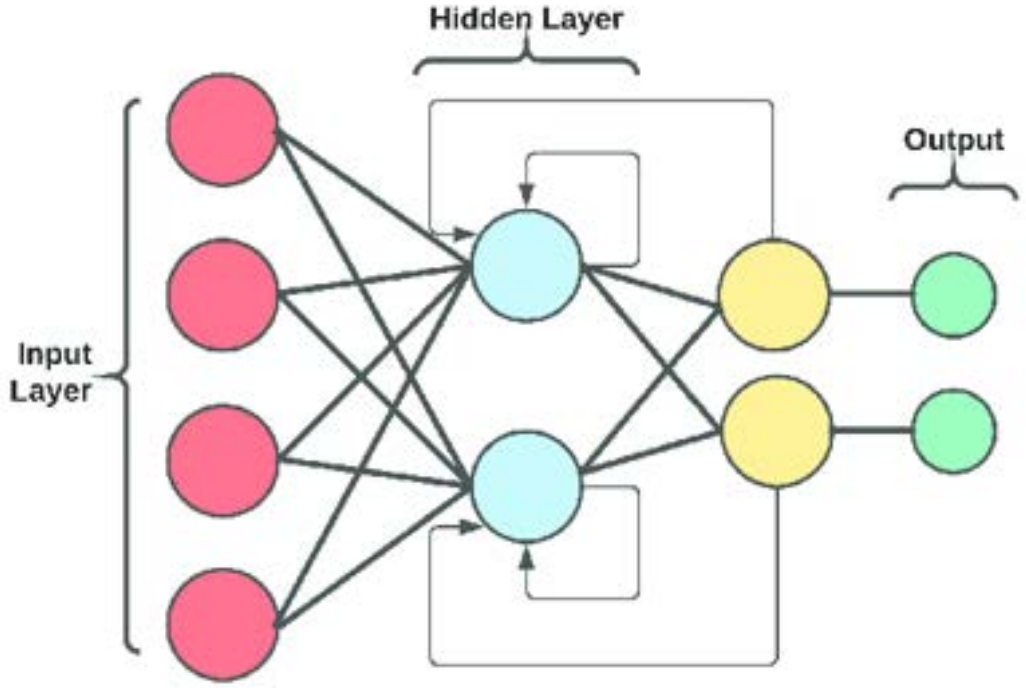
ANN ARCHITECTURES

Fully-connected networks



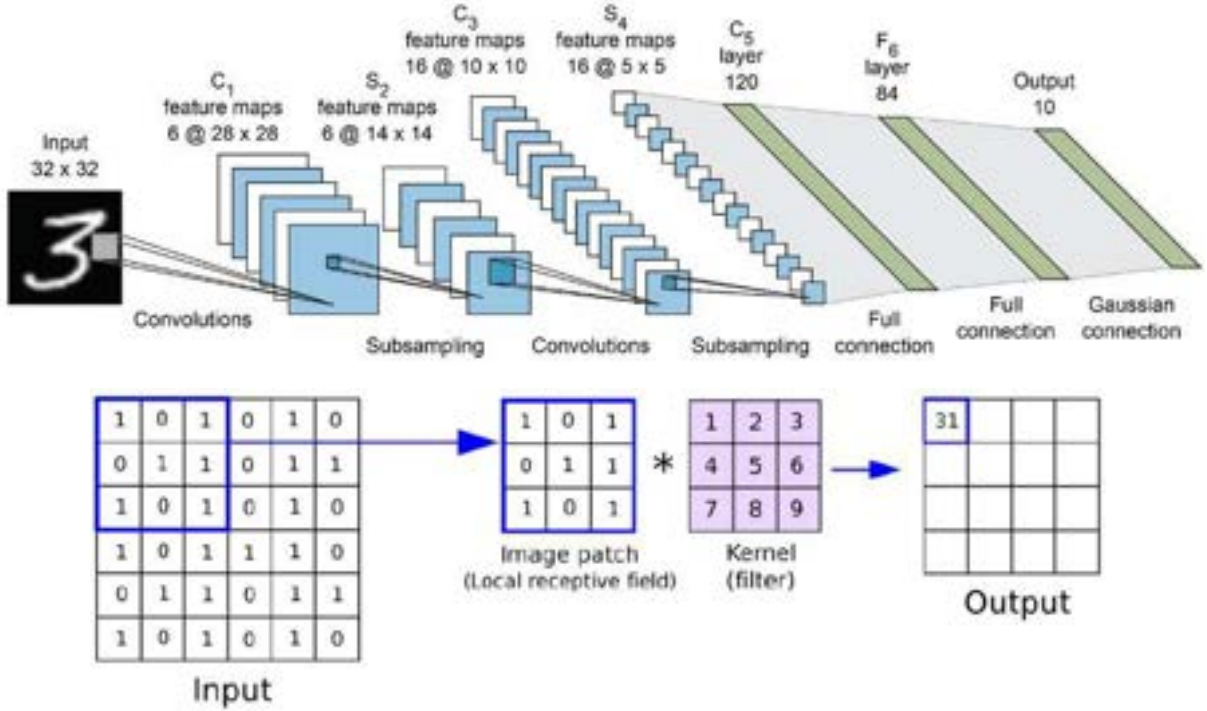
ANN ARCHITECTURES

Recurrent neural networks



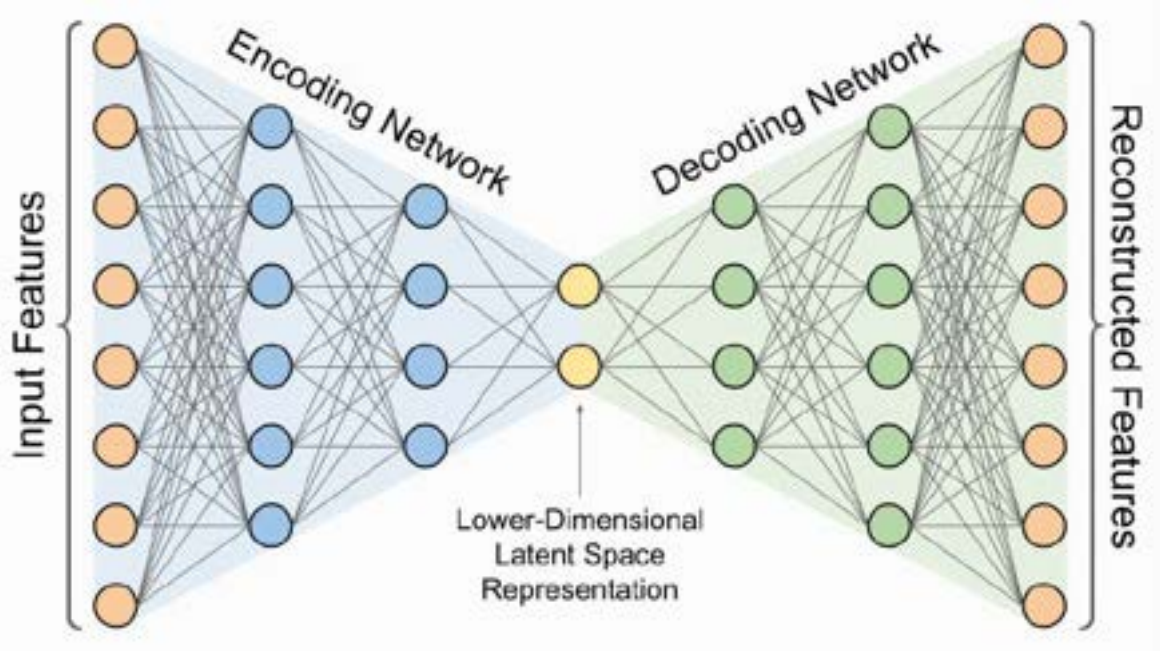
ANN ARCHITECTURES

Convolutional networks



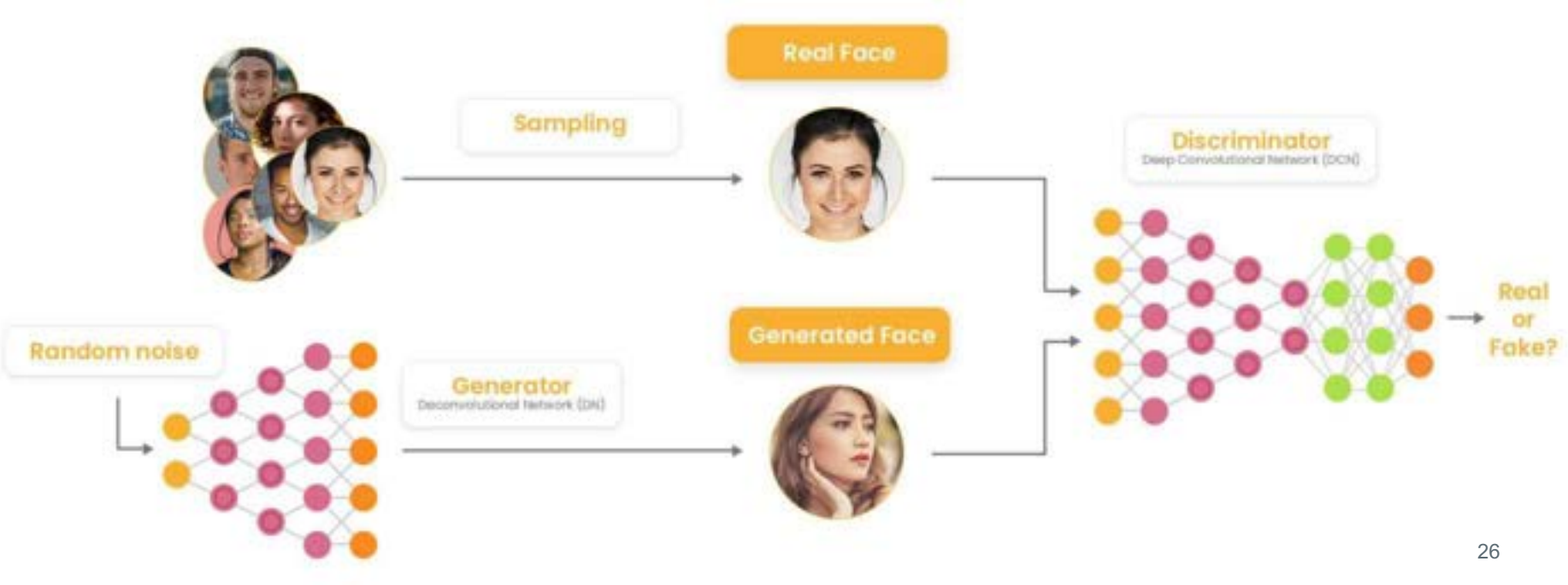
ANN ARCHITECTURES

Auto-encoders



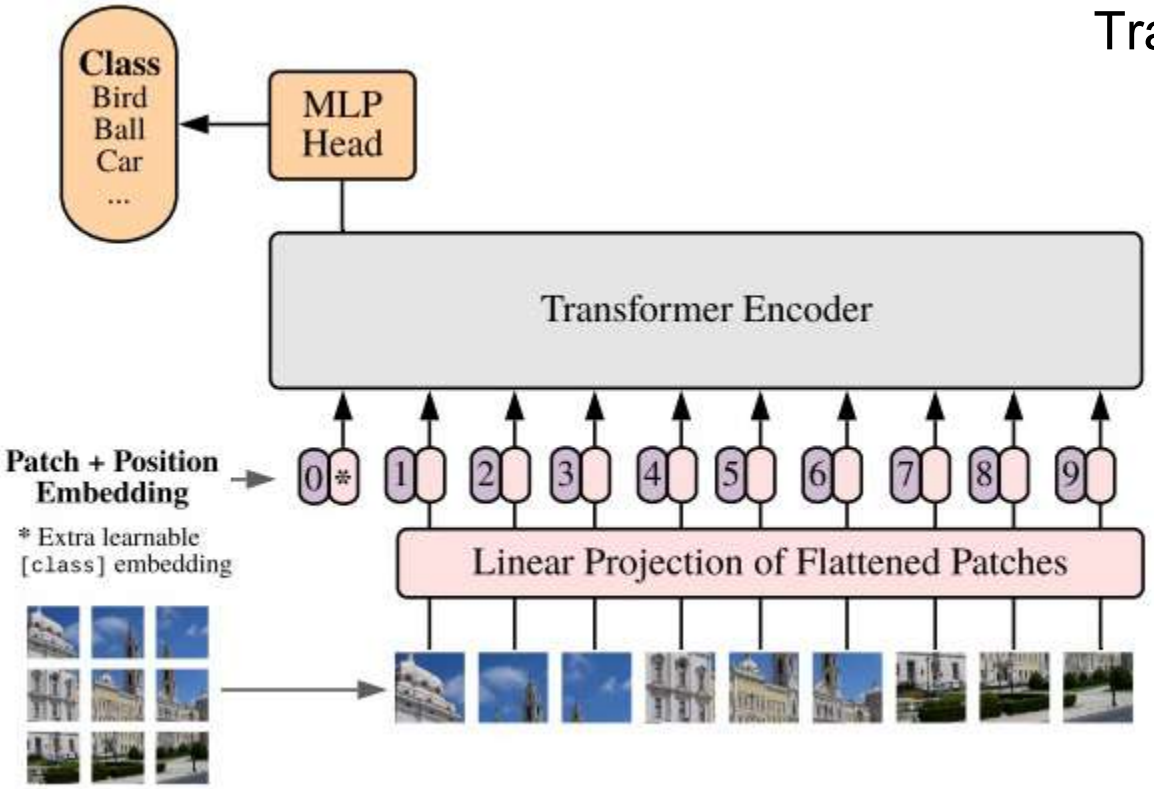
ANN ARCHITECTURES

Generative Adversarial Networks

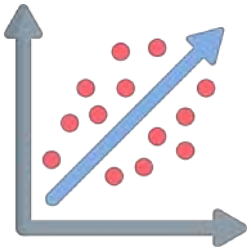


ANN ARCHITECTURES

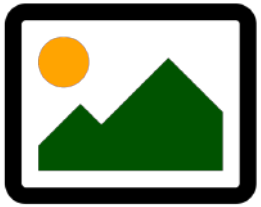
Transformers



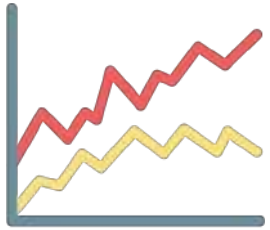
HOW TO CHOOSE?



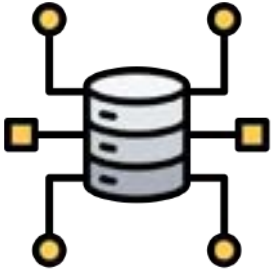
Fully-connected networks



Convolutional networks



Recurrent networks

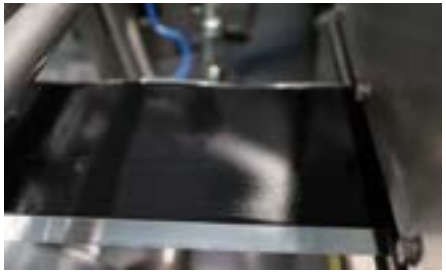


Transformers

Rule of thumb:

- classification and regression tasks, FCN
- Visual and spatial data CNN,
- time series and text RCN or Transformers

HOW IS IT USED? 3BELIEVE



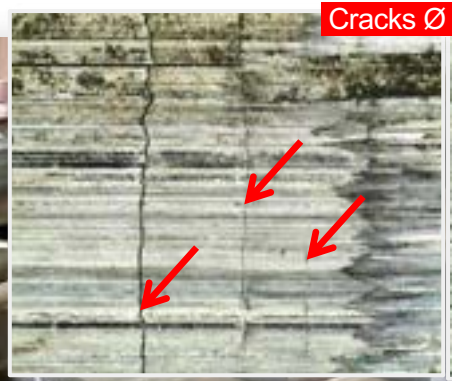
Agglomerations

Cracks

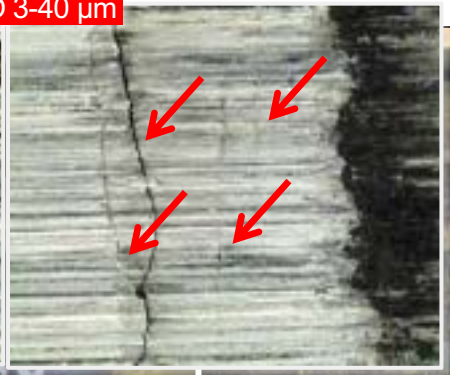
Cavities

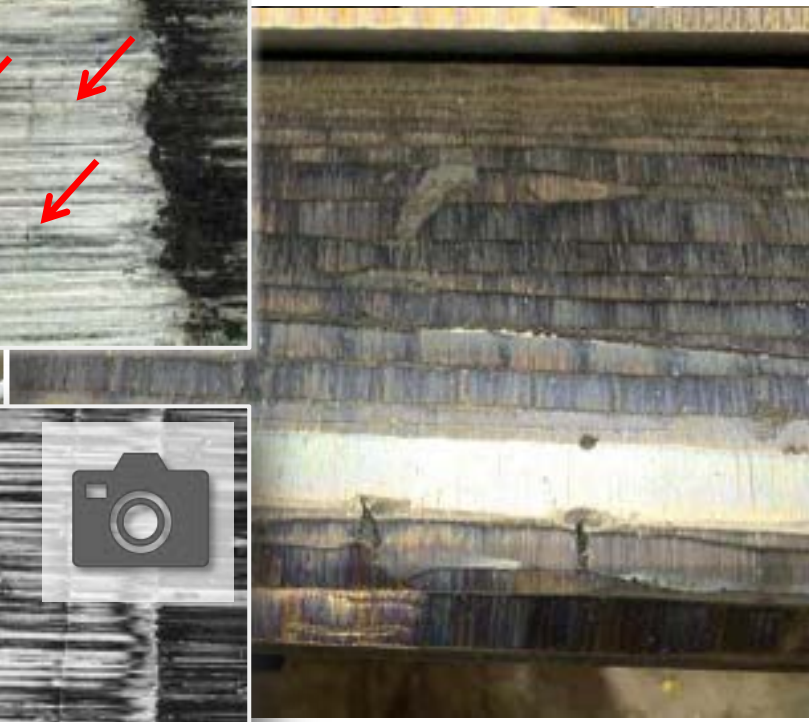
Blade trails

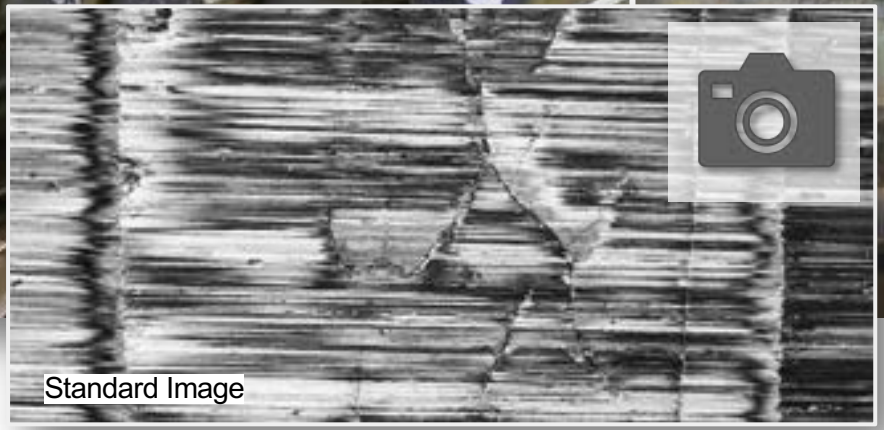
CRACK DETECTION ON STEEL BILLTES | CHALLENGE



Cracks Ø 3-40 µm

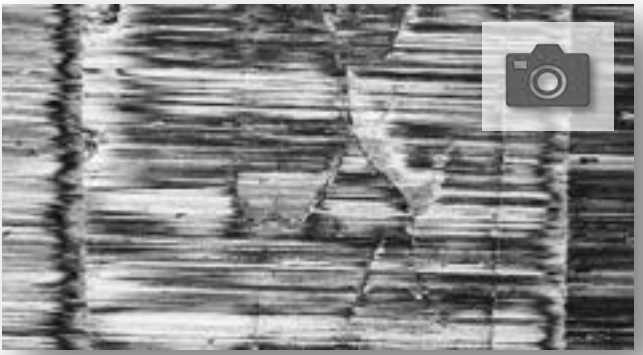




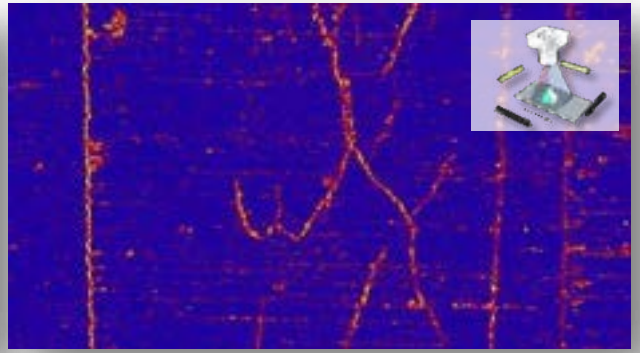


Standard Image

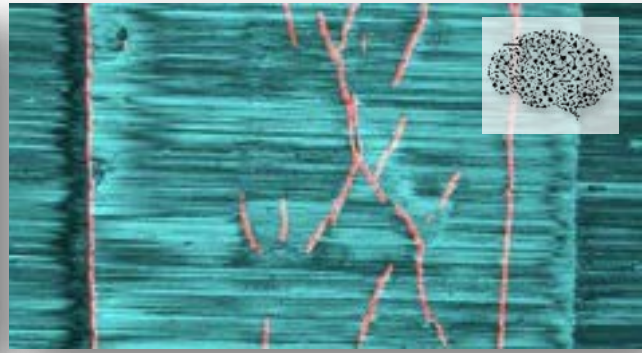
CRACK DETECTION ON STEEL BILLETS | SOLUTION



Standard Image



ICI | Photometric Stereo



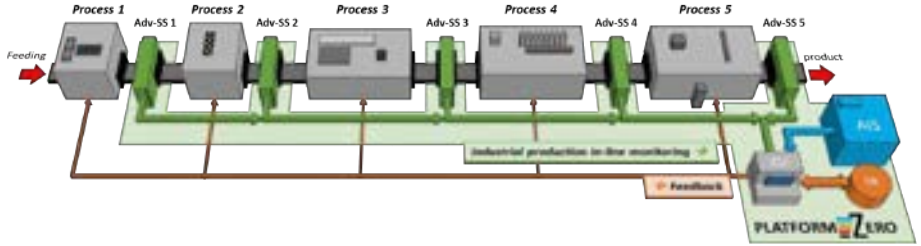
Deep Leaning

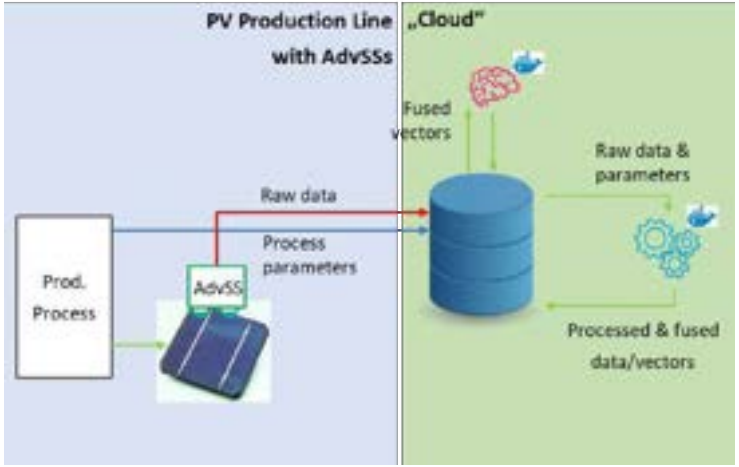
The solution combines

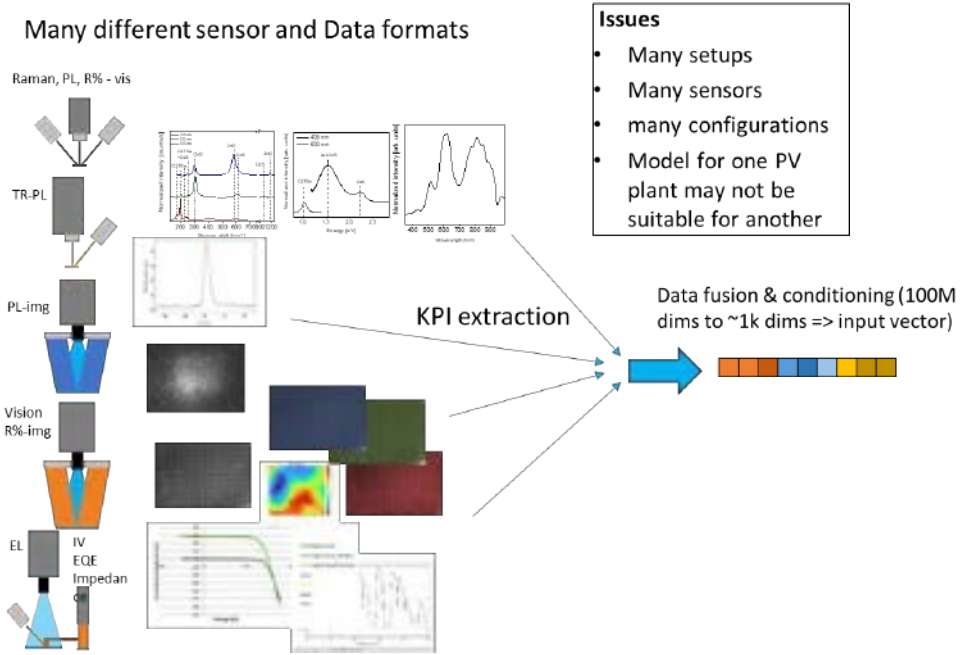
- modern AI approaches with the
- costomized ICI technology (Inline Photometry) and

➢ enables for robust and reliable crack detection.

PLATFORM ZERO PRODUCTION OF THIN FILM PHOTOVOLTAICS

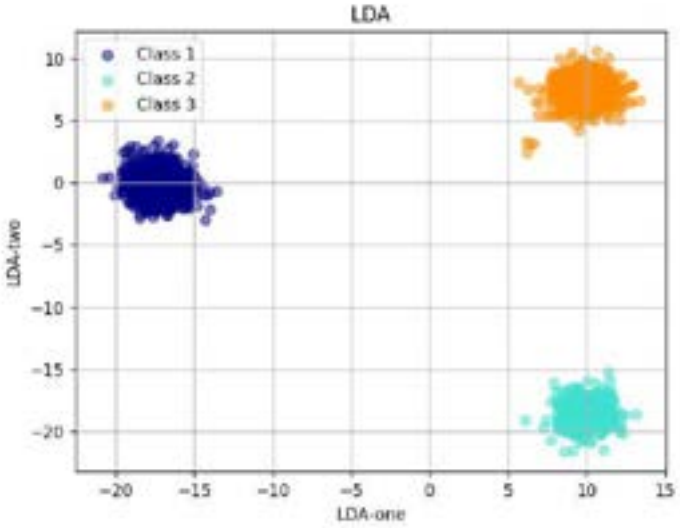






CLUSTER ANALYSIS

- First test sets of Kesterite sampels



WP3 Development of AI system:
Task 3.3 Implementation, testing and optimization of AI-system

Results – first data testing

LDA fitted to each senor exclusively

Train/Test split 80/20

	PL405	PL633	Raman405	Raman532	Raman633	ReflectanceImg	ReflectanceSpec	XRF
Accuracy	87.5	83.8	69.8	69.4	56.6	29.2	97.0	51.5
F1 score	87.3	83.5	69.2	68.7	55.9	37.4	97.0	54.8

All F1 scores demonstrate at least moderate performance, except for ReflectanceImg, which shows poor performance likely due to the limited dimensionality of the spectra. Combining different sensor modalities leads to an F1 score of 100%! This gives us confidence that with the integration of even more sensor information and data fusion, we are well-prepared for various PV production modalities.

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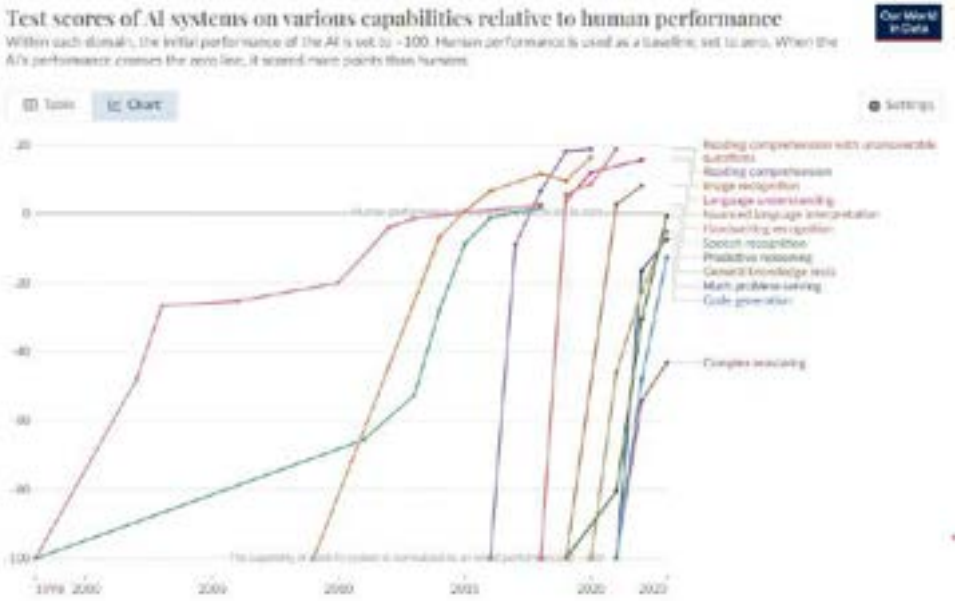
NEW FRONTIERS

- Large Language Models
  - Human language recognition and interpretation
  - Chat bots
  - Sentiment analysis
  - Online search

- Vision Language Models
  - Text-to-image and Image-to-text interpretation
  - Semantic analysis

- Segment Anything Model

EXAMPLES OF WHAT AI CAN ACHIEVE



https://ourworldindata.org/brief-history-of-ai

FUTURE PERSPECTIVE

- AI researcher Ajeya Cotra:
  AI system could match that of the human brain. The idea is that, at this point, the AI system would match the capabilities of a human brain. **50% probability** that such "transformative AI" will be developed by the **year 2040**, less than two decades from now.
- **Hinton 2023**: expresses concerns about the rapid progress of AI, considerable change to society.
- Unclear what happens if that happens, how smart will it be, how much influence can it develop, how manipulative can it be?
- **These things need to be regulated especially self-improving AI Systems**

https://ourworldindata.org/brief-history-of-ai

CONCLUSION

It WORKS!

But regulations are needed

https://www.marketresearchfuture.com/

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THANK YOU

SUNPLUGGED

UPSCALING OF ADVANCED NANO-AND MICROTECHNOLOGIES FOR THE PRODUCTION OF MADE-TO-MEASURE PHOTOVOLTAICS

NEXTGEN 2024 Palma de Mallorca– 9/Sep/2024

Andreas Zimmermann– Sunplugged GmbH

Co-funded by
the European Union

Outline

- The idea and the setting
- Our technologies
- Some challenges in the upscaling process
- Platform-Zero as enabler for the production of made-to-measure photovoltaic modules

Photovoltaics today

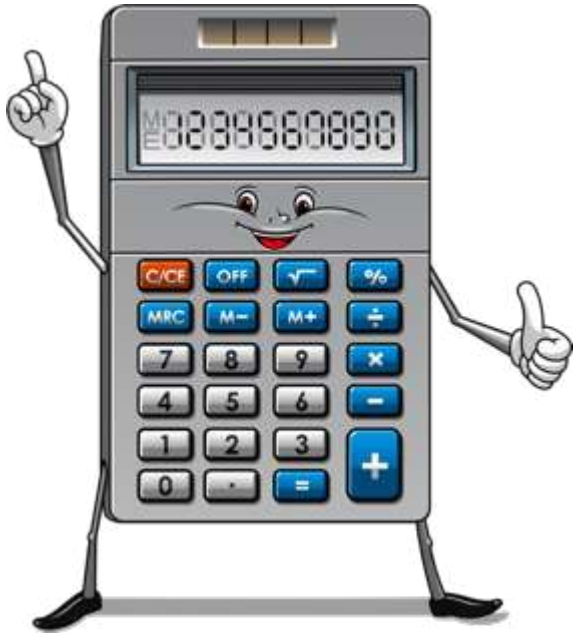
Economies of scale, standardisation has led to **enormous cost reduction** and **market expansion**

Silicon solar cells are the work horse of the industry

New photovoltaic technologies are emerging (e.g. Tandem, Perovskites,…)

Industrial exploitation is happening on the fringes in niche applications

The power of integration…

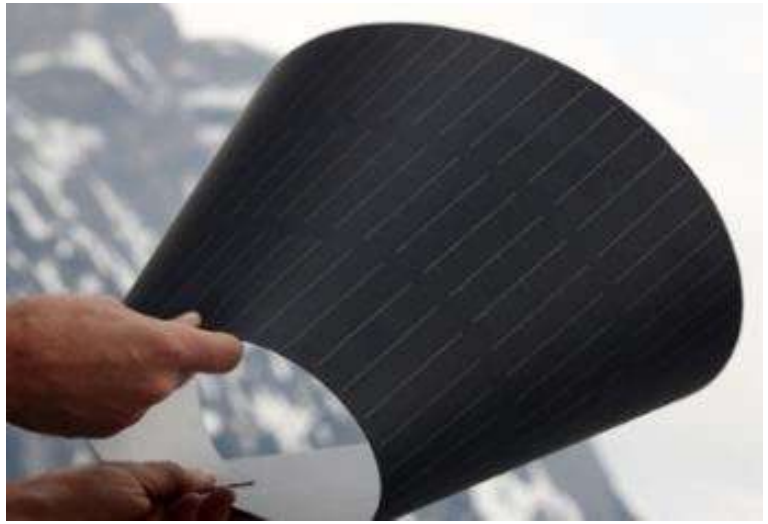


There´s a lot more space in between..

Internet of Things
Mobile Devices
Automotive
Lighting/Infrastructure
Building Integration

Sunplug your life

Flexible thin-film photovoltaics

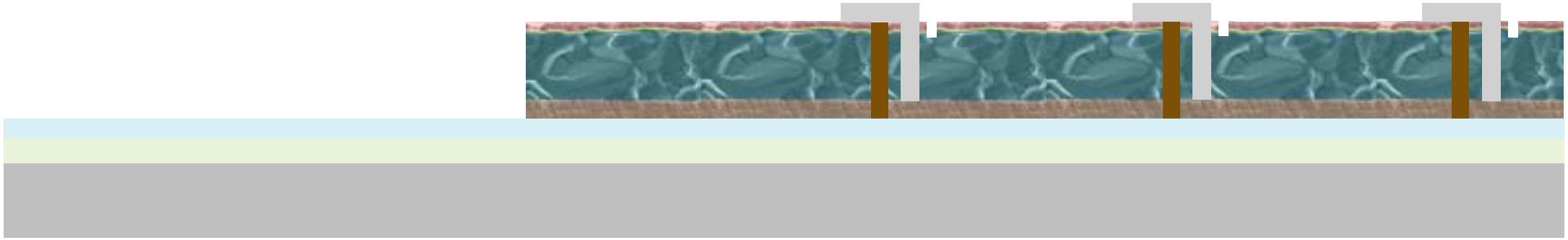


Pliable film for easy integration

Economic roll-to-roll production

Total freedom in module layout

The three pillars of Sunplugged´s made-to-measure PV foil



Glass/Steel Substrate

sustains high temperatures

deposition processes (>550 C)

Mechanically robust, yet pliable

Acts as backside barrier against water vapour.

Alkali metal source

SunP CIGS Process

Pure metals enable
low production costs

Good adhesion of CIGS

Good controllability due to sputtering of metallic precursors

Homogeneity over web width

Printed interconnection

Full freedom of module design

Output voltage is determined by number of scribes per given area

Reduced interconnection losses

Deferred process on soiar cell

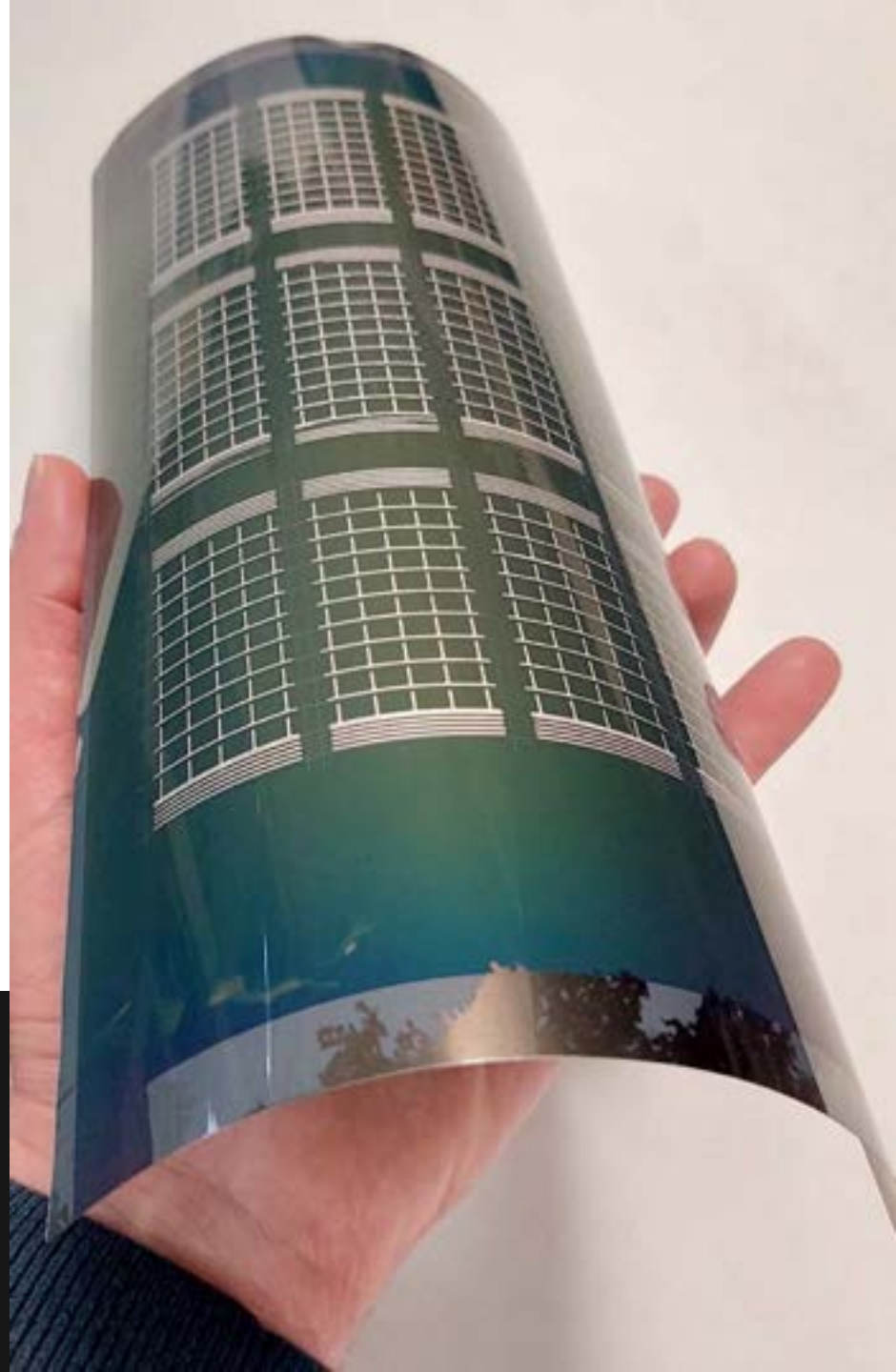
Serial interconnection of solar cells is needed to obtain a certain voltage

Defines main characteristics of the final PV product like voltage, size, shape

Mission:

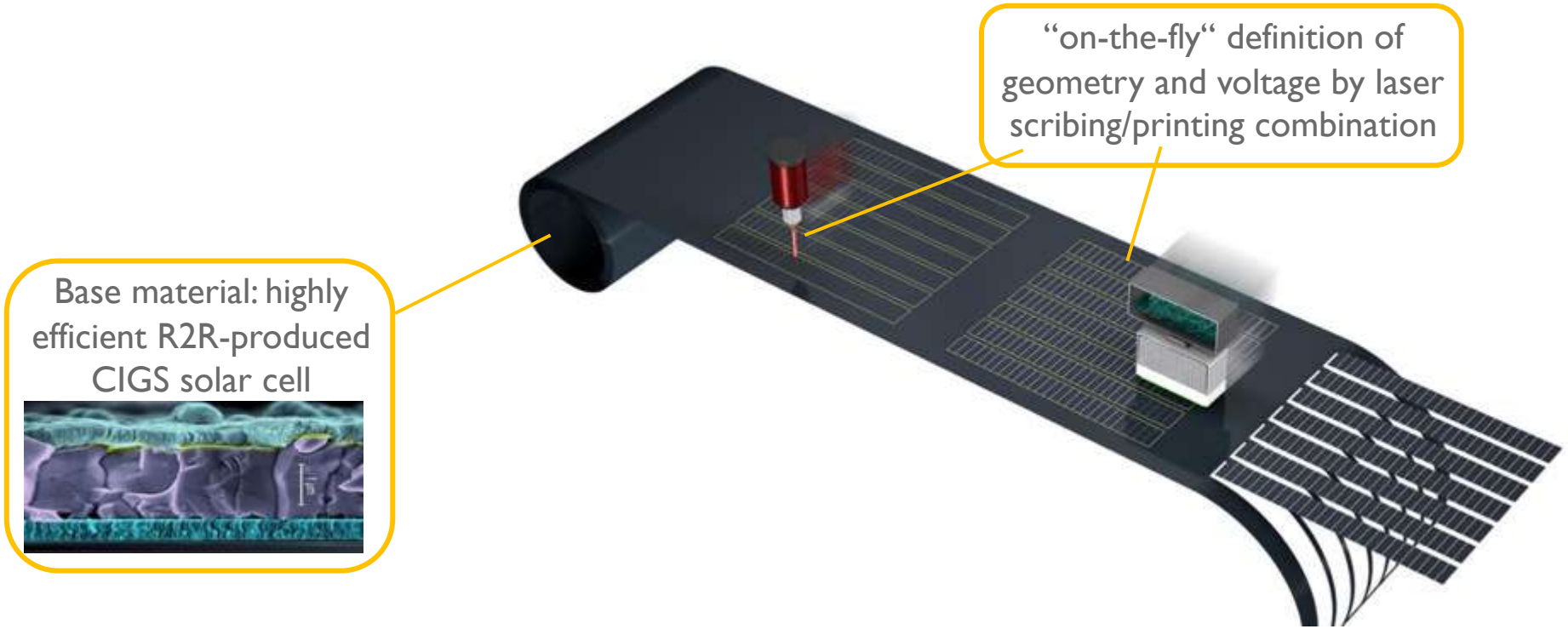
Conceptualise and develop a serial interconnection that allows the production of photovoltaic modules with **varying voltages, sizes and shapes ”on the fly”**

The interconnection



Deferred interconnection utilizes laser and printing techniques

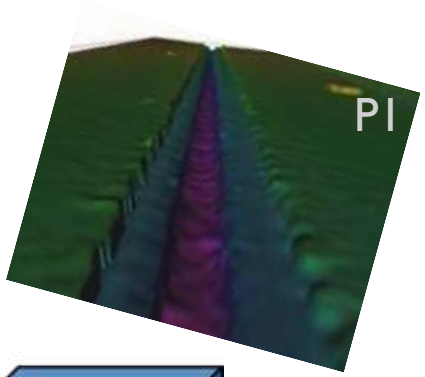
Material removal only from top side after entire layer stack has been deposited

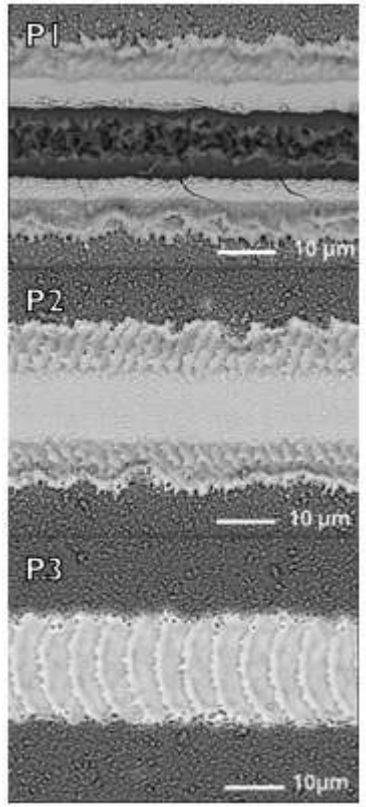


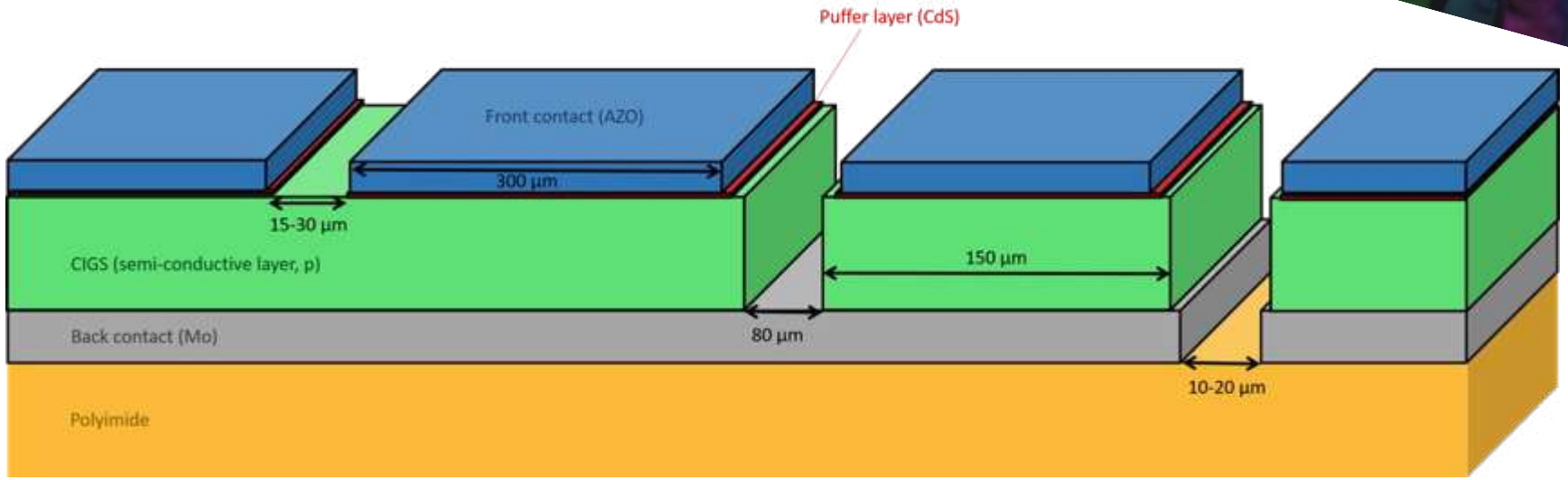
Step 1: Laser process

Laser grooves of different depths are cut into layer stack using a short-pulse laser

- P1: Material is divided into individual cells
- P2: Exposure of back contact
- P3: separation of front contact

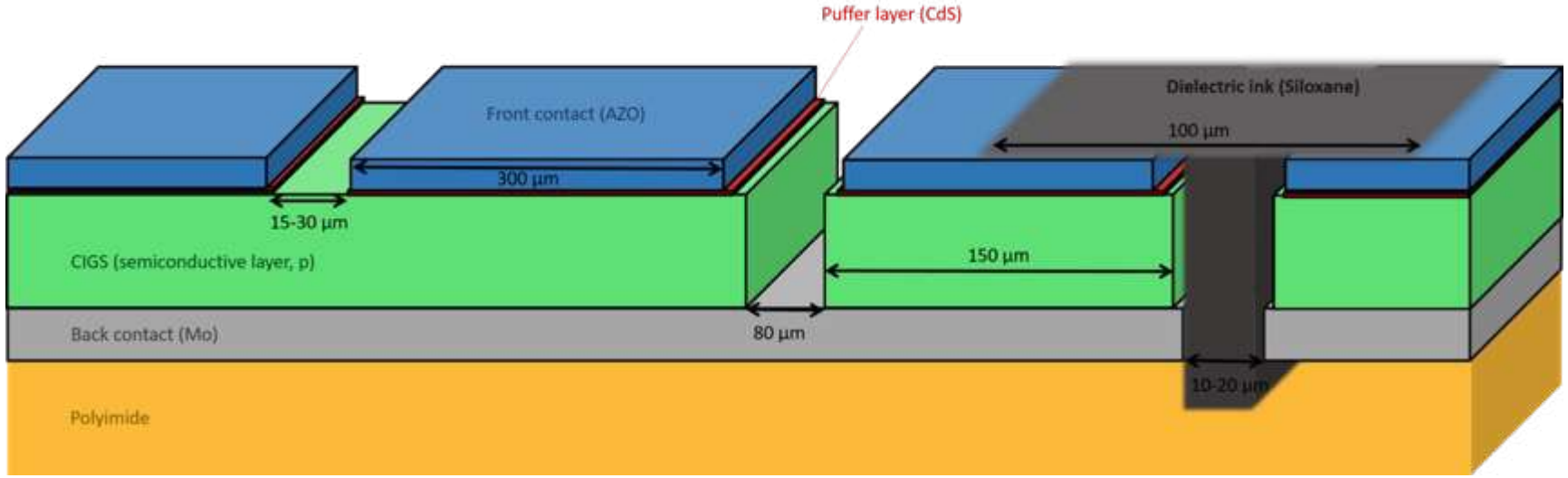


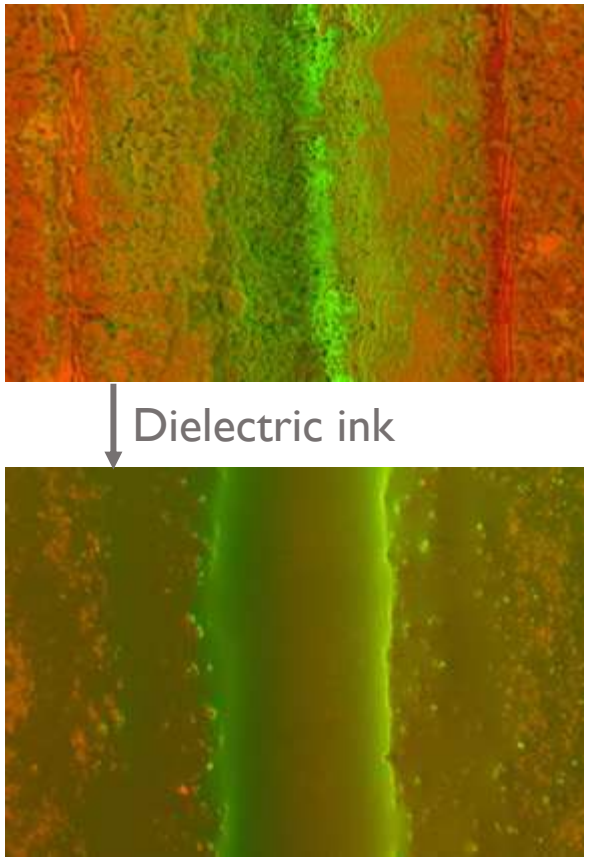




Step 2: Printing of dielectric ink

- "Isolating" laser groove is filled with dielectric ink my means of inkjet printing

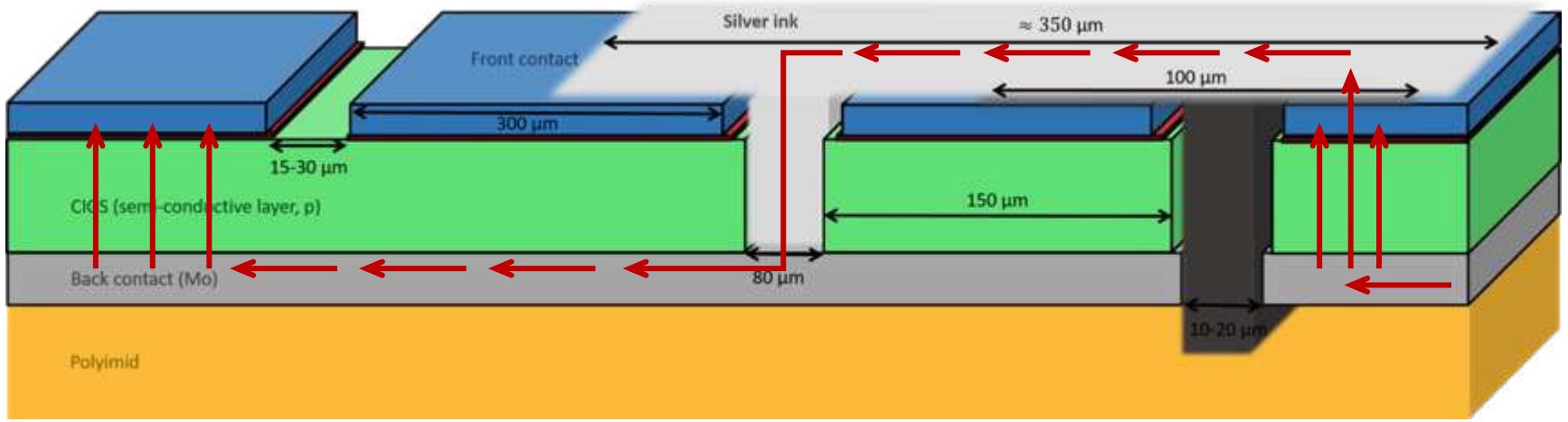


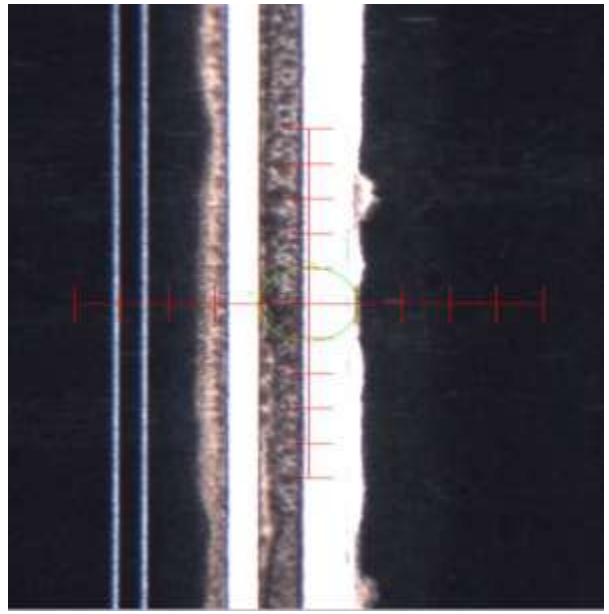


Step 3: Serial interconnection by printing silver ink

"Back contact" laser groove is filled with **conductive ink** by means of inkjet printing or dispensing

Back contact of "left" cell is electrically connected to front contact of "right" cell





Advantages of the printed interconnection

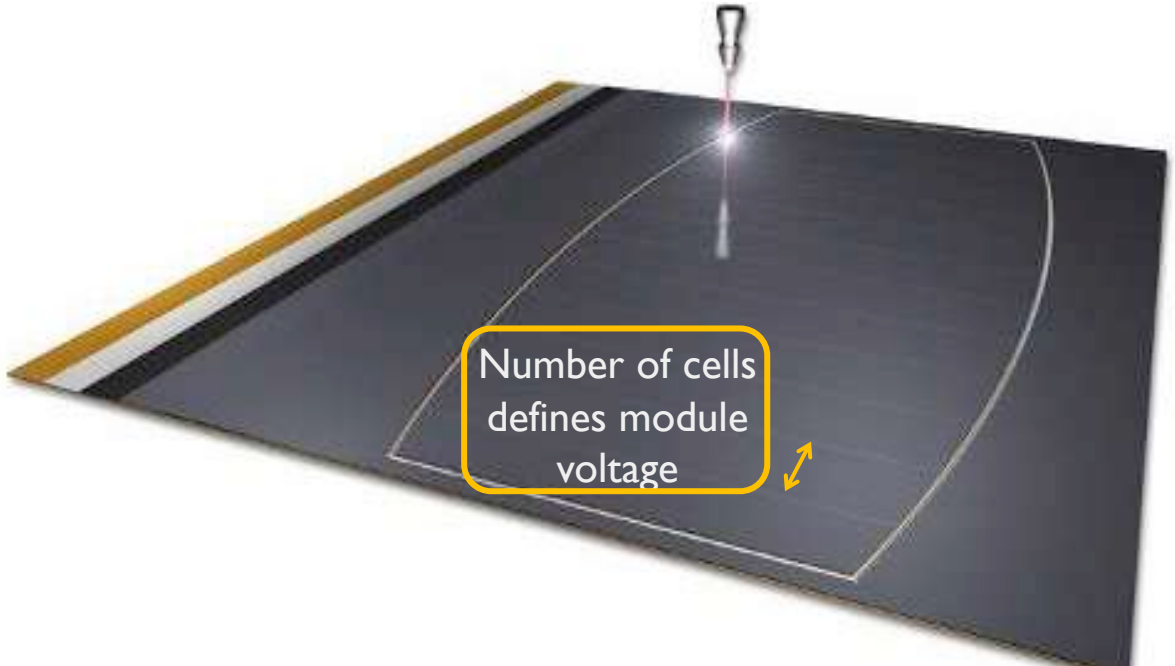
Total freedom in design

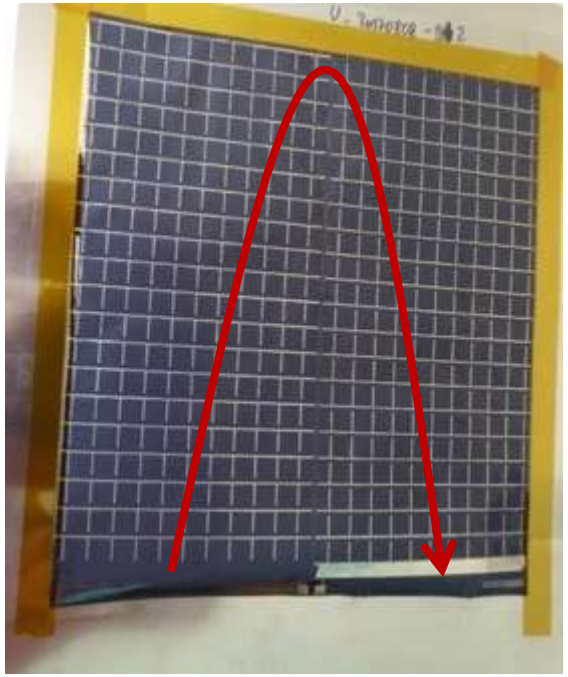
Variable module voltage, size,geometry

Simplified Module Assembly –e.g U-shape

Location of junction boxes

Additional printing process





Mission:
Develop a **high efficient solar cell on a flexible substrate**

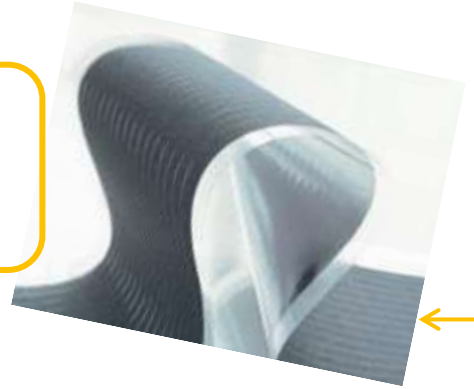
Enable the printed interconnection
High efficiency potential
Lightweight
Thin
Flexible for integrated applications
Cost-effective Roll-to-Roll production

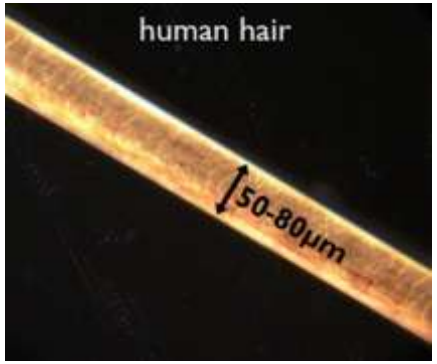
The solar cell

Flexible thin-film photovoltaics

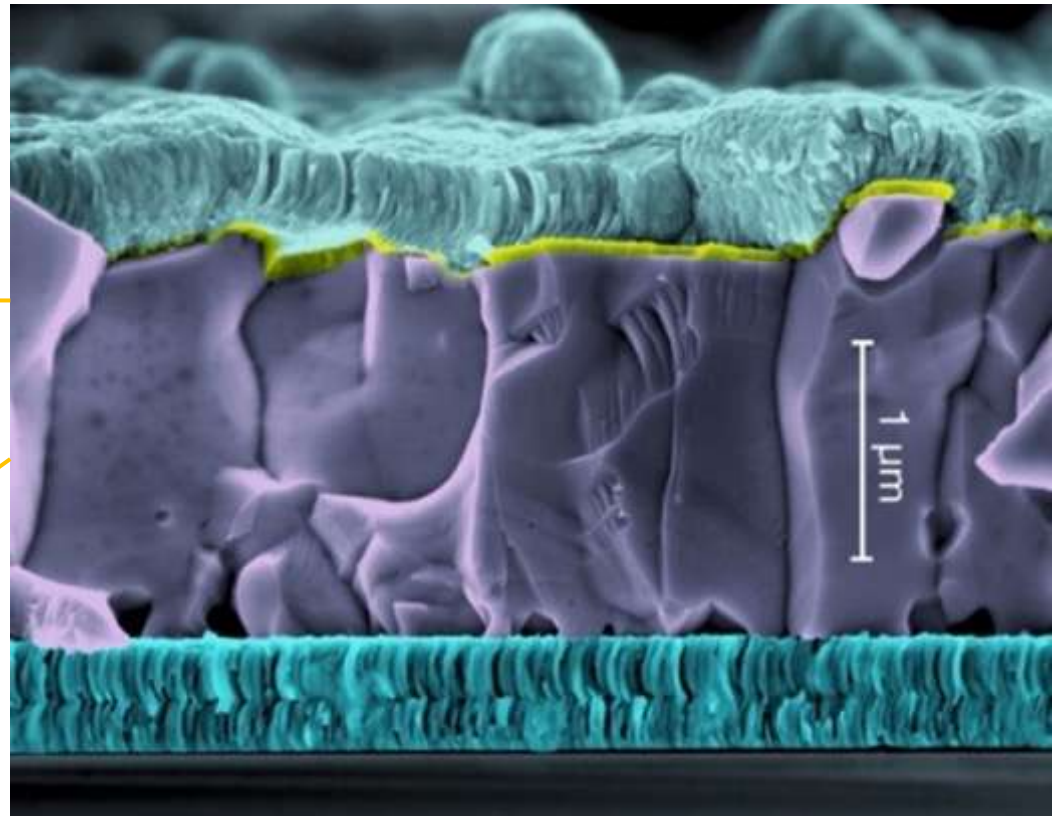
Sunplugged‘s solar cell based on **C**opper **i**ndium **g**allium di**s**elenide (CIGS)

High Efficiency
Stable
Energy Yield





Thickness of thin film: 3µm



Front contact

Buffer layer: CdS

Absorber: CI(G)S

Back contact: molybdenum

Substrate

The choice between two processes

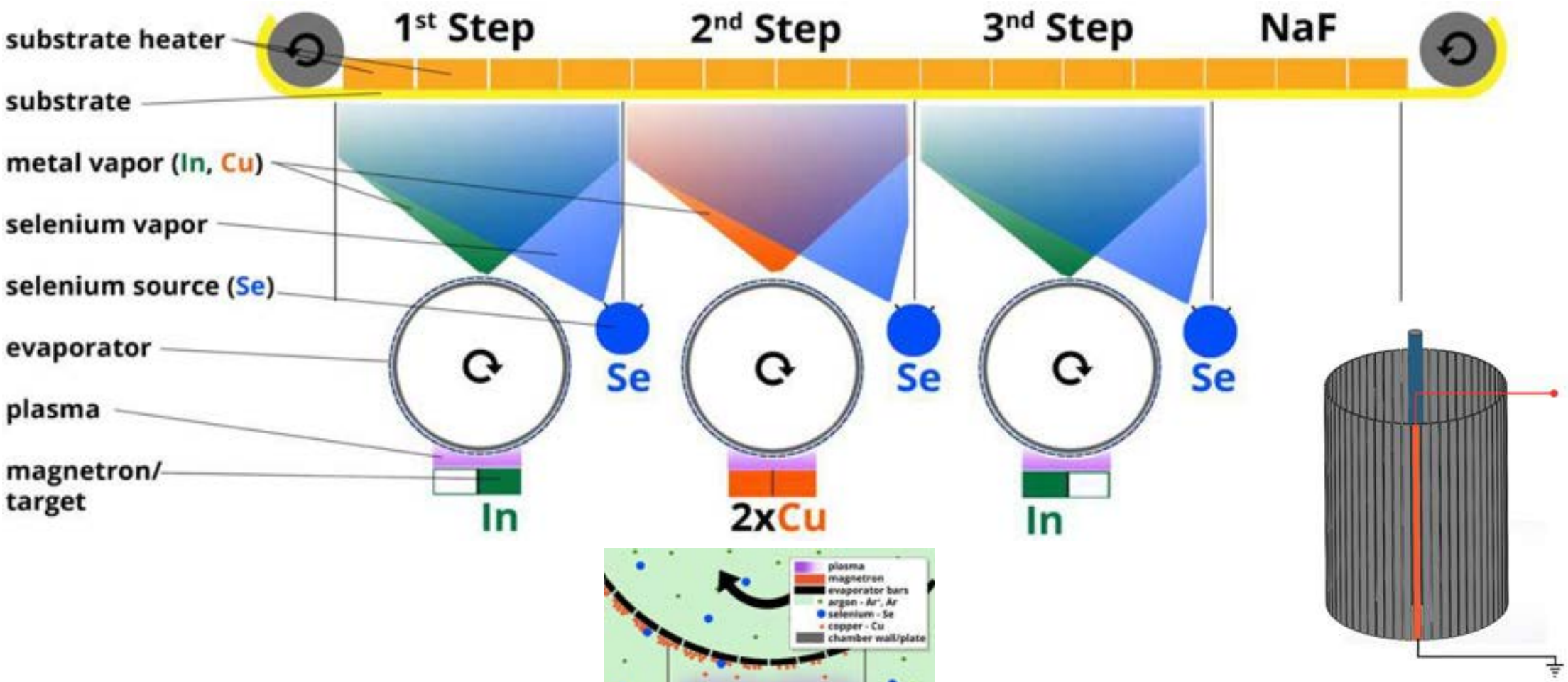
Sequential CIGS Process
Precursor CIG plus selenisation

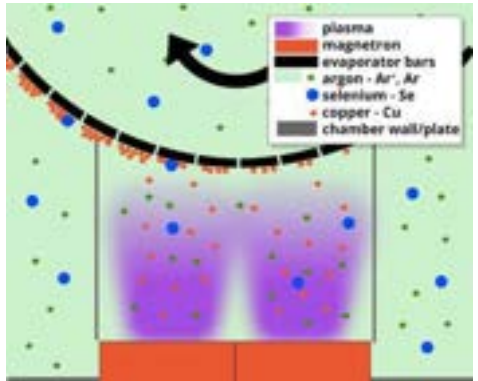
our first approach together with an Austrian equipment manufacturer (2012-14)

Hybrid Sputtering/Evaporation process developed on lab-scale together with Uni Bicocca Milan

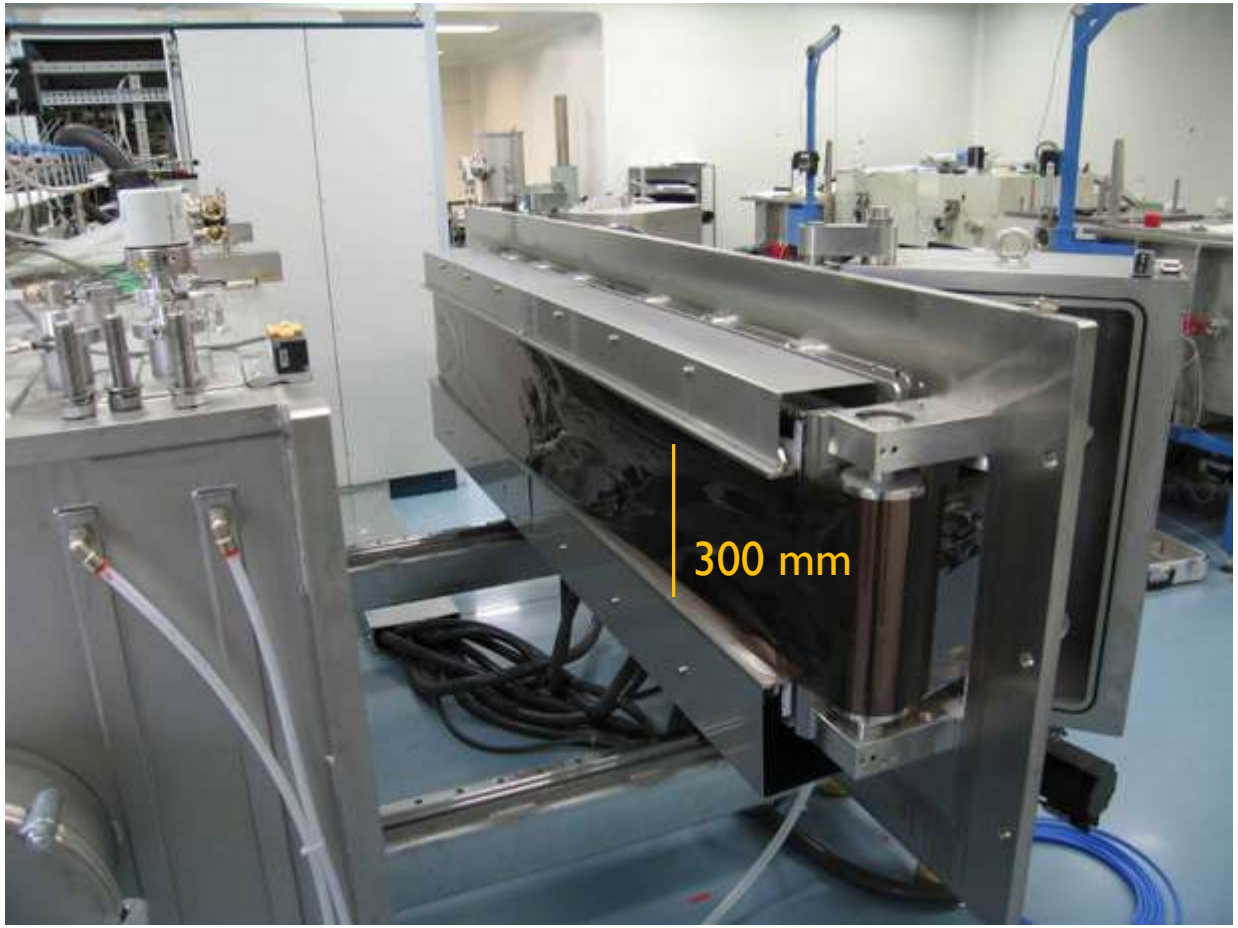
From 2015 onwards on
On polyimid foils

The principle of our CI(G)S process





Hybrid Evaporation/Sputtering Process



Upscaling of CIGS process was a nightmare

Complete breakage of foil during R2R run

Selenium poisoning of targets

Gallium melting during process

“Dirty“ Process Data,etc ….

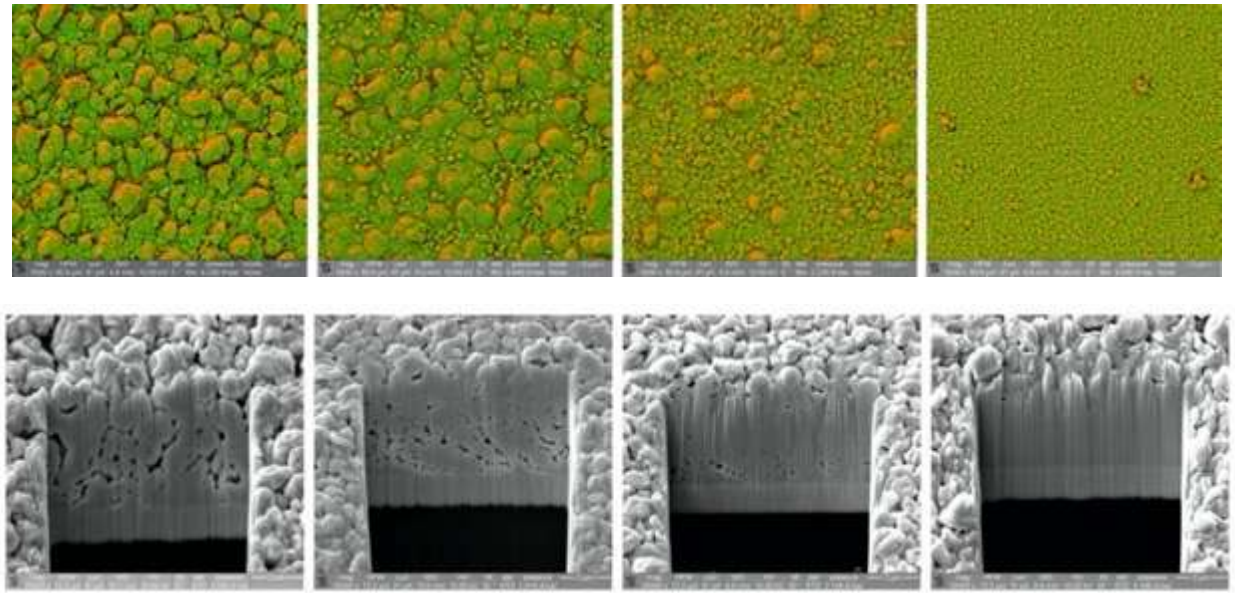
Some milestones

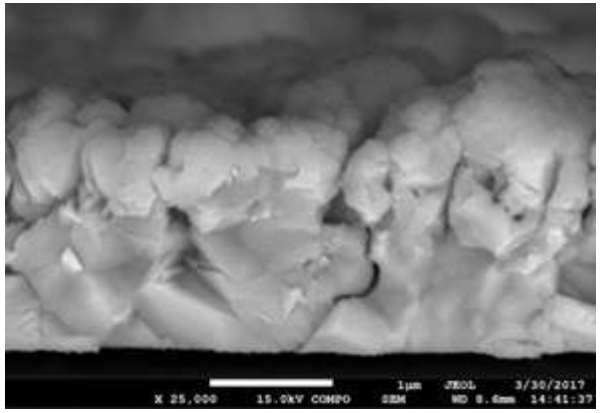
Novel R2R CIGS process is **now stable and works**

CIS Solar Cells with 11,8 ´% Efficiency (Autumn 2017)

CIGS Solar Cells with 12,4% Efficiency (Spring 2019)

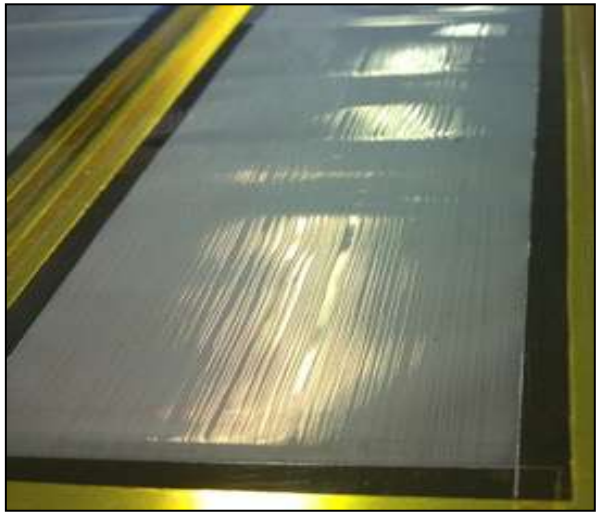
CIGS Solar Cells with 14,7% in Roll-to-Roll (Summer 2021)

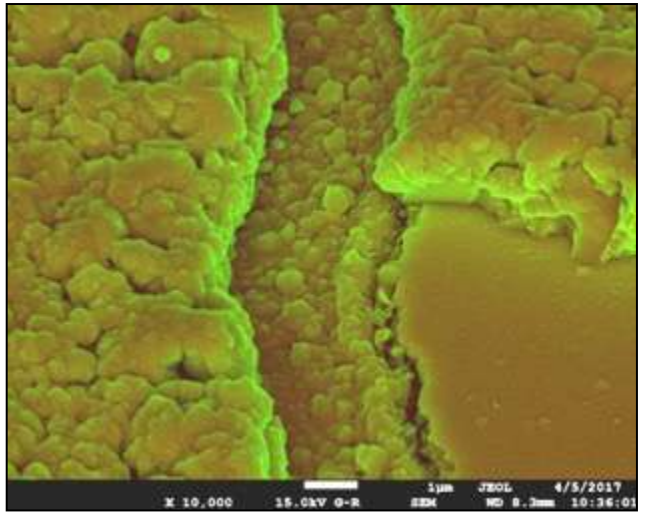


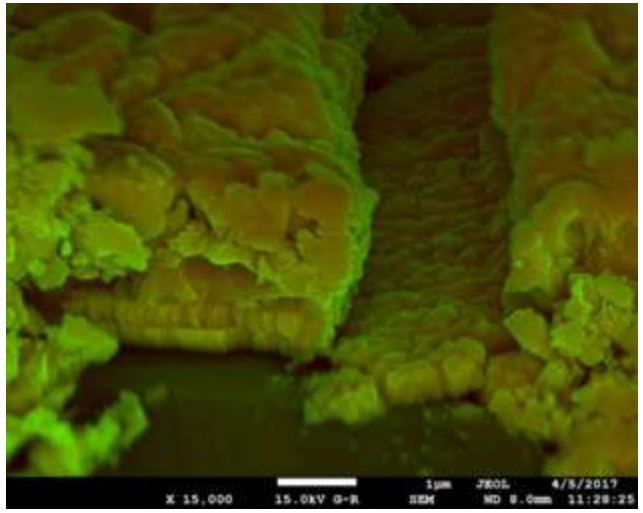


Ordered vacancy crystal phases on top of the CI(G)S layer

Micro cracks still occured on polymer substrates







…so one more thing:

Develop a novel flexible substrate that sustains high-temperatures and

can be used together with the printed interconnection

Glass-like barriere coating on steel foils

Thin and **flexible glass-like layer** on thin steel foil
Application by spray-coating, R2R-coating or **slot-coating for mass production**

Corrosion protection and **iron ion diffusion barrier**

Optionally alkali supplying layer for increasing the solar efficiency of CI(G)S

Coating Material developed by INM Saarbrücken
Sodium-silicate sol-gel system "NaSi"
Potassium-silicate sol-gel system "KSi"

Flexible dielectric substrate

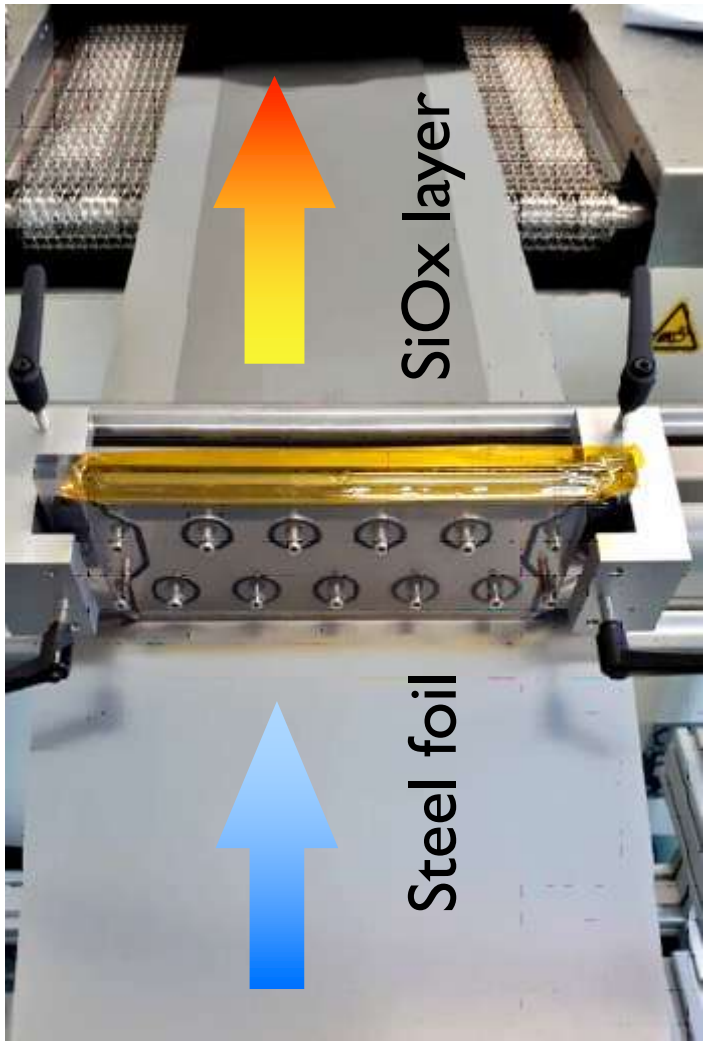
Thickness can be controlled

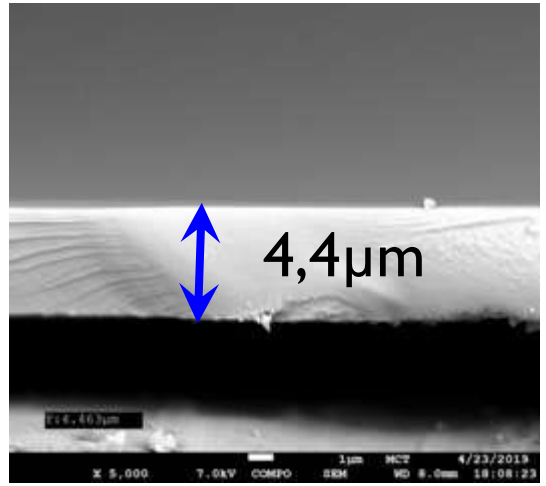
by varying v_{foil}

Multilayer structure

Pinhole-free

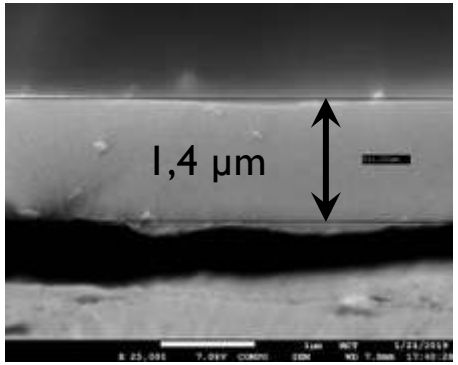
Fully flexible due to alkali addition



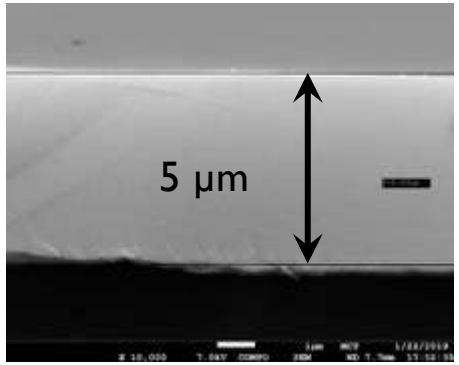


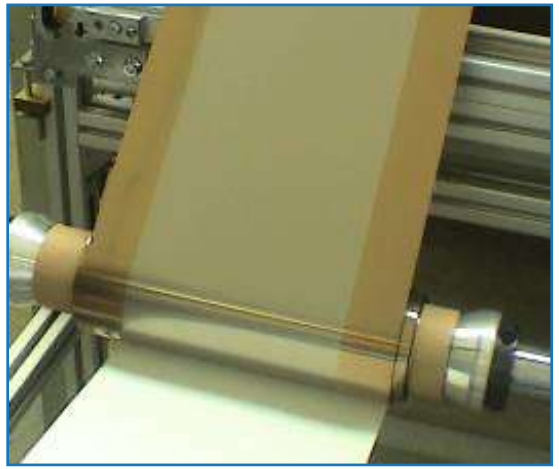
SEM Cross-section single layer

Thin Monolayer



Bi-Layer





Issues, like large scale adhesion..

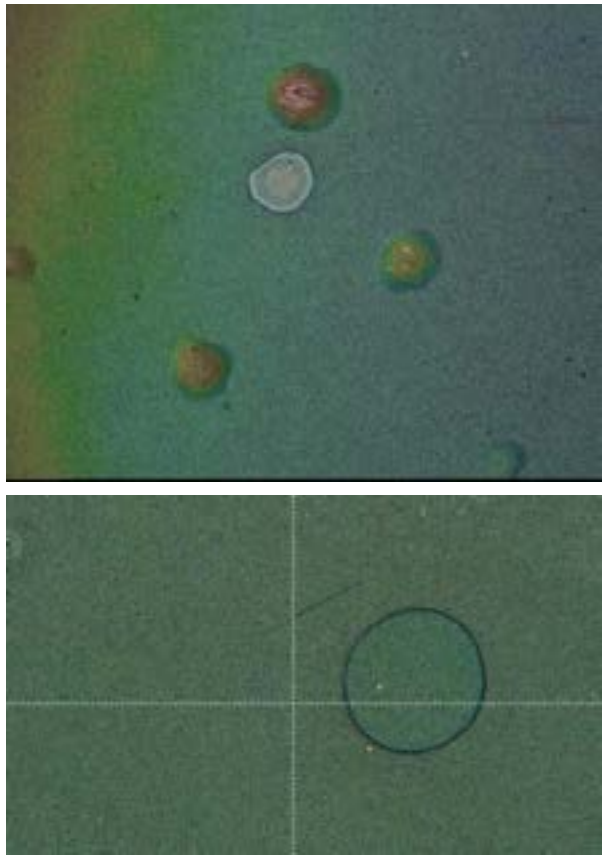
The origin of large-scale poor adhesion lies in the incompatibility of CTE between Mo and the passivation layer

A metallic interlayer (Ti) has been introduced to compensate for the large difference between CTE values of the passivation layer and Mo back-contact

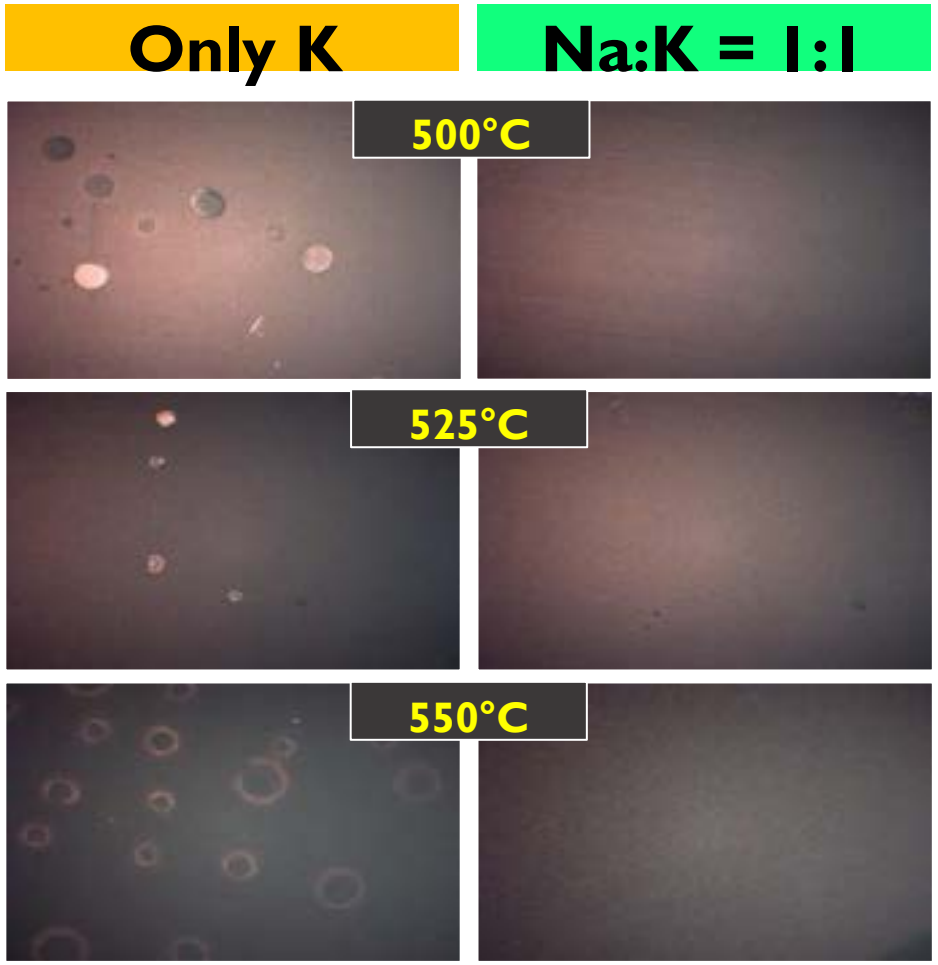
large difference

Material	Passivation layer	Molybdenum	Titanium	Chromium
Mean CTE (10^{-6}/°C)	~ 9 - 10	4,8	8,4	6,2

..and other defects were finally solved



If delamination happens early in process, CIGS is deposited in crater



Optimisation of recipe

Defect-reduced large scale CIGS Solar cells

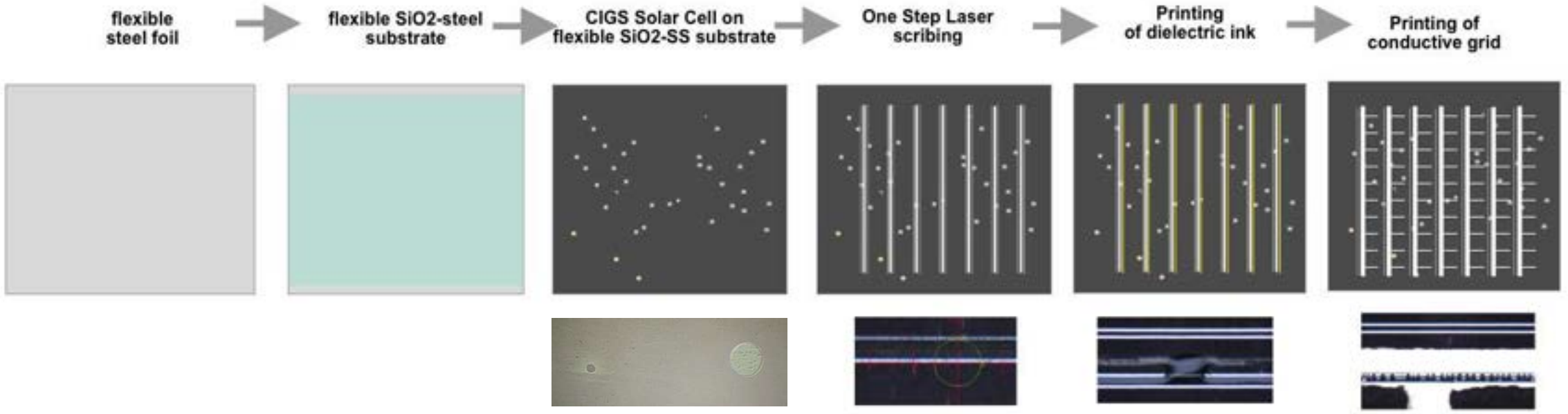
The importance of defect-free layers for PV modules

Every defect and inhomogeneity adds up and **increases the Cell-to-Module gap in efficiency**

Serial interconnection demands uniform solar cell material

The bigger the underlying solar cell the more "risk" of defects, resistivity losses

Propagation of defects



Mission:

Upscaling of all processes to Roll-to-Roll production (500 mm for cell and 250 mm for interconnection)

Achieve an annual pilot production capacity: of **5 Mwpeak**
(average >14 % module efficiency)

Production yield >90%

The upscaling

Completion of 5 MWpeak in progress

R2R Substrate Production

Slot dye coating of SiOx Gel

R2R CIGS Production

Sputtering of back contacts

Formation of absorption layer

Sputtering Buffer & Front Contact

R2R Interconnection

R2R Laser Scribing & Inkjet Printing

R2R Application of conductive circuits

R2R Back-End

Module Production

Hardware and **process know-how** is constantly evolving

Process data is monitored

However for full production inline process monitoring of Device properties is crucial

Crying need for „in-line“ quality control

R2R Substrate Production

Advanced Sensor Station

Slot dye coating of SiOx Gel

R2R CIGS Production

Sputtering of back contacts

Advanced Sensor Station

Formation of absorption layer

Advanced Sensor Station

Sputtering Buffer & Front Contact

R2R Interconnection

Advanced Sensor Station

R2R Laser Scribing & Inkjet Printing

Advanced Sensor Station

R2R Application of conductive circuits

R2R Back-End

Module Production

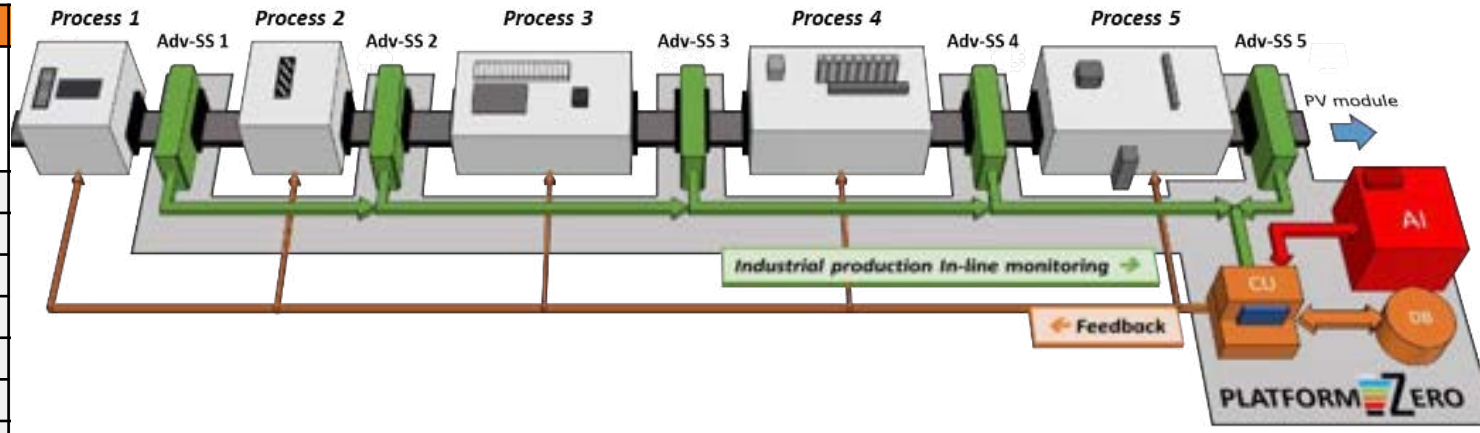
AI system

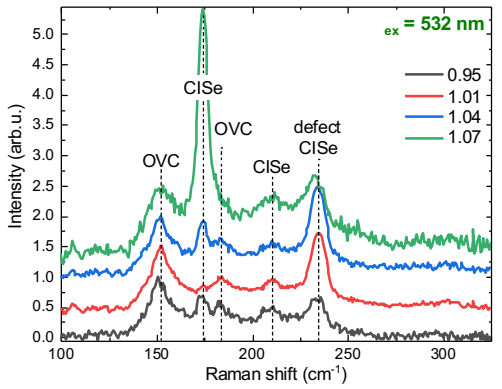
Data Management

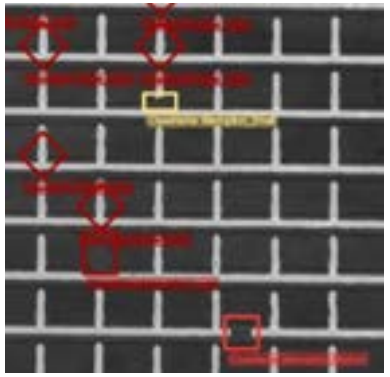
Platform-ZERO

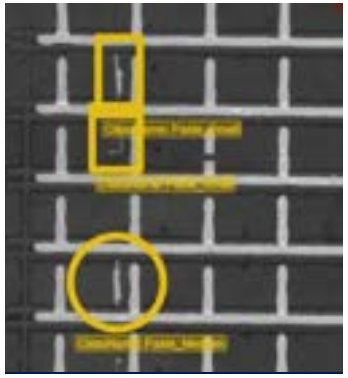
Integration all along the process chain

Adv-SS (Process)	Sample type	Inspection techniques
Adv-SS Su1 (Dielectric coating)	Coated steel foil (roll)	Visual
Adv-SS Su2 (Absorber synthesis)		LIBS
		Raman
		Reflectance
		Reflectance imaging
		PhotoLuminiscence
		PL imaging
		Visual inspection
Adv-SS Su3 (ZnOS buffer + TCO deposition)		Raman
		Reflectance
		Reflectance imaging
		PhotoLuminiscence
		PL imaging
		Time-Resolved PL
		Impedance
		External Quantum Efficiency
		Current-Voltage IV
		Visual inspection
Adv-SS Su4 (Monoscribe interconnection)		Current-Voltage IV
		ElectroLuminiscence
		Visual inspection



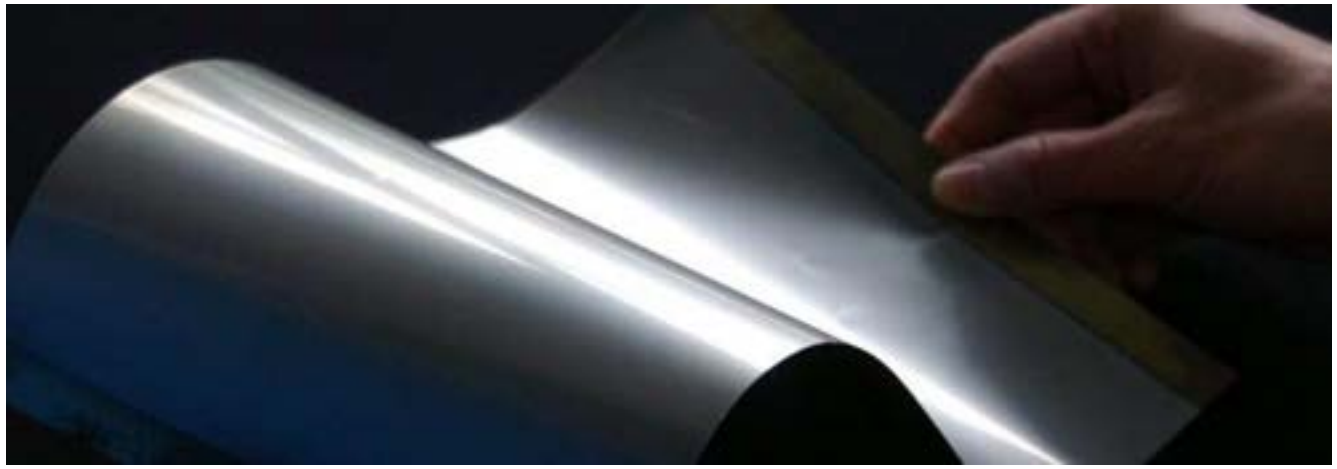


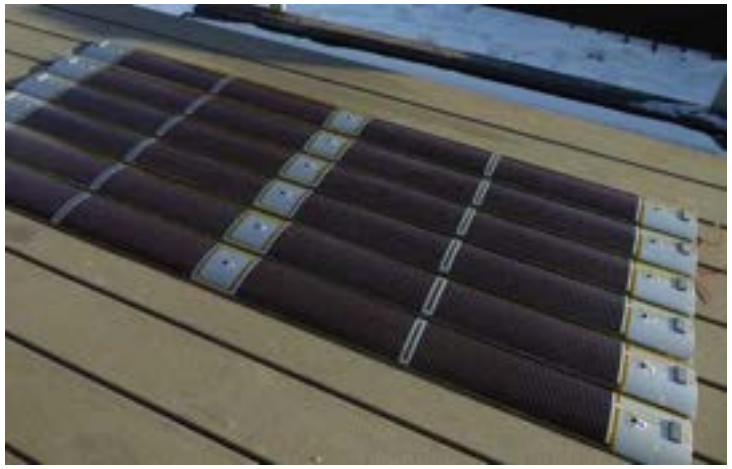




Expected outcome

- Better understanding of material properties, processes – what is noise and what is important
- Making the processes „knowable“ and reproducible
- Integrate automated feedback loops for automated process control.
- For instance fully automated selenium flux and adjustment of sputtering parameters in CIGS process due to inline data





Summary

- **Reducing defects** and inhomogeneities is crucial for production
- Sometimes it´s just simple things but small details matter
- Data is crucial for upscaling and continuous improvement
- Delicate processes can be controlled by active feedback loops
- **Inline process monitoring** and **active control loops** are **key for reproducibility, high process yields** and **low scrap rate.**

With the modular tool set developed in Platform Zero viable manufacturing of novel PV materials is achievable!

R2M
RESEARCH TO MARKET
SOLUTION

Platform ZERO
From Laboratory to Industry

NEXT GEN
International School and Workshop

Régis Decorme
Davide Quaggiotto

9 September 2024

From Research to Market

R2M Solution

Founded	People	Research	Funds raised	Funds raised	First time EU
2012	**130** 5 branches	**100+** R&D projects	**395 M** Total R&D Portfolio	**23.2 M** Client technology Development	**50+** Organizations

About us

Our Branches

Italy
R2M Solution S.r.l.
Via F.lli Cuzio 42
27100 Pavia, Italy
P.IVA: IT04998380879

Spain
R2M Solution Spain, S.L.
Calle Villablanca 85
28032 Madrid, España
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London, W11 3SL
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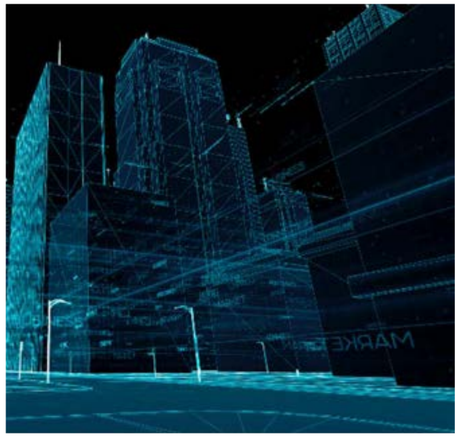
Our Journey

Innovation

European Commission

Innovative Products & Services

Real Estate
Digitalization
Sustainability
Smart Grid and Local Energy Communities
(R2M Energy - ESCO)



Sustainability Consulting

LEED AP BD+C
LEED AP O+M
LEED AP ID+C

WELL AP

BREEAM LICENSED ASSESSOR COMPANY greenbooklive.com

CEPAS Commissioning Authority (CxA)

WIRED SCORE ACCREDITED PROFESSIONAL

FIRE

GBC HISTORIC BUILDING

GBC HOME

COPILOT BUILDING COMMISSIONING SOLUTIONS
Powered by EUROVENT

Innovation portfolio
(Examples)

All AI / Machine Learning BIM / Digital Construction Biofuels Building Integrated Photovoltaics (BIPV) Deep Renovation Demand Response Digital Platform Energy Efficiency & Management Geoscience Heating and Cooling / Indoor Climate Renewable Energy Robotics Smart Buildings Smart Cities Smart Grid

metabuilding labs
MEDiate
MEZeroE
MINISTOR
NEON Network of Competence on Internet of Things
flow
FEDECOM
Nebula A Built4People Project
Z
PV 4 Plants
REGEN2 by
REMODULES
HYSTORE
HYBRID plus
S/R
Step-WISE CO2
SRI2MARKET
trineflex
6G TWIN

Funded by the European Union

Innovative products

IES ICL: digital twin for local energy communities

Zutec: Management platform for the construction sector

Synavision: Building commissioning software

AI for building HVAC optimization and automation

Matterport: 3D scan for building digital twins

BIMcollab: BIM management

GREENPASS: nature-based solutions in urban areas

Onyx Solar: semi-transparent photovoltaic glass

SUSTAINABLE PLACES 2024
R2M RESEARCH TO MARKET SOLUTION
LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY
LIST
23 - 25 SEPTEMBER 2024
EUROPEAN CONVENTION CENTER LUXEMBOURG
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Maximising the impacts of Platform-ZERO research: our Dissemination, Exploitation and Communication (DEC) strategy

Co-funded by the European Union

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R2M Italian branch serves as the Platform-ZERO innovation manager, while R2M French branch serves also as communication and dissemination manager.

It will develop a tailored strategy to ensure maximum success of project impact by performing Dissemination, Exploitation and Communication (DEC) actions in line with the methodologies, results and outcomes generated in the project.

Make a difference – make an impact.

Implementation Strategy: guiding principles

- **Maximising impacts**
- **Greater transparency and further simplification (model grant agreement and guidance to beneficiaries)**
- **Fostering synergies** with other EU funding programmes
- **Easing access** through digital transformation and outreach (Funding and tenders portal project

Horizon Europe legislation defines three types of impact tracked through **Key Impact Pathways**

Communication, dissemination and exploitation activities are **an integral part of Horizon projects** – and in Horizon Europe in particular! - to help **maximise the impacts** of EU research & innovation funding.

European Commission

European Commission

COMMUNICATION, DISSEMINATION AND EXPLOITATION
WHY THEY ALL MATTER AND WHAT IS THE DIFFERENCE?

Communication:
Promote your action and results

Inform, promote and communicate your activities and results

Reaching multiple audiences
Citizens, the media, stakeholders

How?
- Having a well-designed strategy
- Conveying clear messages
- Using the right media channels

When?
From the start of the action until the end

Why?
- Engage with stakeholders
- Attract the best experts to your team
- Generate market demand
- Raise awareness of how public money is spent
- Show the success of European collaboration

Legal obligation of your Grant Agreement

Dissemination:
Make your results public

Open Science: knowledge and results (free of charge) for others to use

Only to scientists?
Not only but also to others that can learn from the results: authorities, industry, policymakers, sectors of interest, civil society

How?
Publishing your results on:
- Scientific magazines
- Scientific and/or targeted conferences
- Databases

When?
At any time, and as soon as the action has results

Why?
- Maximise results' impact
- Allow other researchers to go a step forward
- Contribute to the advancement of the state of the art
- Make scientific results a common good

Legal obligation of your Grant Agreement

Exploitation:
Make concrete use of results

Commercial, Societal, Political Purposes

Only by researchers?
Not only, but also:
- Industry including SMEs
- Those that can make good use of them: authorities, industrial authorities, policymakers, sectors of interest, civil society

How?
- Creating roadmaps, prototypes, softwares
- Sharing knowledge, skills, data

When?
Towards the end and beyond, as soon as the action has exploitable results

Why?
- Lead to new legislation or recommendations
- For the benefit of innovation, the economy and the society
- Help to tackle a problem and respond to an existing demand

Legal obligation of your Grant Agreement

What else? Acknowledge the EU funding!

EUROPEAN COMMISSION TOOLS

Research and Innovation success stories

A collection of the most recent success stories from EU-funded Research & Innovation.

Horizon Dashboard

An intuitive and interactive knowledge platform where you can extract statistics and data on EU Research and Innovation programmes – sorting by topics, countries, organisations, sectors, as well as individual projects and beneficiaries!

CORDIS

Multilingual articles and publications that highlight research results, based on an open repository of EU project information.

Horizon Results Booster

A service free of charge in case you would like to apply to benefit from one of these services:

1. Portfolio Dissemination & Exploitation Strategy
2. Business plan development
3. Go-to-Market Support

Horizon Magazine

The latest news and features about thought-provokingscience and innovative research projects funded by the EU.

Innovation Radar

A data-driven method focused on the identification of high potential innovations and the key innovators behind them in EU-funded Research and Innovation projects.

Horizon Results Platform

A public platform that hosts and promotes research results thereby widening exploitation opportunities. It helps to bridge the gap between research results and generating value for economy and society. You can create your own page to showcase your results, find collaboration opportunities and get inspired by the results of others!

Horizon Impact Award

An annual prize to recognise and celebrate outstanding projects that have used their results to provide value for society. The award enables individuals or teams to showcase their best practices and achievements, and inspire beneficiaries of research and innovation funding to maximise the impact of their research!

- Communication
- Dissemination
- Exploitation

Keep in touch

- Contact your PO
- Funding & Tenders Opportunities portal
- Research Enquiry Service

European Commission | Log in | English | Search

CORDIS - EU research results

Home | Thematic Packs | Projects & Results | Videos & Podcasts | News | Datalab | Search

HORIZON EUROPE

Customizable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in the PV industry

Fact Sheet | Results

Project description

DE | EN | ES | FR | IT | PL

AI-based process-monitoring platform for third-generation photovoltaics

Photovoltaics (PV) are crucial in fighting climate change and transitioning to green energy sources. Third-generation photovoltaic technology aims to achieve high-efficiency devices and improved adaptability for different applications in different sectors. However, the precise and complicated production process results in huge amounts of waste due to defects. In this context, the EU-funded Platform-ZERO project is developing a new industrial process-monitoring platform for third-generation PV using AI to revolutionise the production process and impactfully reduce defects and costs. To achieve its goals, the project will develop novel sensors and methods for in-line industrial inspection that will improve the quality of third-generation PV and reduce its environmental impact by minimising the waste of energy and valuable materials during production.

Show the project objective

Fields of science

natural sciences > computer and information sciences > **artificial intelligence**

engineering and technology > materials engineering > **coating and films**

Project Information

Platform-ZERO
Grant agreement ID: 101058459

DOI
10.3030/101058459

EC signature date
9 December 2022

Start date
1 January 2023

End date
31 December 2026

Funded under
Digital, Industry and Space

Total cost
€ 10 190 043,75

EU contribution
€ 9 131 043,00

Coordinated by
FUNDACIO INSTITUT DE RECERCA DE L'ENERGIA DE CATALUNYA
Spain

Dissemination, exploitation and communication (DEC) of the project results

Platform-ZERO

D7.1 – Dissemination and Communication strategy, roadmap and KPIs

Project Information

Grant Agreement Number	101058459
Project Full Title	Customizable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in the PV industry
Project Acronym	Platform-ZERO
Funding scheme	IA
Start date of the project	1st January 2023
Duration	48 Months
Project Coordinator	Victor Izquierdo Roca (IREC)
Project Website	https://www.platform-zero-project.eu

Deliverable Information

Deliverable n°	7.1											
Deliverable title	Dissemination and Communication strategy, roadmap and KPIs											
Partner no.	1	2	3	4	4.1	5	6	7	8	9	10	11
Part. Short name	IREC	AIT	ZSW	R2M-IT	R2M-FR	LUR	SUN	LENZ	RISC	HZB	UPO	SAU
Deliverable Leader					✓							
Contributing Partners	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Authors	Regis Decorme, Pascal Torres, Mojtaba Maktabifard (R2M-FR)											
Contributors	All project partners contributed to review and to provide inputs for this deliverable, in particular for the identification of D&C multipliers (chapter 8) and for the identification of activities to be conducted over the first year of the project (chapter 12)											
Reviewers	Anna Magrasó, Victor Izquierdo, Ignacio Becerril (IREC)											
Contractual Deadline	31-May-2023											
Delivery date to EC	30-May-2023											

Dissemination Level

PU	Public	✓
PP	Restricted to other programme participants (incl. Commission Services)	
RE	Restricted to a group specified by the consortium (incl. Commission Services)	
CO	Confidential, only for the members of the consortium (incl. Commission Services)	

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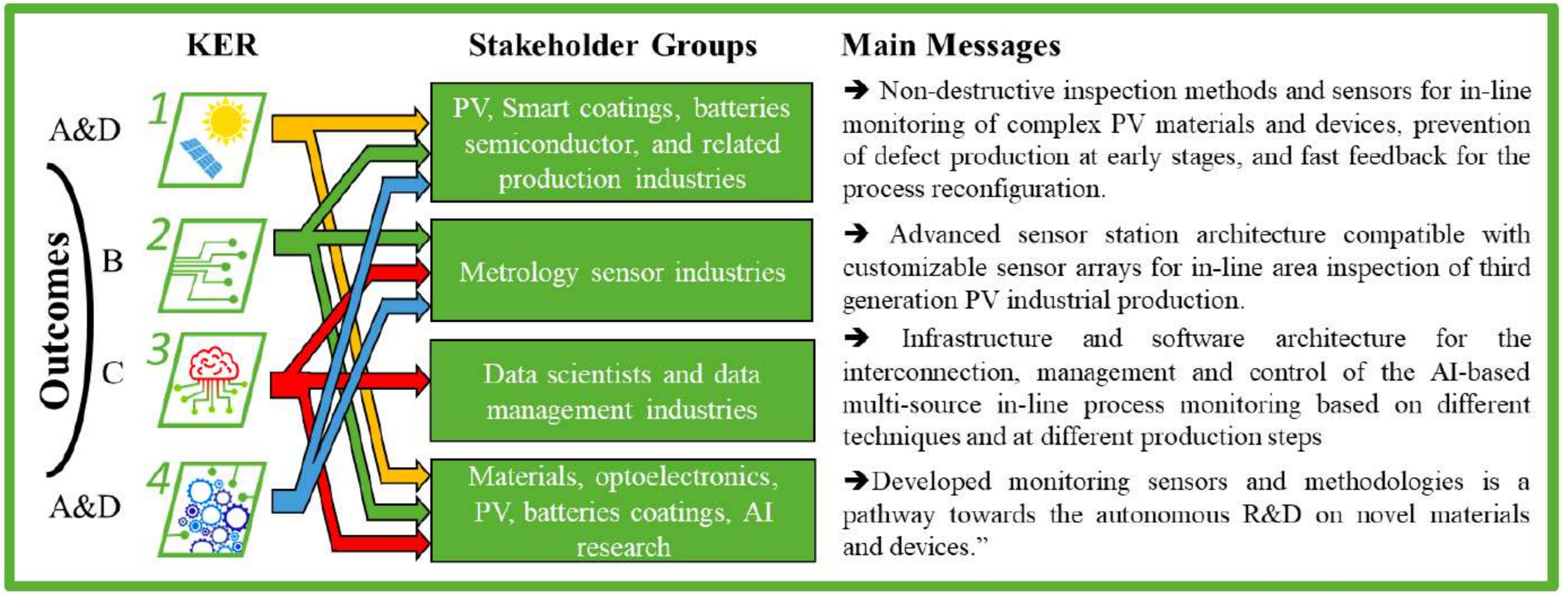
DEC Strategy, roadmap and KPIs

Stage 1. M1-M12 D&C for awareness	Stage 2. M13-M36 D&C for awareness and understanding	Stage 3. M37-M48 D&C for awareness, understanding, and action
Completed and continuing	***Started, ongoing***	***Not started yet***
In the first instance, the purpose of the Platform-ZERO D&C plan is to raise awareness and communicate broadly about Platform-ZERO aims and objectives targeting the general public and relevant external organizations and stakeholders of the Platform-ZERO project outputs.	A subset of the "Stage 1" target audience for whom D&C for awareness activities is targeted, will potentially be able to directly benefit from the project in significant ways. For this group, an important function of the D&C plan is to provide a deeper understanding of Platform-ZERO project's work and innovations.	Yet another "Stage 2" subset of the Platform-ZERO stakeholders will be potentially interested to adopt and implement the project's outputs such as the Platform-ZERO developed in-line process monitoring platform. This group will be equipped with the required skills, knowledge and understanding of the Platform-ZERO project in order to achieve a real change and to foster a greater uptake of zero-defect PV manufacturing.

Dissemination, exploitation and communication (DEC) of the project results

Development of the *"Dissemination & Communication strategy, roadmap, and KPIs"*
Key Stakeholder groups and main messages



Dissemination, exploitation and communication (DEC) of the project results

DEC KPIs and targets

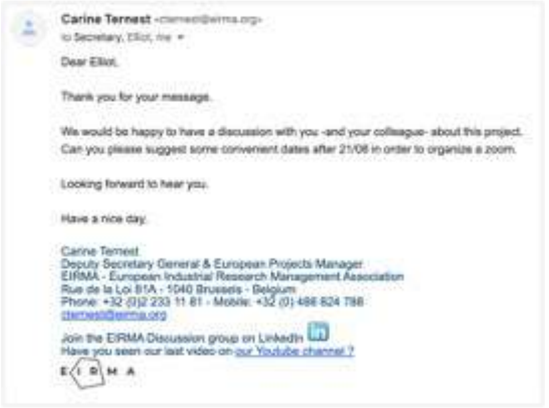
KPI	Stage 1. target M1-M12	Actual performance M18	Stage 2. target M13-M36	Stage 3. target M37-M48	Cumulative target
Public website					
N° of views	500	Around 1000	5000	4500	10000
Social media posts (posted both on Twitter and Linkedin)					
N° of posts	5	Over 30	25	20	50
Peer-reviewed papers (T7.1)					
N° of papers	-	3 published 2 about to be released	2	10	12
Clustering workshops with sister R&I project (T7.3)					
N° of workshops	-	1 in progress	1	1	2
National and international press releases (T7.1)					
N° of press releases	1	1 released 2nd in preparation	2	2	5
Presentations of scientific research at conferences (T7.1)					
N° of presentations	1	10	8	6	15
Industrial fairs (T7.1)					
N° of attendance	-	5	5	5	10
Training for industry and SMEs (T7.2)					
N° of trainings	-	1	4	3	7

Dissemination, exploitation and communication (DEC) of the project results

DEC multipliers

NextGen2024

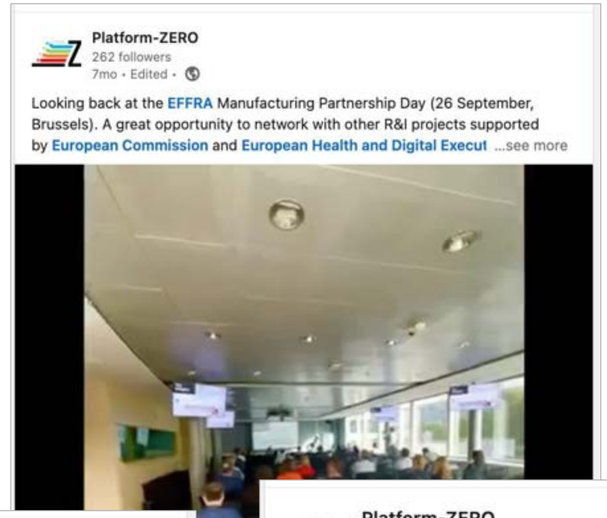
P2M Solution

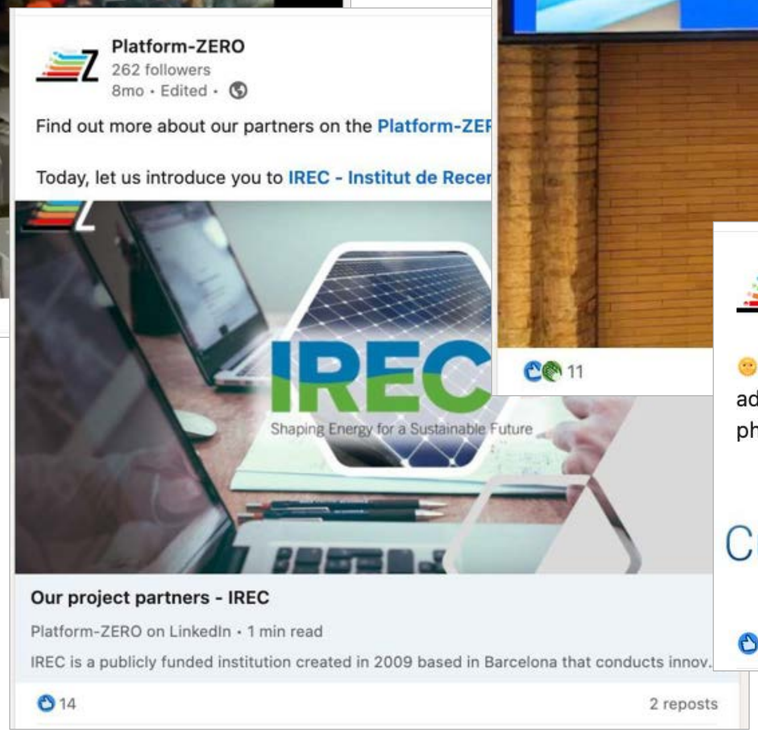


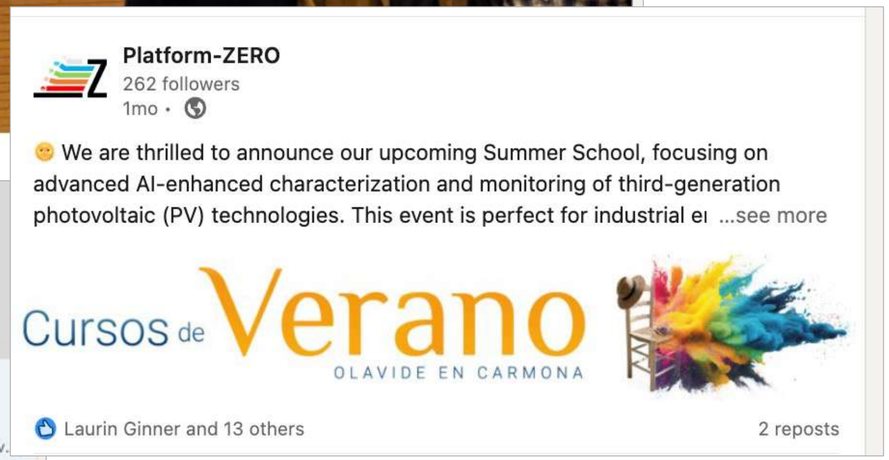
Dissemination, exploitation and communication (DEC) of the project results

Social media

- Regular posts to promote project partners, events, publications, milestones, etc.
- The EC, Hadea and EFFRA are always tagged.

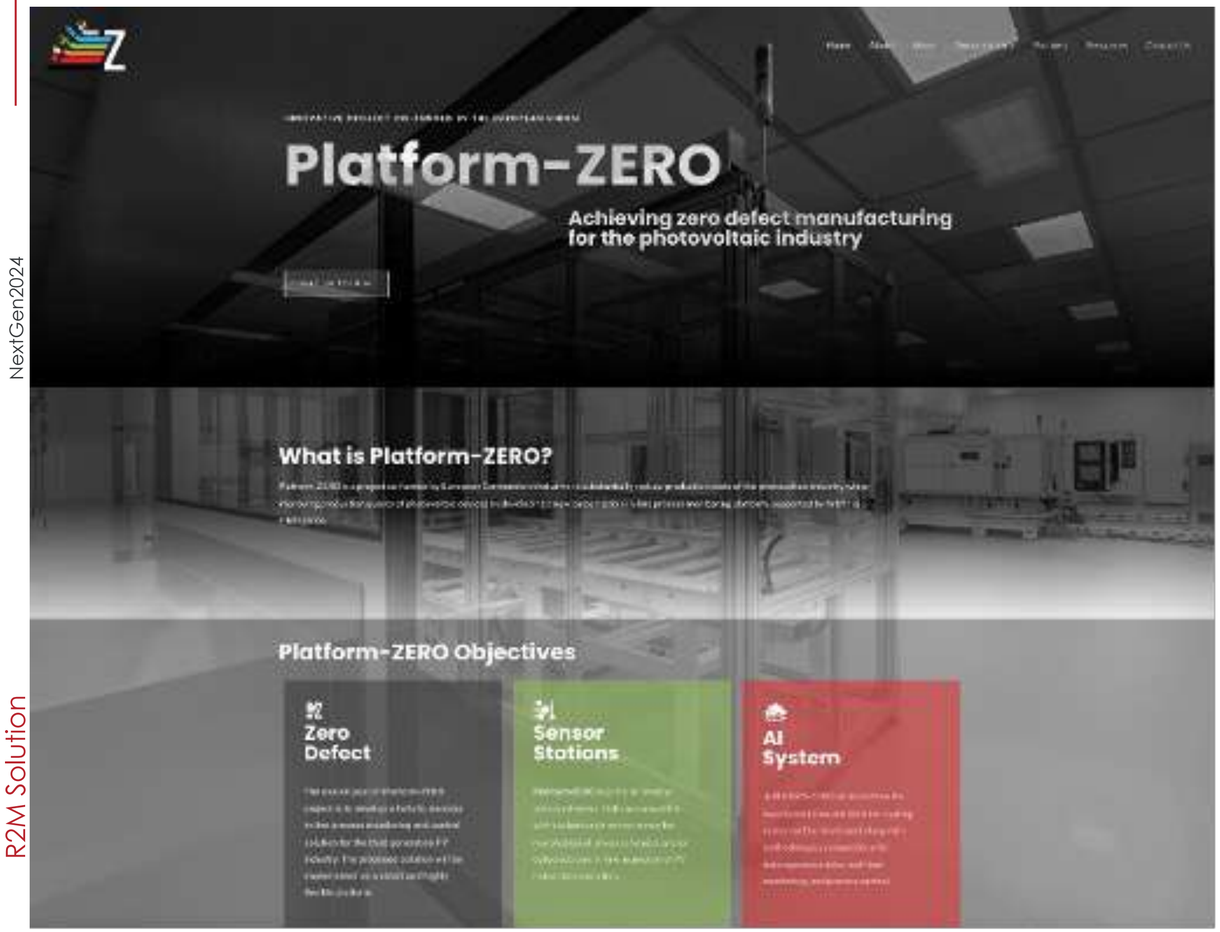


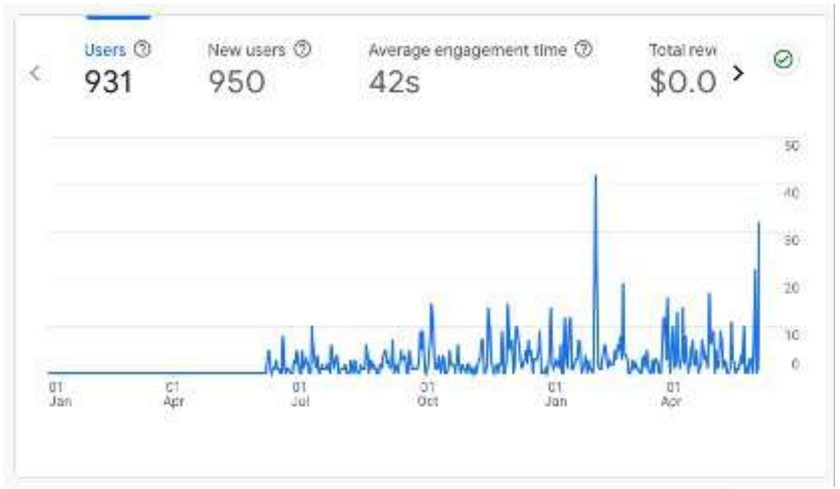


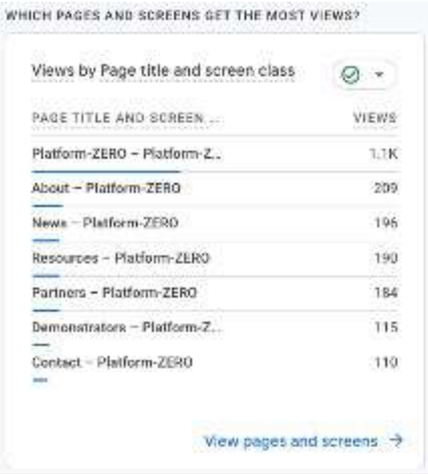


Dissemination, exploitation and communication (DEC) of the project results

Project Website: Regular posts (over 30 during the first reporting period) published in the News section



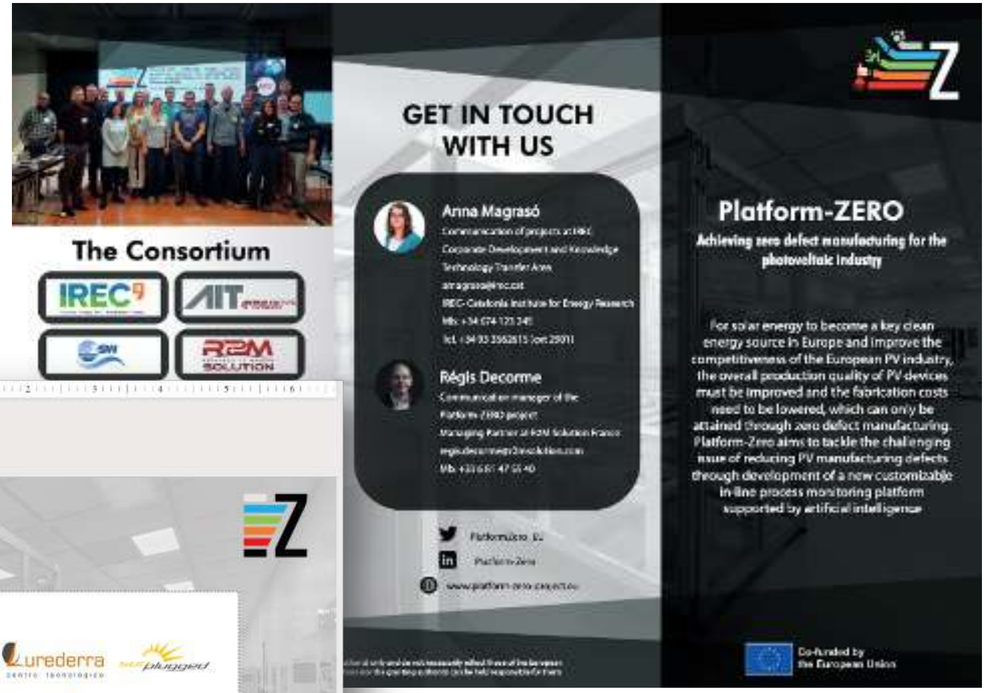


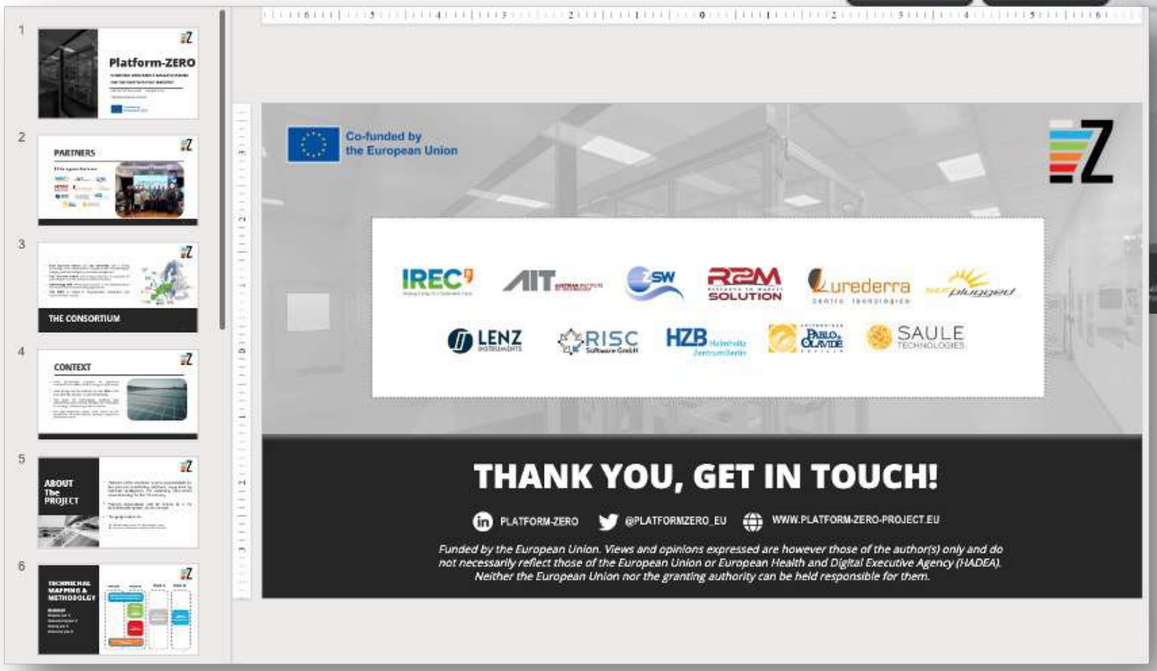


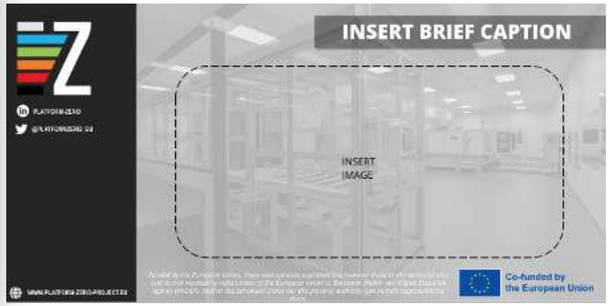
Dissemination, exploitation and communication (DEC) of the project results

DEC toolkit:

- Various materials translated in local language (EN, CA, ES, DE and FR).
- Updated according to the needs of project partners.







Dissemination, exploitation and communication (DEC) of the project results

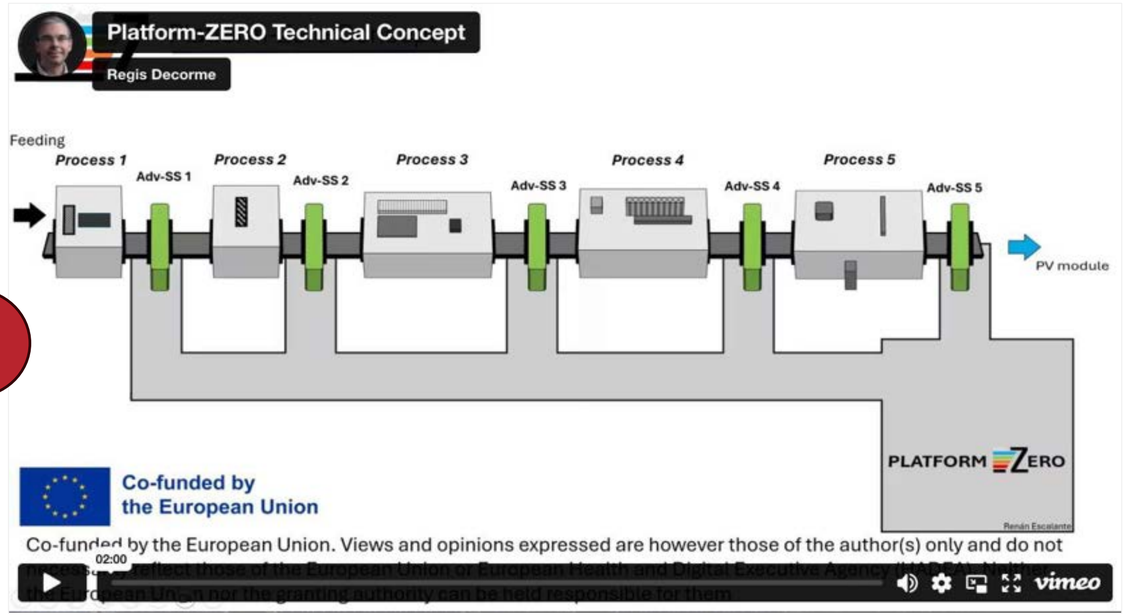
2 promotional videos

- One general introduction
- One on the technical concept (animation)

vimeo

1

2



NextGen2024

R2M Solution

Dissemination, exploitation and communication (DEC) of the project results

Press releases

Press release

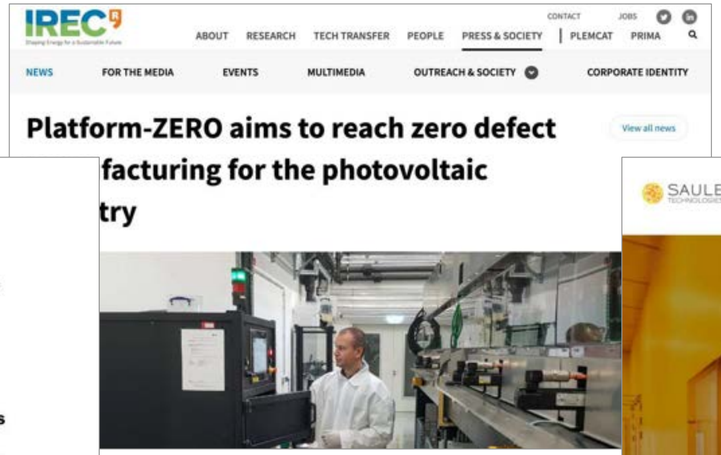
Platform-ZERO aims to reach zero defect manufacturing for the photovoltaic industry

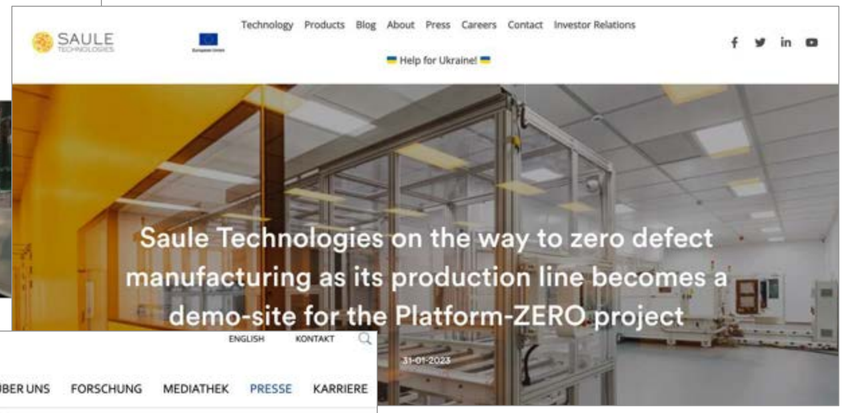
- **Platform-ZERO is a new project co-funded by the European Commission that aims to substantially reduce production costs for industry in the photovoltaic sector**
- **In-line process monitoring, control and artificial intelligence strategies are key technologies to reach zero defect manufacturing**
- **This strategy will now be tested in four different PV industrial pilot plants throughout Europe**

Barcelona, January 31st, 2023. The Platform-ZERO project, starting this month,aims to improve the overall production quality of photovoltaic devices, and at the same time to lower fabrication costs, through zero defect manufacturing. This will be achieved by applying in-line process monitoring, control and artificial intelligence strategies, and implemented in four different pilot plants in four different countries.

Solar photovoltaic (PV) already provides an important contribution to the European energy mix (3.1% of EU-28 gross electricity generation in 2020 (source: Eurostat), and solar energy has the potential to meet 20% of the EU electricity demand in 2040 (source: BloombergNEF). The latest generation of PV technologies combine high performance with a strong flexibility for integration in buildings, vehicles, agrivoltaics and internet-of-things devices. However, their high-complexity makes them prone to the appearance of critical defects with just small deviations from standard manufacturing conditions, leading to significant production waste.

Platform-ZERO addresses this challenge by developing a new customizable in-line process monitoring platform, supported by artificial intelligence, for achieving zero-defect manufacturing in the third generation PV industry to allow an early detection, correction and/or prevention of pre-critical production faults. The strategy will be tested in four pilot plants from PV and PV-related industrial partners in Spain, Germany, Austria and Poland. The pilots are devoted to smart coatings for PV, high-efficiency solar modules and flexible solar foils of different photovoltaic materials and processes.





Dissemination, exploitation and communication (DEC) of the project results

Articles: 9 released in various magazines and news portals

DAS MAGAZIN

FÜR PARTNER-INNEN UND KUND-INNEN

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

01/23

Null-Emissions-LKW
AIT leitet europäisches Konsortium

Industrie: Szenarien für die Zukunft
Wie Dekarbonisierung gelingen kann

Gesundheit für Mensch und Umwelt
One Health: Ein neuer Exzellenzcluster mit AIT-Beteiligung führt rote und grüne Mikrobiomforschung zusammen

High-tech-Training für Notfallhelfer:innen
Besser vorbereitet durch Extended Reality

Technologie beim Forum Alpach
AIT ist Premium Partner

Vision, Automation & Control
Fehlerlose Produktion von PV-Modulen

Technology Experience
Keine Chancengleichheit im Energiesektor

Low-Emission Transport
Effizienterer Antrieb für Nutzfahrzeuge

Das zu Jahresbeginn gestartete EU-Projekt Platform-ZERO zielt darauf ab, die allgemeine Produktionsqualität von Photovoltaikgeräten zu verbessern und gleichzeitig die Ressourceneffizienz durch eine Null-Fehler-Fertigung zu steigern. Langfristig sollen so die Herstellungskosten gesenkt werden können. Erreicht werden soll dies durch die Anwendung von Schlüsseltechnologien zur Inline-Prozessüberwachung und -steuerung in Verbindung mit künstlicher Intelligenz. Für die Umsetzung und Testung der Strategien stehen vier verschiedene Pilotanlagen in Spanien, Deutschland, Österreich und Polen zur Verfügung. Die zwölf Kooperationspartner aus sechs europäischen Staaten befassen sich dabei insbesondere mit intelligenten Beschichtungen für Photovoltaikoberflächen, hocheffizienten Solarmodulen und flexiblen Solarfolien aus verschiedenen Materialien und Herstellungsprozessen. Das AIT bringt dabei u. a. die Inline Computational Imaging Technologie ein: Diese kombiniert sehr schnelle optische 2D und 3D Prüfmethoden mit intelligenten Algorithmen. „Damit können wir selbst feinste Defekte bei hohen Produktions- und Prüfgeschwindigkeiten erkennen, auch wenn die Oberflächeneigenschaften des Materials schwierig sind", erläutert Govinda Lilley, der das Projekt am AIT leitet.

Von einem ausgeglichenen Geschlechterverhältnis ist der Energiesektor in Österreich noch weit entfernt. Zu diesem Ergebnis kommt die Studie "Chancengleichheit in der Energiebranche" des AIT im Auftrag des Klima- und Energiefonds. Für die umfassende Analyse wurden Kennzahlen aus Geschäftsberichten und Nachhaltigkeitsberichten herangezogen. Außerdem wurden Umfragen zu Strategien zur Förderung von Chancengleichheit und zu erlebter Diskriminierung sowie Workshops zur Maßnahmenerarbeitung durchgeführt. Insgesamt wurden Daten von 116 Organisationen unterschiedlicher Größe aus allen neun Bundesländern analysiert. Bei der umfassenden Studie wurde die Expertise des AIT Center for Technology Experience, des AIT Center for Energy und des AIT Center for Innovation Systems & Policy gebündelt. Demnach sind mittlerweile 24 Prozent der Angestellten in der österreichischen Energiebranche weiblich. Mit zunehmenden technischen-manuellen oder führungsbezogenen Aufgaben nimmt der Anteil der Frauen überproportional ab. Im Top-Management sind nur rund 10 Prozent Frauen vertreten. „Wir müssen Geschlechterstereotypen entschieden entgegenwirken und Klimaberufe auch für Frauen attraktiv gestalten", sagte Klimaschutzministerin Leonore Gewessler anlässlich der Präsentation der Studie. Zur Studie ist ein umfassendes Dossier erschienen. **https://www.klimafonds.gv.at/dossier/chancengleichheit**

Kommunale Nutzfahrzeuge sind meist modular aufgebaut und werden vielfältig eingesetzt. In dieser Fahrzeugklasse hat sich in jüngster Zeit ein hydrostatisches Hybrid-Antriebssystem etabliert: Die Hydraulik-Einheit kann den Antrieb unterstützen, alleinig für Vortrieb oder auch für den Betrieb der Zusatzgeräte (Mäher, Baggerschaufeln etc.) sorgen. Zum Einsatz kommt dabei ein so genanntes CVT-Getriebe (Stufenlosgetriebe), das unabhängig von der Drehzahl des Motors geregelt werden kann. Im Teillastbereich gibt es dabei allerdings starke Verluste und hohe Emissionen. In dem vom LKR Leichtmetallkompetenzzentrum Ranshofen des AIT geleiteten FFG-Pprojekt eCVT (Emissionsreduzierendes CVT-Getriebes mit elektrischem Variator für Nutzfahrzeuge) wurde gemeinsam mit sechs Partnern eine neuartige Getriebeeinheit entwickelt, die die Nachteile herkömmlicher CVT-Einheiten durch ein Kopplung mit elektrischen Maschinen kompensieren kann. Um die Kühlung der elektrischen Einheiten zu gewährleisten, wurde am LKR ein Gehäuse mit entsprechend innovativem Kühlsystem entwickelt und als Prototyp in neuartiger hybrider Guss-Schweiß-Konstruktion ausgeführt. Nach dem Gießen mittels Niederdruckgussverfahrens wurde das hochkomplexe Aluminium-Bauteil in weiterer Folge durch Materialauftrag im Wire-based Additive Manufacturing-Verfahren fertiggestellt. **www.ait.ac.at/themen/casting-technologies/projekte/ecvt**

REVISTA DE GENERACIÓN DE ENERGÍA

Nº 224 · MARZO 2023 · Año XXIII

energética

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SOLAR FOTOVOLTAICA
- Metaverso para instalaciones fotovoltaicas
- Fabricación de nuevas tecnologías fotovoltaicas
- Instalación de autoconsumo con baterías y *full backup* con gestión inteligente
- Estructuras fotovoltaicas

INGENIERÍA ENERGÉTICA
- Entrevista a Daniel Carazo Álvarez, director técnico de la ingeniería y asesoría energética Ofeinco
- La ingeniería en España y el desafío del desarrollo de las renovables

EÓLICA
- Operación y mantenimiento en eólica flotante y offshore
- Hibridación
- Reciclaje de palas

ecomotion

- Acumulación de ener… sistemas de recarga
- Laboratorio de movil… inteligente
- Electrificación de cocheras de…

1 / 76

SOLAR FOTOVOLTAICA

Avanzando hacia los 'cero defectos' y la Industria 4.0 en la fabricación de nuevas tecnologías fotovoltaicas

El proyecto Platform-ZERO, impulsado por IREC, está desarrollando una innovadora plataforma de monitorización de procesos para lograr 'cero defectos' en el proceso de fabricación de dispositivos fotovoltaicos de nueva generación.

DR. VÍCTOR IZQUIERDO ROCA
JEFE ADJUNTO DEL GRUPO MATERIALES Y SISTEMAS PARA ENERGÍA SOLAR DEL IREC

DR. IGNACIO BECERRIL ROMERO
INVESTIGADOR SENIOR DEL GRUPO MATERIALES Y SISTEMAS PARA ENERGÍA SOLAR DEL IREC

La fotovoltaica desempeñará un papel clave en la transición de Europa hacia la neutralidad climática, descentralizando y descarbonizando la producción de energía. Actualmente, la fotovoltaica ya representa un porcentaje significativo del mix energético europeo (el 3,1% en 2020, Eurostat) y se estima que satisfará el 20% de la demanda de electricidad de la UE en 2040[1]. La UE está apostando fuertemente por el I+D en nuevas tecnologías fotovoltaicas de mayor eficiencia, menores costes, menor huella de carbono y mayor personalización en la forma, transparencia, color o flexibilidad. Esto las hace aptas para su integración en diferentes entornos como edificios, vehículos, explotaciones agrícolas o dispositivos electrónicos[2]. Estas tecnologías, como el CIGS o las perovskitas, están conquistas por materiales de alto valor que son escasos, de alta pureza y/o con alto impacto ambiental, y están basadas microarquitecturas multicapa. Esta alta complejidad hace que pequeñas desviaciones de las condiciones estándar de fabricación provoquen defectos críticos que dan lugar a dispositivos de baja calidad y/o al desperdicio de materiales de alto valor, lo que afecta directamente al coste de producción.

En este contexto, un consorcio europeo formado por 11 socios coordinado por el Institut de Recerca en Energia de Catalunya (IREC) ha impulsado Platform-ZERO, un proyecto que tiene como objetivo lograr 'cero defectos' en el proceso de fabricación de dispositivos fotovoltaicos de nueva generación. Para ello, Platform-ZERO está desarrollando una innovadora plataforma de monitorización de procesos modular, personalizable y autocalibrable que proporciona una evaluación holística de la producción empleando métodos de inspección no destructivos e inteligencia artificial para detectar, corregir y/o prevenir los defectos de fabricación antes de que afecten a la producción. Esta plataforma de monitorización está basada en la combinación de los siguientes elementos:

1. **Estaciones sensóricas avanzadas**. Son estaciones modulares y personalizables que combinan sensores espectroscópicos, de visión artificial y optoelectrónicos. Estas estaciones están distribuidas en distintas etapas de fabricación y envían datos a una unidad de control inteligente para detectar desviaciones en la producción.
2. **Sistema de inteligencia artificial**. Es un conjunto de algoritmos de autoaprendizaje que procesan los datos heterogéneos recogidos por las estaciones sensóricas para detectar y predecir desviaciones del proceso de producción, y sugerir acciones correctivas.
3. **Unidad de control inteligente**. Es una infraestructura de hardware y software para interconectar y controlar los diferentes elementos de la plataforma permitiendo el intercambio de información entre ellos, gestionando el big data generado por las estaciones sensóricas, y proporcionando una interfaz gráfica para la visualización de los datos y las acciones correctivas generados por la inteligencia artificial.

La combinación de estos elementos proporciona una comprensión profunda del proceso de producción que permite: la detección precoz de desviaciones pre-críticas, el diagnóstico del origen de las desviaciones, y la sugerencia de medidas correctivas. Además, la autocalibración de la tecnología Platform-ZERO ofrece una gran flexibilidad para adaptarse a cambios en el proceso de producción, como la incorporación de nuevo equipamiento o modificación de parámetros, así como a procesos de fabricación más allá de la fotovoltaica.

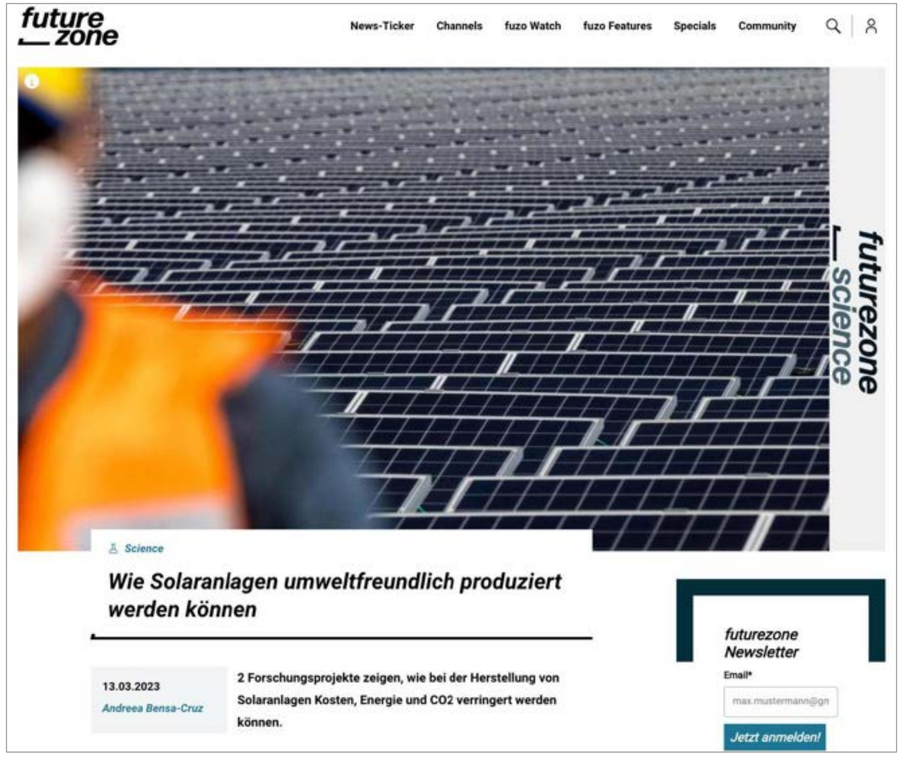
La tecnología Platform-ZERO está siendo desarrollada por socios académicos con gran conocimiento en sensores espectroscópicos (IREC, HZB), visión artificial (AIT), optoelectrónica (UPO), inteligencia artificial (AIT, IREC, RISC) y gestión de datos (RISC). Este equipo se complementa con una empresa de metrología que fabrica equipos de monitorización de procesos industriales (LENZ). Esta tecnología será demostrada en condiciones reales mediante la instalación de prototipos operativos en 4 líneas piloto de producción industrial relacionadas con la energía fotovoltaica: Sunplugged (Austria), producción de paneles solares flexibles y personalizables de CIGS en configuración roll-to-roll; ZSW (Alemania), producción de paneles solares de CIGS de alta eficiencia en configuración sheet-to-sheet; Saulé (Polonia), producción de paneles solares flexibles de perovskita en configuración sheet-to-sheet; y Luredema (Navarra), producción de nanopartículas para recubrimientos fotovoltaicos inteligentes en configuración line powder flow. Un socio más, R2M Solution, completa el consorcio del proyecto encargándose de la difusión, explotación y acciones de comunicación.

Durante los próximos cuatro años, Platform-ZERO contribuirá a incrementar la calidad global y a reducir el coste de los dispositivos fotovoltaicos high-tech, a aumentar la competitividad de la industria fotovoltaica europea y a permitir que esta tecnología verde sea una fuente energética clave para la transición de Europa hacia la neutralidad climática.

1 Energy Outlook 2020, BloombergNEF
2 https://ec.europa.eu/info/research-and-innovation/research-area/energy-research-and-innovation/solar-energy_en

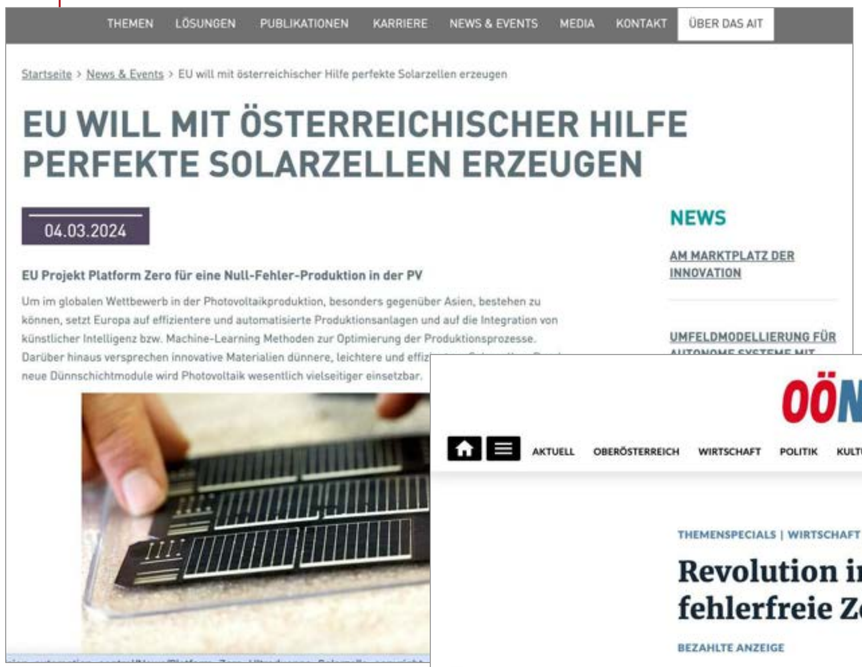
Dissemination, exploitation and communication (DEC) of the project results

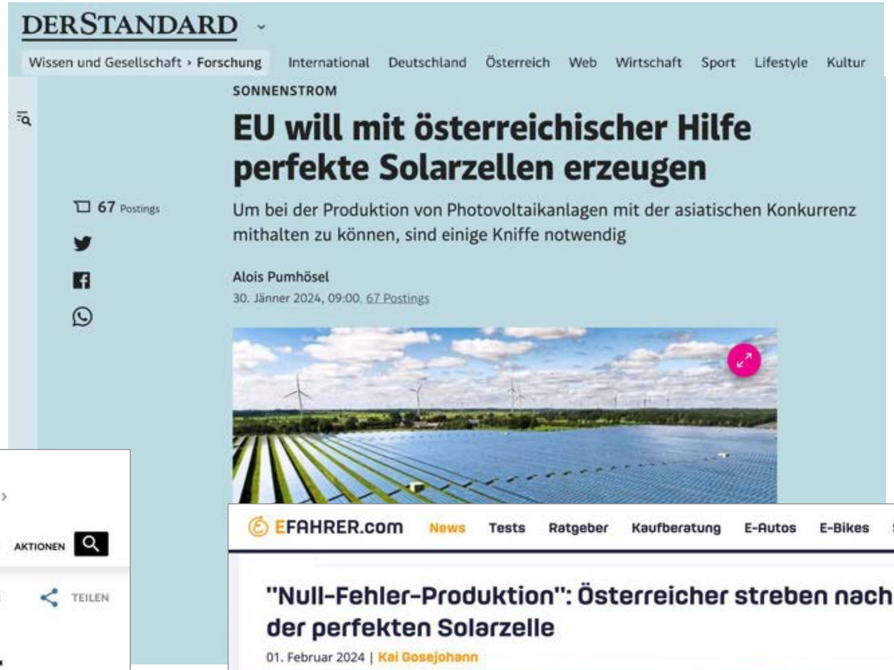
Articles: 9 released in various magazines and news portals

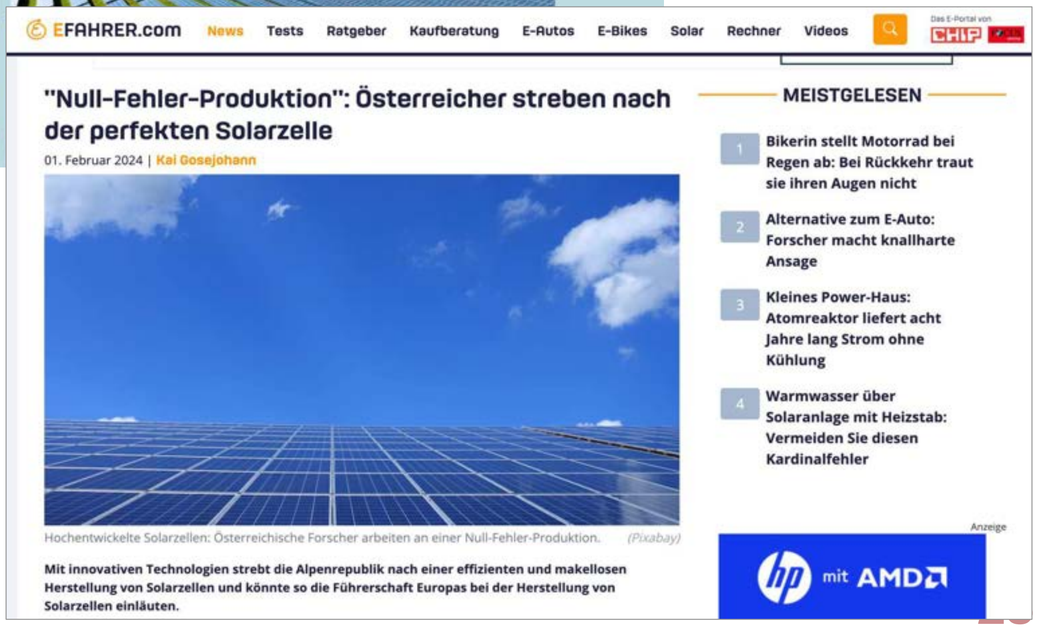


Dissemination, exploitation and communication (DEC) of the project results

Articles: 9 released in various magazines and news portals







Dissemination, exploitation and communication (DEC) of the project results

Journal Papers

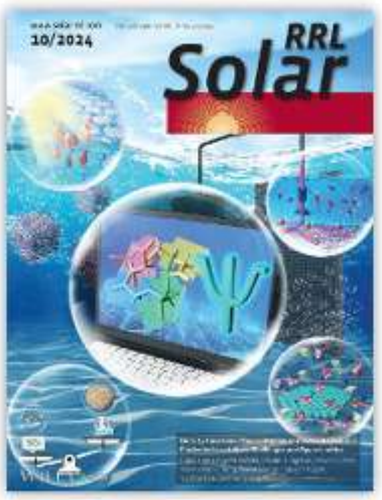
JOSS
The Journal of Open Source Software

pudu: A Python library for agnostic feature selection and explainability of Machine Learning spectroscopic problems

Enric Grau-Luque [1], Ignacio Becerril-Romero [1], Alejandro Perez-Rodriguez [1,2], Maxim Guc [1], and Victor Izquierdo-Roca [1]

1 Catalonia Institute for Energy Research (IREC), Jardins de les Dones de Negre 1, 08930 Sant Adrià de Besòs, Spain. 2 Departament d'Enginyeria Electrònica i Biomèdica, IN2UB, Universitat de Barcelona, C/ Martí i Franqués 1, 08028 Barcelona, Spain.

DOI: 10.21105/joss.05873

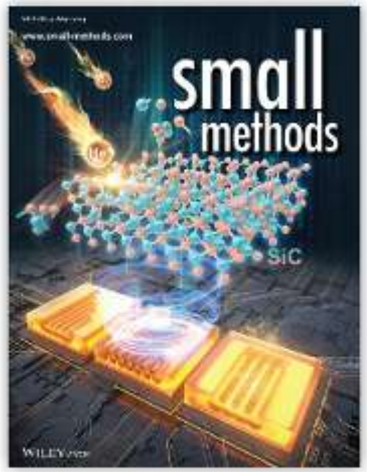


Research Article | Open Access

Accelerating the Development of Thin Film Photovoltaic Technologies: An Artificial Intelligence Assisted Methodology Using Spectroscopic and Optoelectronic Techniques

Enric Grau-Luque, Ignacio Becerril-Romero, Fabien Atlan, Daniel Huber, Martina Harnisch, Andreas Zimmermann, Alejandro Pérez-Rodríguez, Maxim Guc, Victor Izquierdo-Roca

First published: 28 March 2024 | https://doi.org/10.1002/smtd.202301573



Research Article | Open Access

Competition between Transport and Recombination in Dye Solar Cells at Low Light Intensity

Patricia Sánchez-Fernández, Clara A. Aranda, Renán Escalante, Antonio J. Riquelme, Renaud Demadrille, Paul Pistor, Gerko Oskam, Juan A. Anta

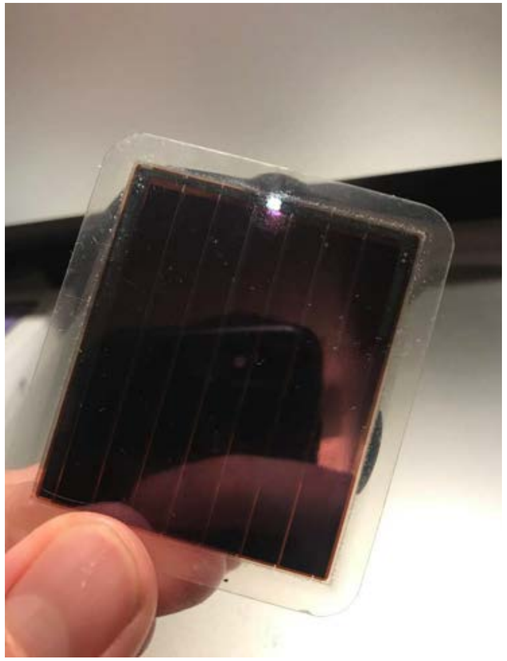
First published: 25 April 2024 | https://doi.org/10.1002/solr.202400149

Dissemination, exploitation and communication (DEC) of the project results

Industrial fairs

Dissemination, exploitation and communication (DEC) of the project results

Industrial fairs:



Dissemination, exploitation and communication (DEC) of the project results

Industrial fairs:

Dissemination, exploitation and communication (DEC) of the project results

Presentations in events: targeting very diverse stakeholders, from students to scientific & professional audience

NIT EUROPEA DE LA RECERCA | Què és? | Programació | Programa Magnet | Notícies | Vídeos

Nom i cognoms / Name and surname

Ignacio Becerril Romero

Afiliació / Affiliation

Institut de Recerca en Energia de Catalunya (IREC)

Programa de finançament europeu en que s'enmarca aquest projecte? / European funding programme in which this project is being carried out?

EU support (FP7, H2020, etc.) other than MSCA

Títol del projecte / Project title

Customizable AI-based in-line process monitoring

Dissemination, exploitation and communication (DEC) of the project results

Presentations in events: targeting very diverse stakeholders, from students to scientific & professional audience

Dissemination, exploitation and communication (DEC) of the project results

Presentations in events:

NextGen2024

R2M Solution

Dissemination, exploitation and communication (DEC) of the project results

Presentations in events:

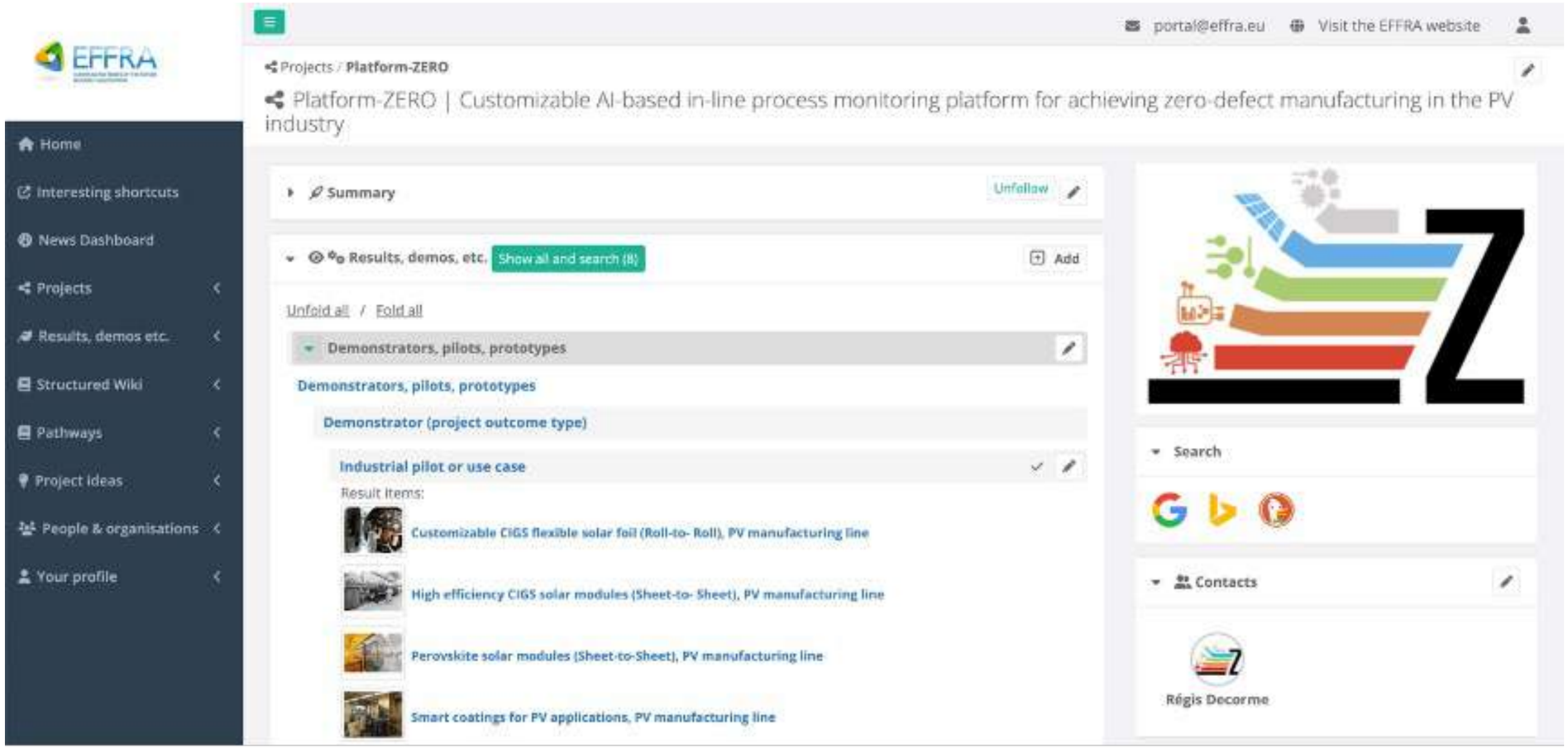
Dissemination, exploitation and communication (DEC) of the project results

Presentations in events:

Dissemination, exploitation and communication (DEC) of the project results

EFFRA Portal

Platform-ZERO info and results updated on the EFFRA Reporting Portal



Dissemination, exploitation and communication (DEC) of the project results

NEXTGEN 2024 International School & Workshop

IREC and Platform-ZERO are delighted to announce the return of the **NEXTGEN (Next Generation High Efficiency Photovoltaics) International School and Workshop**, now entering its 5th Edition, in collaboration this year with the RenewPV School.

After a pause due to the global COVID-19 pandemic, our eagerness to reconvene, reconnect, and rekindle our shared passion for pioneering photovoltaic research is stronger and more necessary than ever.

We are pleased to invite you to join us in the inspiring setting of **Palma, Mallorca, Spain, from the 9th to the 12th of September 2024**.

This year's edition, set against the backdrop of Caixa Forum Palma, aims not only to continue the tradition of excellence established by previous editions but also to elevate the discourse to new heights. Our commitment to advancing the field of high-efficiency photovoltaics remains unwavering, with an enhanced focus on fostering greater interaction between academia and industry. The dialogue between young researchers, senior academics, and industry members is more crucial than ever as we navigate the challenges and opportunities presented by the transition from laboratory to industrial scale.

NEXTGEN 2024 will boast a roster of top-tier presentations by keynote and invited speakers, reflecting the cutting-edge in new and emerging materials, novel device concepts addressing advanced PV applications and their transfer to industry for the successful industrial implementation of competitive PV technologies.

Please remember to save these dates and stay tuned for more information!

NextGen2024

R2M Solution

Dissemination, exploitation and communication (DEC) of the project results

NextGen2024

1. Clustering workshop scheduled for September

“Advanced manufacturing of new-generation renewable plants”

With the participation of:

- ENGINE
- SuperTandem
- SEAMLESS-PV

R2M Solution

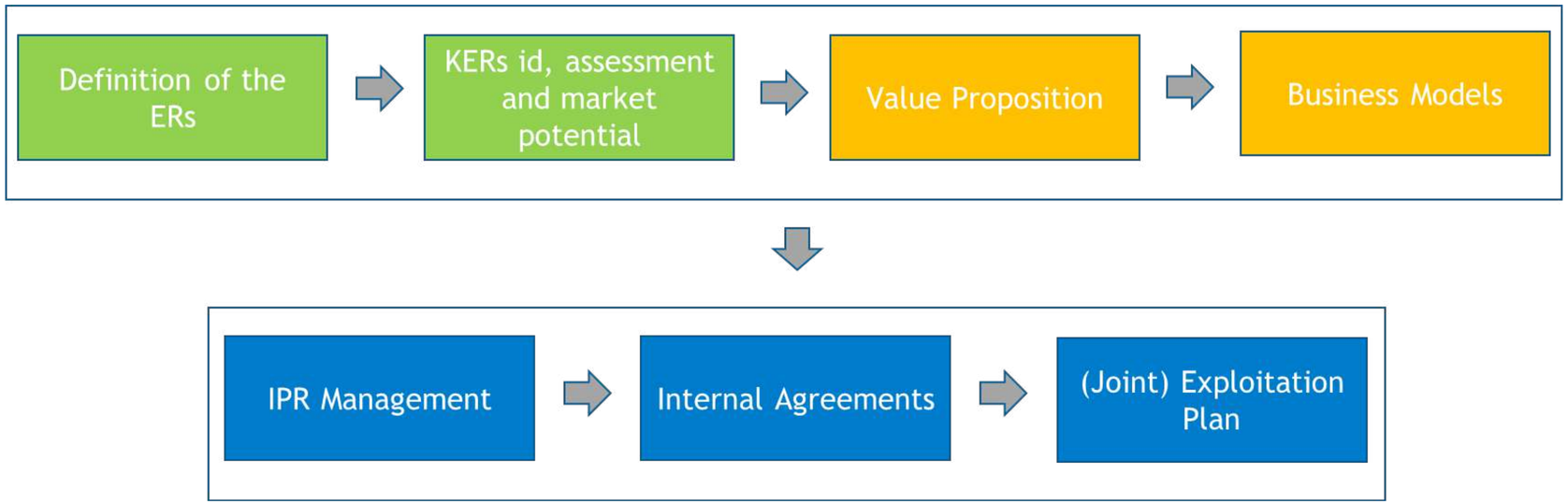
2. Start of collaboration in the 4ZDM cluster

To work on a joint white paper about existing and new standards concerning the use of AI in zero-defect manufacturing

Dissemination, exploitation and communication (DEC) of the project results

Key Exploitable Results (KERs): exploitation strategy

KER 1 – Defect-free PV manufacturing methodologies	KER 2 – Advanced sensor stations	KER 3 – Artificial Intelligence decision-making	KER 4 Holistic manufacturing control platform
AI-assisted non-destructive inspection methods for the improvement of sustainable PV manufacturing processes.	Development of advanced multi-sensor inspection tools compatible with in-line acquisition for detection of pre-critical process deviations.	Decision-making protocols for early prediction of defect formation at the earliest possible production stages and proposal of process correction measures.	Creation of a new holistic diagnostic system for in-line monitoring and control of complex solid state devices manufacturing processes.
▶ *New methods*	▶ *New product*	▶ *New methods*	▶ *New product*



Basic concepts: Exploitation of results

Participants receiving European Union funding must use their best efforts to take measures aiming at ensuring the exploitation of their results up to four years after the project, either directly or indirectly by a third party (through transfer or licensing). This means that participants must take steps to make sure the results they owned are used:

1. in further research activities other than those covered by the project concerned,
2. in developing, creating and marketing products or processes,
3. in creating and providing services, or
4. in standardisation activities.

The use of the Horizon Results Platform becomes mandatory, if one year after the end of the action, key exploitable results are not exploited.

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News and events

Second EIC extracellular vesicle-based cluster event held in Brussels

2 June 2024

Representatives of the EU extracellular vesicle (EV)-based community discussing over emerging scientific/technological, innovation and market path challenges.

Attention to projects in Aerospace and Defence: Join the ILA Connect & Meet 2024 at Berlin ExpoCenter Airport this June!

12 May 2024

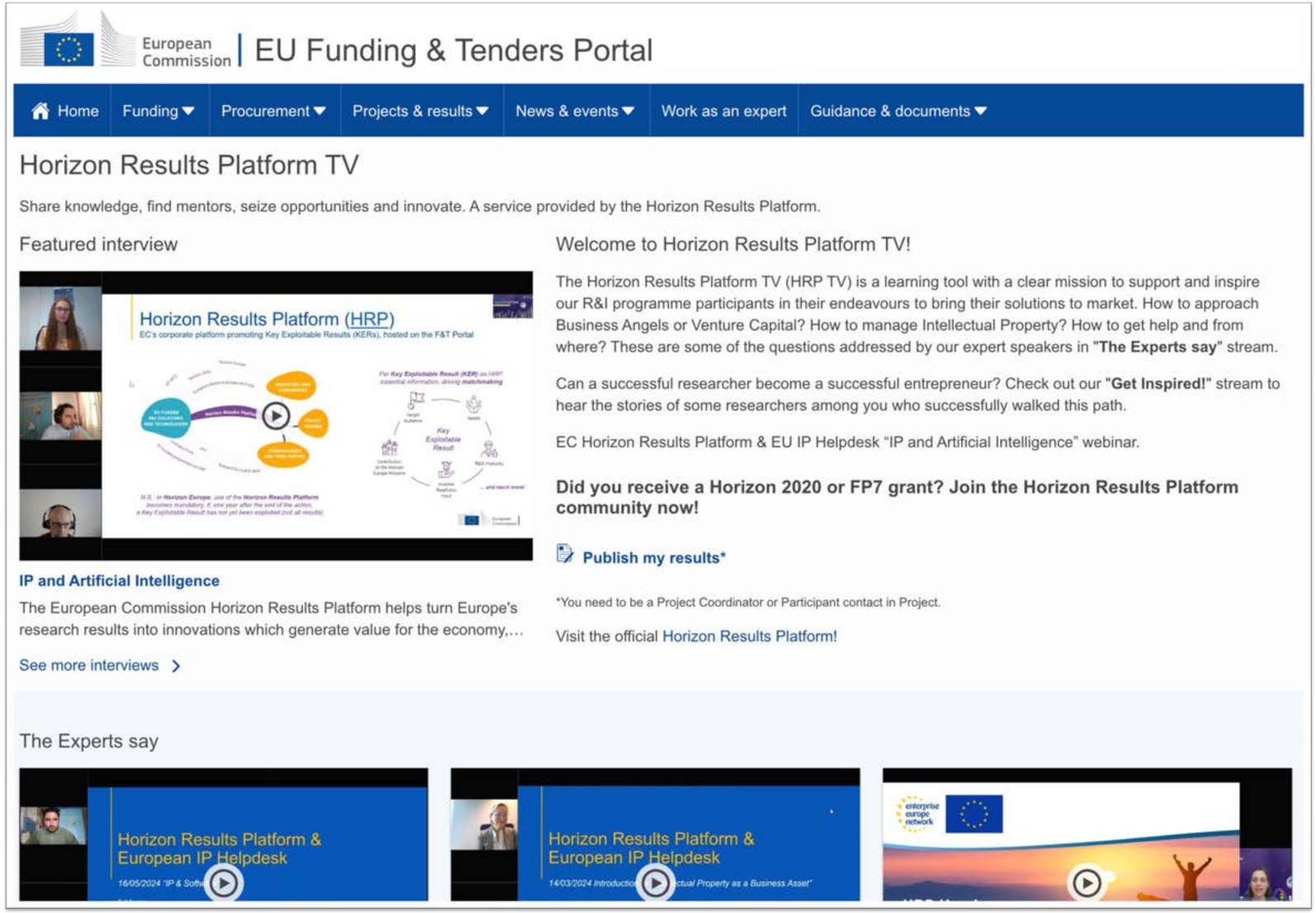
Network with aerospace leaders, explore advancements in aviation, defense, and space technology!

Join the Health Revolution Congress 2024!

7 May 2024

Dive into digital health innovation at the Health Revolution Congress in Barcelona from May 16-23, 2024.

See more news >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Featured interview
Horizon Results Platform (HRP)
EC's corporate platform promoting Key Exploitable Results (KERs), hosted on the F&T Portal
IP and Artificial Intelligence
The European Commission Horizon Results Platform helps turn Europe's research results into innovations which generate value for the economy,…
See more interviews
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The Horizon Results Platform TV (HRP TV) is a learning tool with a clear mission to support and inspire our R&I programme participants in their endeavours to bring their solutions to market. How to approach Business Angels or Venture Capital? How to manage Intellectual Property? How to get help and from where? These are some of the questions addressed by our expert speakers in "The Experts say" stream.
Can a successful researcher become a successful entrepreneur? Check out our "Get Inspired!" stream to hear the stories of some researchers among you who successfully walked this path.
EC Horizon Results Platform & EU IP Helpdesk "IP and Artificial Intelligence" webinar.
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*You need to be a Project Coordinator or Participant contact in Project.
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The Experts say
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enterprise europe network

HRP
TV
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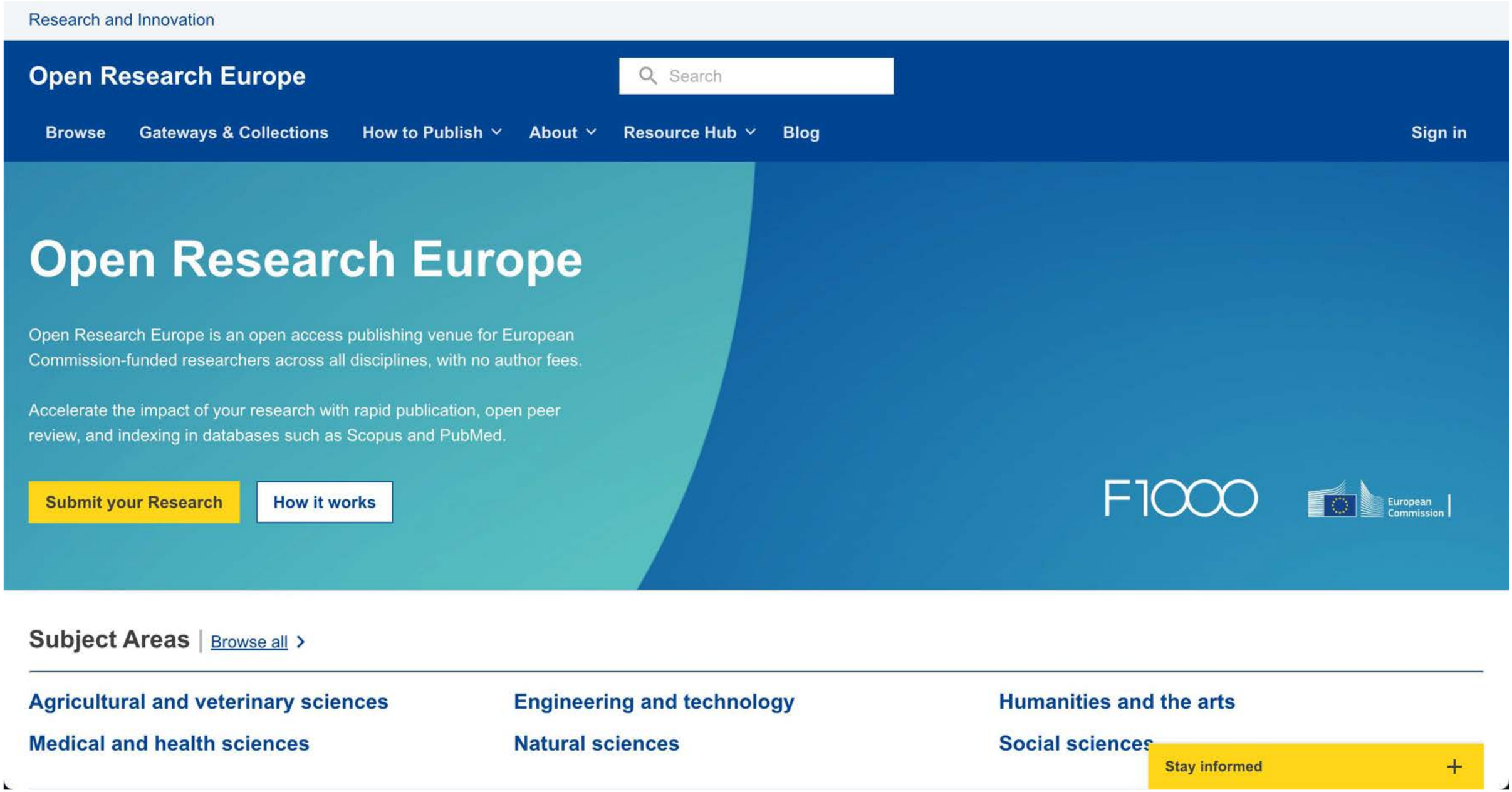
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Engineering and technology
Humanities and the arts
Medical and health sciences
Natural sciences
Social sciences
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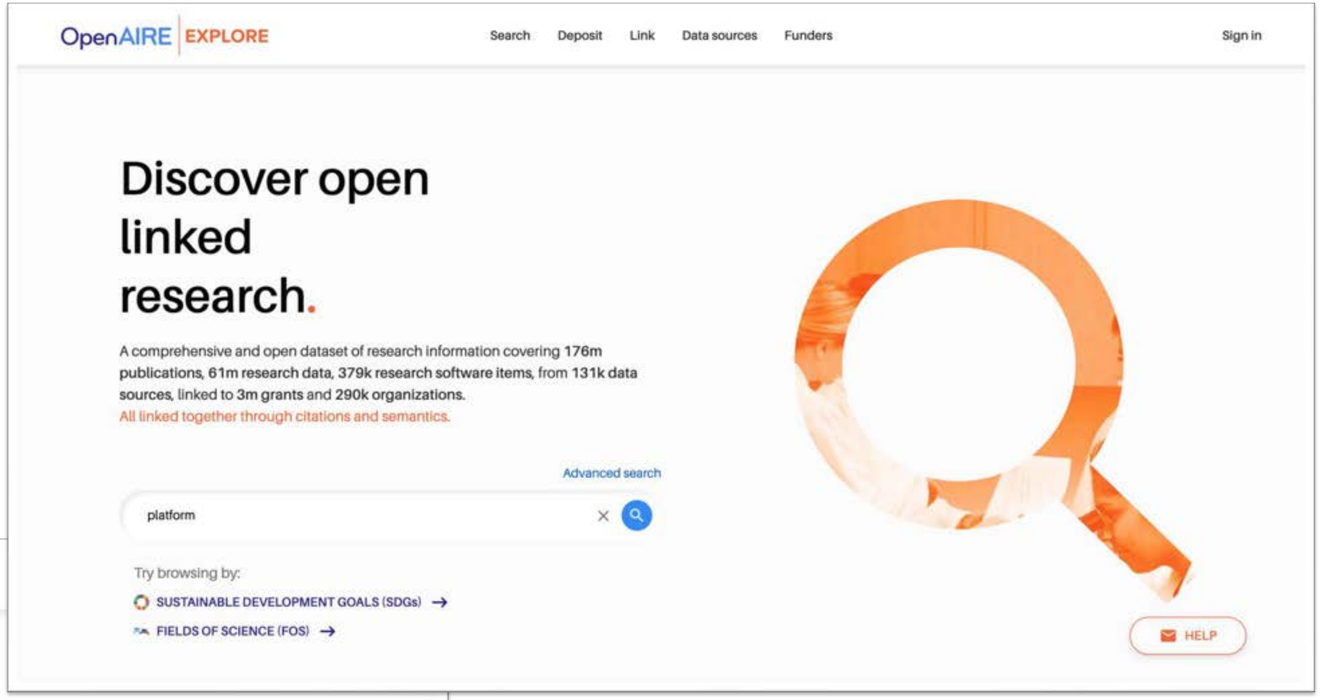

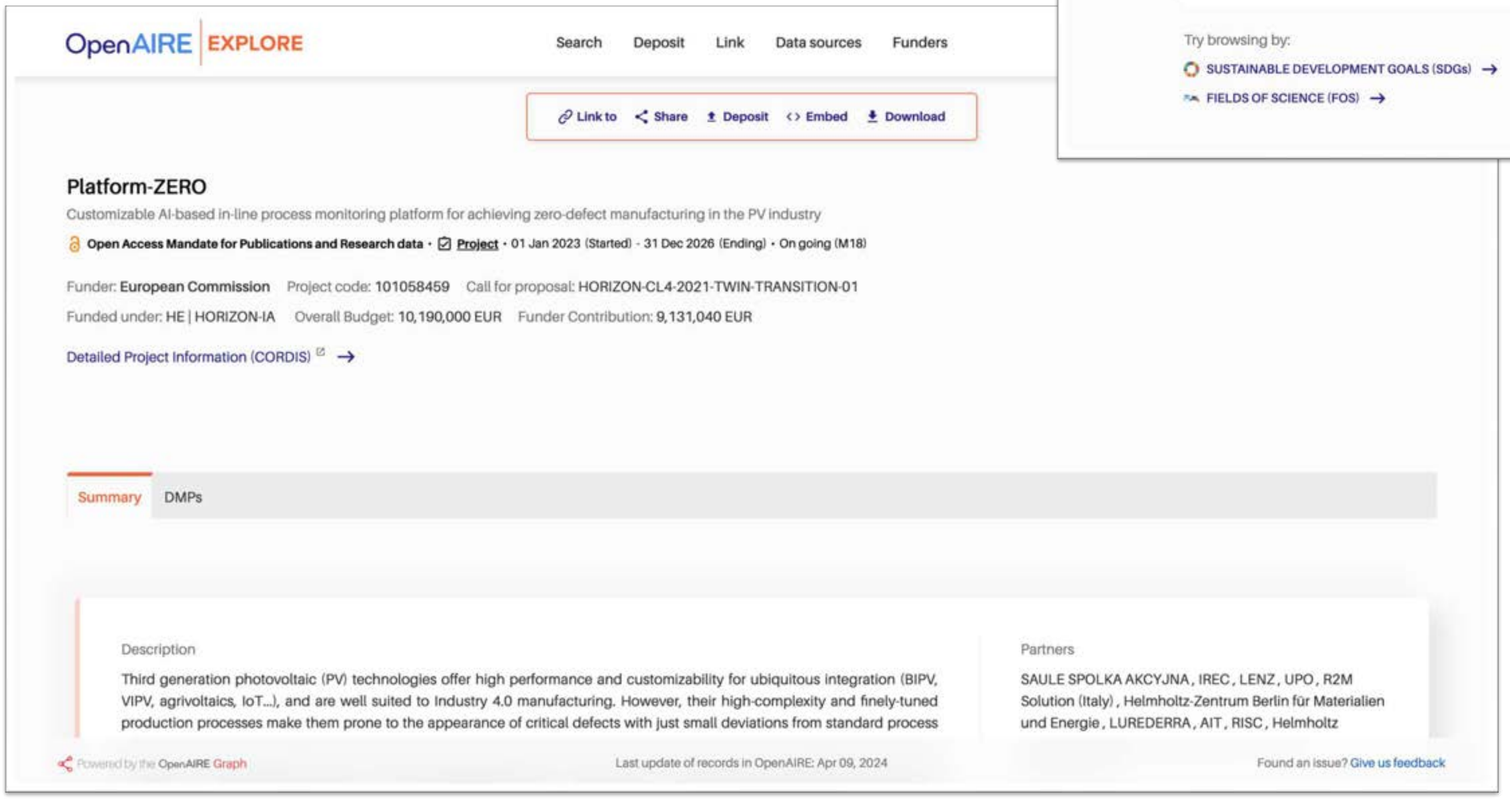

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Receive expert free of charge support services to boost the exploitation potential of your research results, disseminate effectively, and go to market.

Standardisation Support for Research & Innovation Projects

RESEARCH TO MARKET SOLUTION

Bibliography and useful resources

European IP Helpdesk

- Your Guide to Intellectual Property Management in Horizon Europe
- Successful valorisation of knowledge and research results in Horizon Europe
- Your guide to IP in Horizon 2020
- e-learning: IP Basics
- Webinar: Dissemination & Exploitation in Horizon Europe

An example of EU Research transfer to the Market in the PV sector

ONYX SOLAR:
WORLD LEADER ON PHOTOVOLTAIC GLASS FOR BUILDINGS

R2M Solution

PV TECHNOLOGIES

AMORPHOUS

CRYSTALLINE

Photo: Verres en silicium cristallin, teinte bleue, Miami, USA

PV FLOOR

Photo: Verres en silicium cristallin, boutique, Californie

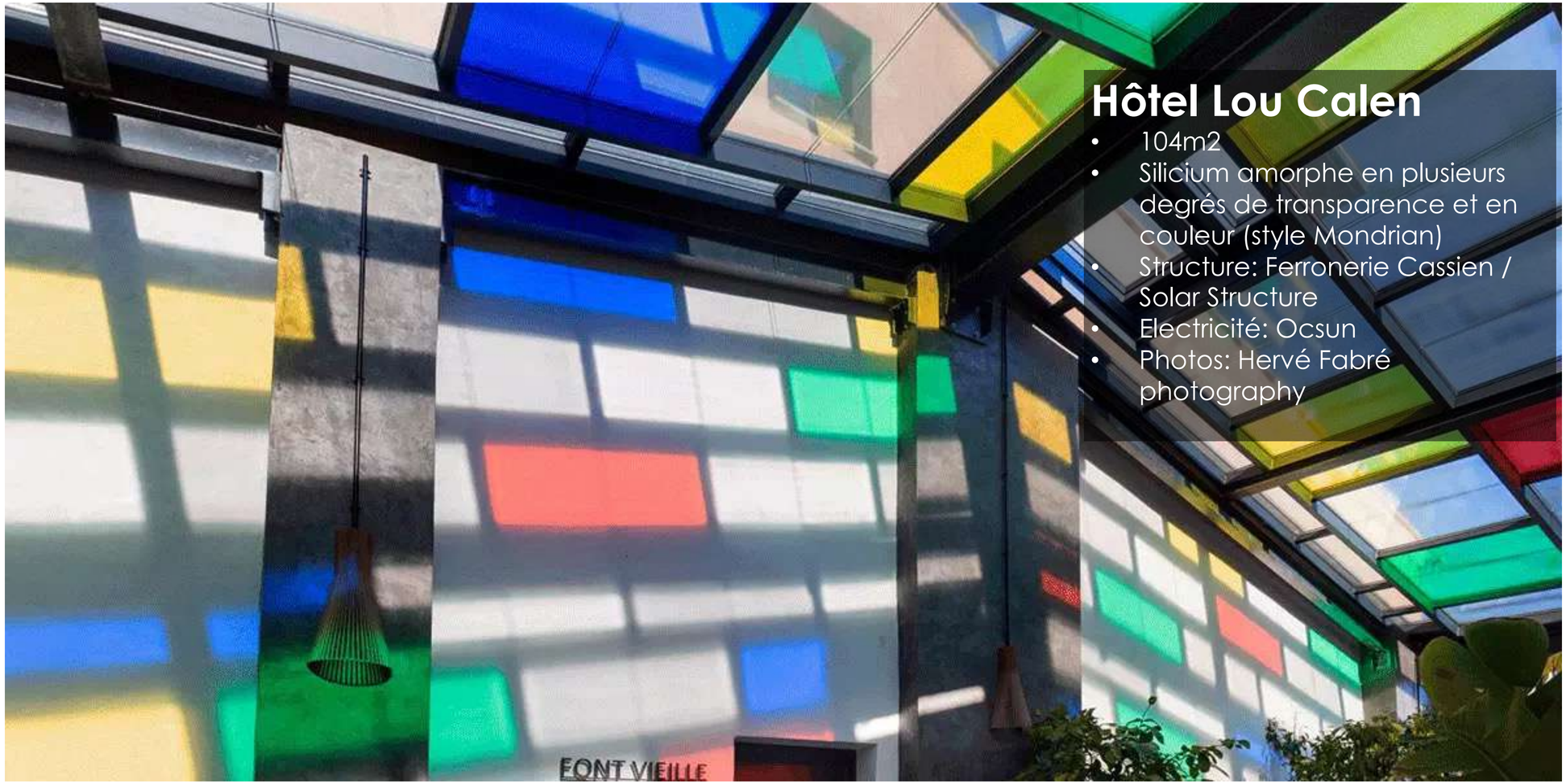
Government of Monaco

Réhabilitation d'un bâtiment à usage de bureaux du gouvernement
Direction du travail / Inspection du travail / Service de l'emploi

- Verrière en toiture
- 50 m2
- Technologie silicium cristallin
- Différentes dimensions de modules , la plupart avec chambre argon
- Puissance installée: 5,5 kWc
- Installateur mécanique et électrique: La fonderie de Monaco

R2M Solution

Lou Calen, Var, France



Hôtel Lou Calen

- 104m2
- Silicium amorphe en plusieurs degrés de transparence et en couleur (style Mondrian)
- Structure: Ferronerie Cassien / Solar Structure
- Electricité: Ocsun
- Photos: Hervé Fabré photography

Thank you !

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FROM LIGHT TO DECISIONS: THE JOURNEY OF IMAGE FORMATION IN PIXELS

Filip Hendrichovsky, Laurin Ginner

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Digitrans best answers for future transport
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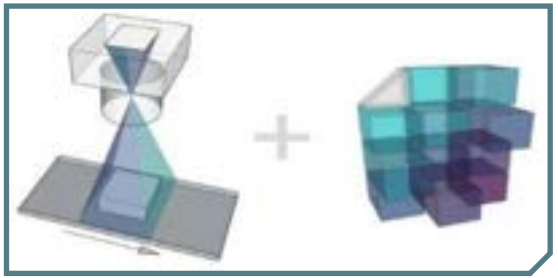
HIGH-PERFORMANCE VISION SYSTEMS

RESEARCH FIELDS

High-speed Sensing

- High-performance camera and illumination concepts and systems
- High-speed sensing concepts



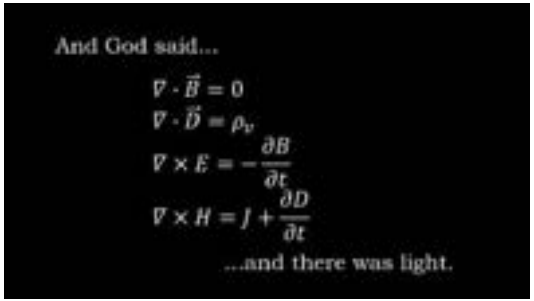
Inline Computational Imaging

- Simultaneous 2D & 3D Imaging
- High-performance algorithms for 3D reconstruction and image enhancements

AI-based Inspection

- Vision + Computation + AI Combination of model-based and data-driven learning
- Semantic segmentation

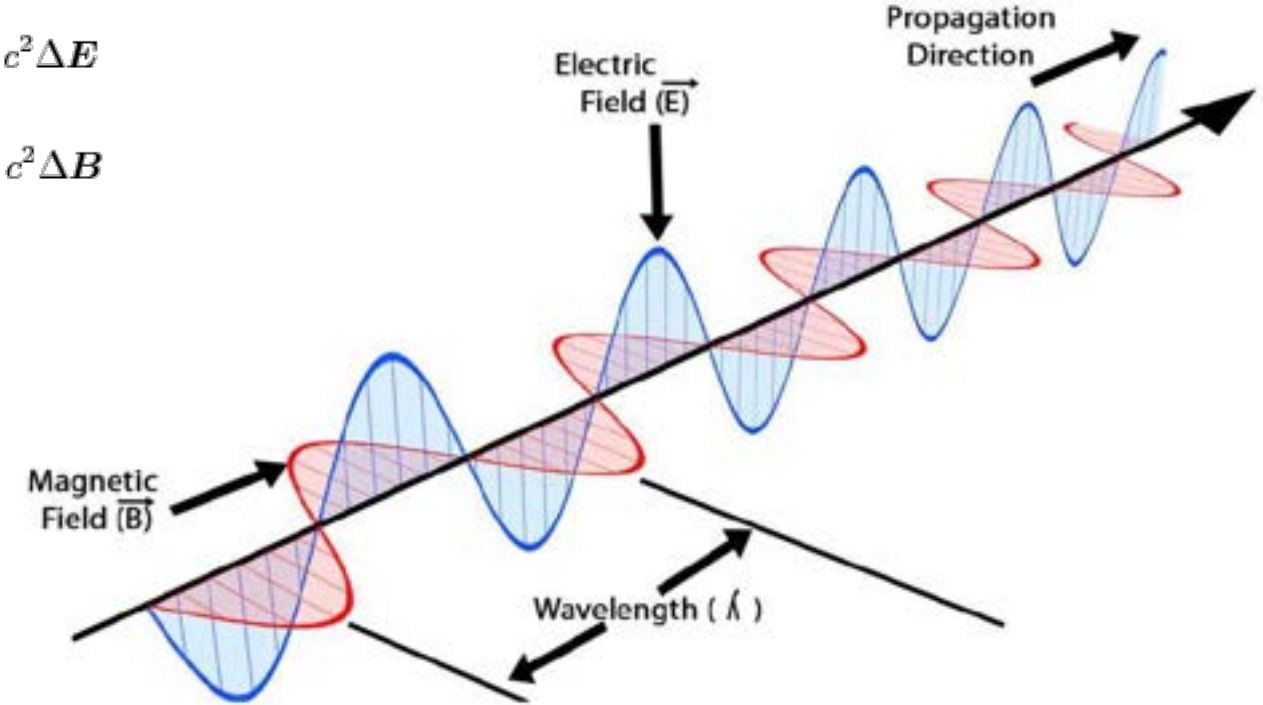
LIGHT



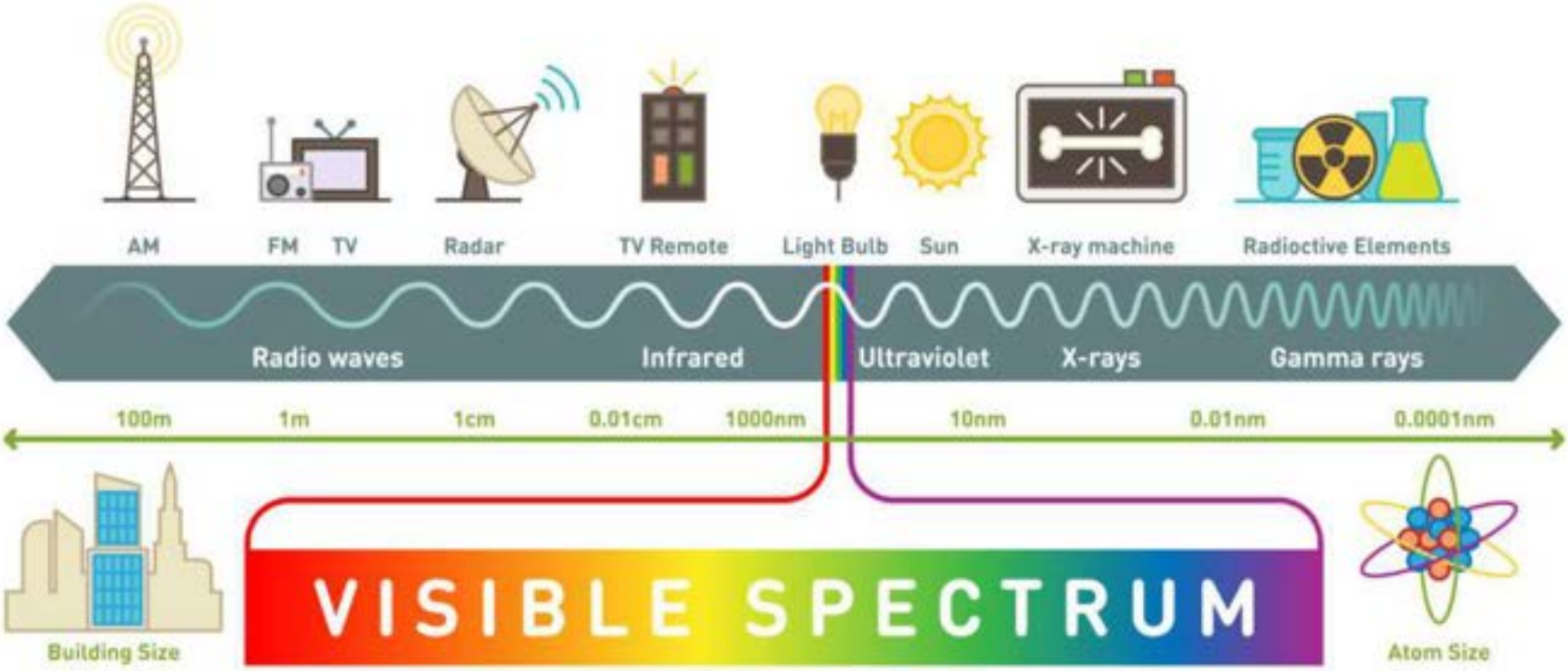
- $\nabla \times (\nabla \times E) = \nabla \times (-\frac{\partial B}{\partial t})$

$$\Rightarrow \quad \frac{\partial^2 \boldsymbol{E}}{\partial t^2} = c^2 \Delta \boldsymbol{E}$$

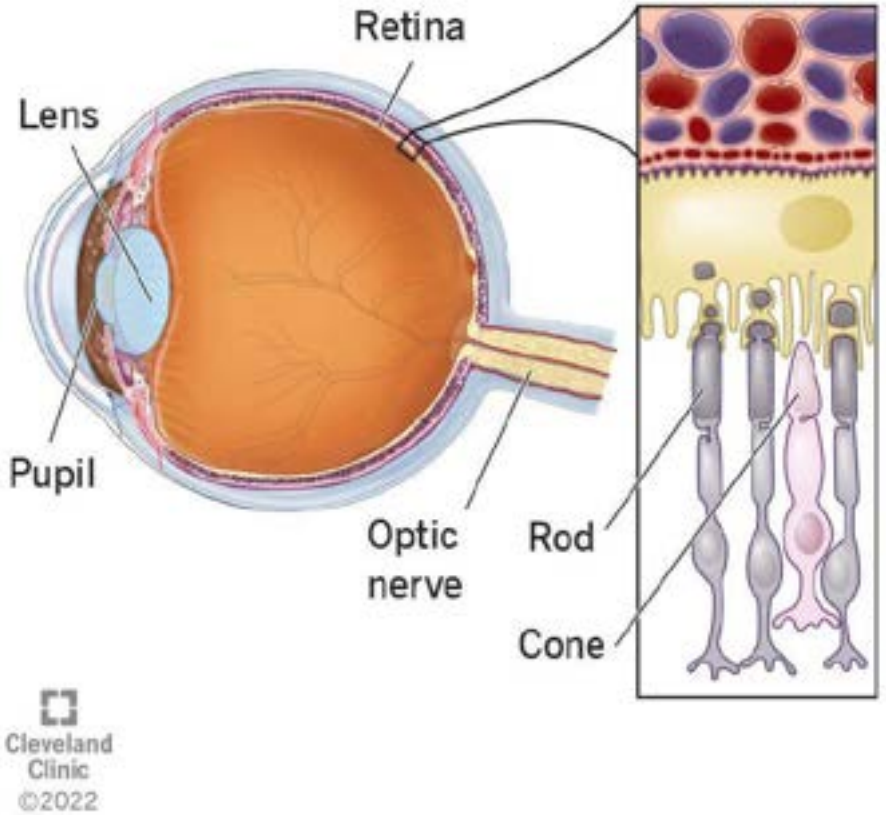
$$\frac{\partial^2 \boldsymbol{B}}{\partial t^2} = c^2 \Delta \boldsymbol{B}$$



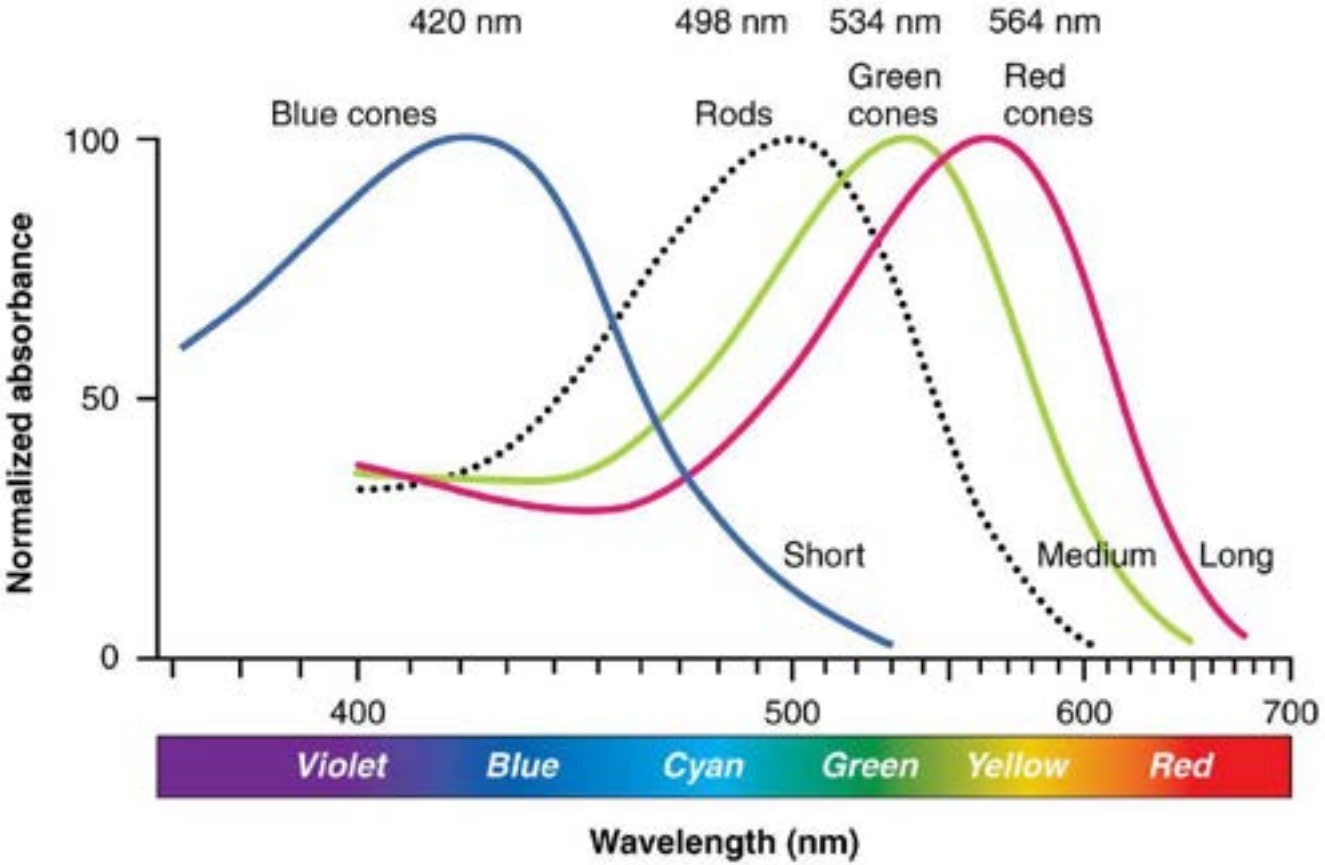
ELECTROMAGNETIC SPECTRUM



THE HUMAN EYE

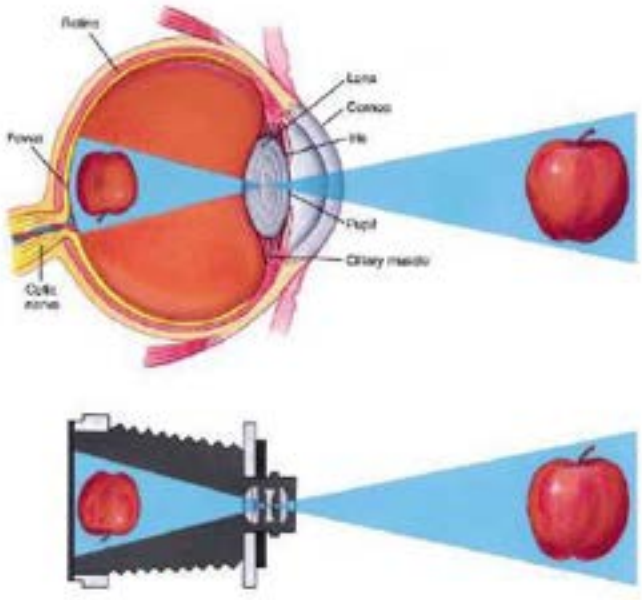


COLOR PERCEPTION



CAMERA MODEL

Pinhole camera



THE FIRST IMAGE

- 'View from the Window at Le Gras' by N. Niepce (1826)

THE PHOTOELECTRIC EFFECT

- Albert Einstein, 1905

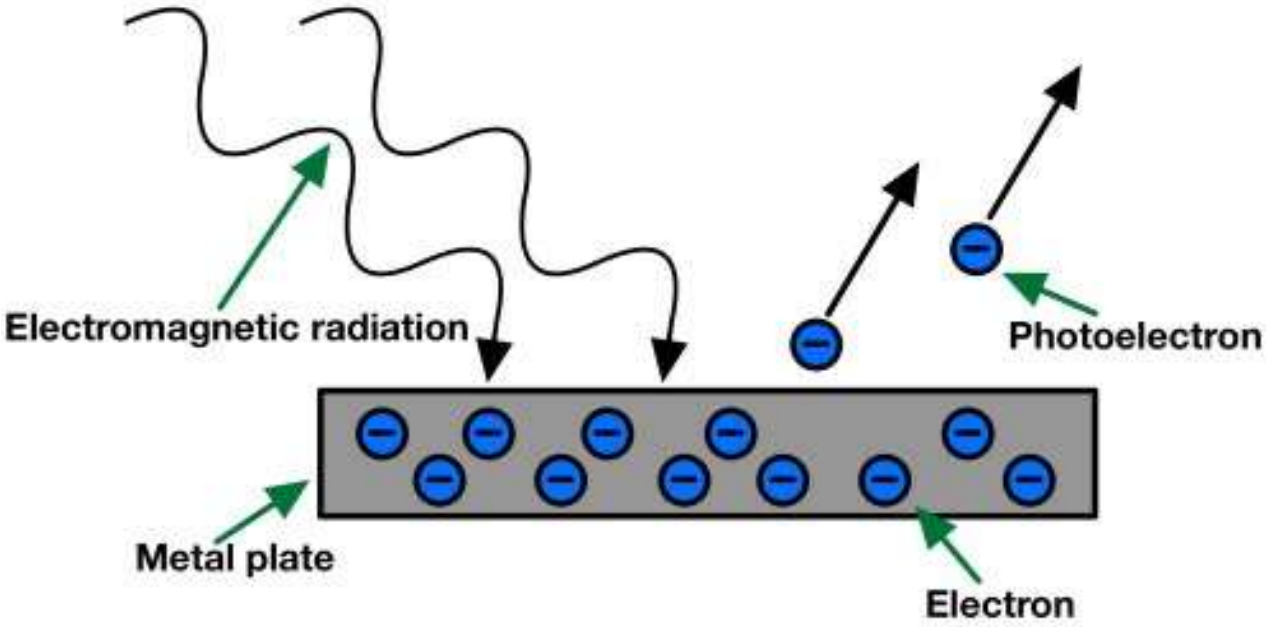
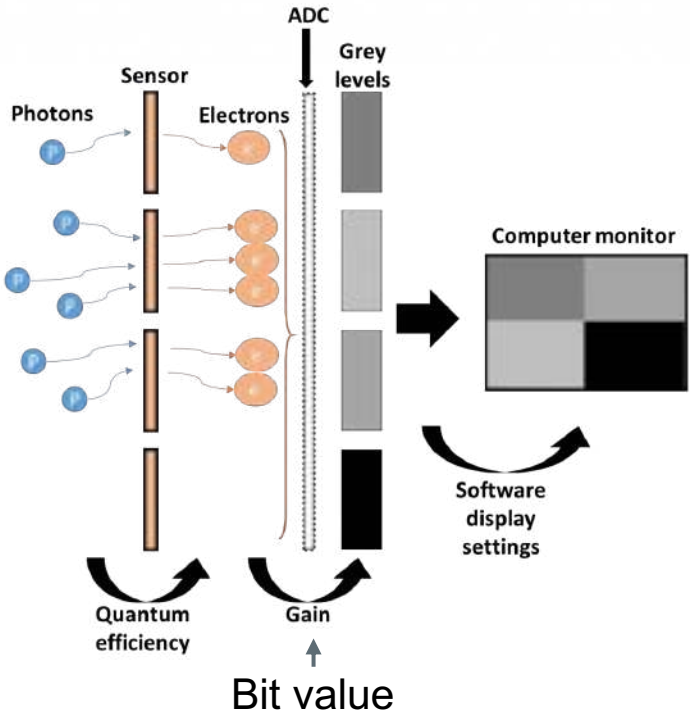
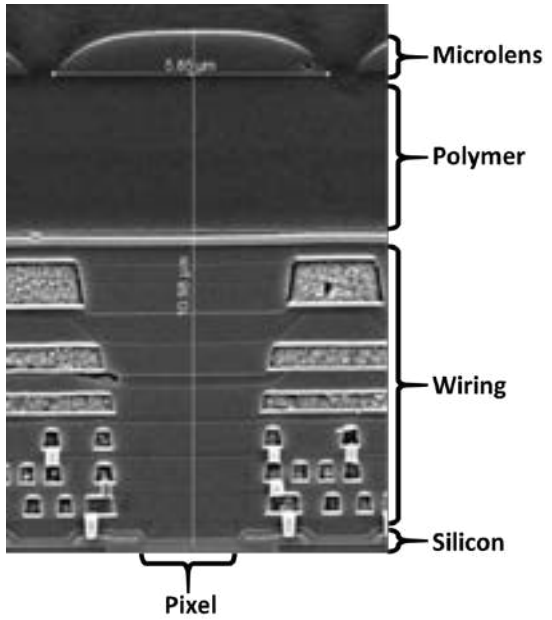
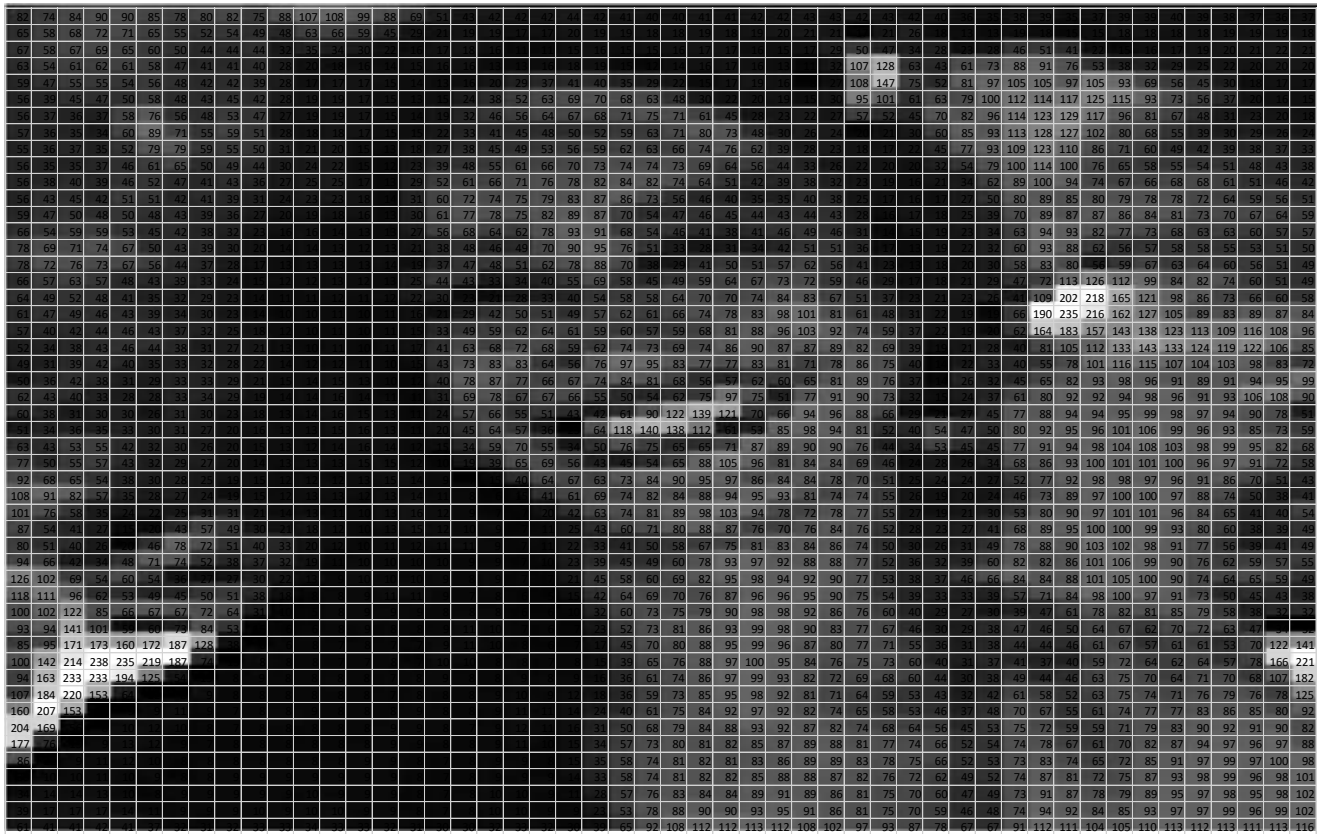


IMAGE SENSOR



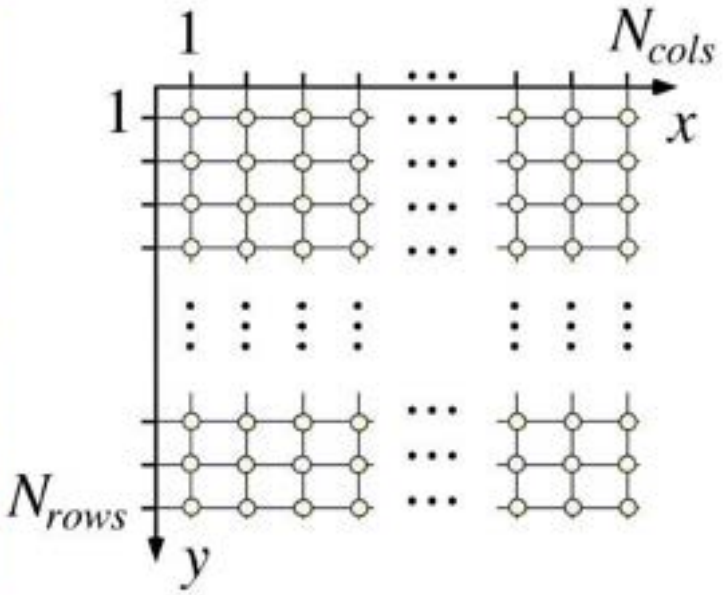


DIGITAL IMAGE



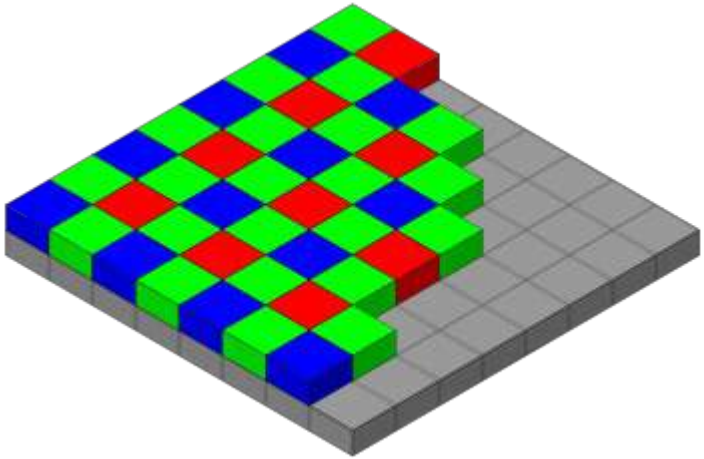
DIGITAL IMAGE

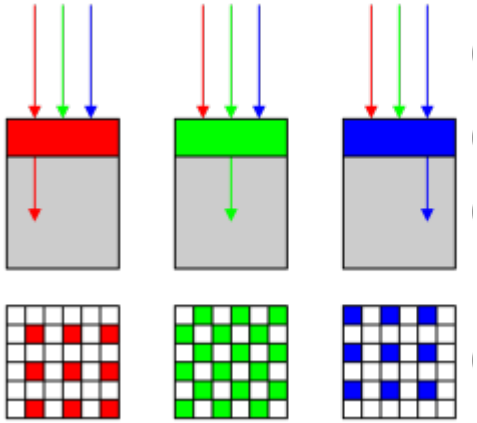
IMAGE



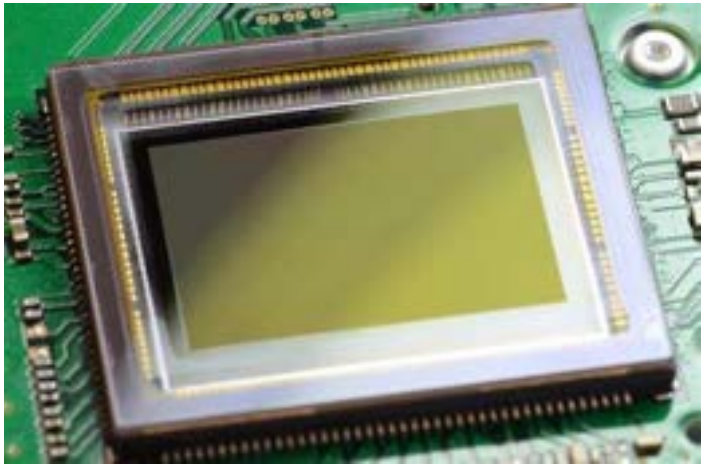
RGB IMAGE

- Bayer pattern (U.S. Patent No. 3,971,065)

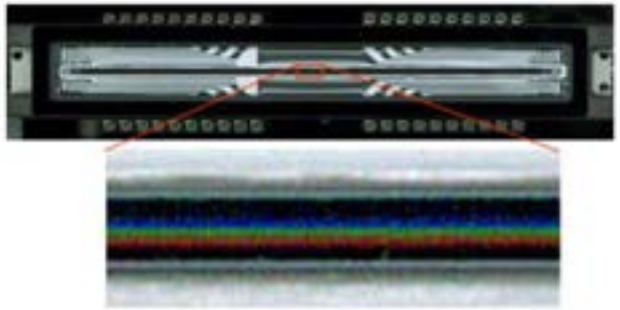


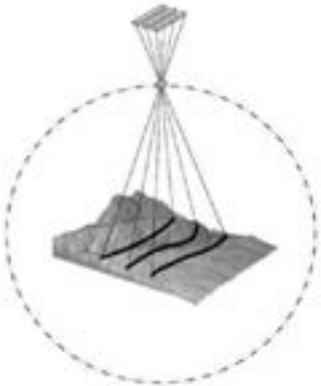


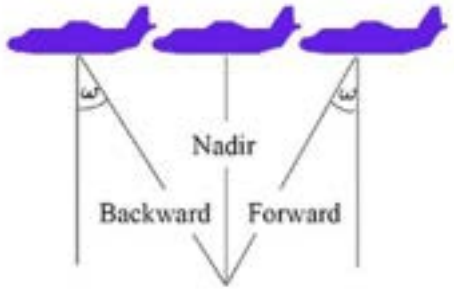
AREA SENSORS



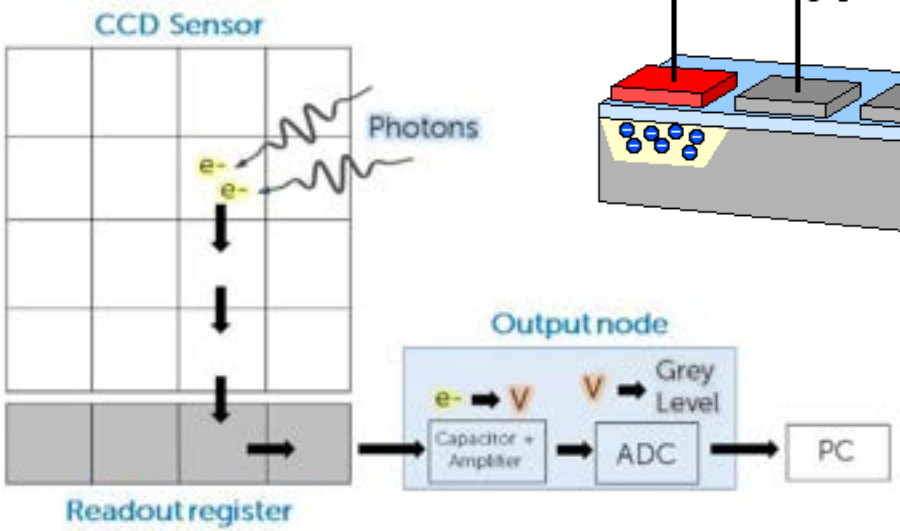
LINE SENSOR

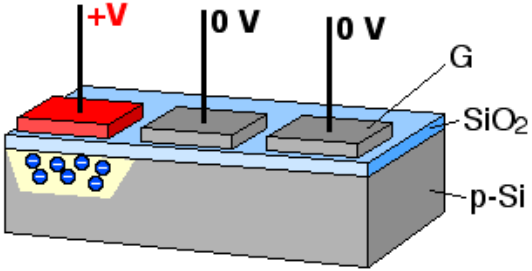


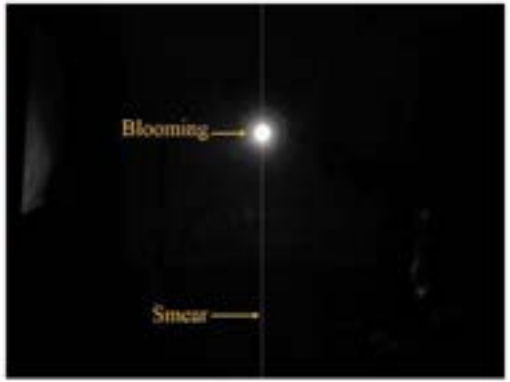




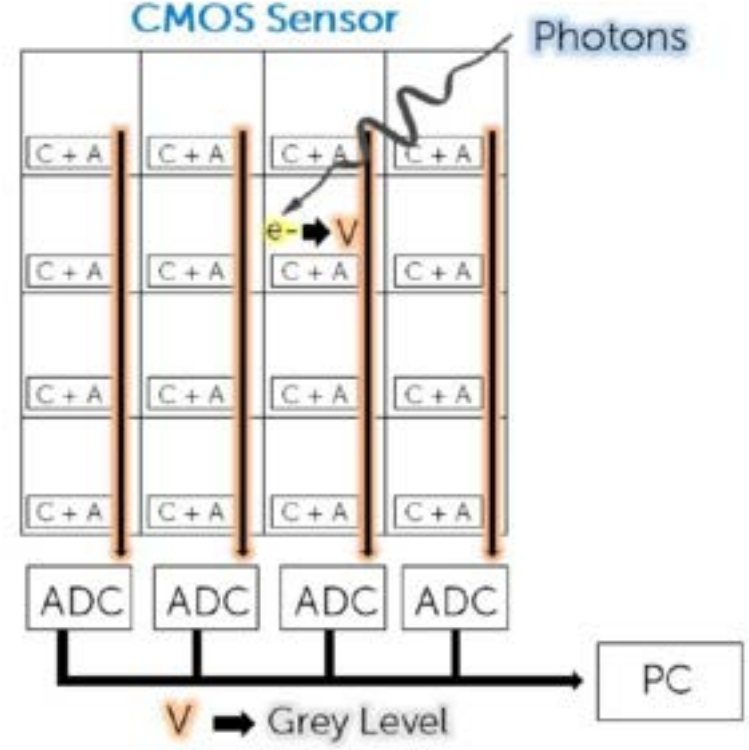
CHARGE-COUPLED DEVICE (CCD)

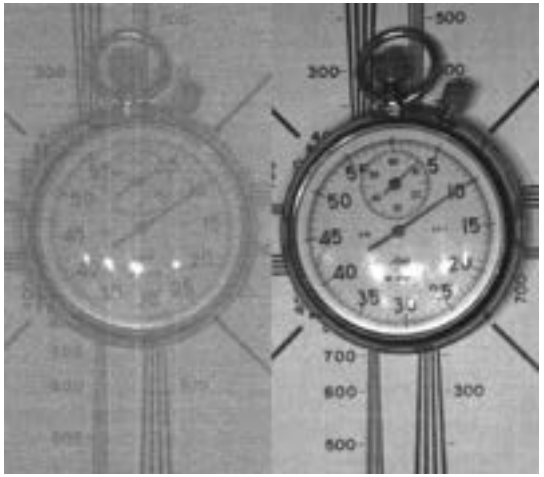






COMPLEMENTARY METAL-OXIDE-SEMICONDUCTOR (CMOS)

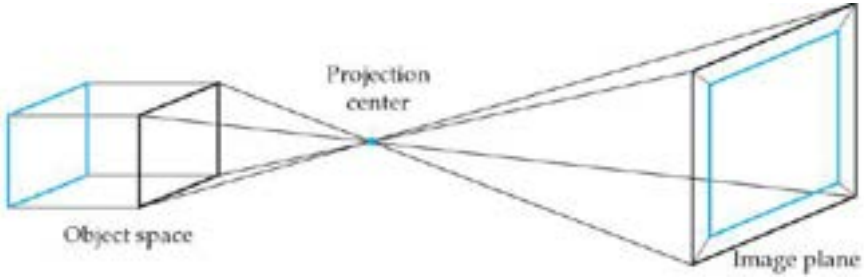




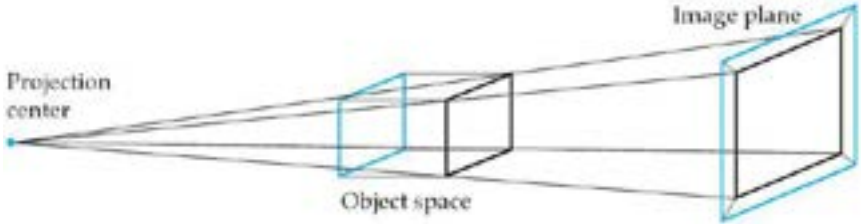
CCD CMOS

PERSPECTIVE PROJECTIONS

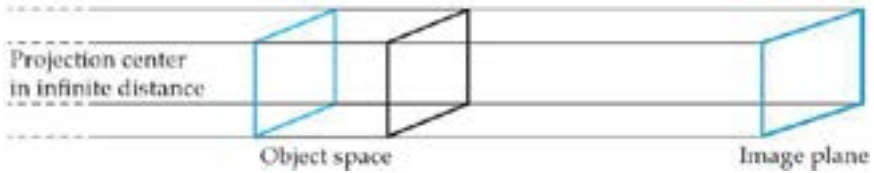
Entocentric:

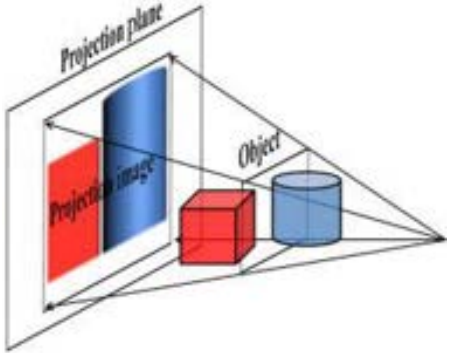


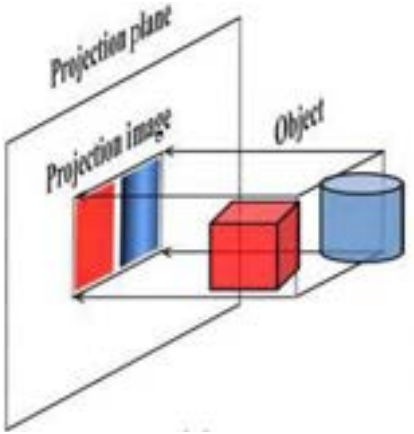
Hypercentric:



Telecentric:







PINHOLE CAMERA MODEL

$$p = K[R|t]P$$

p – projection point

K – camera intrinsics

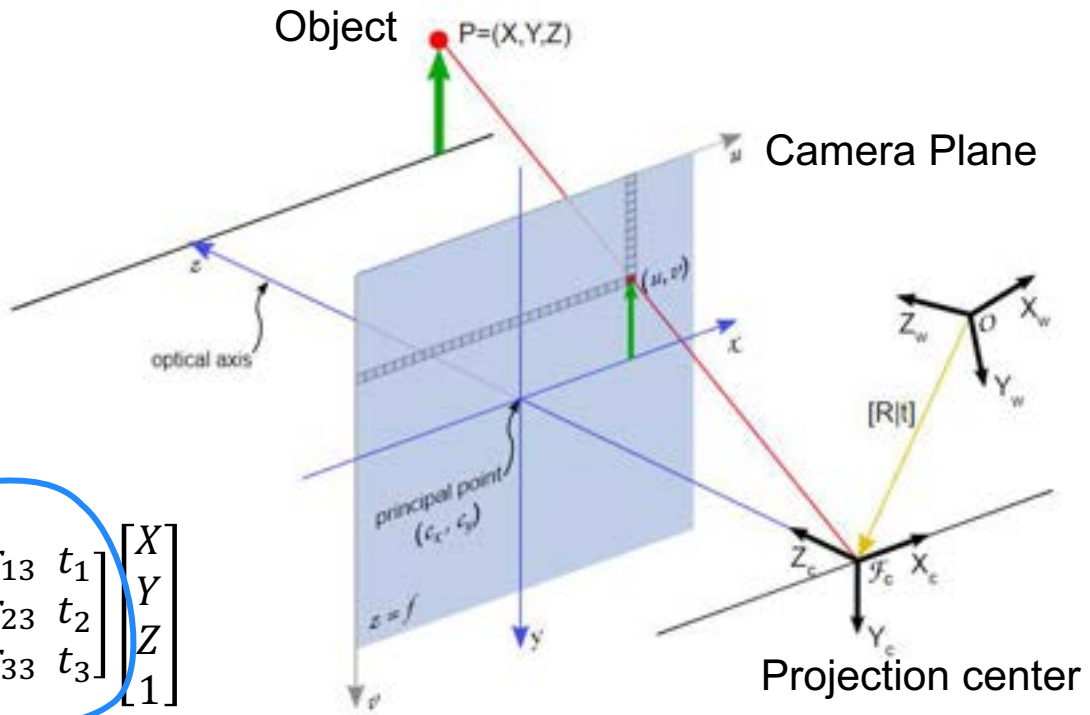
R – camera rotation

t – camera translation

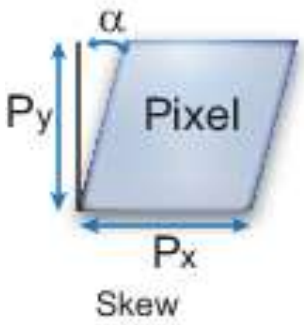
P – projected point

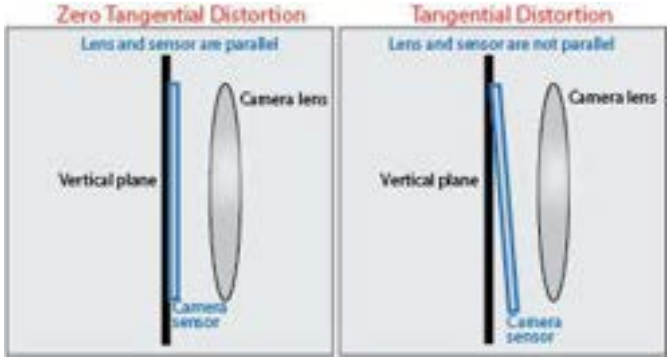
$[R|t]$ – camera extrinsics

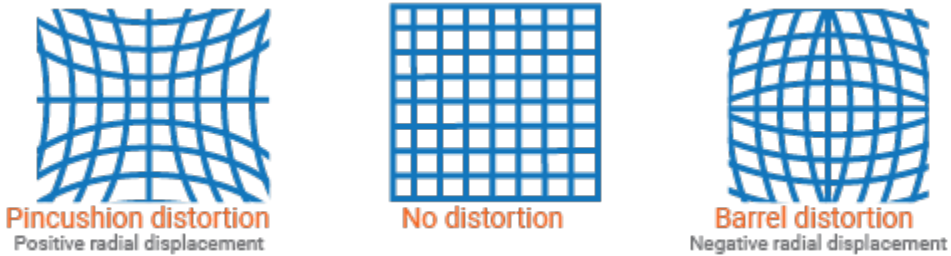
$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} sf_x & 0 & c_x \\ 0 & sf_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$



CAMERA CALIBRATION

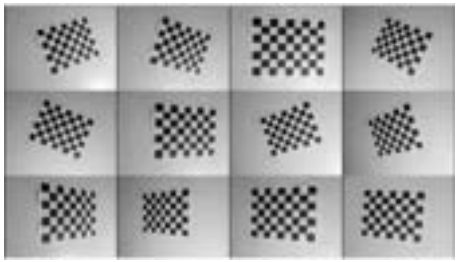






CAMERA CALIBRATION

Image distortion

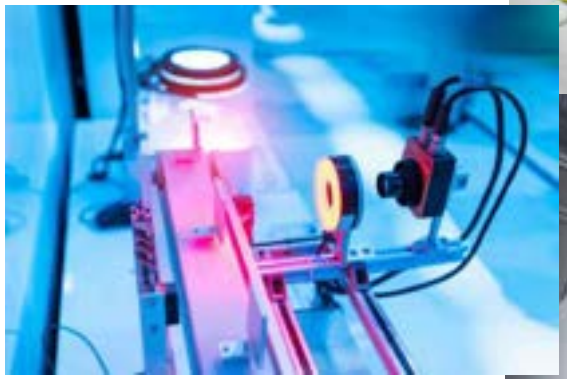


Calibration images

Image correction

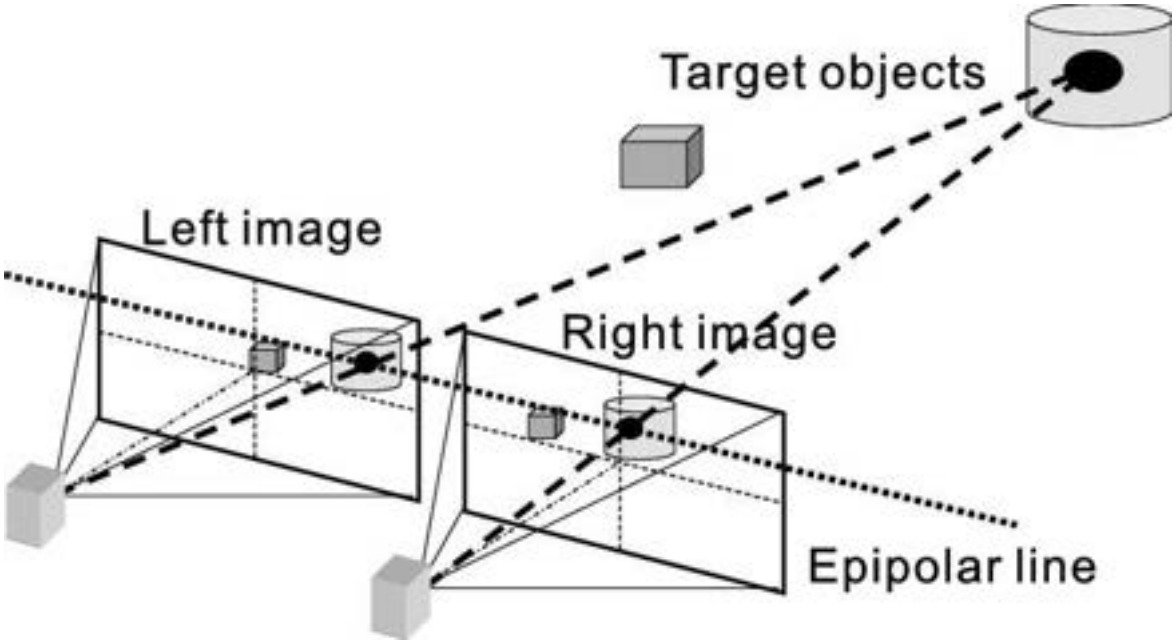
CAMERA USAGE

- What do we want to do with cameras?
  - measurements
  - visual inspection
  - quality control
  - navigation
  - …

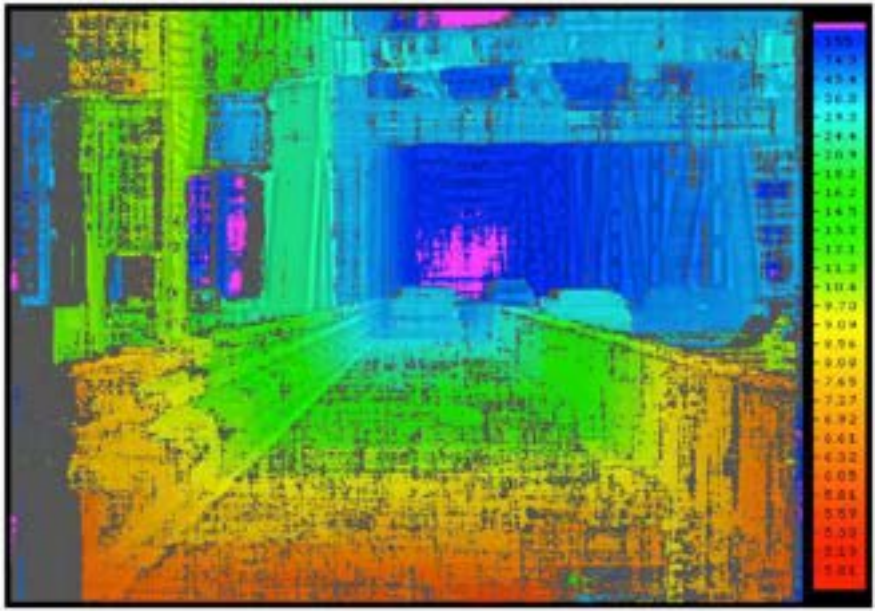


STEREO MATCHING

STEREO MATCHING



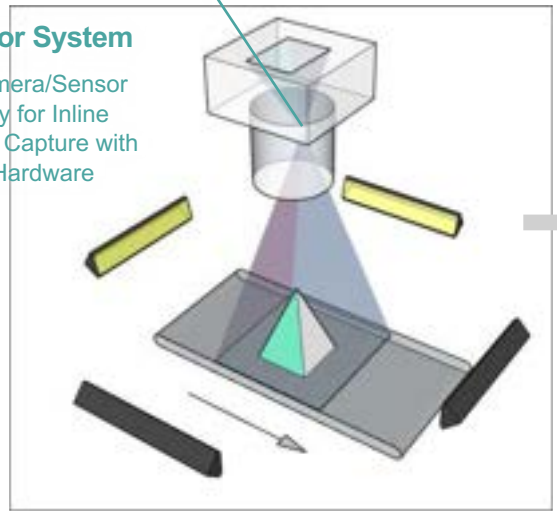
DISPARITY MAP



AIT INLINE COMPUTATIONAL IMAGING: SOFTWARE FOR DIFFERENT SENSORS

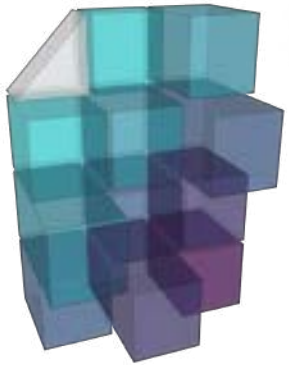
ICI Sensor System

Single Camera/Sensor Technology for Inline Light Field Capture with Standard Hardware



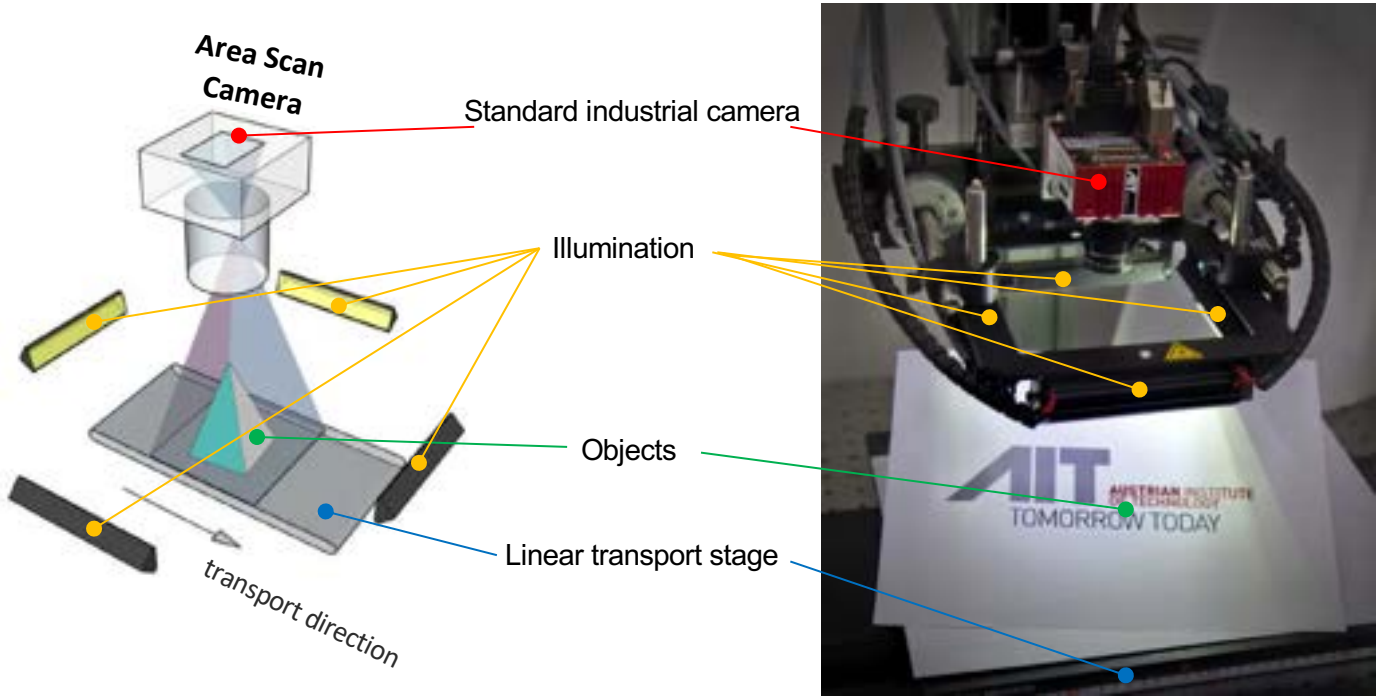
ICI Software Modules

Generic Computational Imaging Library for 2D/3D Imaging Tasks



INLINE COMPUTATIONAL IMAGING INTRODUCING OUR NEW SYSTEM

- **Area scan** light field imaging [Traxler et al. 2021, *submitted*]



ANIMATION @50µm

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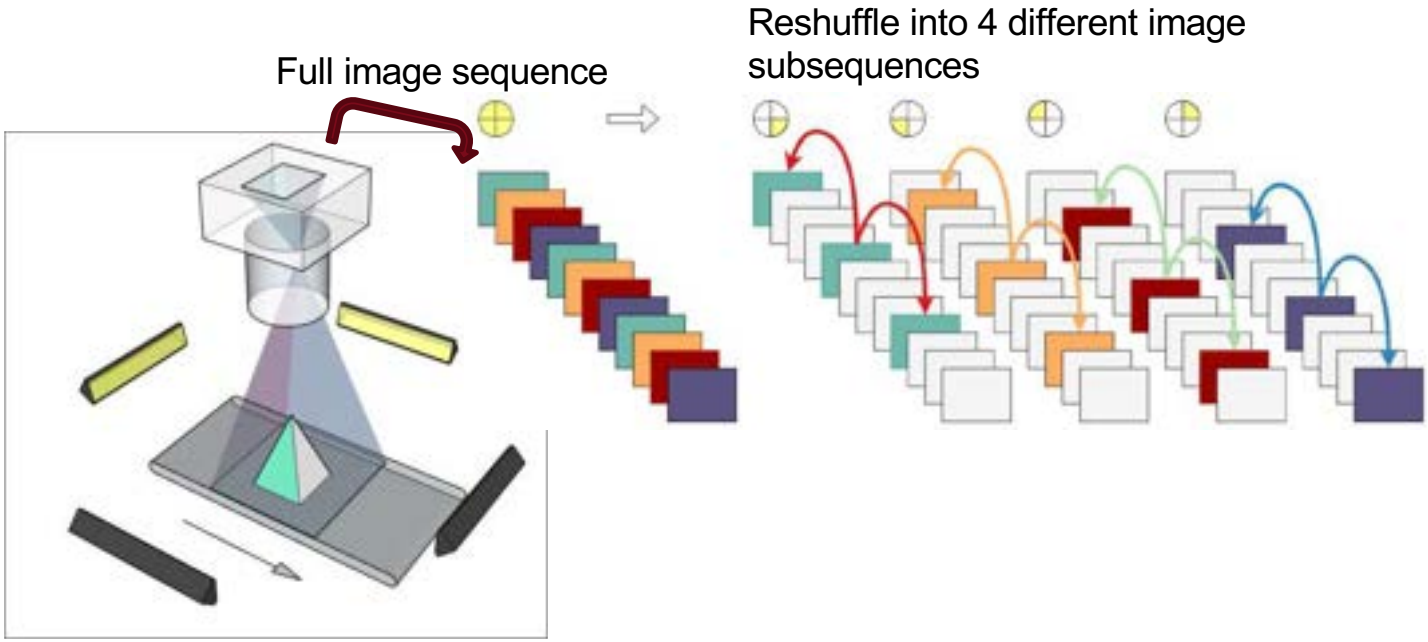
TOMORROW TODAY

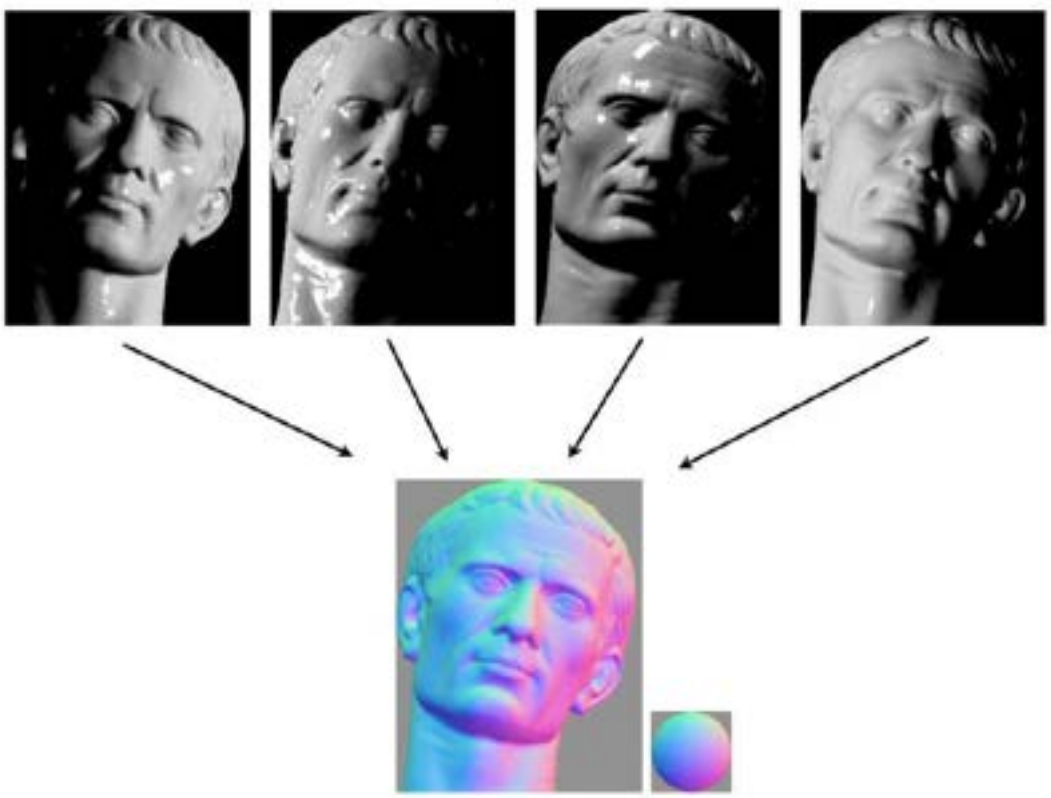
ALGORITHMIC FRAMEWORK

Details of how area-scan ICI works

INLINE LIGHTFIELD ACQUISITION



PHOTOMETRIC STEREO



PHOTOMETRIC STEREO

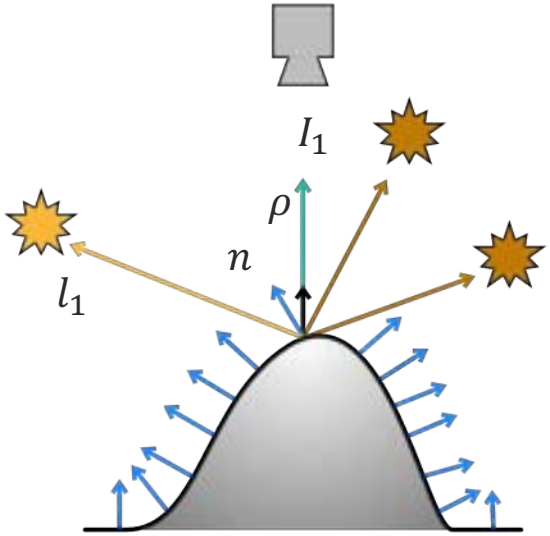


Image Formation under the Lambertian assumption

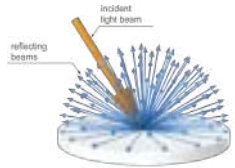
$$I_1 = \rho n \cdot l_1$$
$$I_2 = \rho n \cdot l_2$$
$$I_3 = \rho n \cdot l_3$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \rho n \cdot \begin{bmatrix} l_1^T \\ l_2^T \\ l_3^T \end{bmatrix}$$

$$I = \rho N \cdot L$$

Surfaces normal recovery from images

$$\rho N = M = L^{-1} I$$



Albedo

$$\rho = ||M||_2$$

Surface normals

$$\mathrm{N} = \frac{M}{\rho}$$

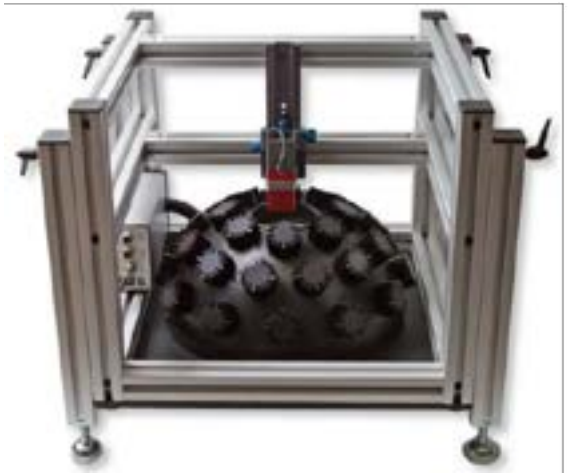
ρ ... *albedo - reflectance independent of light*
I_k ... *observed intensities, k^{th} light*
l_k ... *light direction*
n ... *surface normal*

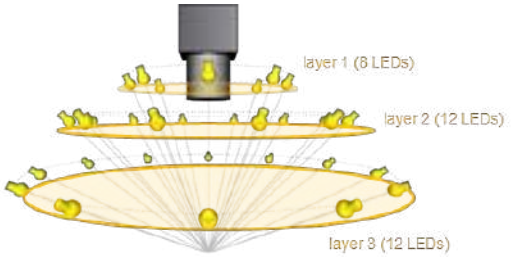
[Woodham1980]

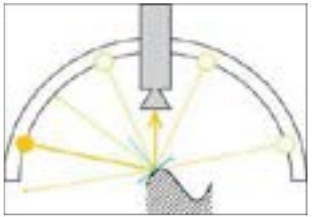
ACQUISITION SYSTEMS AT AIT

Light Dome

- Sampling: 10-20 µm/px
- Illumination: 32 light directions
- Field of view: ca. 6-12 x 4-8 cm



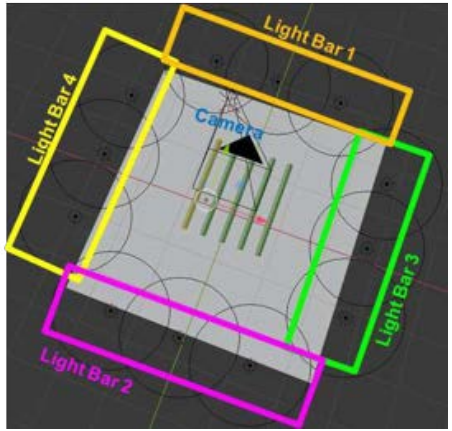


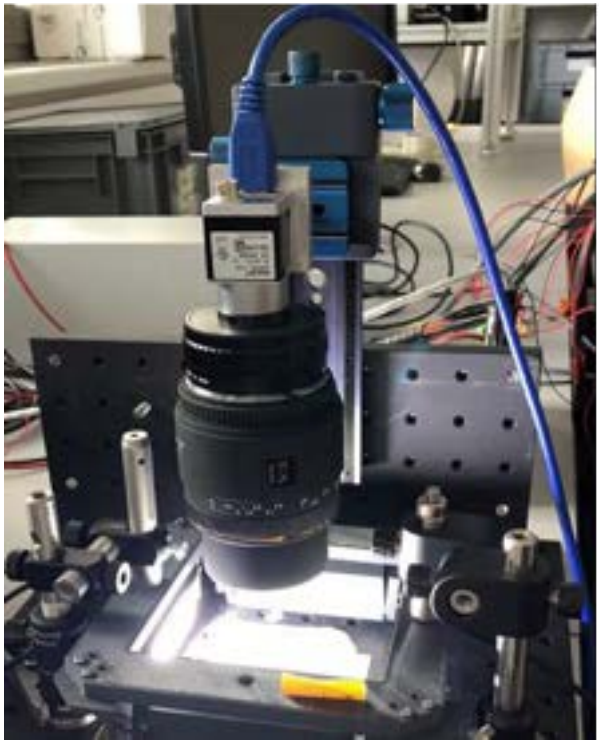


ACQUISITION SYSTEMS AT AIT

Bar Lights

- Sampling: 4.8 µm/px
- Illumination: 4 bar light directions
- Field of view: ca. 26 x 17 mm

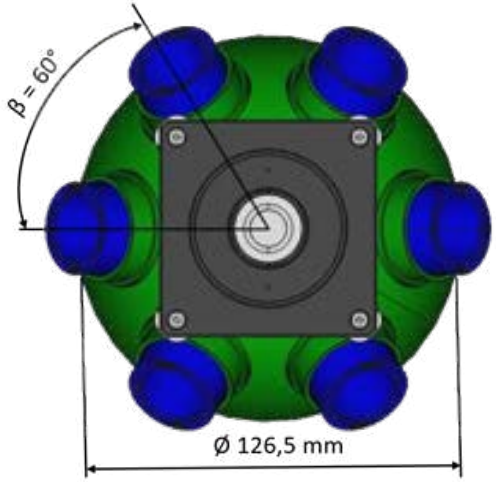




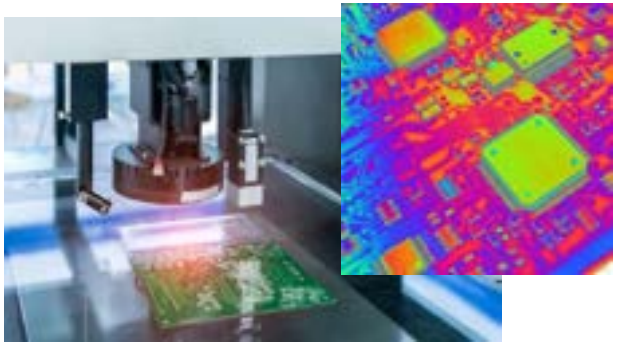
ACQUISITION SYSTEMS AT AIT

Microscopy Dome

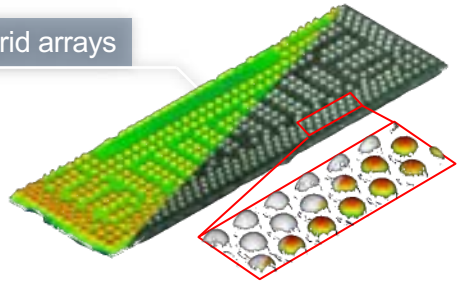
- Sampling: 0.7 µm/px
- Illumination: 6 light directions
- Field of view: ca. 1.6 x 1.25 cm

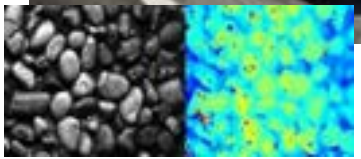


HIGH-PERFORMANCE VISION SYSTEMS

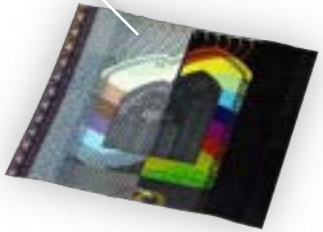


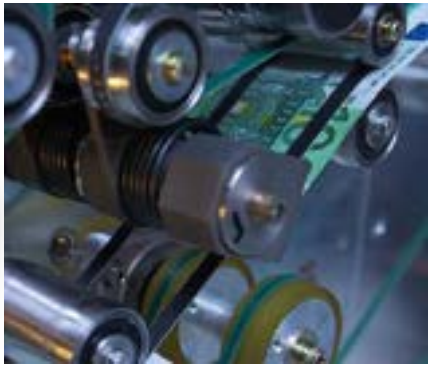
Ball grid arrays





Security print / OVD





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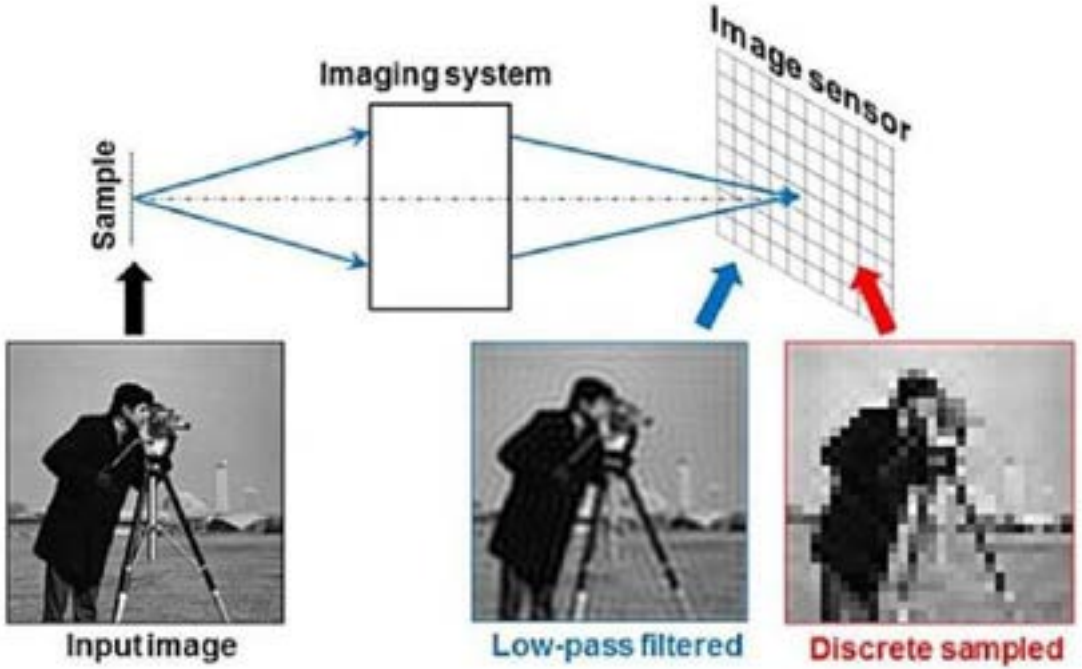
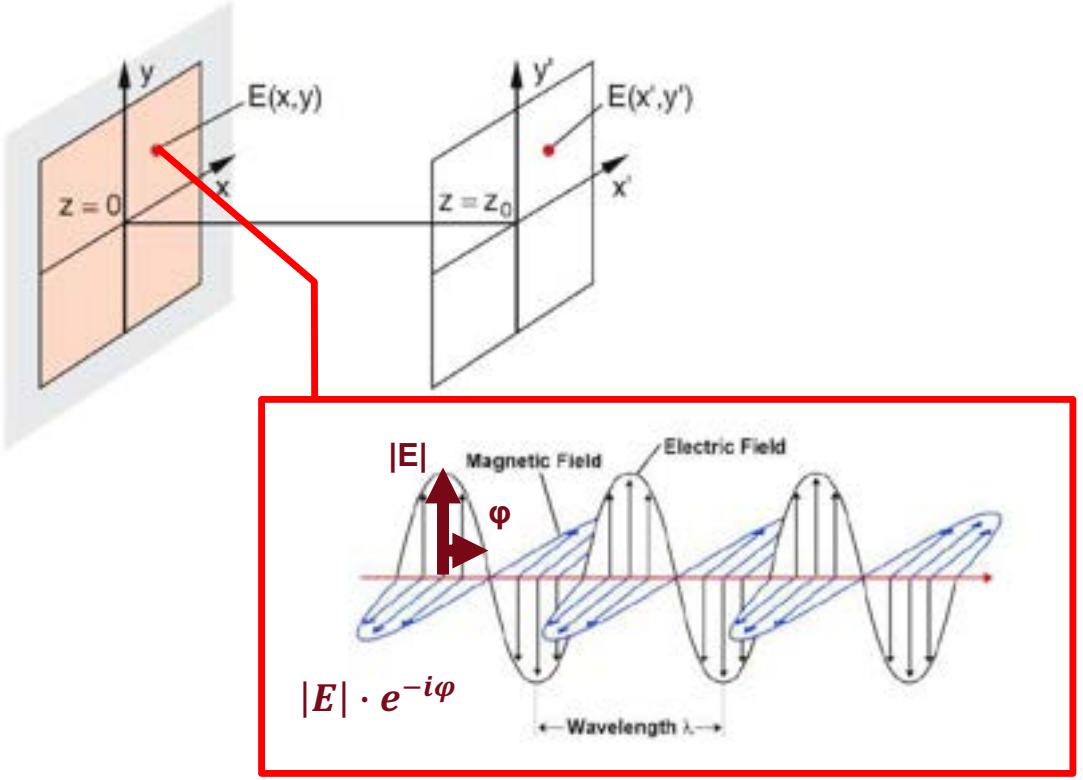
THANK YOU

BASICS FOURIER OPTICS



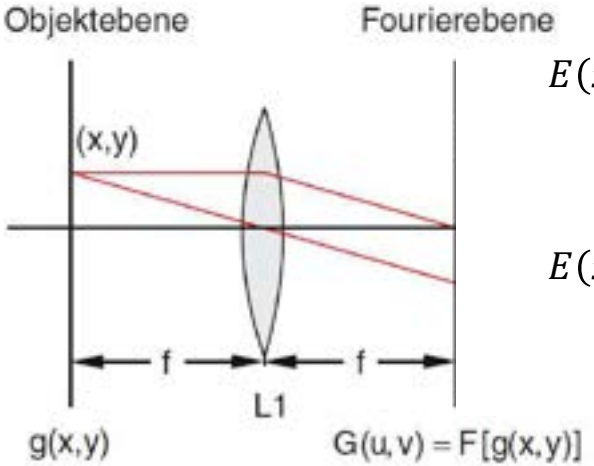
BASICS FOURIER OPTICS

- How does the light (EM-wave) propagate through space?



BASICS FOURIER OPTICS

- The far-field approximation (Fraunhofer approximation) is also true for the back focal plane of a focusing lens



$$E(x',y') = A(x',y',f) \cdot \iint_{-\infty}^{+\infty} E(x,y) \cdot e^{-i2\pi(\nu_x x, \nu_y y)}\, dxdy$$

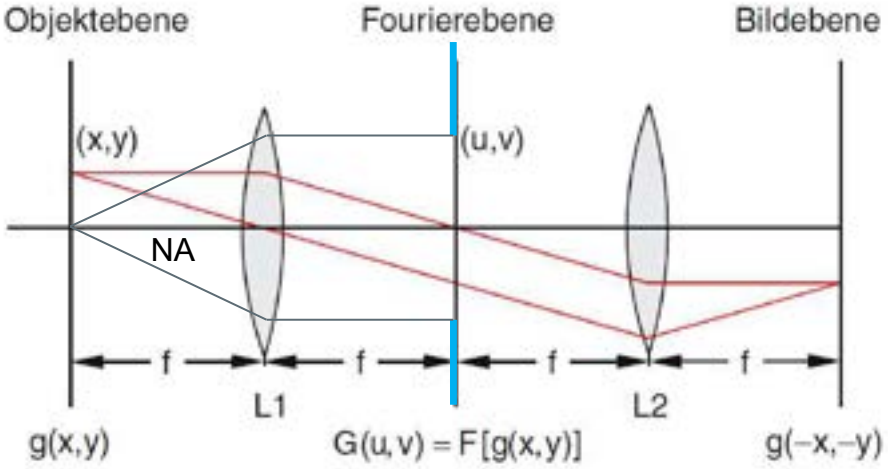
$$E(x',y') = A(x',y',f) \cdot \mathcal{F}(E(x,y))$$

$$A(x',y',f) = e^{-ikz} \cdot e^{\frac{i\pi(x'^2+y'^2)}{\lambda z}} \quad \Rightarrow \quad |A| = 1$$

BASICS FOURIER OPTICS – IMAGING SYSTEMS

- Imaging: A simple light microscope can be modeled as 4-f setup ($\mathcal{F}$ - $\mathcal{F}^{-1}$)

$$\boldsymbol{I(x', y') = |E(x', y')|^2}$$



$\boldsymbol{H(k_x, k_y)}$
= transfer function

This holds for the eclectic field amplitude

$$G_{img}(k_x, k_y) = H(k_x, k_y) \cdot G_{obj}\ (k_x, k_y)$$
$$\uparrow \mathcal{F} \qquad \uparrow \mathcal{F} \qquad \uparrow \mathcal{F}$$
$$g_{img}(x, y) = h(x, y) \otimes G_{obj}\ (x, y)$$

BASICS FOURIER OPTICS – IMAGING SYSTEMS

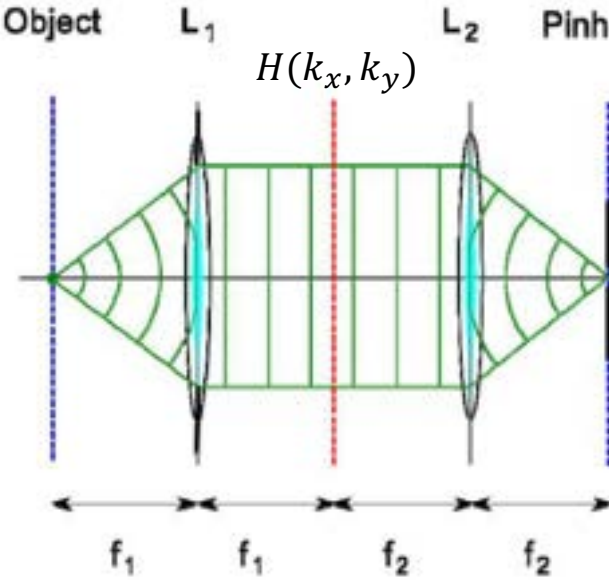
- Imaging Example:

$H(k_x, k_y)$
= transfer function

Guoan Zheng; „Fourier Ptychographic Imaging: A Matlab Tutorial“; 2016

BASICS FOURIER OPTICS – IMAGING SYSTEMS

- Transfer function $H(k_x, k_y)$ – Aperture function
- Simples case: a real valued function 1=transitive, 0=blocks light
- In a perfectly focused aberration free system parallel wavefront (zero/constant phase) in the Fourier plane

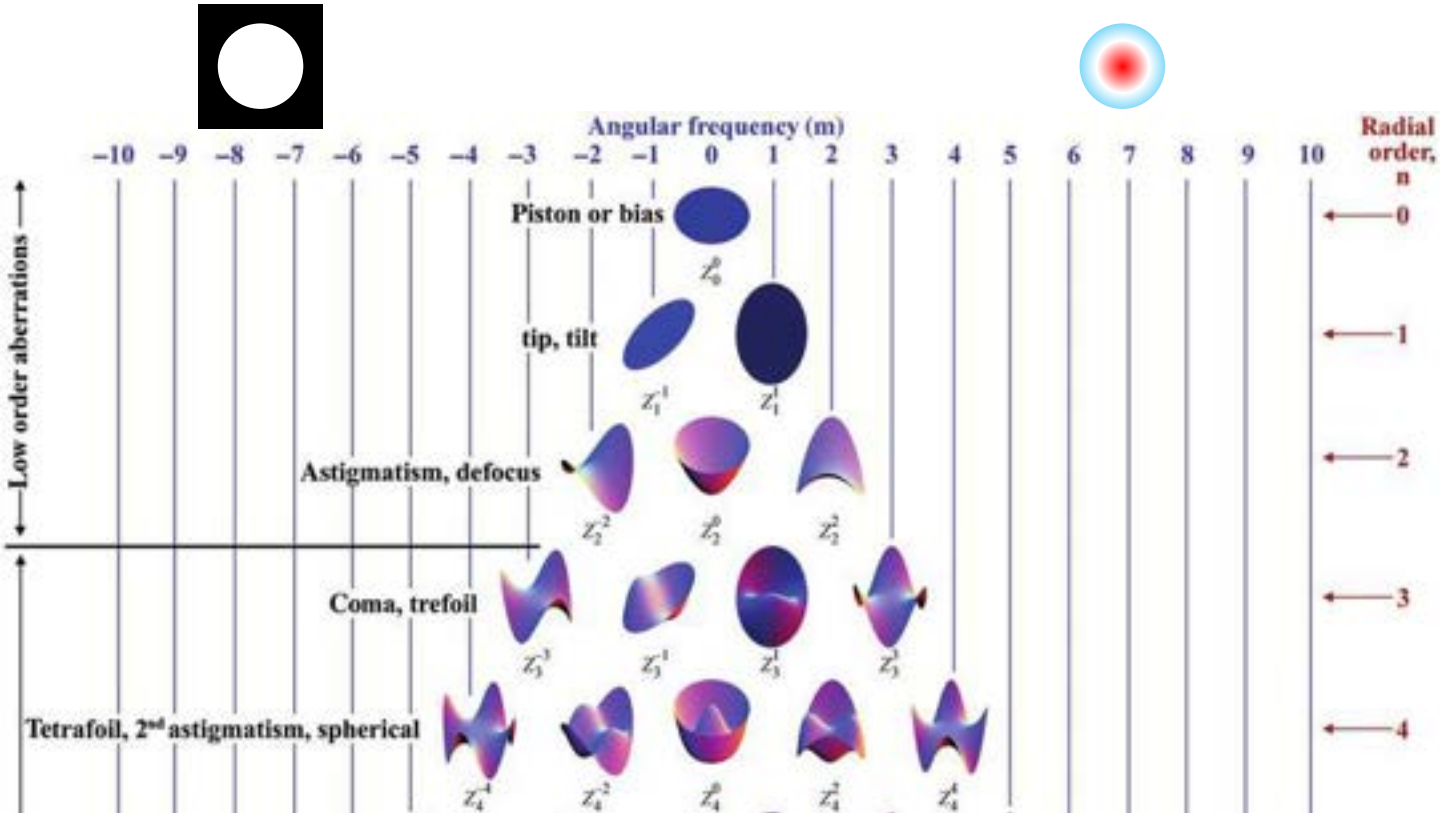


COMPLEX TRANSFER FUNCTION

$$|H|(k_x, k_y) \cdot e^{i\varphi(k_x,k_y)}$$

Transmittance

Phase delay



BASICS FOURIER OPTICS
COHERENT VS. INCOHERENT IMAGING

- Until now coherent imaging

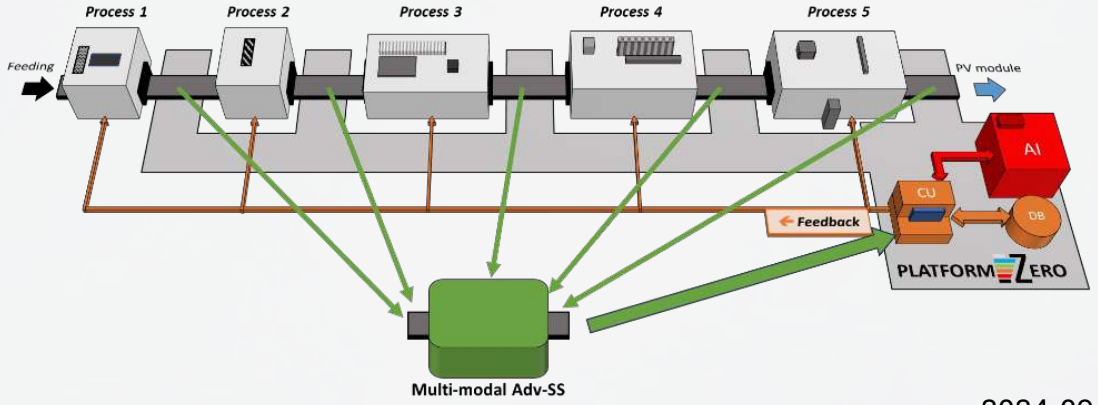
- Incoherent Imaging:
  - Non coherent superposition of E in the image plane → no interference of E-field → simple sum of intensities I

  - Because of $I(x', y') = |E(x', y')|^2$

  - Incoherent imaging is not linear in the Fourier domain
    → linearity in Fourier Domain is necessary for FP

Optoelectronic characterization:

IV Curves, Quantum Efficiency and Impedance Spectroscopy and correlation with performance parameters



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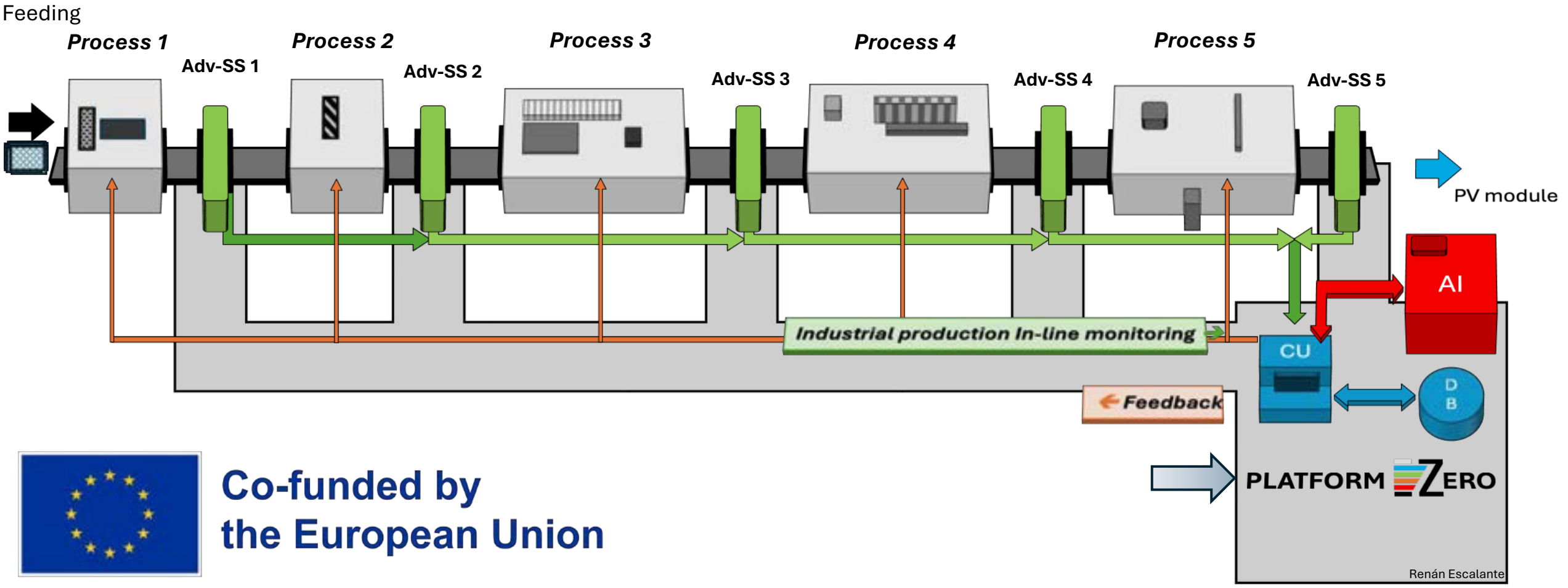
2024-09-09

Platform-Zero Concept



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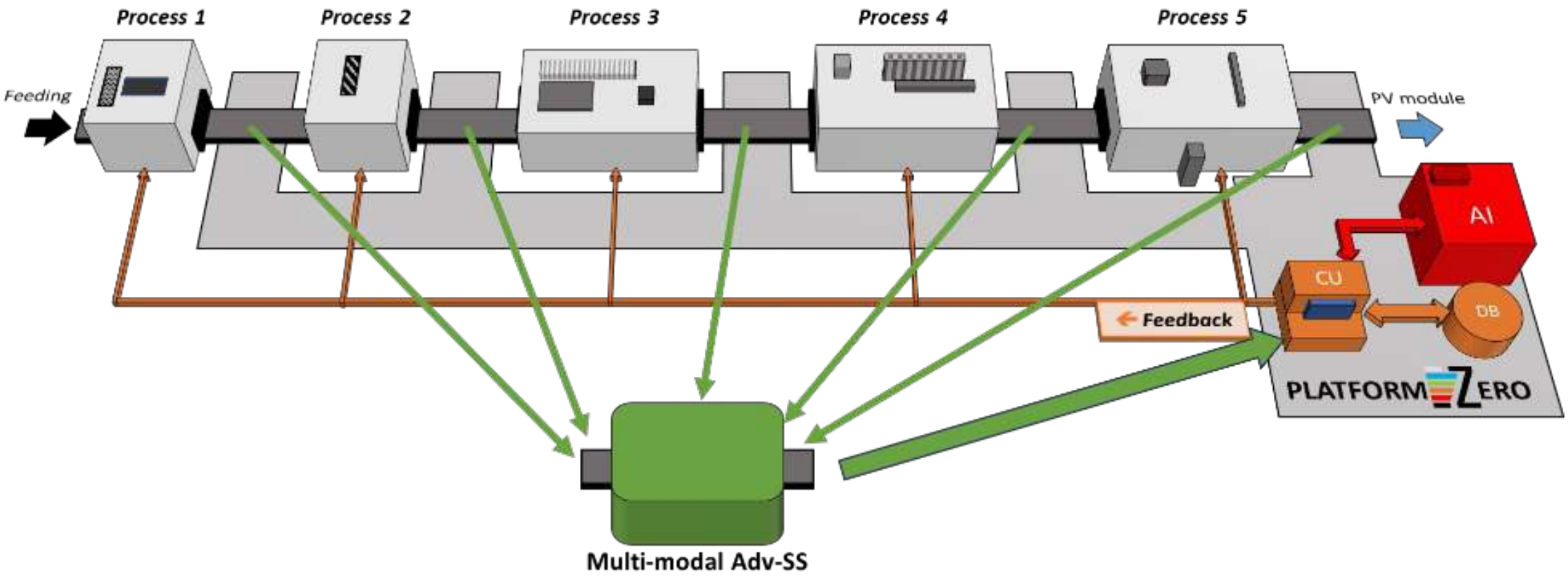
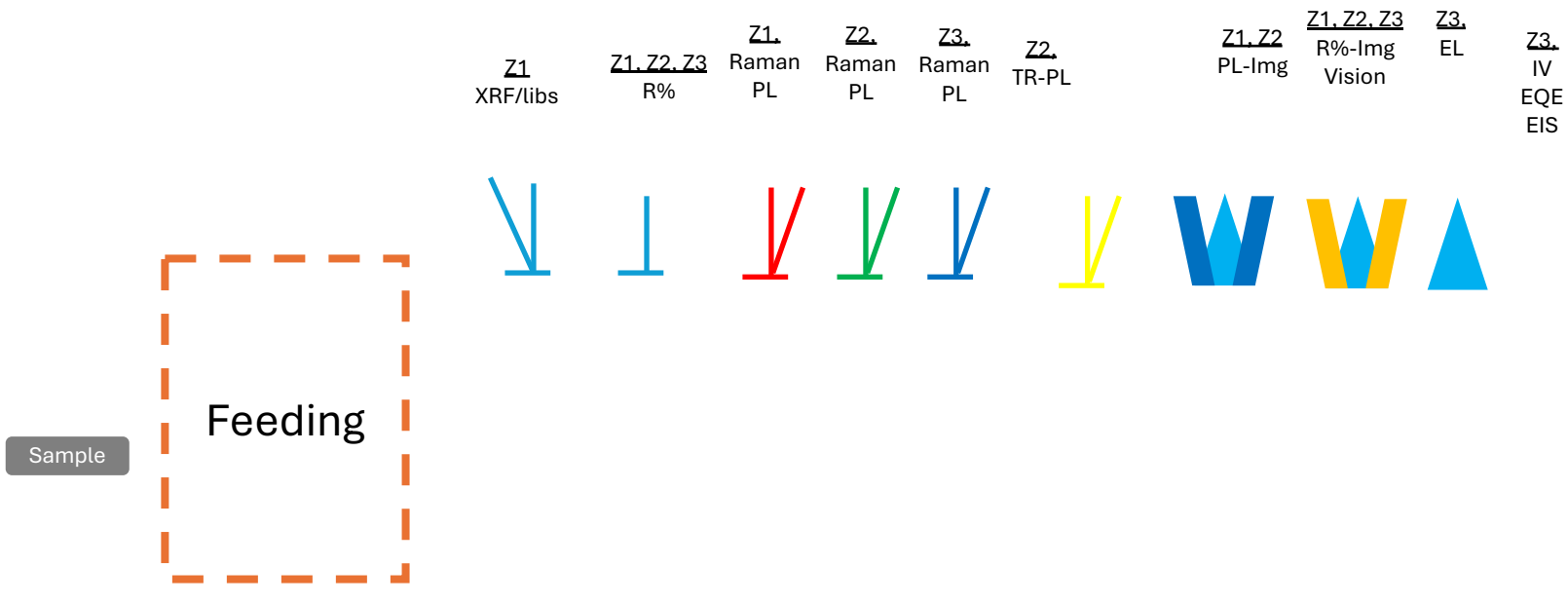
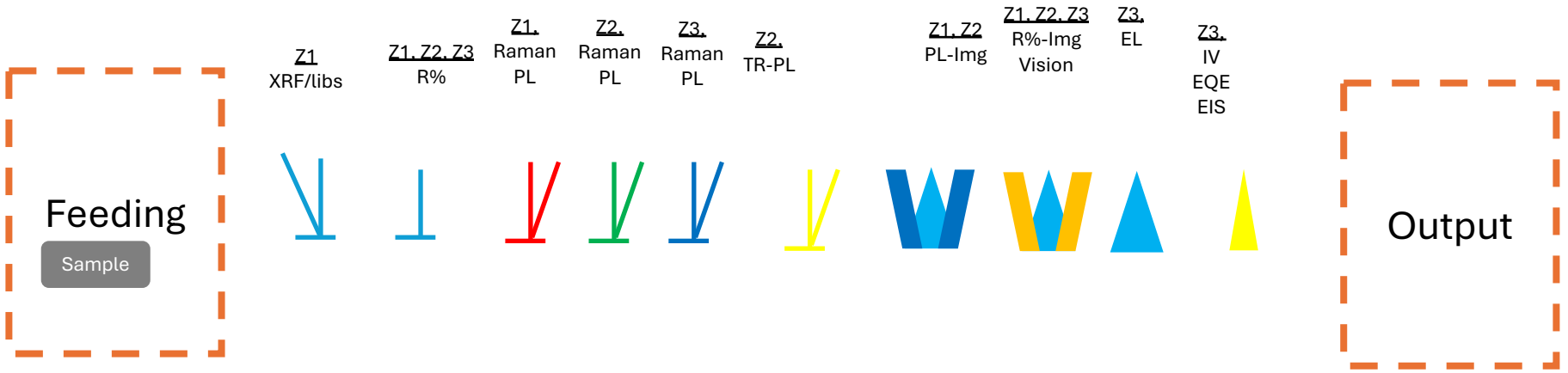
Platform-Zero Concept



Platform-Zero Multimodal Concept



Platform-Zero Multimodal Concept



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Energy Conversion Nanomaterials & Devices Group

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Dr. Gerko Oskam
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Dr. Renán Escalante Quijano
M. Beatriz Heredia Cervera
M. Patricia Sánchez Fernández
M. Juan Carlos Expósito Gálvez
M. Mahmoud Nabil Mahmoud
M. Pablo Romero

What does the group do?

Colodrero S., Mihi A., Anta J. A., Ocaña M., Míguez H., **Experimental demonstration of the mechanism of light harvesting enhancement in Photonic-Crystal-Based Dye-Sensitized Solar Cells,** Journal of Physical Chemistry C-letters, (**2009**), 113, 1150-1154. DOI: 10.1021/jp809789s

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María Elena Guillén Rodríguez, **Photoelectrochemical Characterization Of Dye Solar Cells Based On Nanostructured Zinc Oxide Substrates,** Universidad Pablo de Olavide, Sevilla, **1st of June, 2011**

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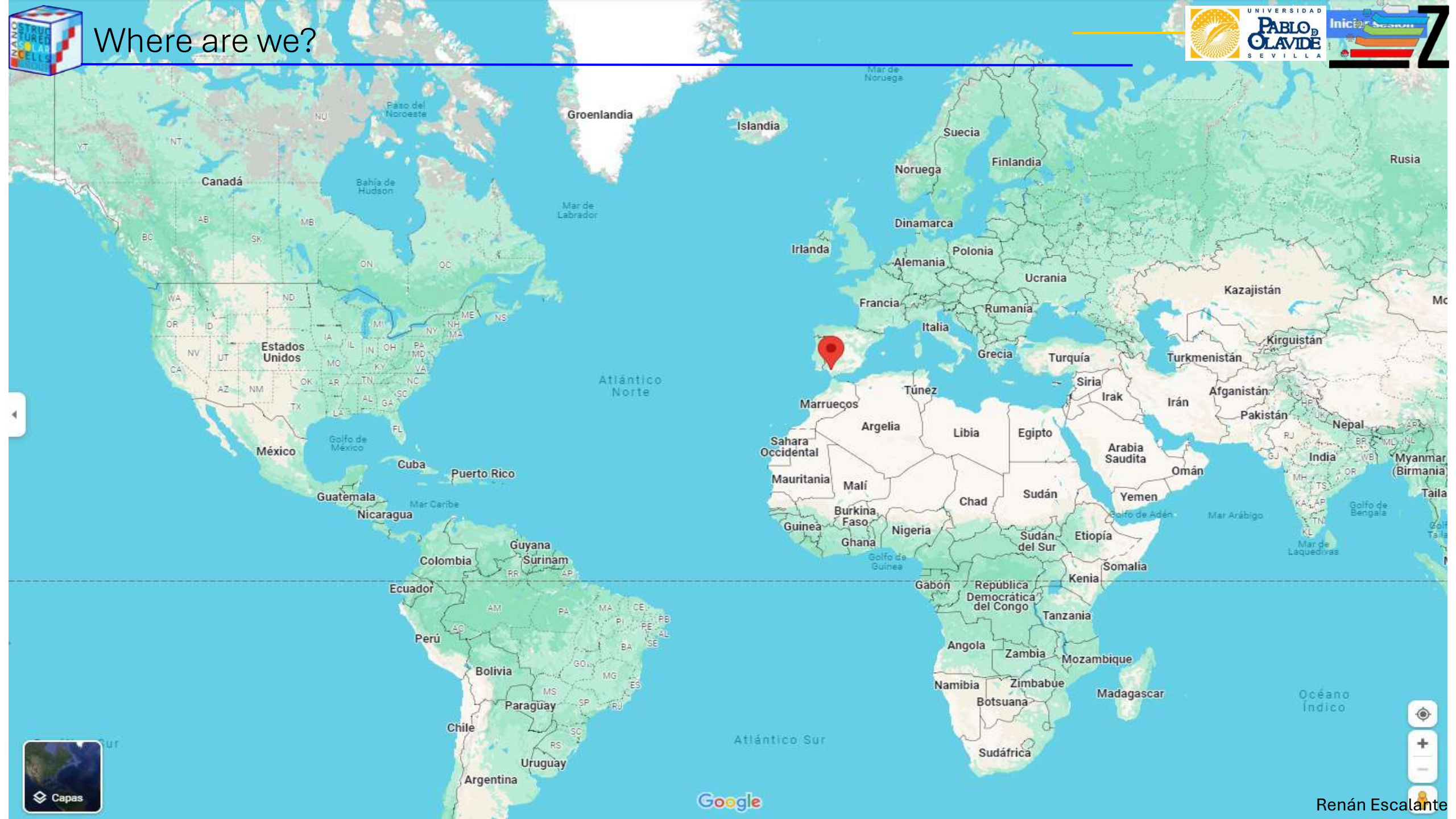
Where are we?



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Where are we?

Spain

Where are we?

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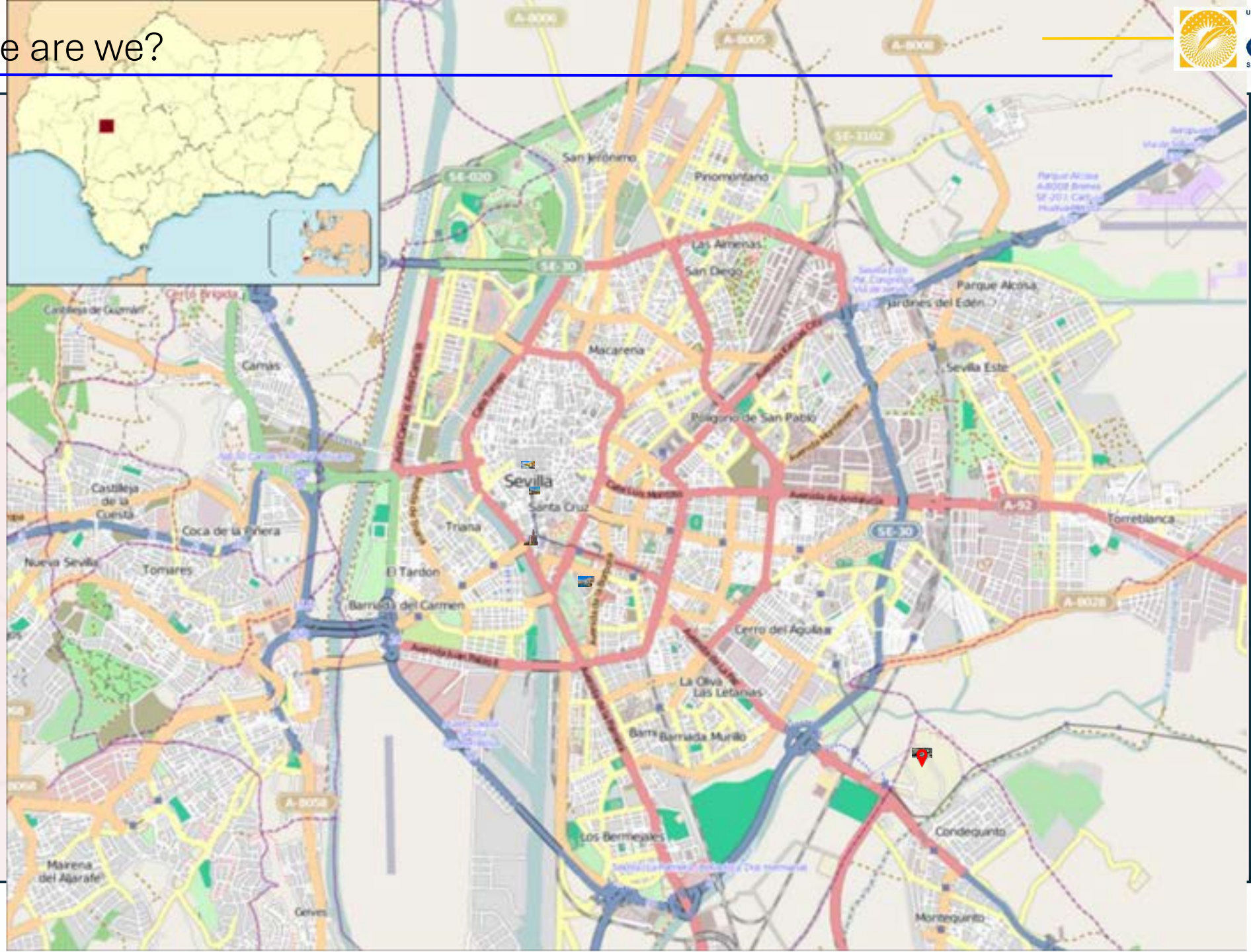
Where are we?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San Diego
Camas
Castilleja de la Cuesta
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Where are we?

Where are we?

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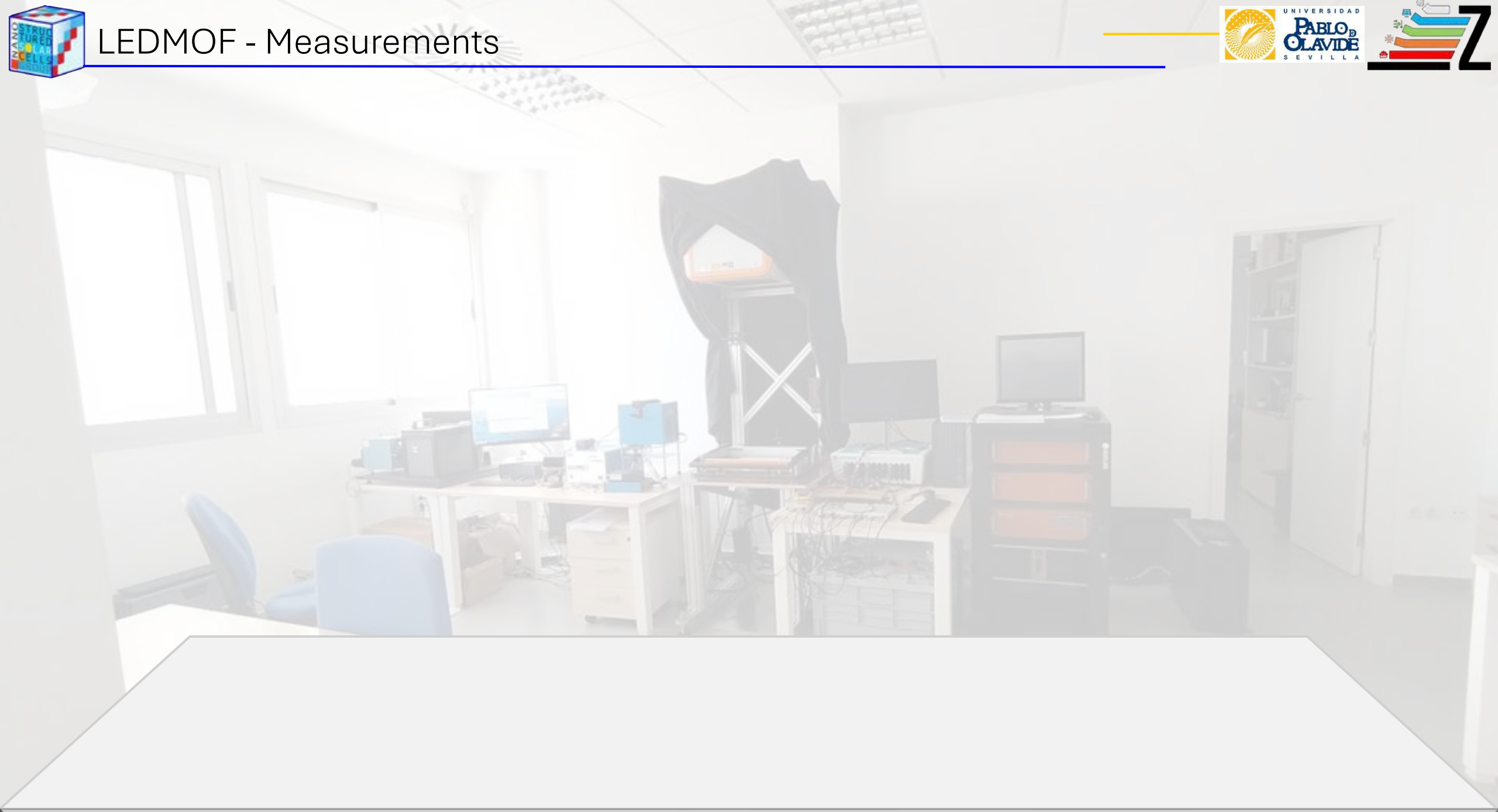
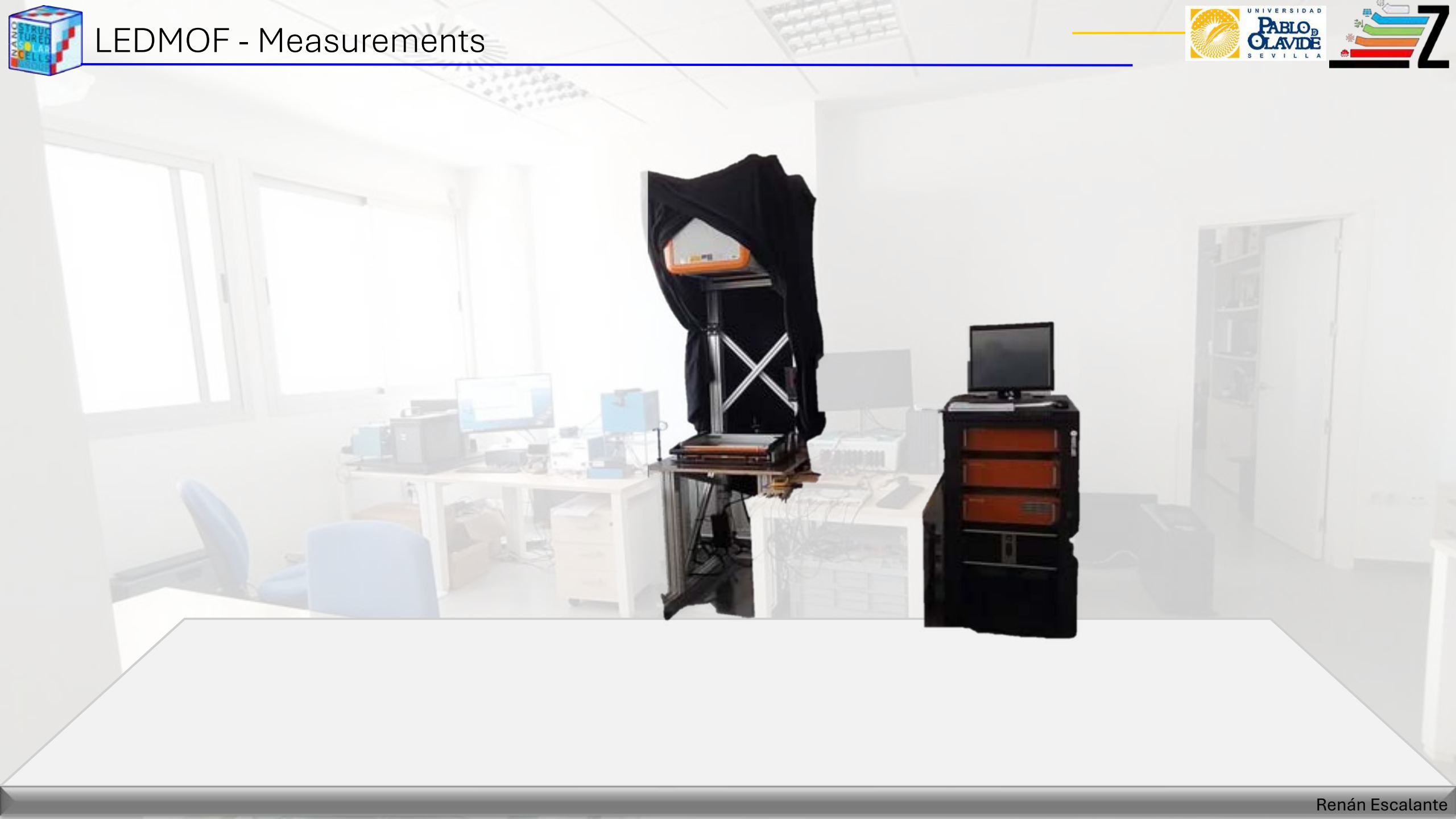
UPO

LEDMOF - Measurements

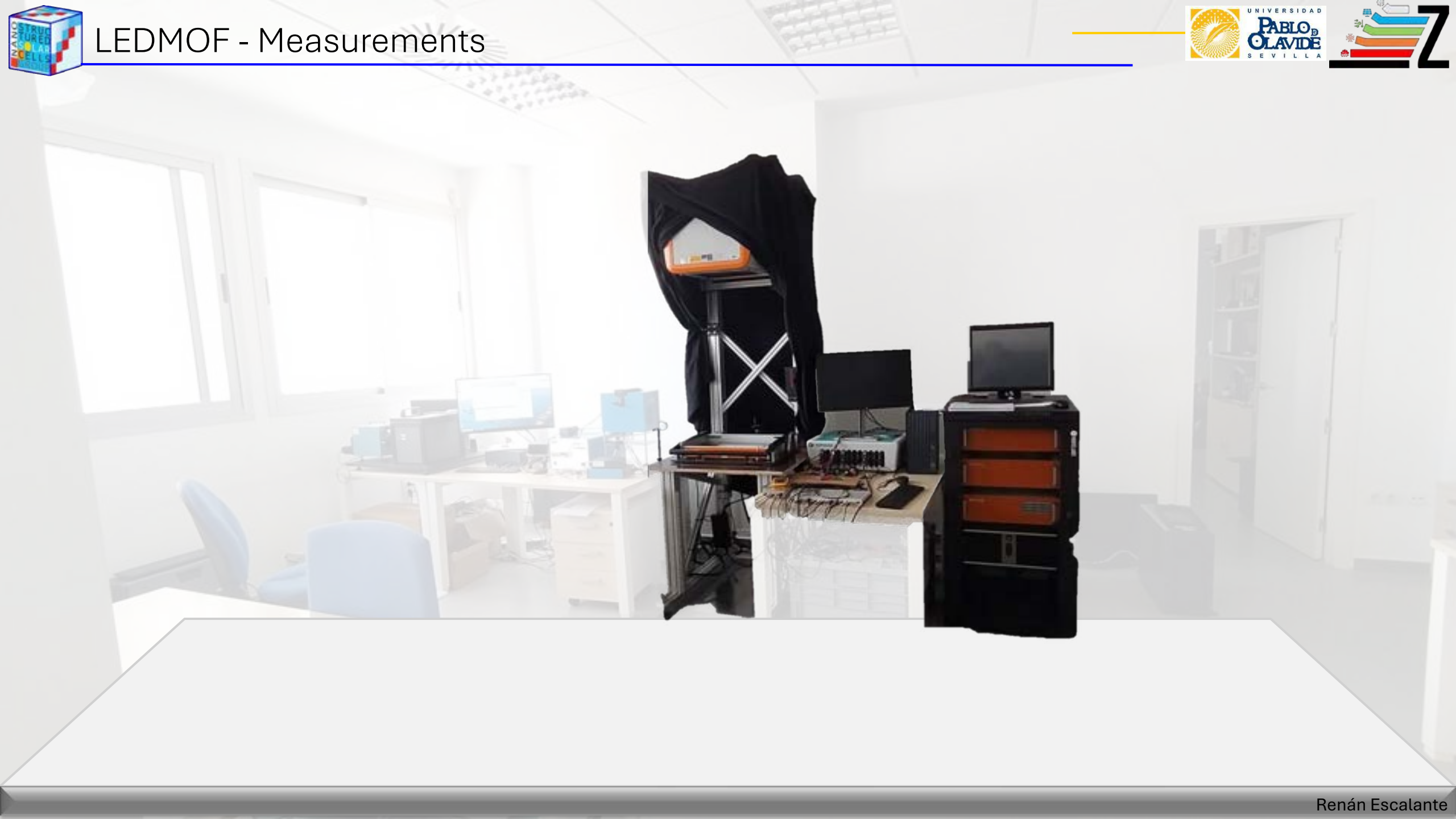
LEDMOF - Measurements



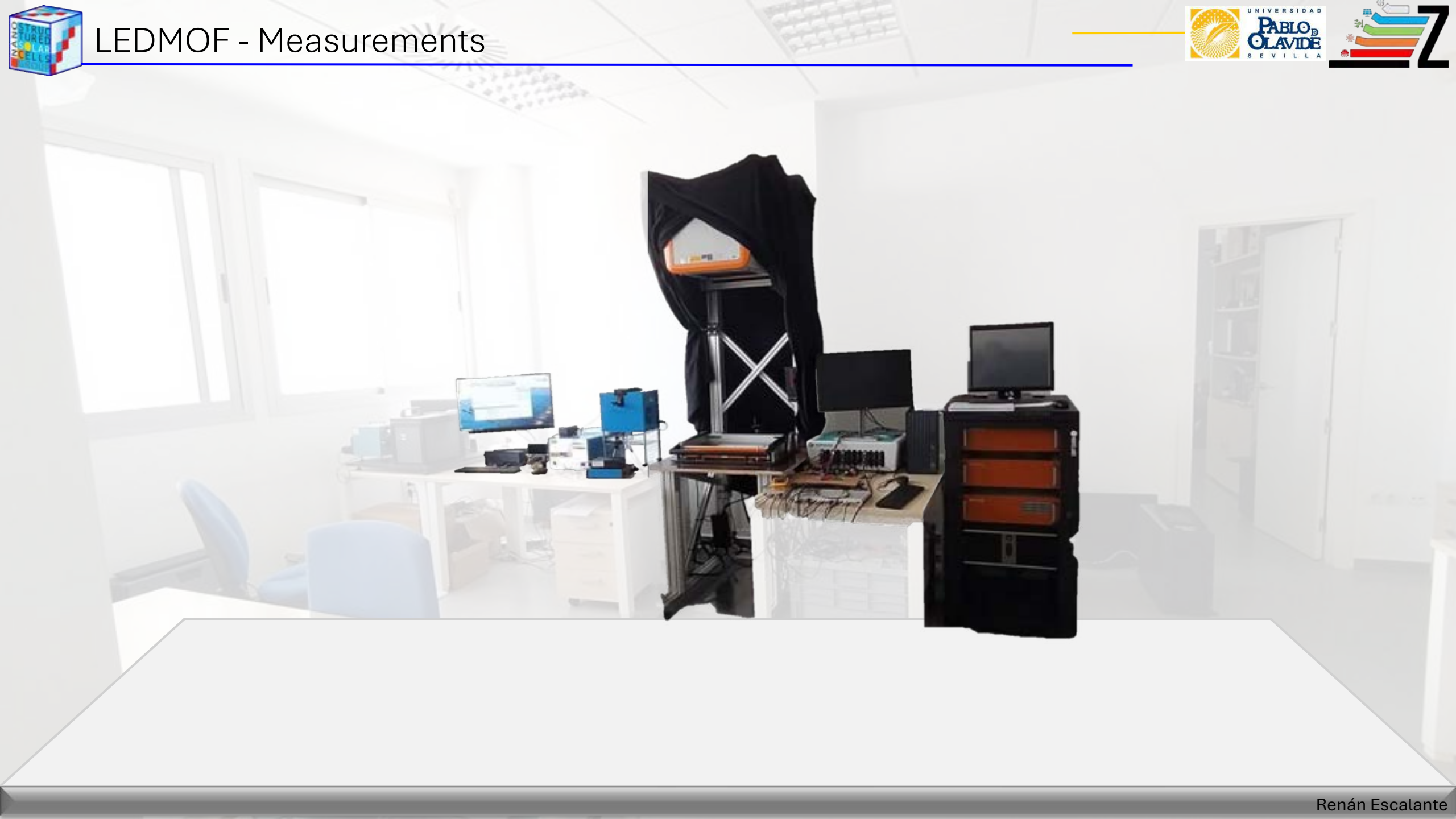
LEDMOF - Measurements



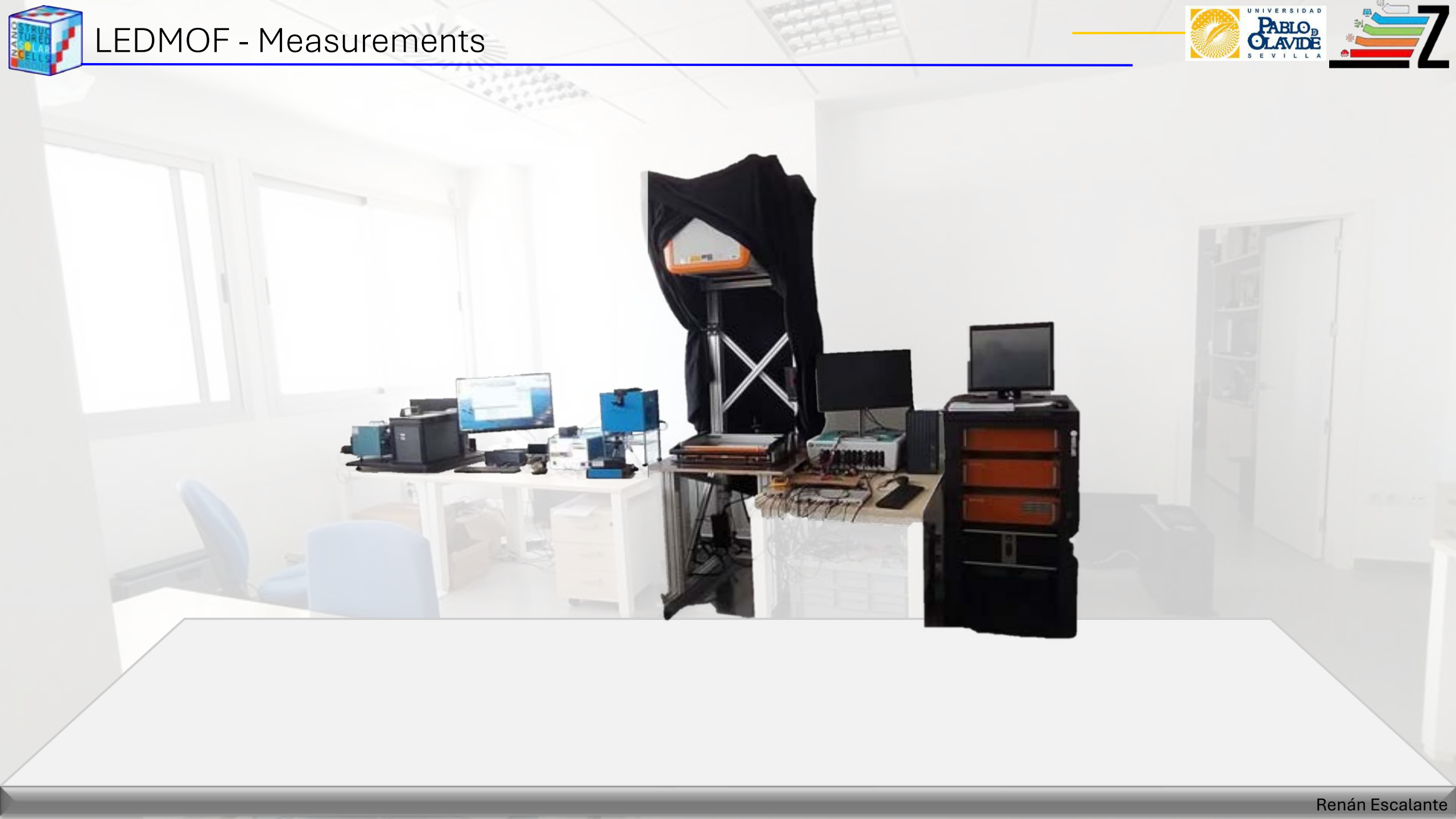
LEDMOF - Measurements



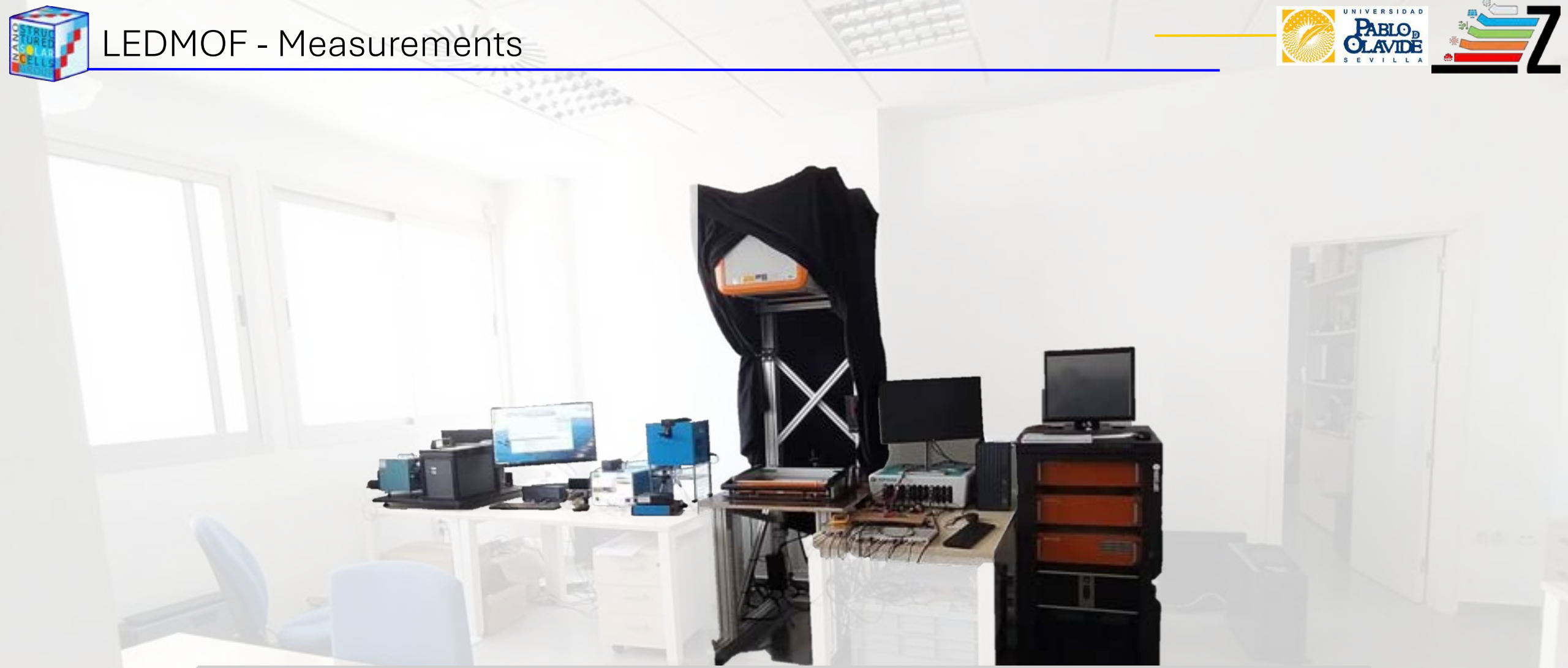
LEDMOF - Measurements



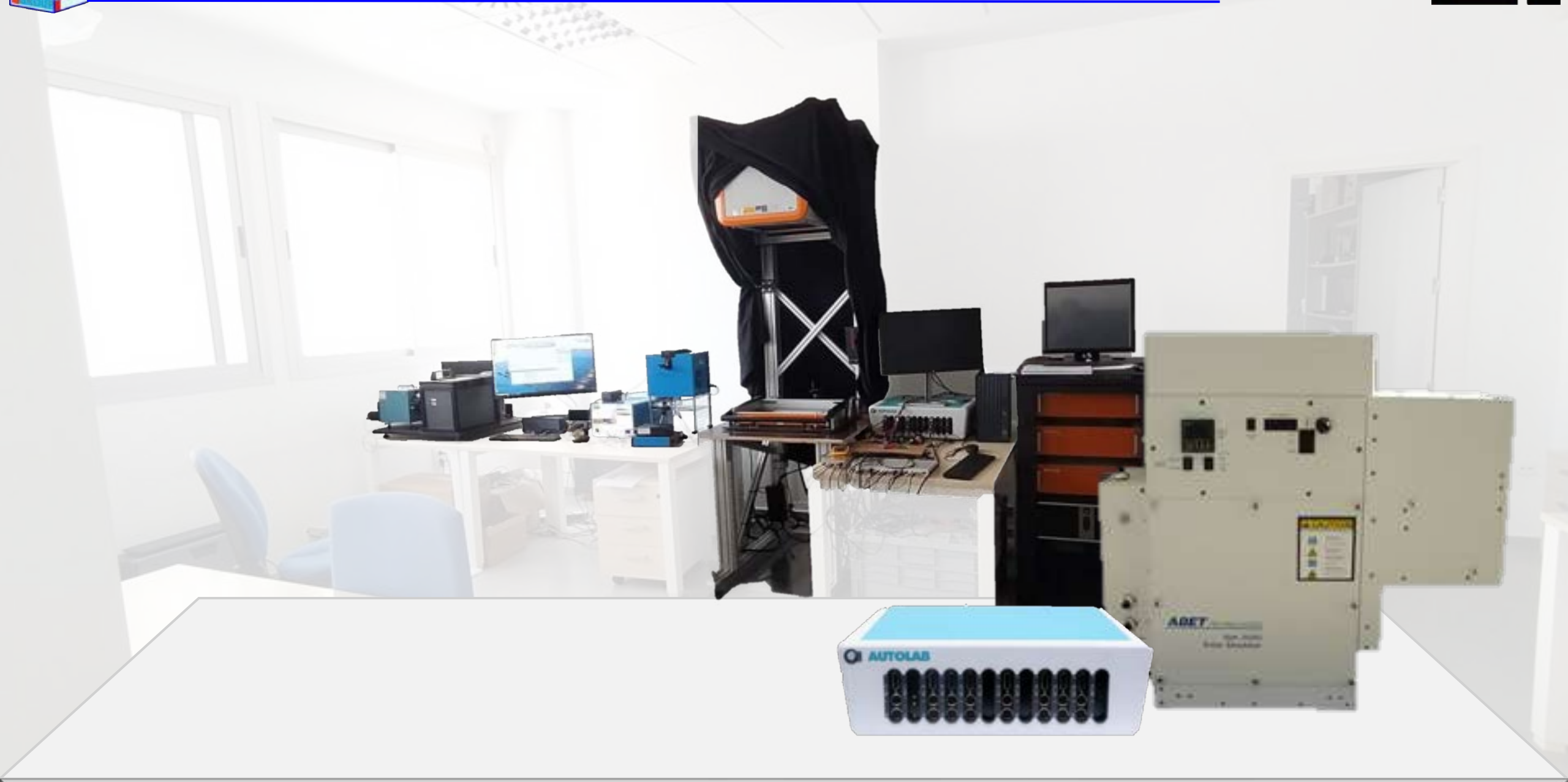
LEDMOF - Measurements



LEDMOF - Measurements



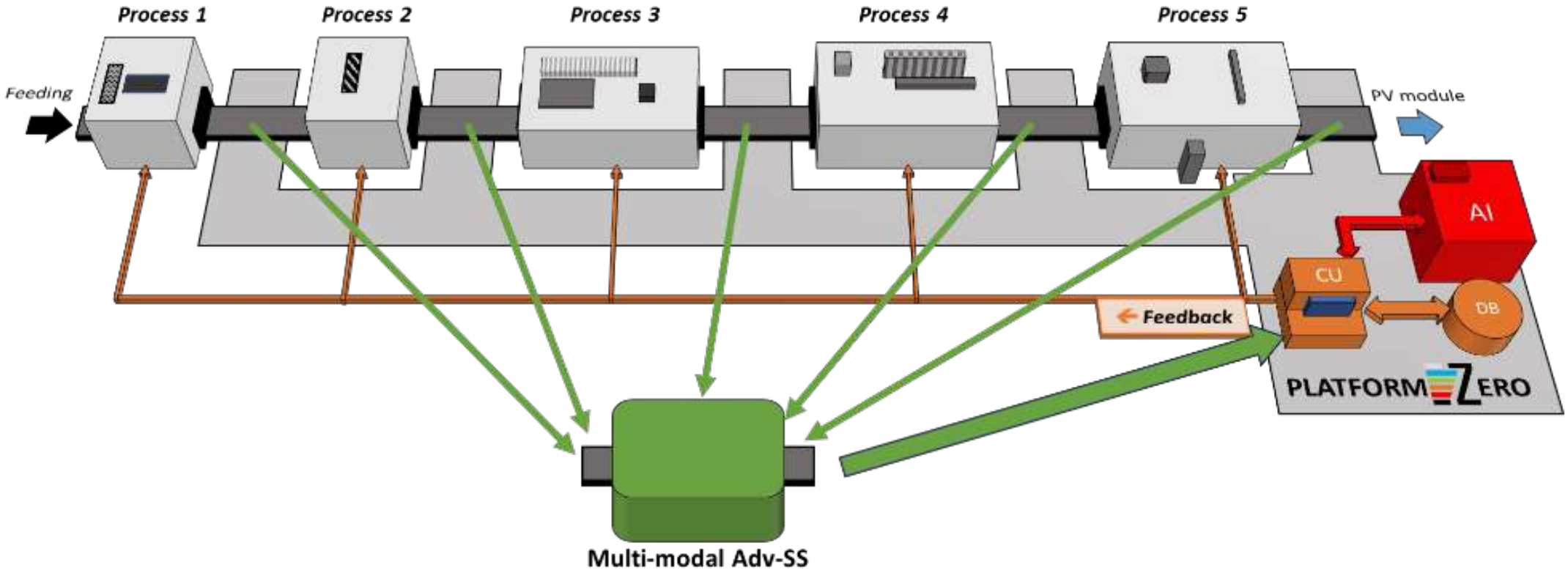
LEDMOF - Measurements



LEDMOF - Measurements

LEDMOF - Measurements

Platform-Zero Concept



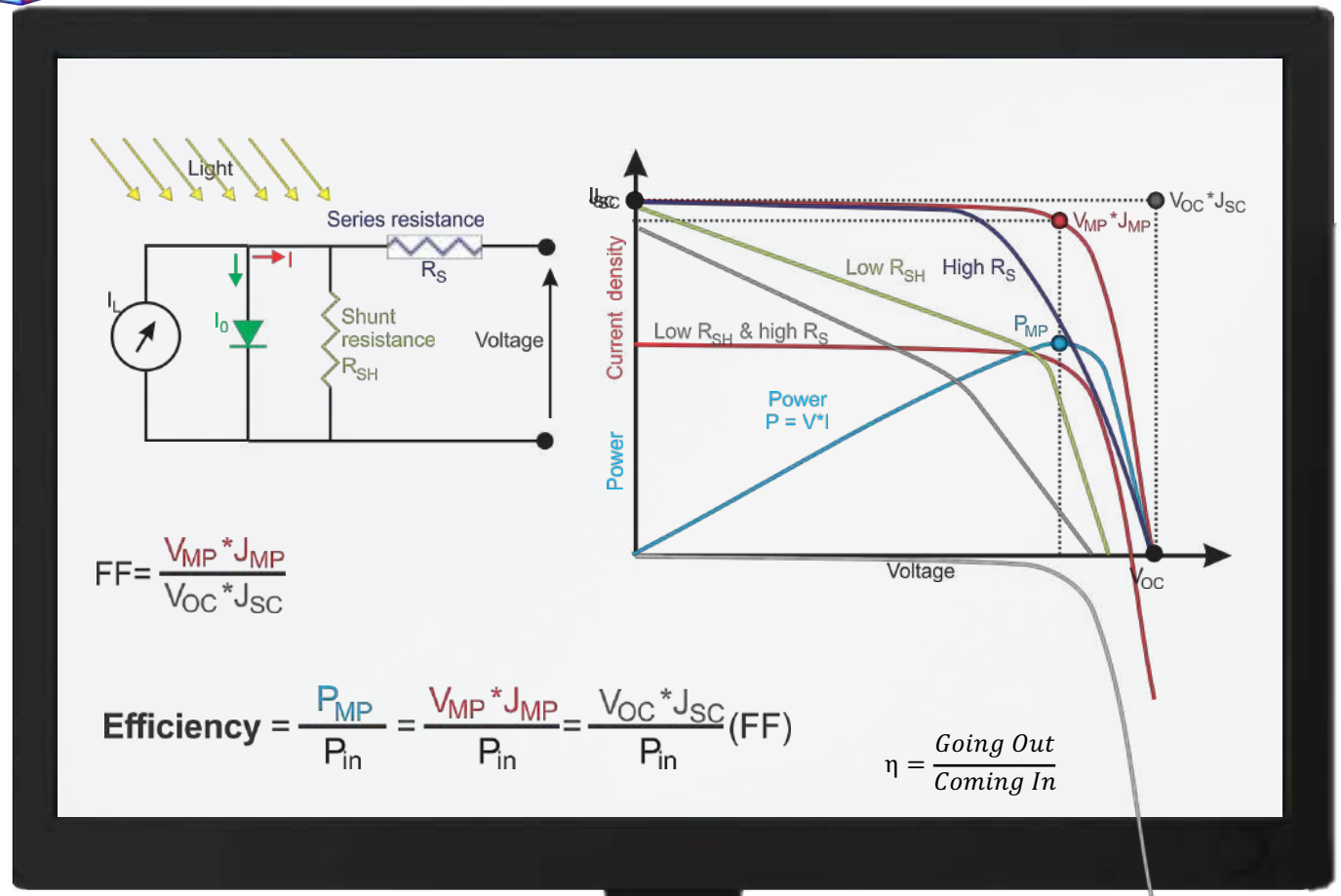
Optoelectronic Characterization Techniques

IV Curves

EIS

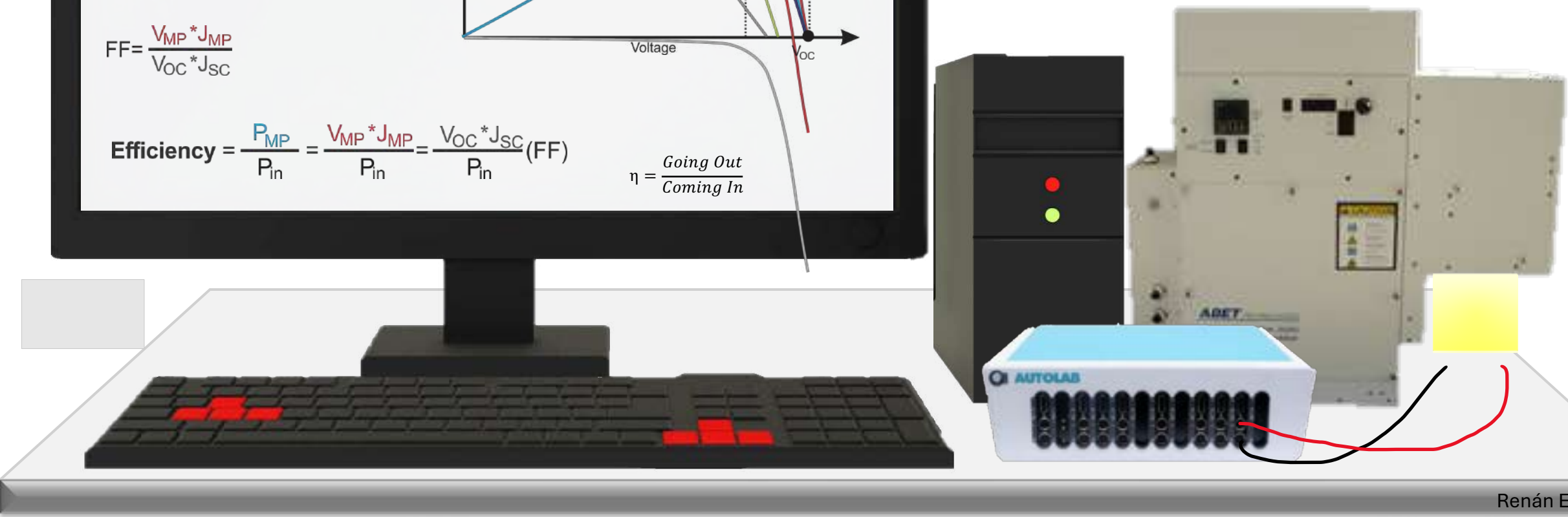
EQE

Optoelectronic Characterization Techniques

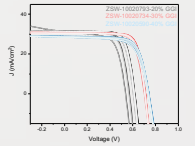


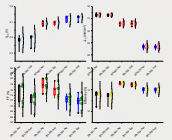
IV Curves

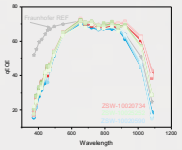
Sample

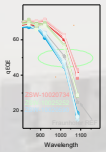


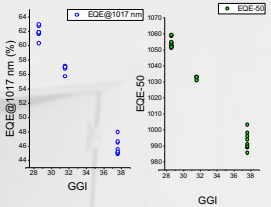
Results

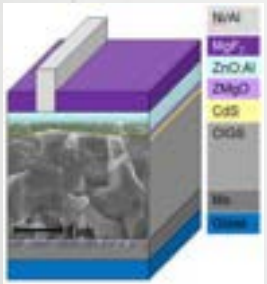

Voltage (V)



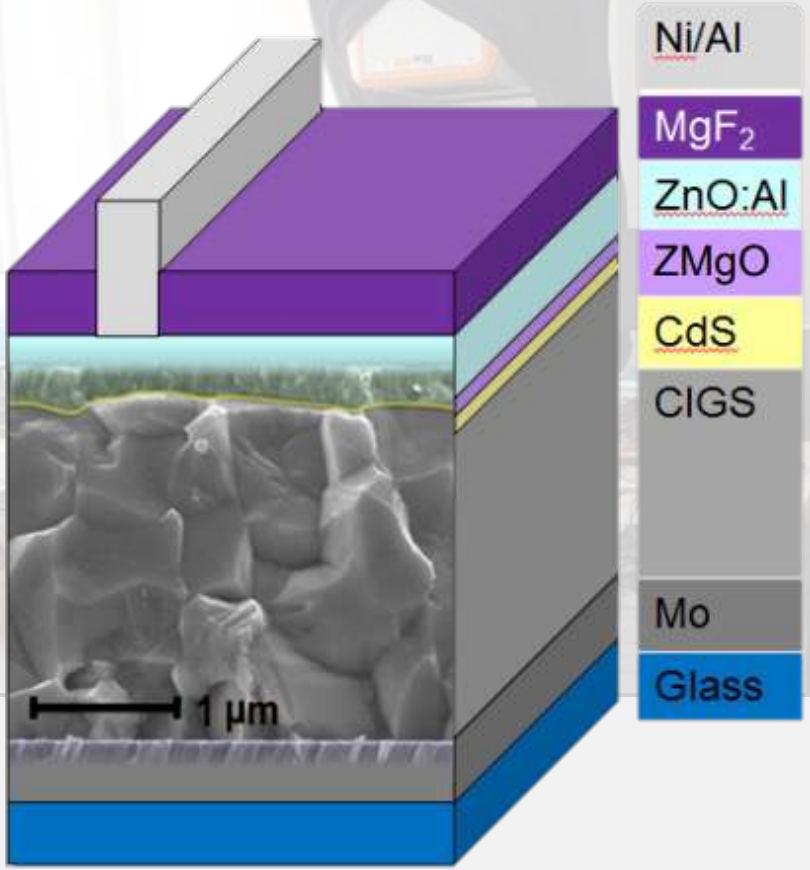

Wavelength

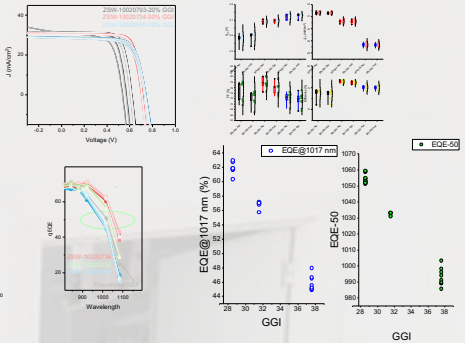

Wavelength


EQE@1017 nm
EQE-50
EQE@1017 nm (%)
GGI
GGI

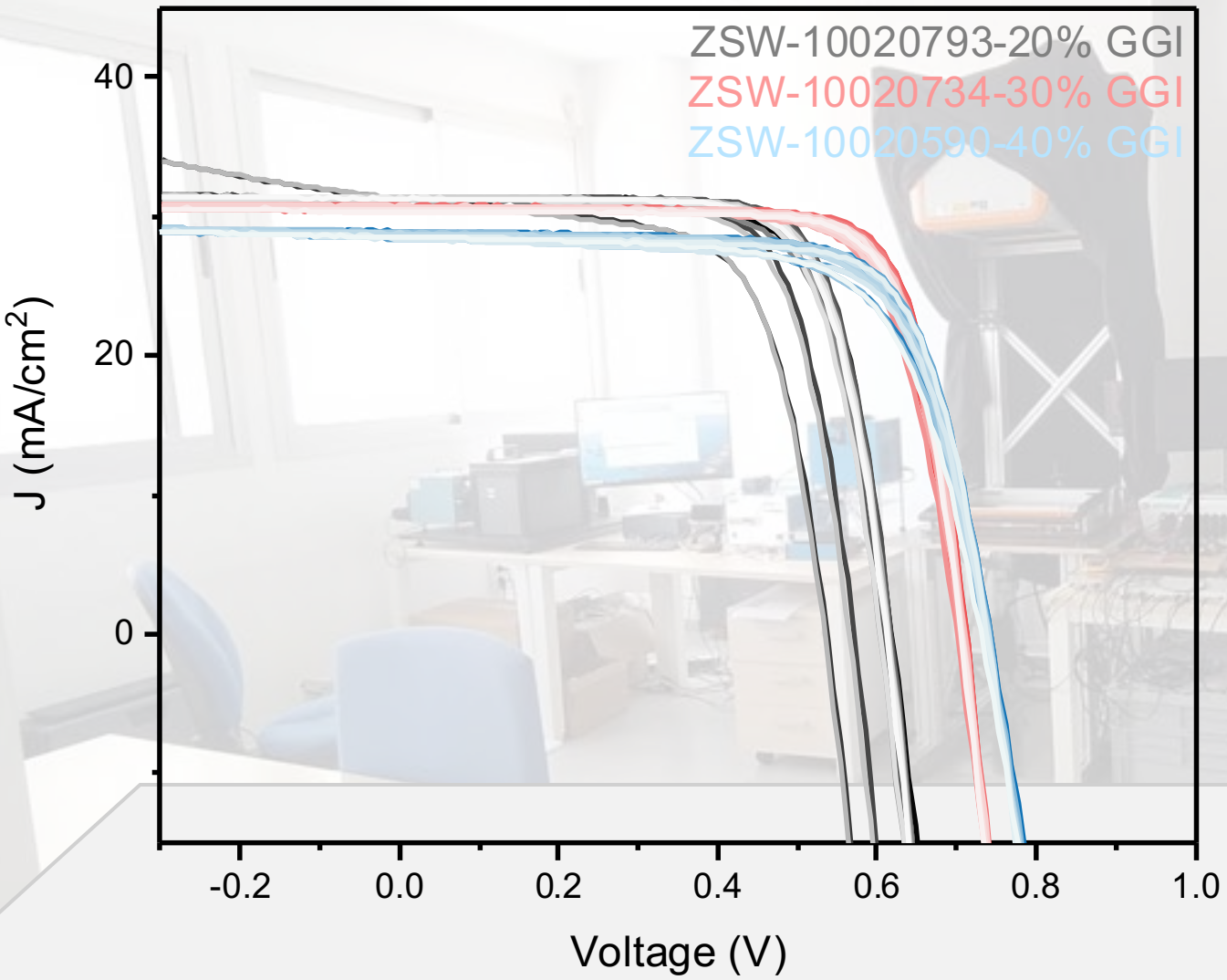

Ni/Al
MgF2
ZnO:Al
ZMgO
CdS
CIGS
Mo
Glass

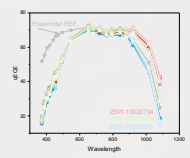
Results

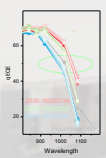

Ni/Al
MgF_2
ZnO:Al
ZMgO
CdS
CIGS
Mo
Glass
1 µm

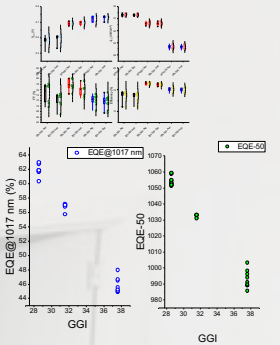

EQE@1017 nm
EQE-50
EQE@1017 nm (%)
GGI
GGI

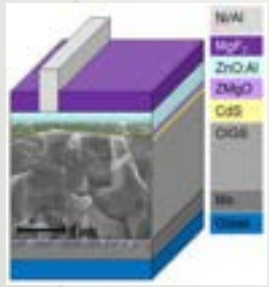
Results – JV Characterization



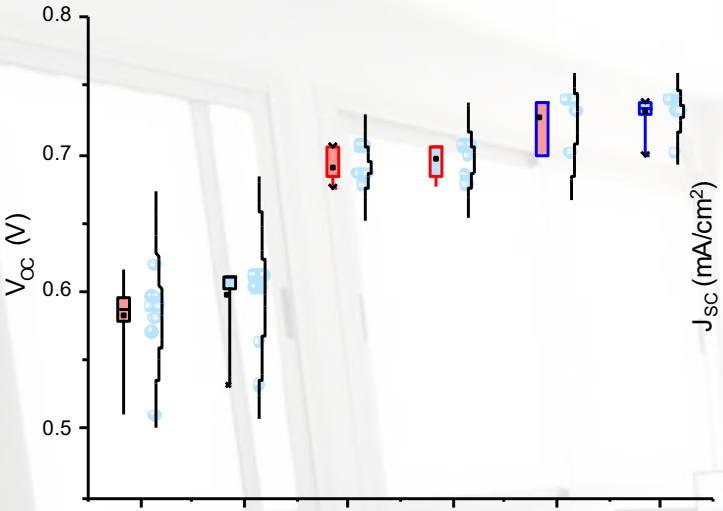


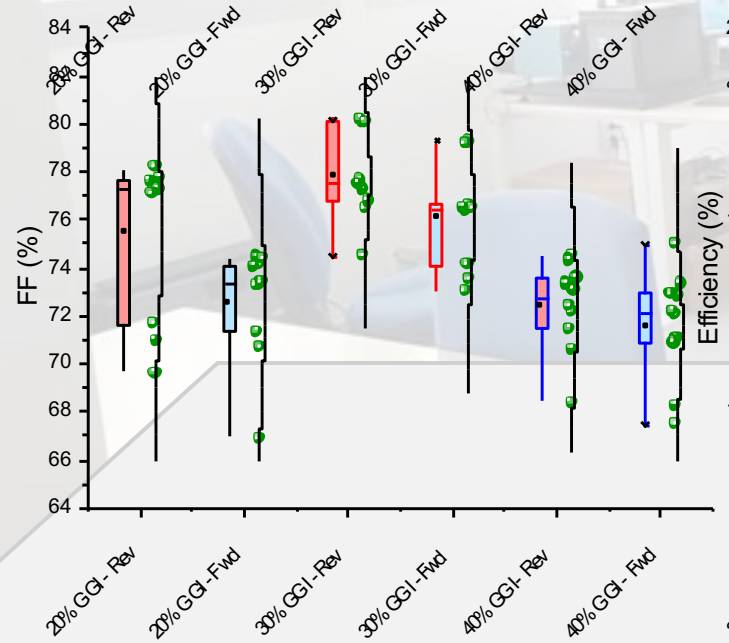


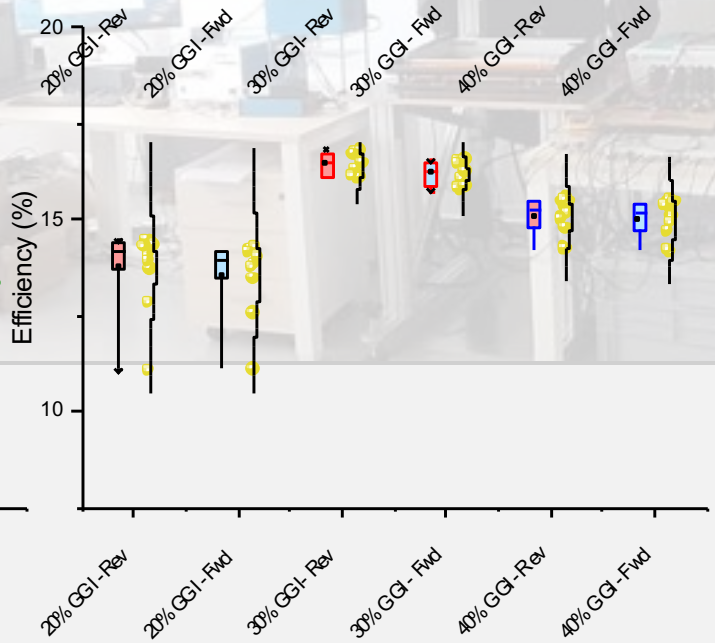


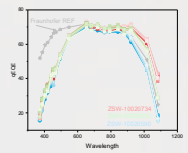


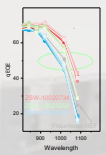
Results – JV Characterization

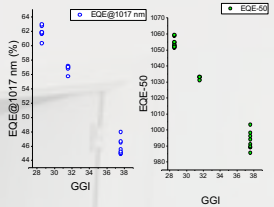


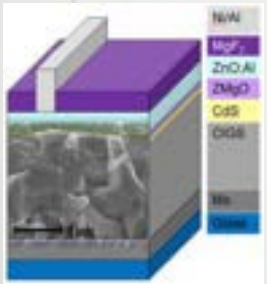


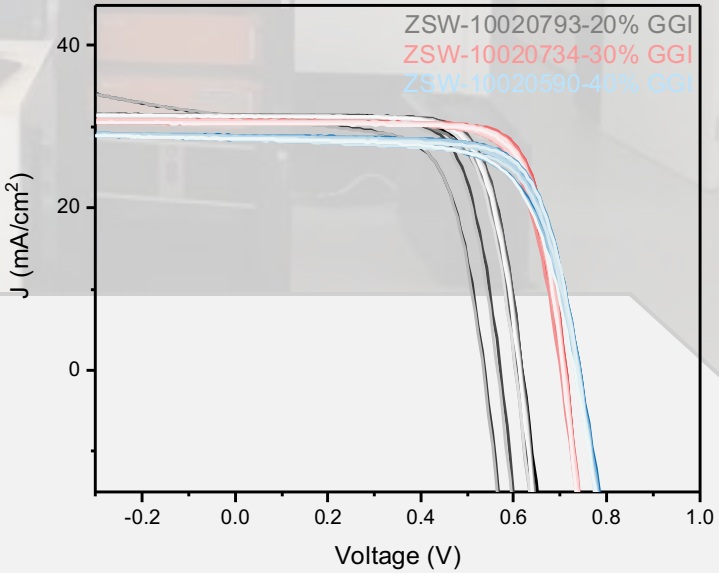












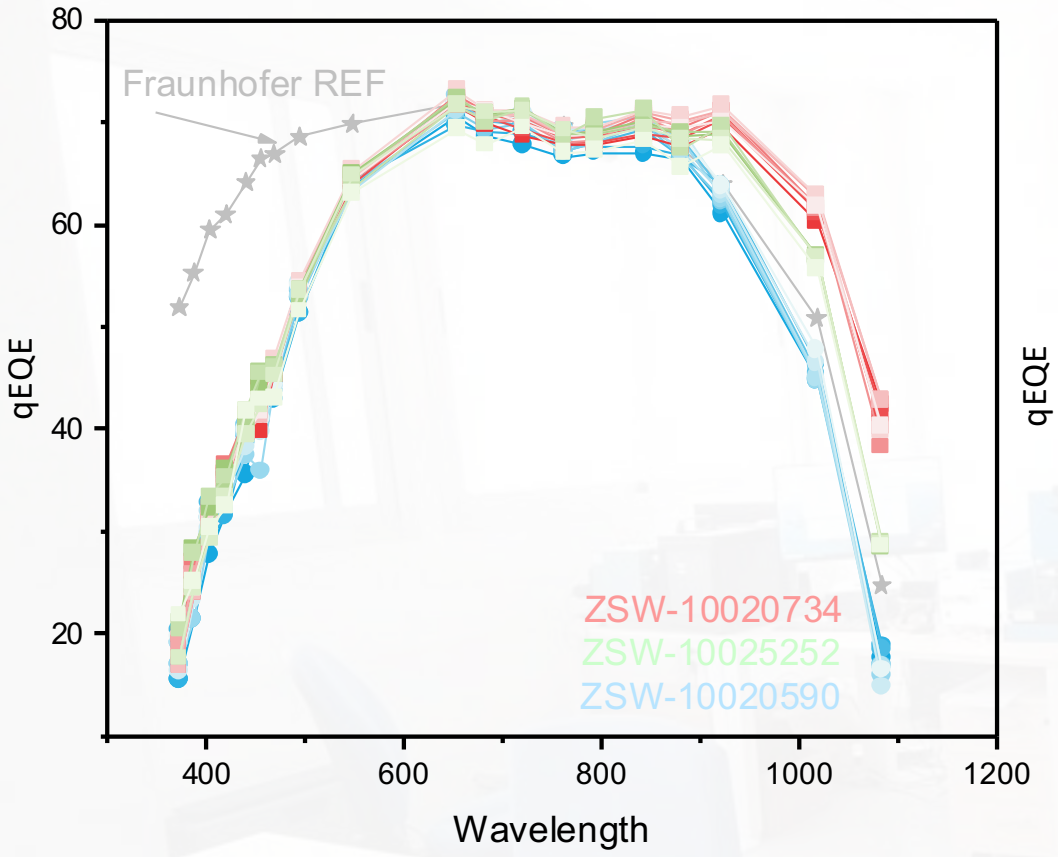
EQE

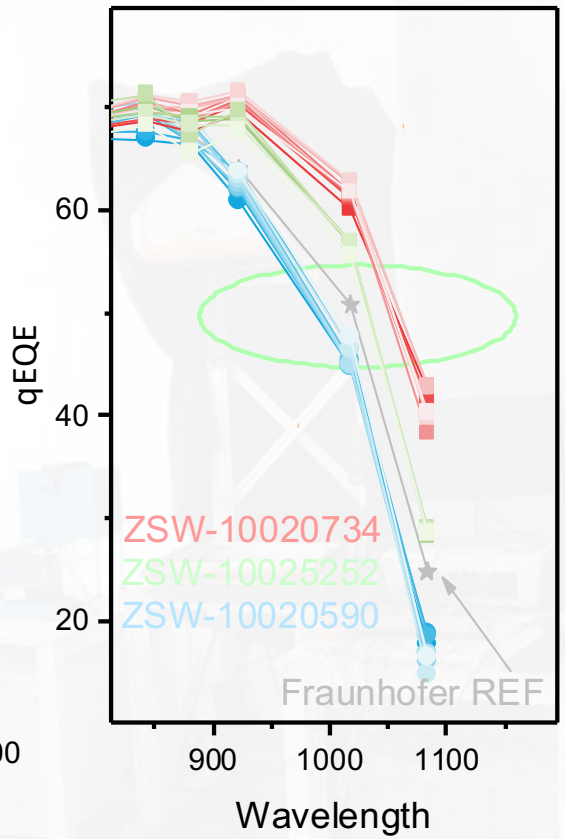
$$EQE(\&) = \frac{hc}{q\lambda} \cdot SR_{ph} \cdot \frac{I_{DUT}}{I_{ph}}$$

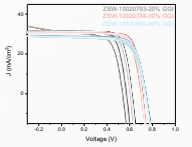
Sample

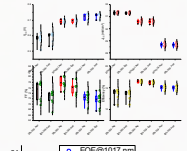
$$J_{SC}(\lambda) = QE \cdot \emptyset_{photons} \cdot electron\ charge$$

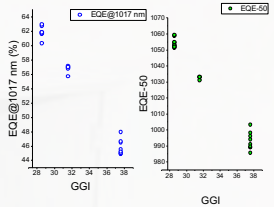
Results

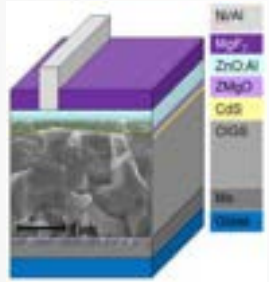

Fraunhofer REF
ZSW-10020734
ZSW-10025252
ZSW-10020590
qEQE
Wavelength
80
60
40
20
400
600
800
1000
1200


ZSW-10020734
ZSW-10025252
ZSW-10020590
Fraunhofer REF
qEQE
Wavelength
60
40
20
900
1000
1100

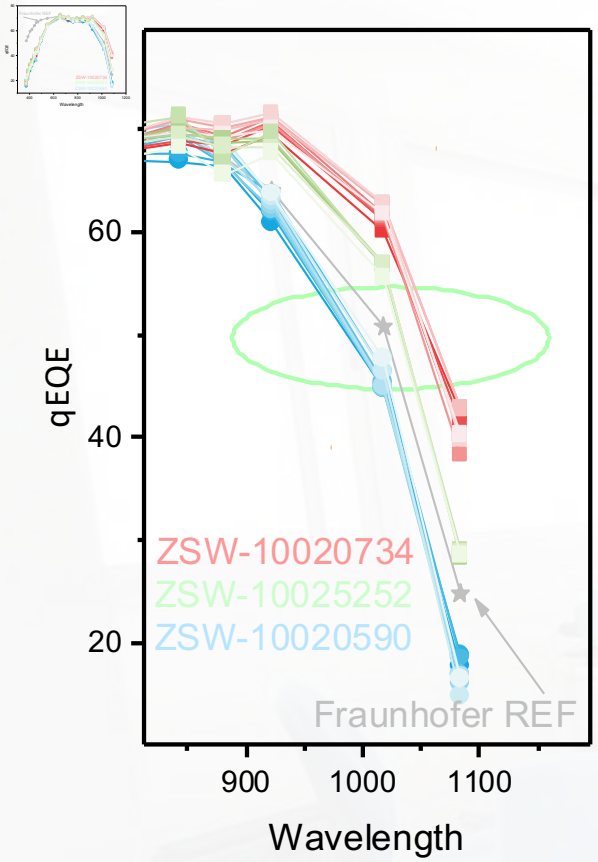


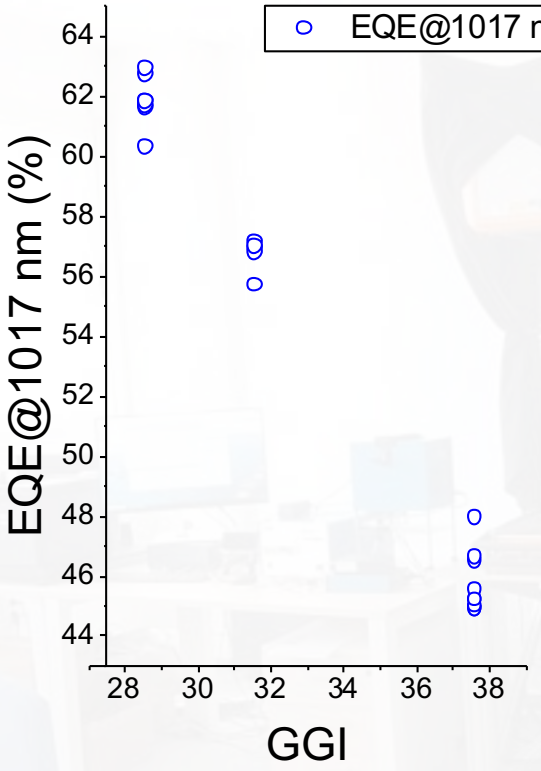


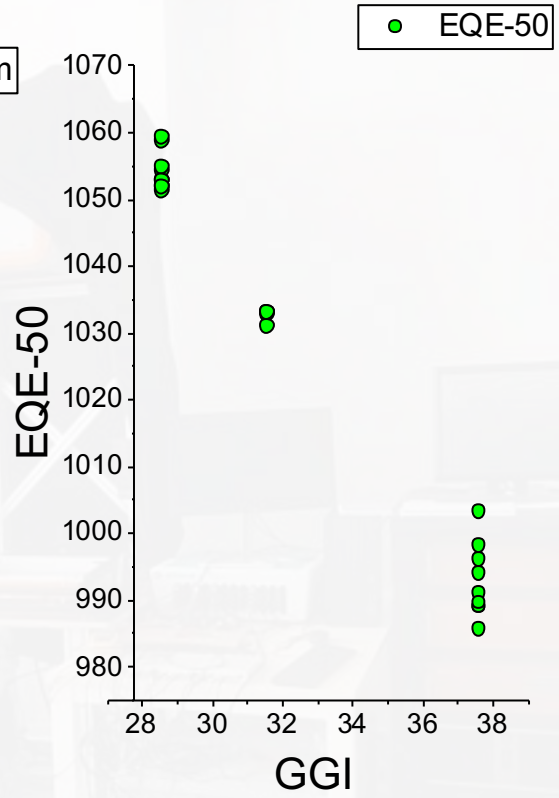

EQE@1017 nm (%)
GGI
EQE-50
GGI

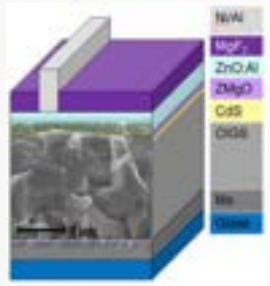

Ni/Al
MgF2
ZnO:Al
ZMgO
CdS
CIGS
Mo
Glass

Results


qEQE
60
40
20
900
1000
1100
Wavelength
ZSW-10020734
ZSW-10025252
ZSW-10020590
Fraunhofer REF


EQE@1017 nm
EQE@1017 nm (%)
64
62
60
58
56
54
52
50
48
46
44
28
30
32
34
36
38
GGI

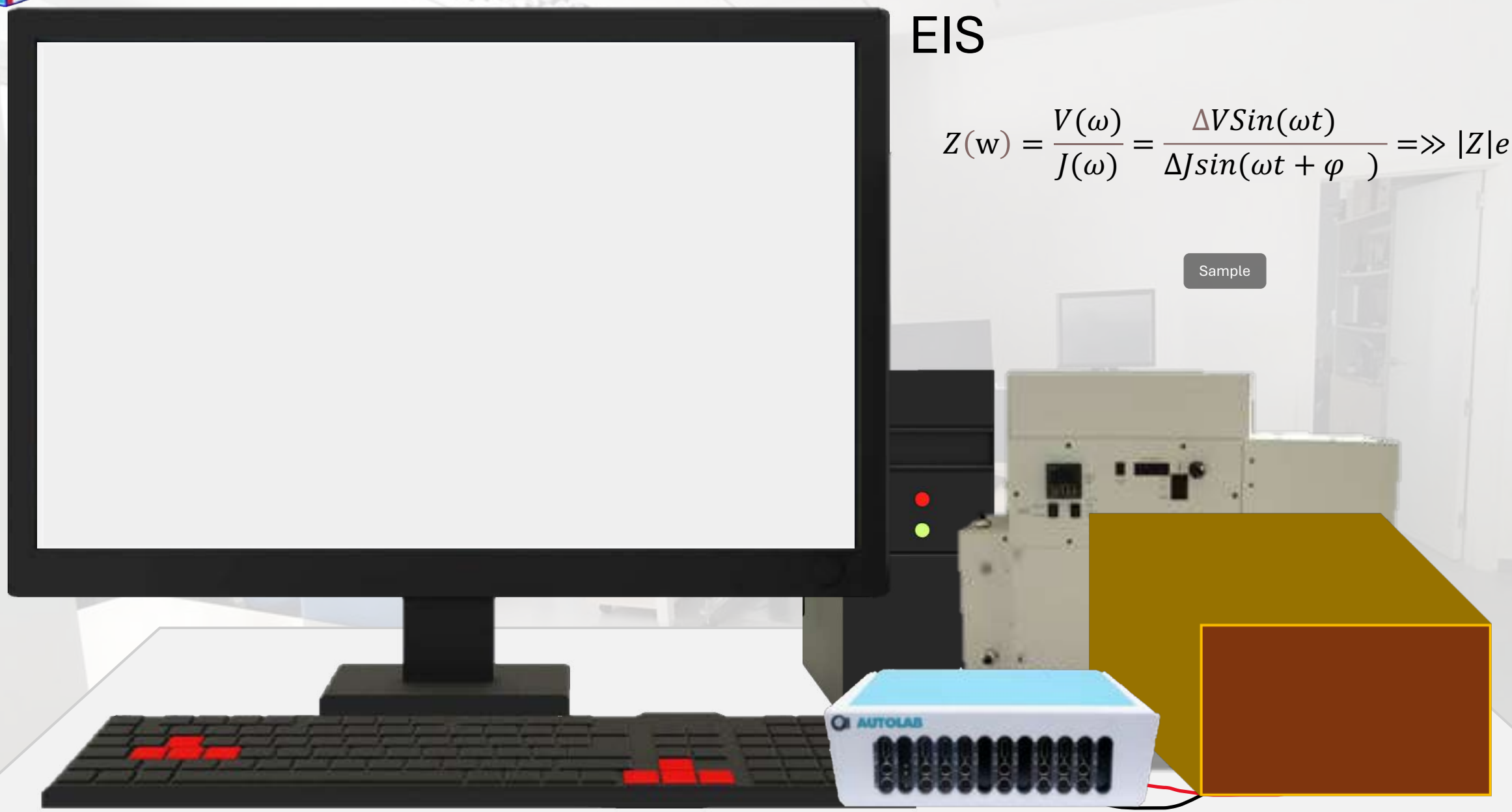

EQE-50
EQE-50
1070
1060
1050
1040
1030
1020
1010
1000
990
980
28
30
32
34
36
38
GGI



Optoelectronic Characterization Techniques

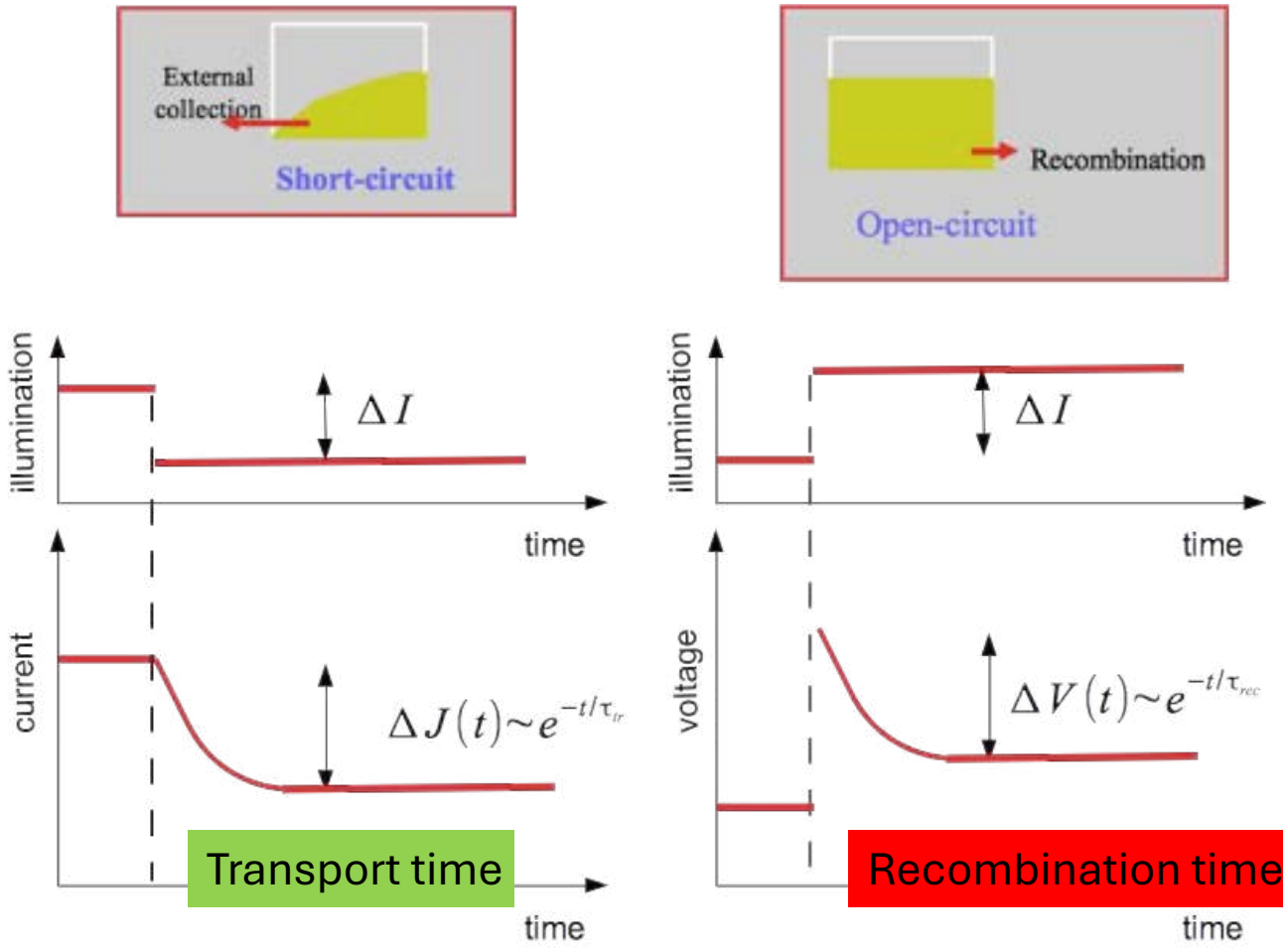
EIS

$$Z(\mathrm{w}) = \frac{V(\omega)}{J(\omega)} = \frac{\Delta V Sin(\omega t)}{\Delta J sin(\omega t + \varphi\ )} =\gg |Z|e^{i\varphi}$$

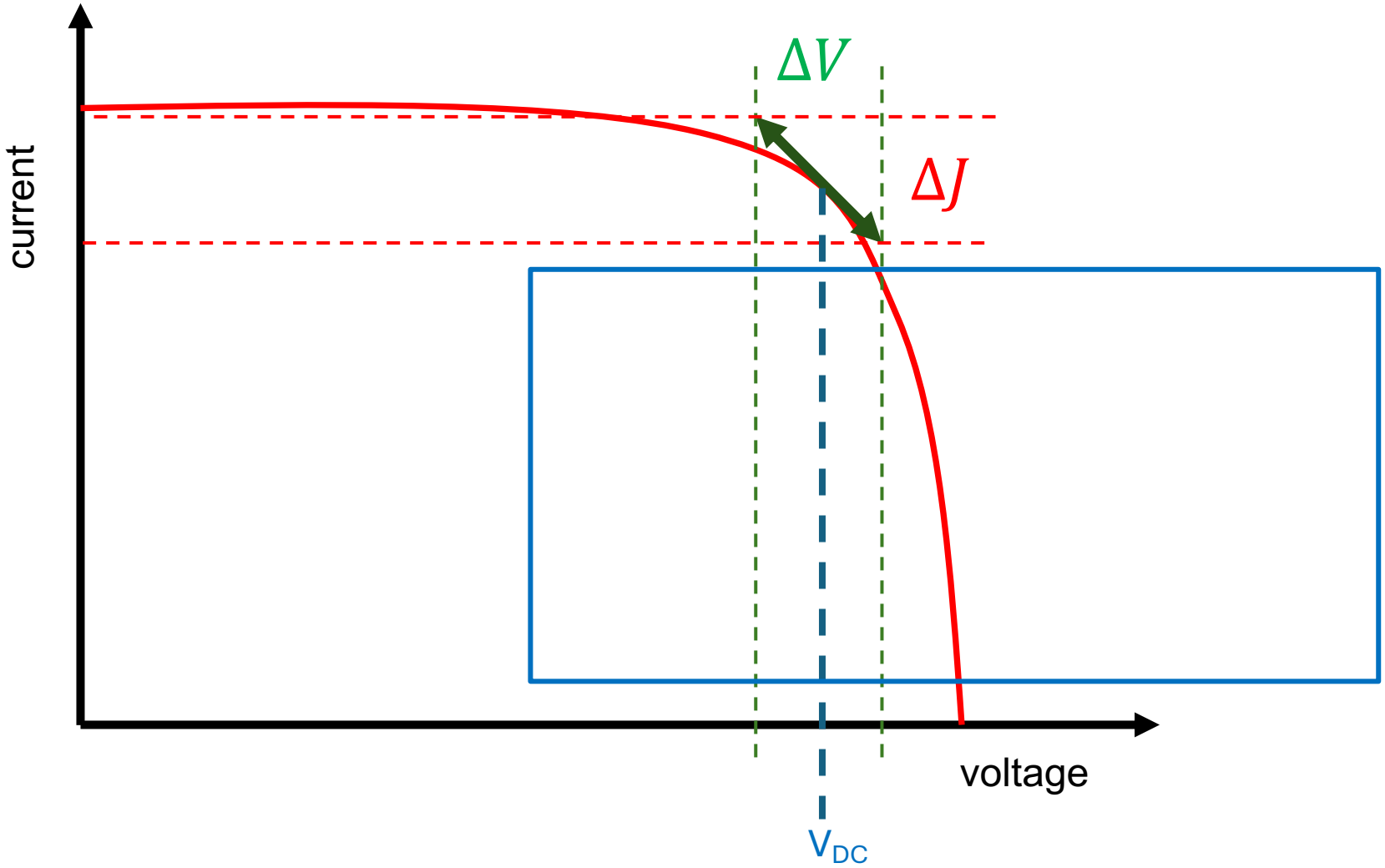


Small Perturbation Techniques – Impedance Spectroscopy

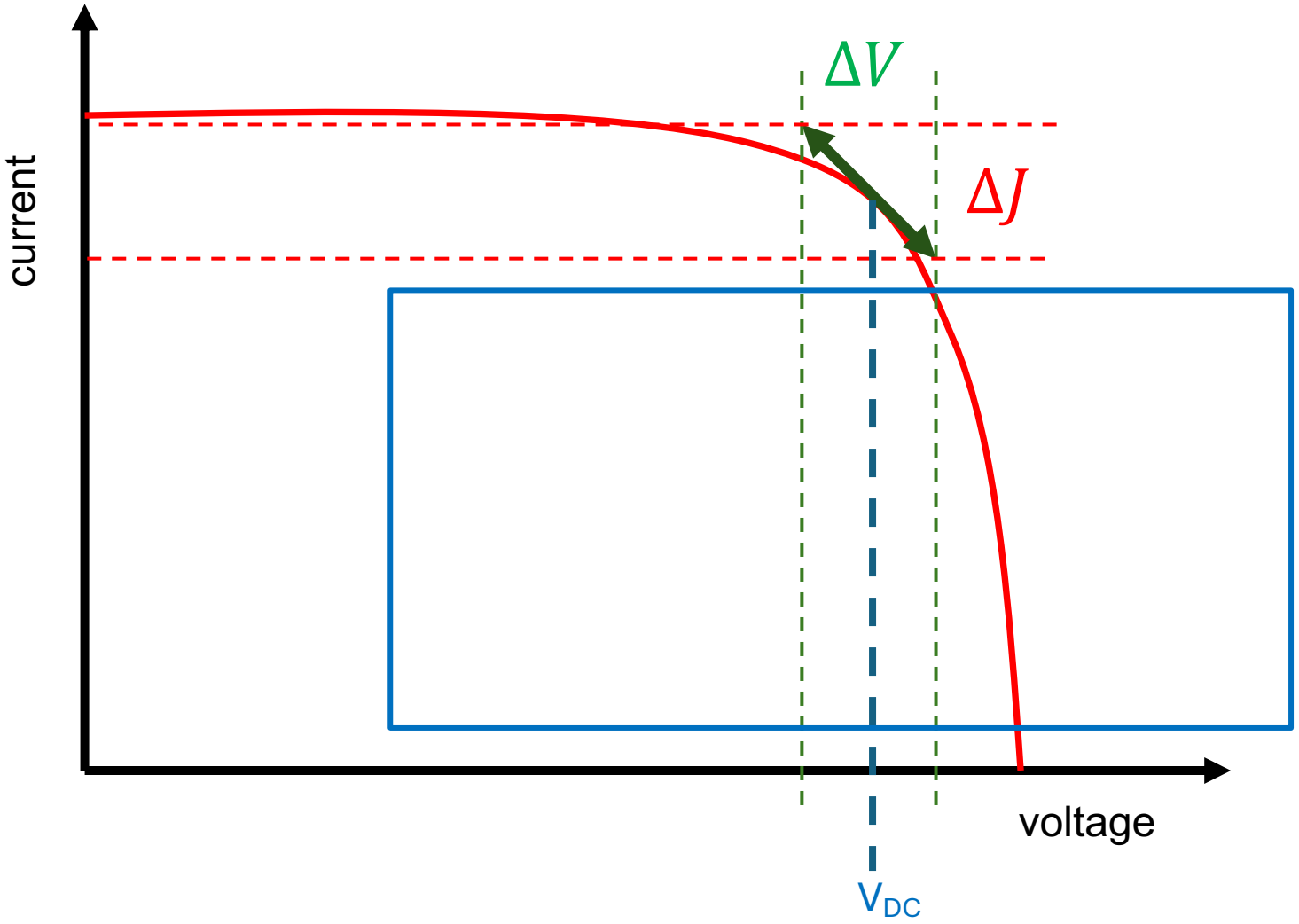
The idea is to separate processes occurring at different time scales and loading conditions, and to simplify the kinetics (small perturbation → first order kinetics)



Small Perturbation Techniques – Impedance Spectroscopy



Small Perturbation Techniques – Impedance Spectroscopy



Linearity

The applied AC amplitude must be small enough so that the response of the cell can be assumed to be **linear**

Stability

The overall state of the system should not change during the acquisition of the data

Causality

The measured AC response of the system must be directly correlated to the applied AC stimulus

Normally, the first and the third conditions are met by tuning the perturbation:

Voltage amplitude (EIS) or illumination step (IMVS/IMPS)

Small Perturbation Techniques – Impedance Spectroscopy

Study of the variation of total impedance of an electrically active system with the frequency of a small-amplitude AC perturbation

Advantages

- in-situ technique
- Relatively simple equipment needed
- non-destructive (but beware!)
- Does not drive the system away from equilibrium/steady-state
- Makes it possible to distinguish individual processes

Drawbacks

- Individual processes can appear overlapped
- Interpretation can be difficult
- Relies on the availability of a model (equivalent circuit) with physical basis

Small Perturbation Techniques – Impedance Spectroscopy

Study of the variation of total impedance of an electrically active system with the frequency of a small-amplitude AC perturbation

Most popular protocol:

1. Fix a voltage (DC) bias: V
2. Fix a voltage perturbation: ΔV
3. Scan different frequencies (from high to low)(10^{-1}–10^{6} Hz)
4. Collect results
5. Analyze data
6. Interpret data (the tricky part!)

Advantages

- in-situ technique
- Relatively simple equipment needed
- non-destructive (but beware!)
- Does not drive the system away from equilibrium/steady-state
- Makes it possible to distinguish individual processes

Drawbacks

- Individual processes can appear overlapped
- Interpretation can be difficult
- Relies on the availability of a model (equivalent circuit) with physical basis

Impedance of simple circuit elements

Ideal resistor

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = R$$

Independent of frequency

Inversely proportional to frequency

Ideal capacitor

$$Q = CV \longrightarrow I = \frac{dQ}{dt} = C\frac{dV}{dt}$$

$$V(\omega) = \Delta V \exp(j\omega t)$$
$$I(\omega) = \Delta I \exp(j\omega t - \varphi)$$
$$Z = |Z| \exp(j\varphi)$$

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = \frac{1}{j\omega C}$$

Small Perturbation Techniques – Impedance Spectroscopy

Impedance of simple circuit elements

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = R$$

Independent of frequency

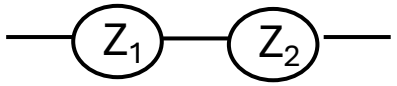
$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = \frac{1}{j\omega C}$$

Inversely proportional to frequency

Combination of circuit elements

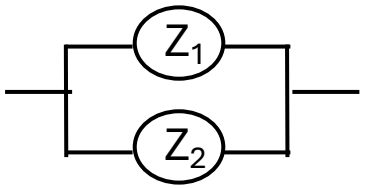
Following Kirchhoff's laws:

Impedance in series:



$$Z = Z_1 + Z_2$$

Impedance in paralell:



$$\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2}$$

Impedance of simple circuit elements

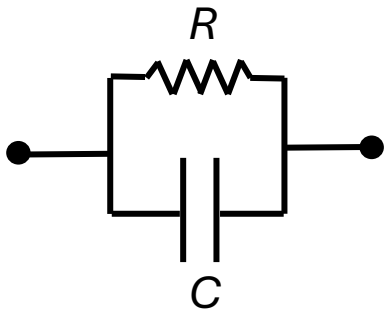
$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = R$$

Independent of frequency

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = \frac{1}{j\omega C}$$

Inversely proportional to frequency

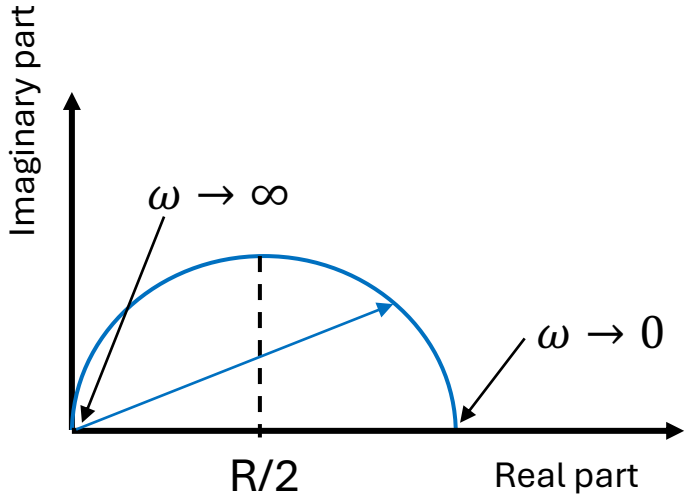
Impedance of a resistor-capacitor element (RC element)



$$Z_{RC} = \left(\frac{1}{R} + j\omega C\right)^{-1}$$

$$Z_{RC} = \frac{R}{1 + (\omega RC)^2} - j\frac{\omega R^2 C}{1 + (\omega RC)^2}$$

$$\left(Re[Z_{RC}] - \frac{R}{2}\right)^2 + Im[Z_{RC}]^2 = \left(\frac{R}{2}\right)^2$$

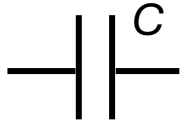


Small Perturbation Techniques – Impedance Spectroscopy

Impedance of simple circuit elements

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = R$$

Independent of frequency



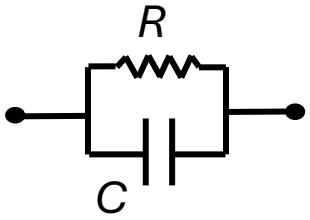
$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = \frac{1}{j\omega C}$$

Inversely proportional to frequency

Impedance of a resistor-capacitor element (RC element)

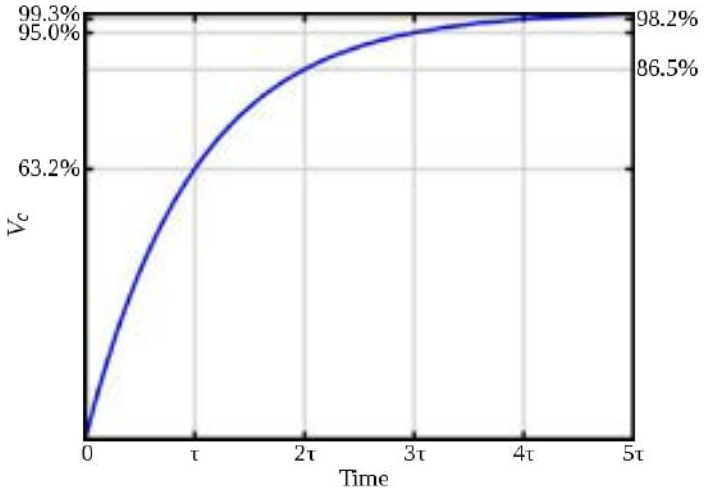
$$Z_{RC} = \left(\frac{1}{R} + j\omega C\right)^{-1}$$

Time constant and characteristic frequency of a RC element



$$\tau_c(\mathrm{s}) = R(\Omega)C(\mathrm{F})$$

Response to a small voltage perturbation



$$V(t) = V_0\left(1 - \exp\left[\frac{t}{RC}\right]\right)$$

Small Perturbation Techniques – Impedance Spectroscopy

Impedance of simple circuit elements

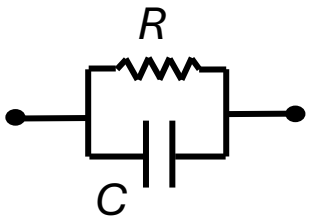
$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = R$$

Independent of frequency

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = \frac{1}{j\omega C}$$

Inversely proportional to frequency

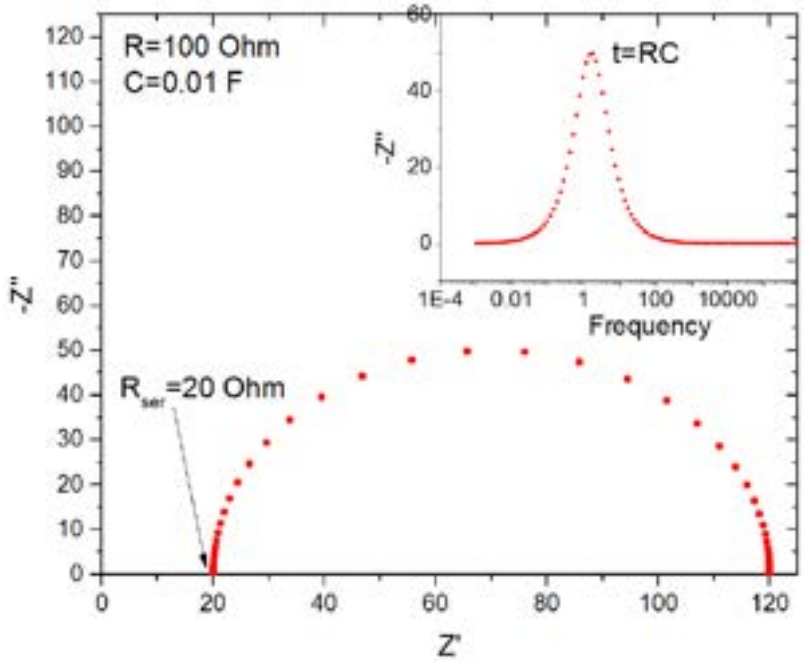
Impedance of a resistor-capacitor element (RC element)

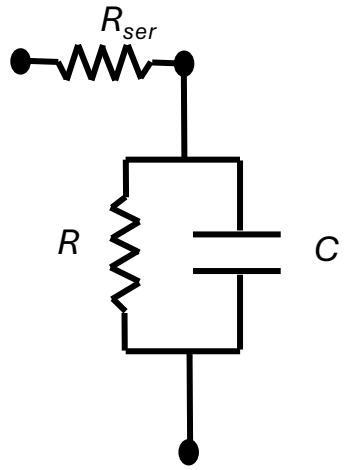


$$Z_{RC} = \left(\frac{1}{R} + j\omega C\right)^{-1}$$

$$\tau_c(\mathrm{s}) = R(\Omega)C(\mathrm{F})$$

$$Z(\omega) = \frac{V(\omega)}{J(\omega)} = \frac{\Delta V \sin(\omega t)}{\Delta J \sin(\omega t + \varphi)} \rightarrow |Z| \exp(i\varphi) = Z'(\omega) - iZ''(\omega)$$





$$Z_{RC} = R_{ser} + \left(\frac{1}{R} + i\omega C\right)^{-1}$$

Is it useful?

imec

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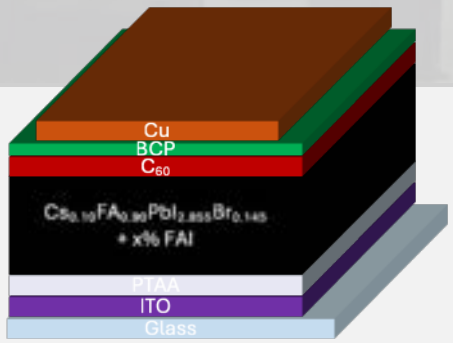
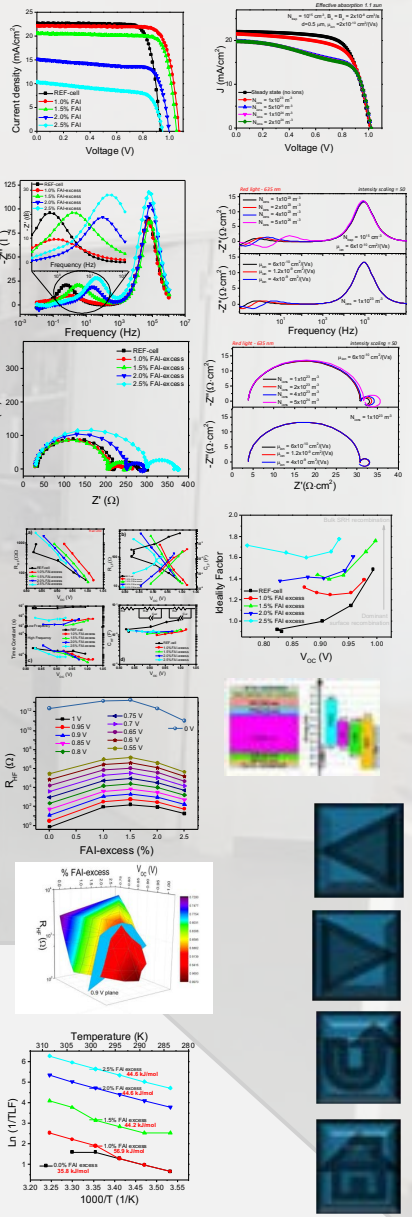
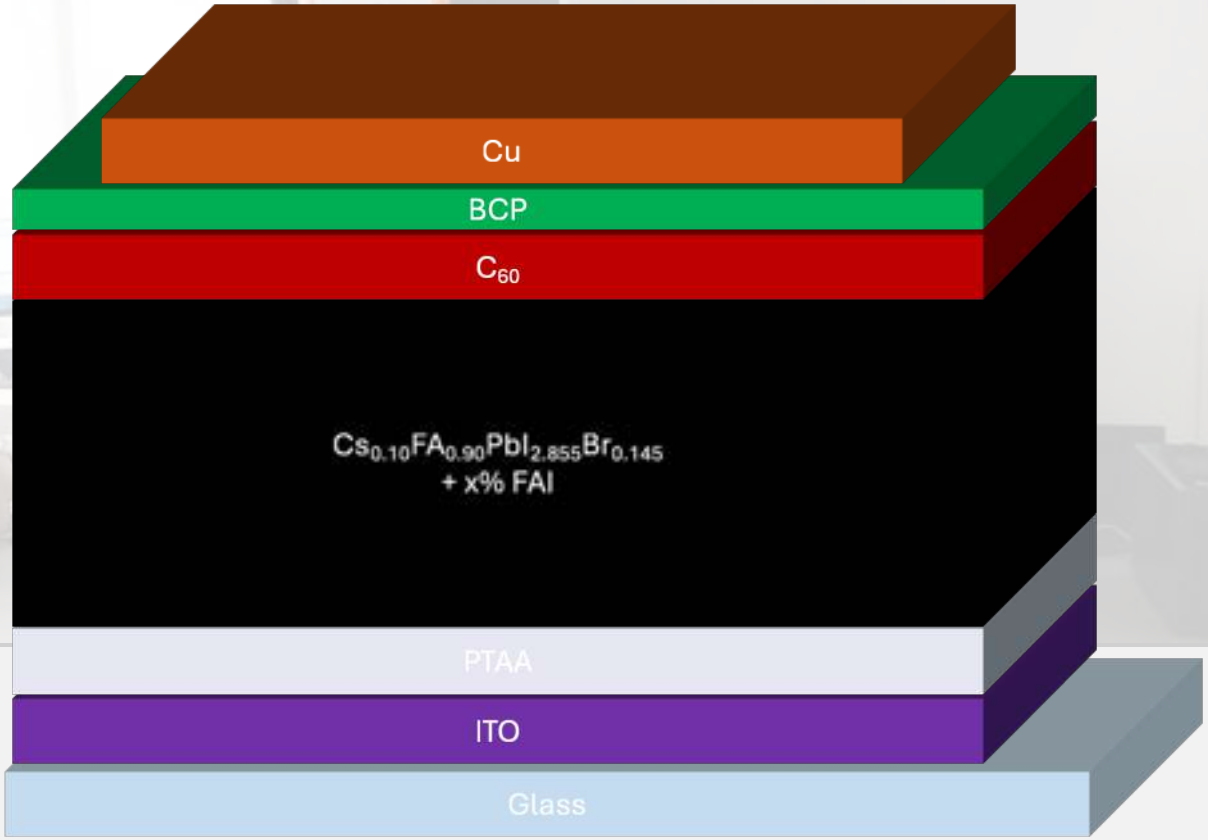
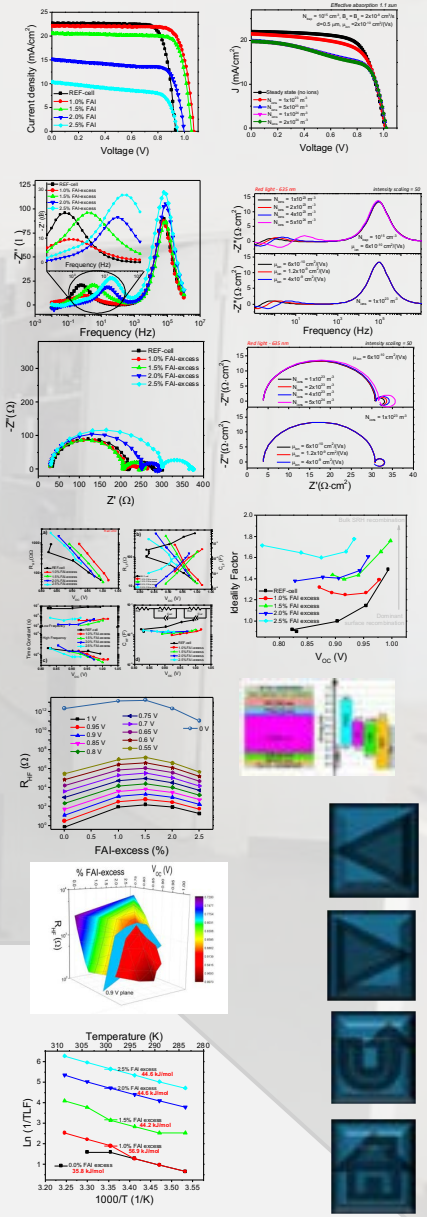




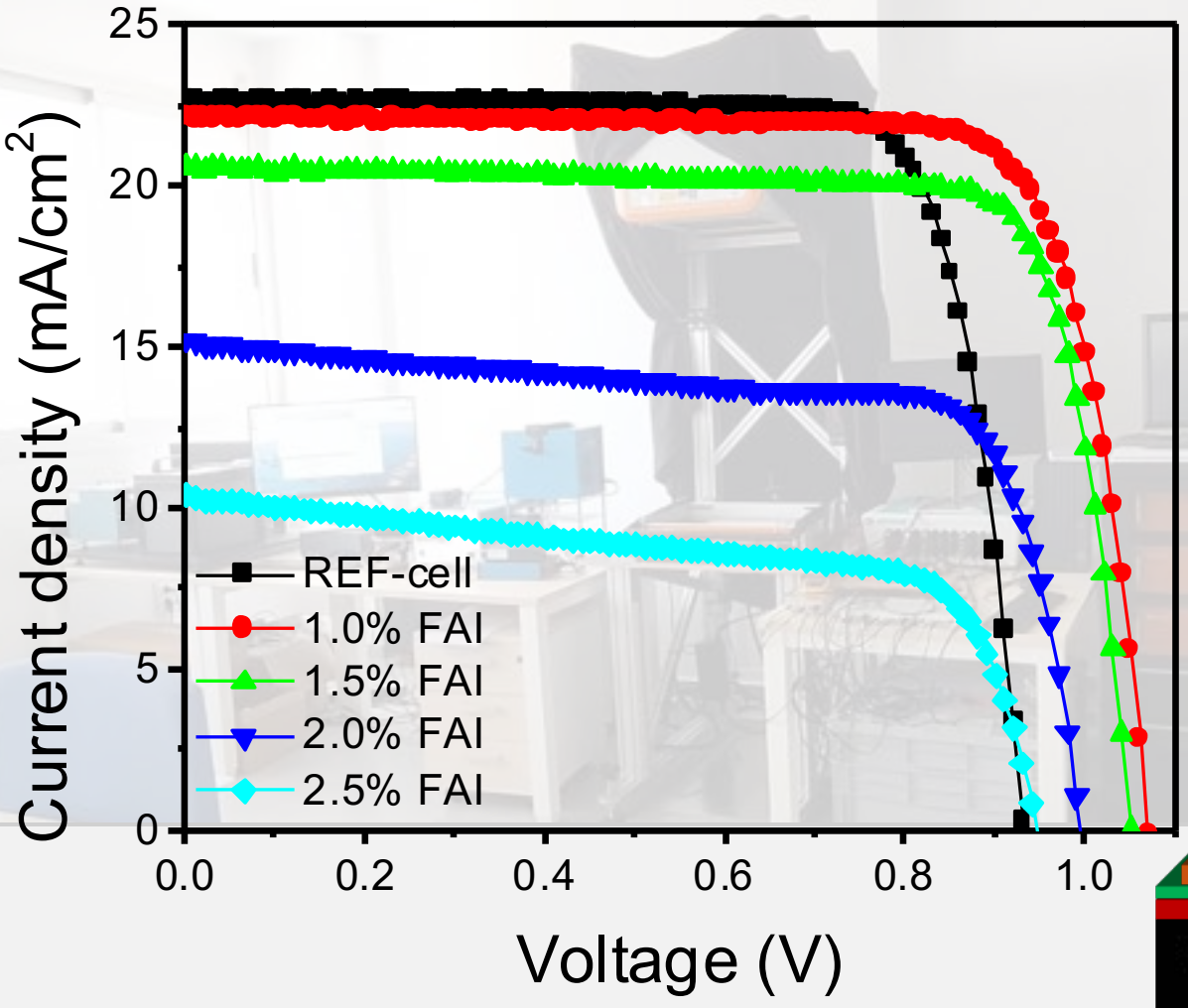
Is it useful?

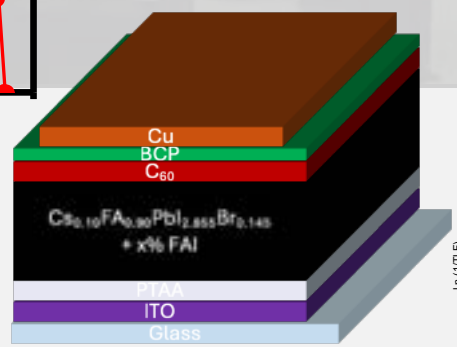
- 2C perovskite composition
  - $Cs_{0.10}FA_{0.90}PbI_{2.855}Br_{0.145}$
- X% = molar% compared to Pb

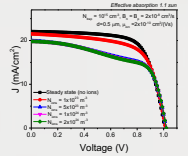


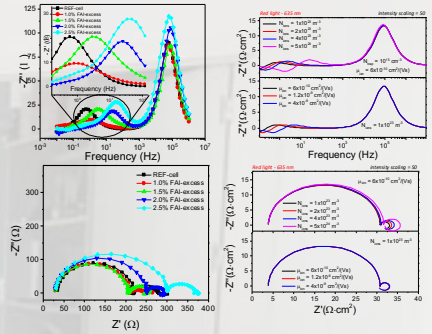


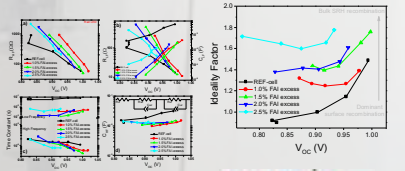
Results

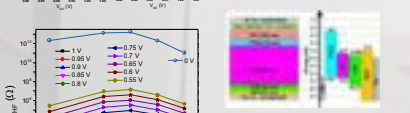

Current density (mA/cm^2)
Voltage (V)
REF-cell
1.0% FAI
1.5% FAI
2.0% FAI
2.5% FAI

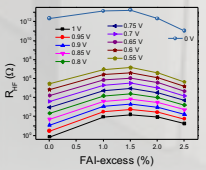

Cu
BCP
C_{60}
$Cs_{0.10}FA_{0.90}PbI_{2.855}Br_{0.145}$
+ x% FAI
PTAA
ITO
Glass

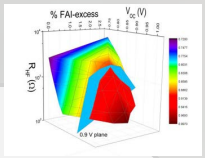

Voltage (V)

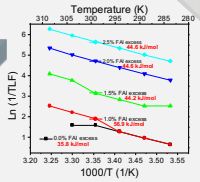

Frequency (Hz)
Z' (Ω)
Z'(Ω·cm^2)


Ideality Factor
V_{OC} (V)

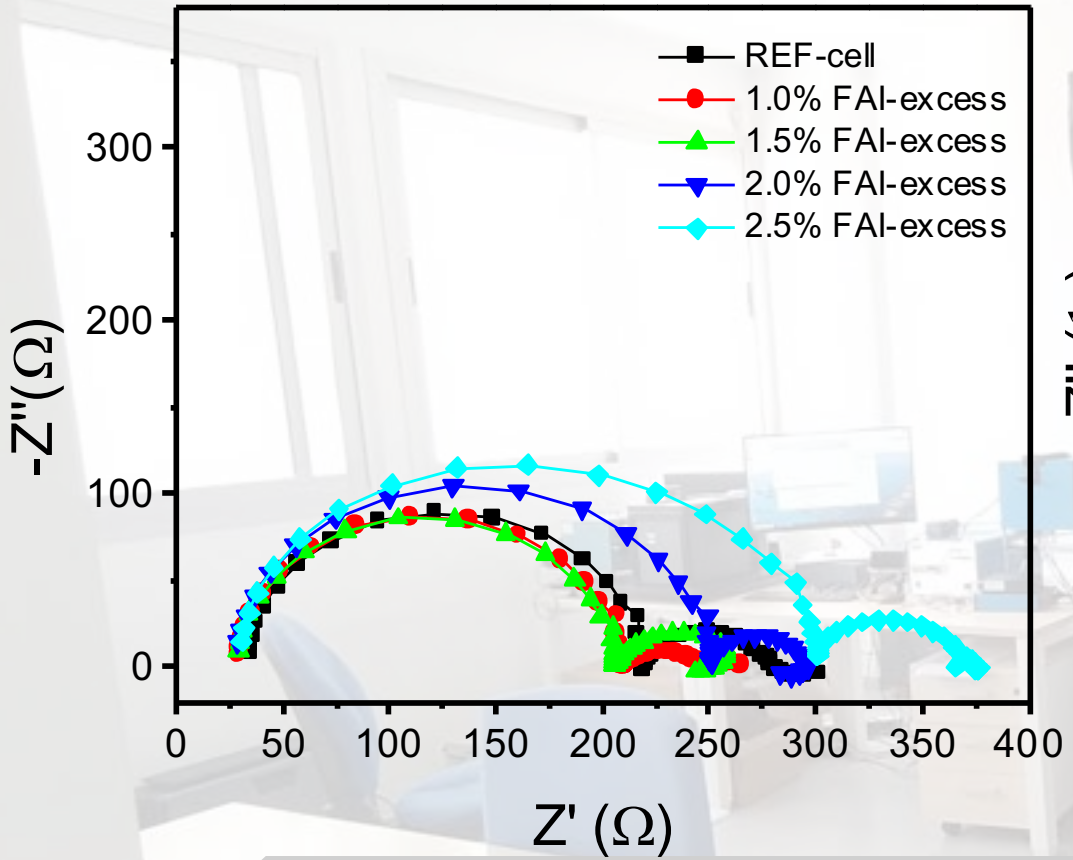


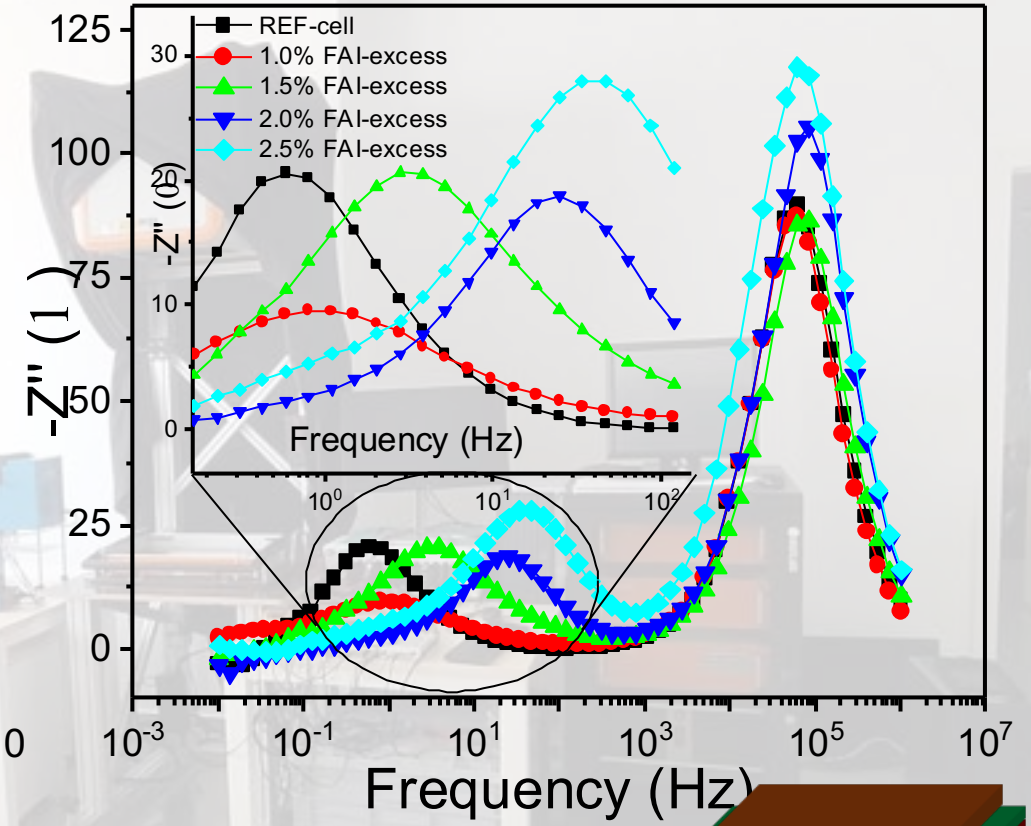

FAI-excess (%)

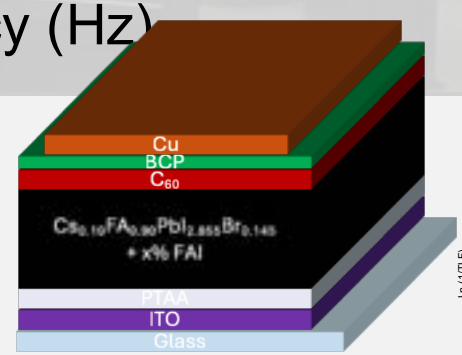

% FAI-excess
V_{OC} (V)

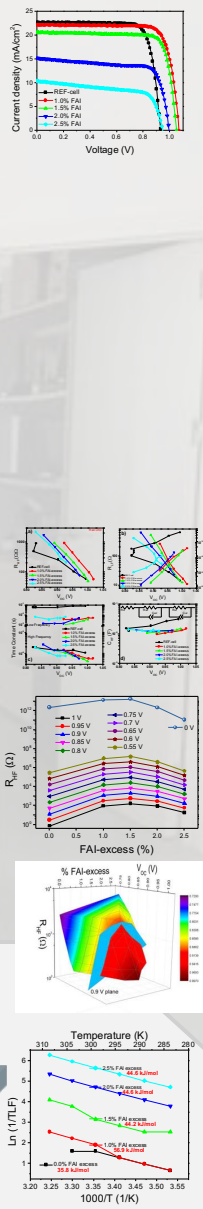

Temperature (K)
Ln (1/TLF)
1000/T (1/K)

Results

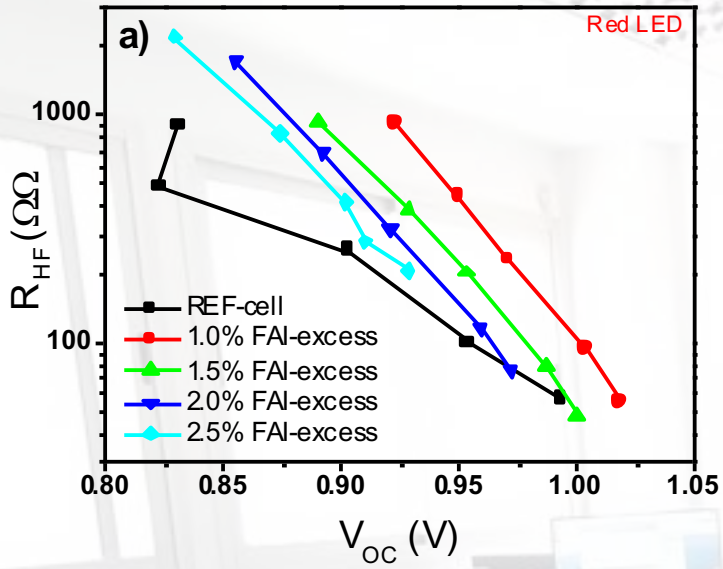

REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
-Z''(Ω)
Z' (Ω)
0
100
200
300
0
50
100
150
200
250
300
350
400

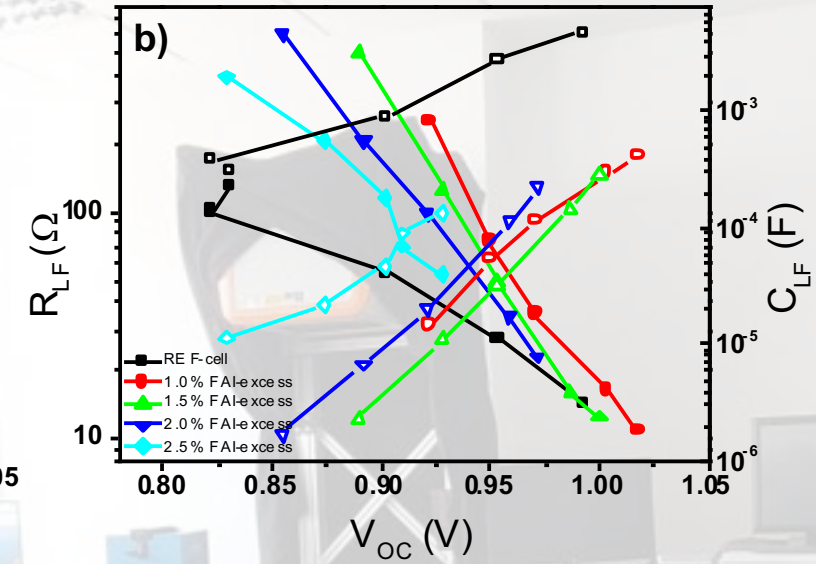

REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
-Z'' (Ω)
Frequency (Hz)
Frequency (Hz)
0
25
50
75
100
125
0
10
20
30
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{5}
10^{7}
10^{0}
10^{1}
10^{2}

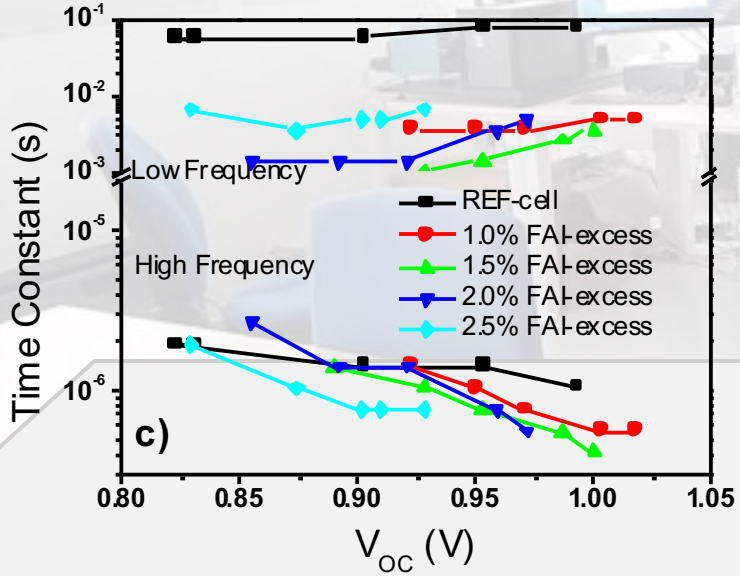

Cu
BCP
C_{60}
$Cs_{0.10}FA_{0.90}PbI_{2.855}Br_{0.145}$
+ x% FAI
PTAA
ITO
Glass

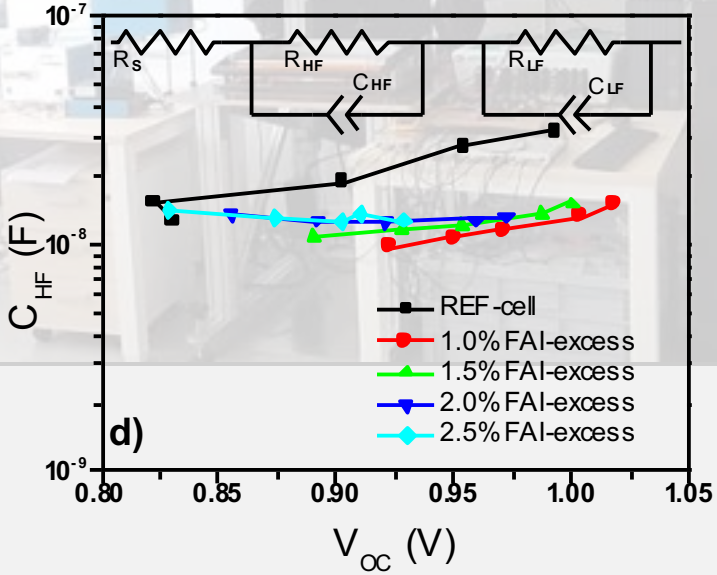


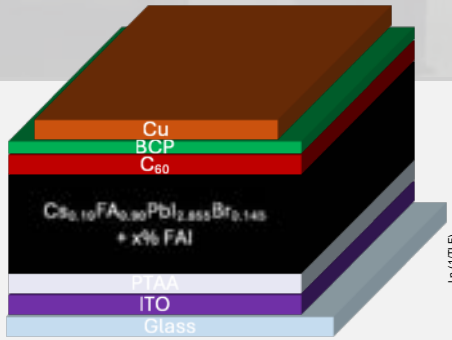
Results

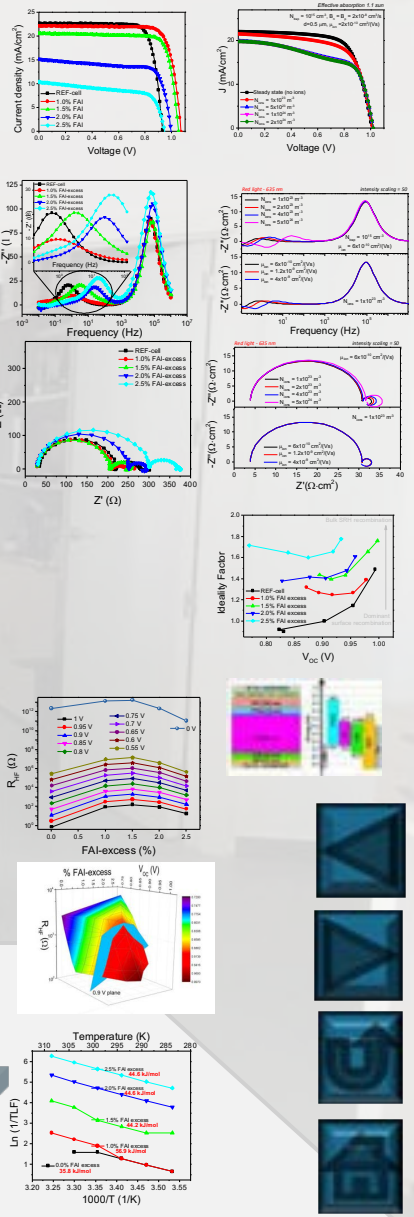

a)
Red LED
R_{HF} (ΩΩ
1000
100
REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
0.80 0.85 0.90 0.95 1.00 1.05
V_{OC} (V)


b)
R_{LF} (Ω
100
10
10^{-3}
10^{-4}
10^{-5}
10^{-6}
C_{LF} (F)
RE F-cell
1.0 % FAI-excess
1.5 % FAI-excess
2.0 % FAI-excess
2.5 % FAI-excess
0.80 0.85 0.90 0.95 1.00 1.05
V_{OC} (V)

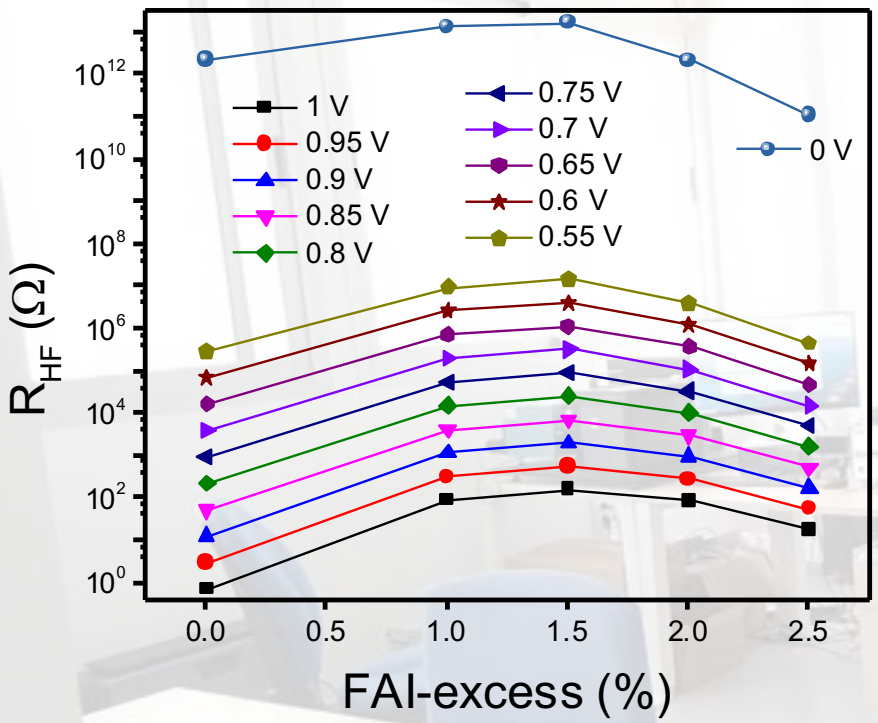

Time Constant (s)
10^{-1}
10^{-2}
10^{-3}
10^{-5}
10^{-6}
Low Frequency
High Frequency
REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
c)
0.80 0.85 0.90 0.95 1.00 1.05
V_{OC} (V)

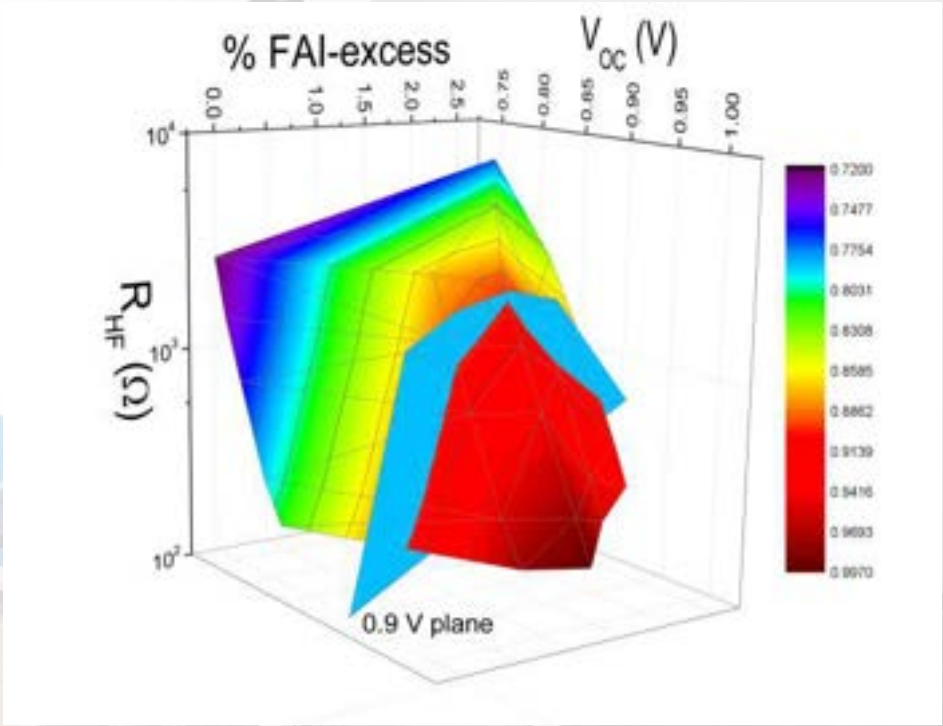

10^{-7}
10^{-8}
10^{-9}
C_{HF} (F)
R_S
R_{HF}
C_{HF}
R_{LF}
C_{LF}
REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
d)
0.80 0.85 0.90 0.95 1.00 1.05
V_{OC} (V)

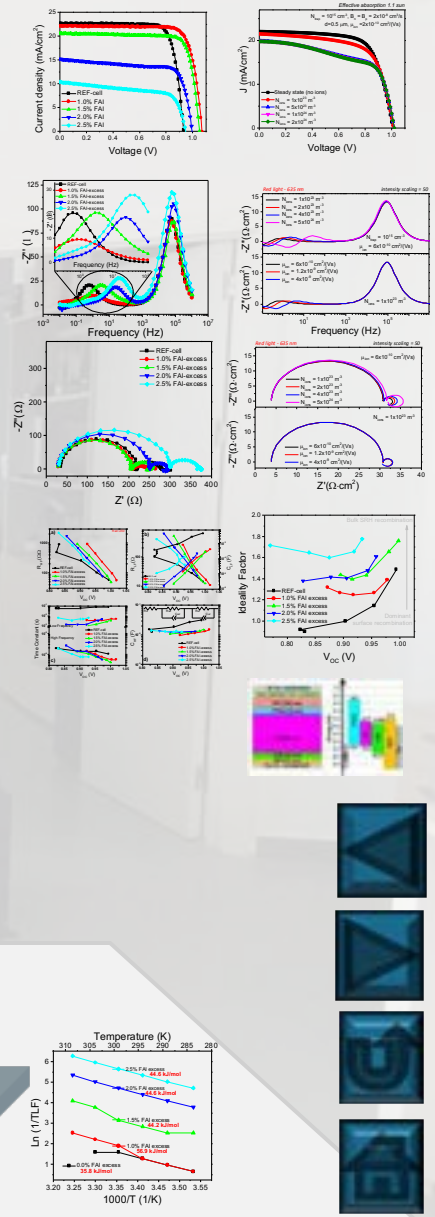

Cu
BCP
C_{60}
$Cs_{0.10}FA_{0.90}PbI_{2.855}Br_{0.145}$
+ x% FAI
PTAA
ITO
Glass

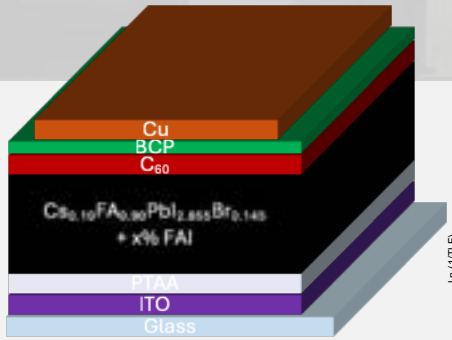


Results


R_{HF} (Ω)
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
1 V
0.95 V
0.9 V
0.85 V
0.8 V
0.75 V
0.7 V
0.65 V
0.6 V
0.55 V
0 V
0.0
0.5
1.0
1.5
2.0
2.5
FAI-excess (%)

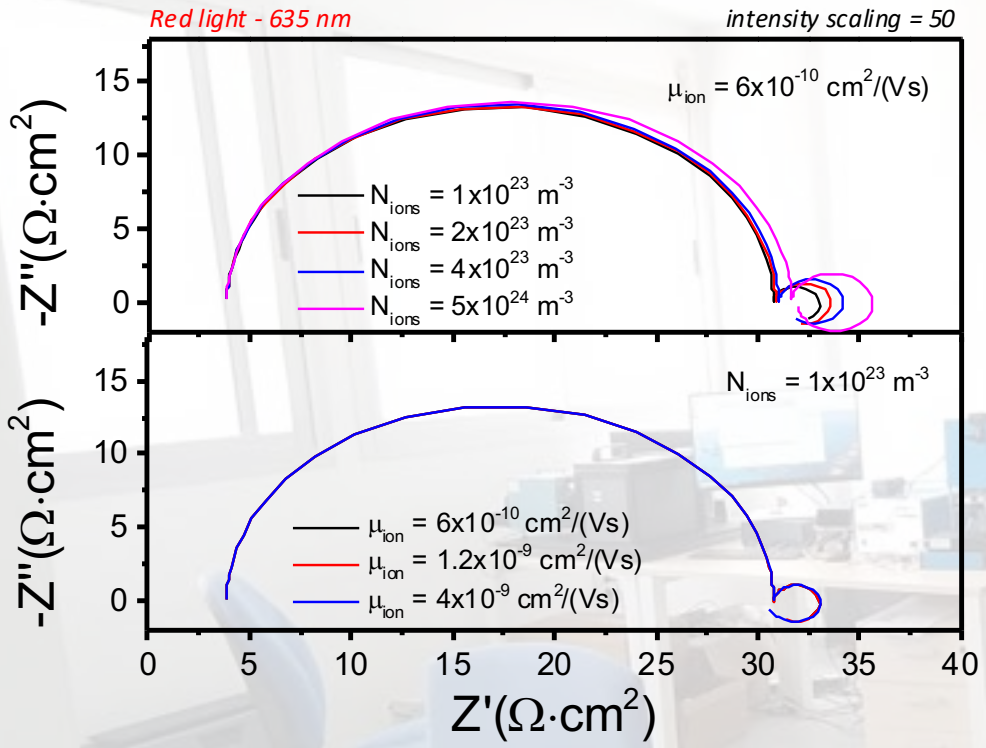

% FAI-excess
V_{OC} (V)
R_{HF} (Ω)
0.9 V plane

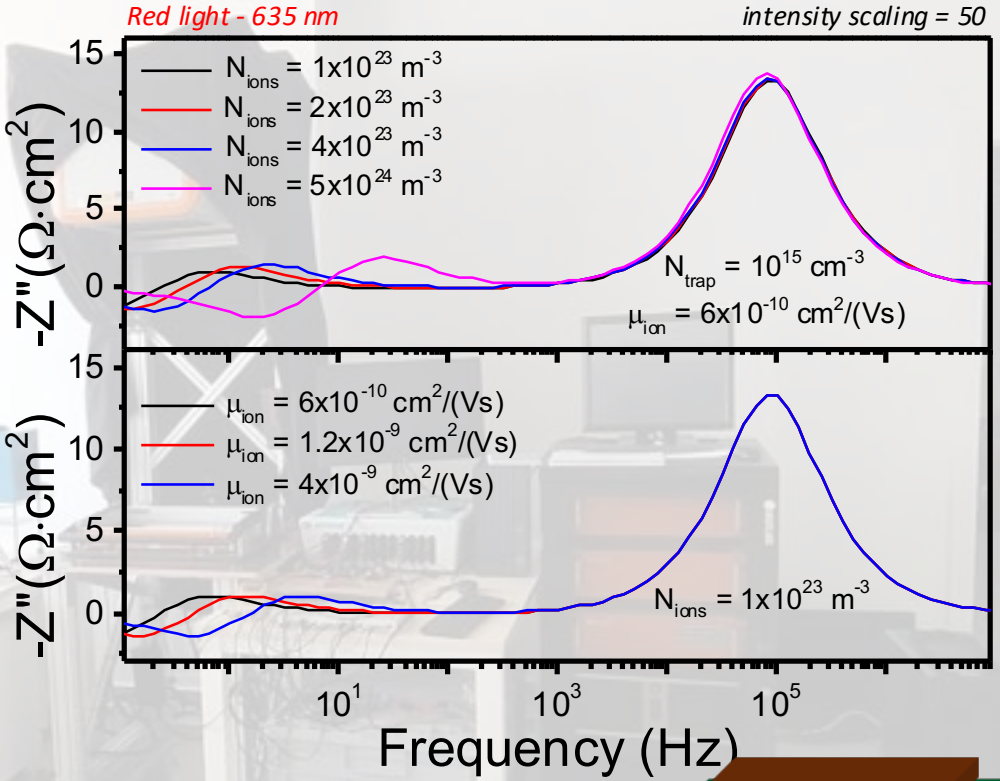


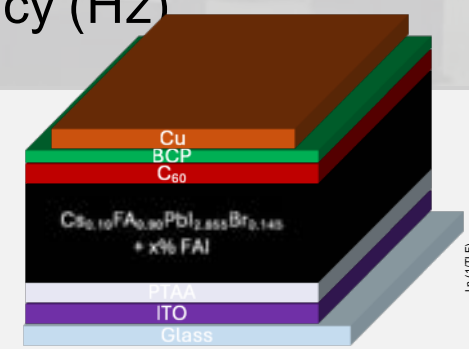

Cu
BCP
C_{60}
$Cs_{0.10}FA_{0.90}PbI_{2.855}Br_{0.145}$
+ x% FAI
PTAA
ITO
Glass

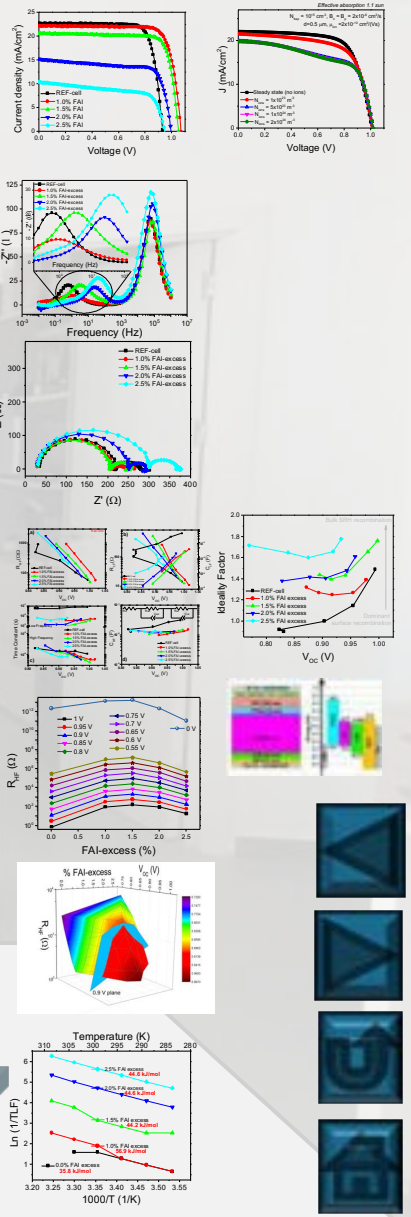
Temperature (K)
Ln (1/TLF)
1000/T (1/K)

Results

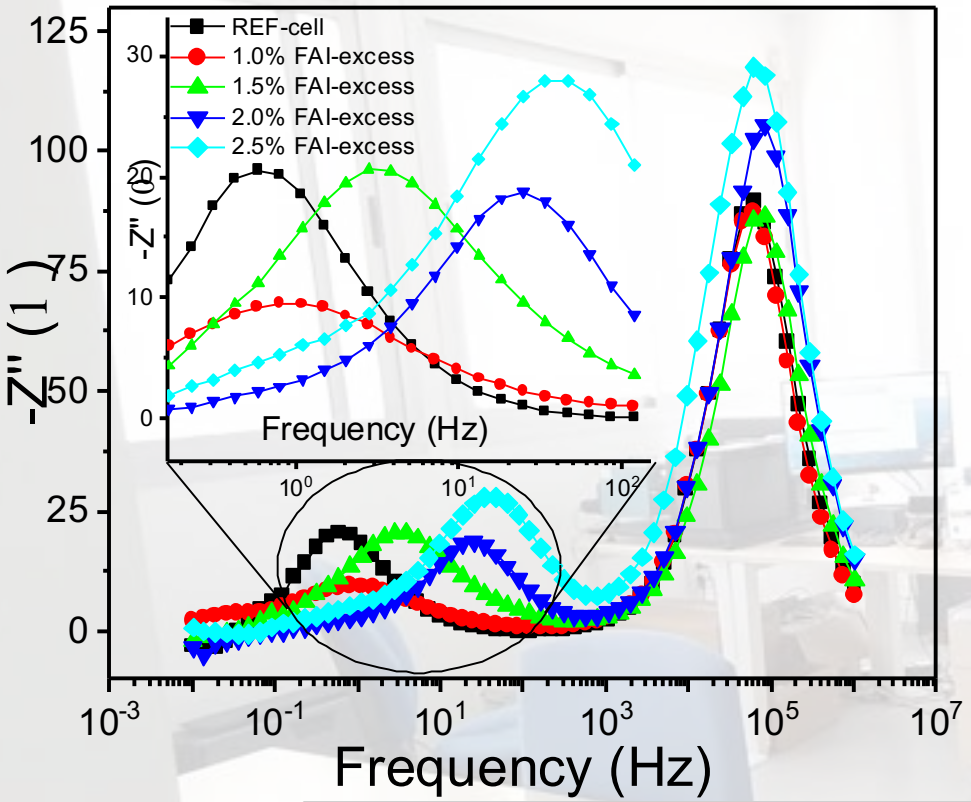

Red light - 635 nm
intensity scaling = 50
μion = 6x10-10 cm2/(Vs)
Nions = 1x1023 m-3
Nions = 2x1023 m-3
Nions = 4x1023 m-3
Nions = 5x1024 m-3
Nions = 1x1023 m-3
μion = 6x10-10 cm2/(Vs)
μion = 1.2x10-9 cm2/(Vs)
μion = 4x10-9 cm2/(Vs)
-Z''(Ω·cm2)
Z'(Ω·cm2)

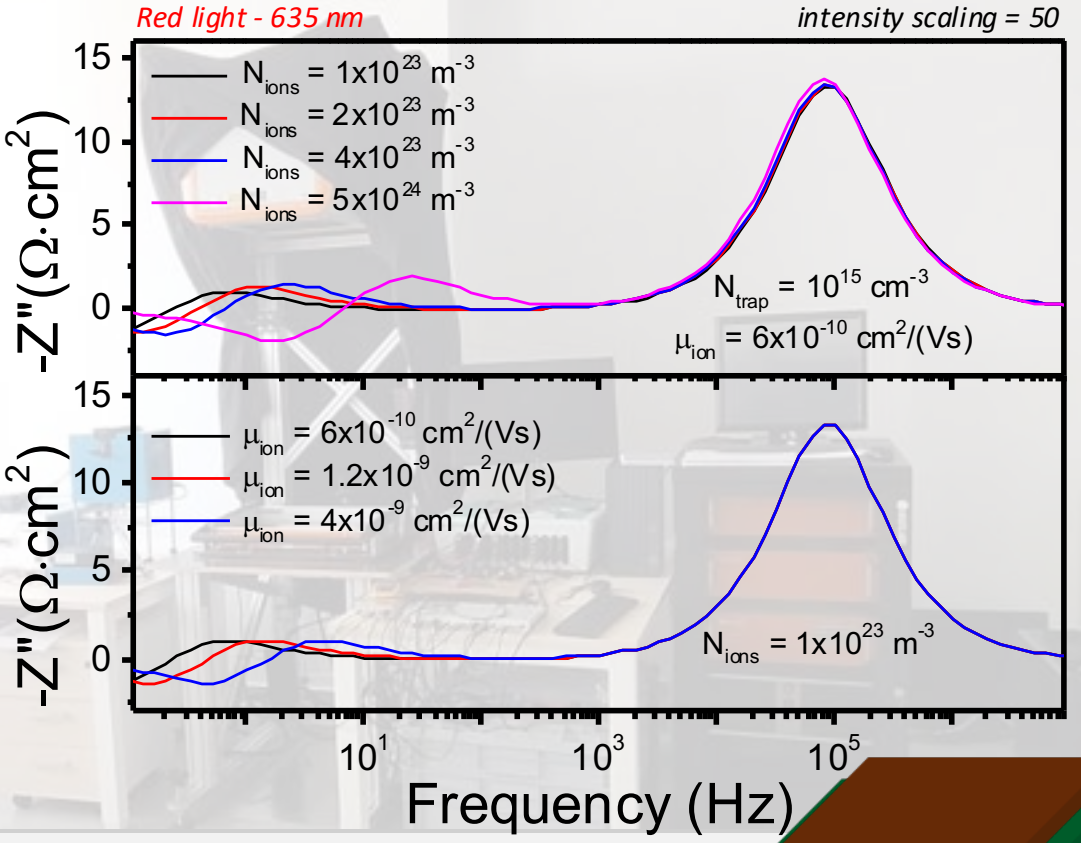

Red light - 635 nm
intensity scaling = 50
Nions = 1x1023 m-3
Nions = 2x1023 m-3
Nions = 4x1023 m-3
Nions = 5x1024 m-3
Ntrap = 1015 cm-3
μion = 6x10-10 cm2/(Vs)
μion = 6x10-10 cm2/(Vs)
μion = 1.2x10-9 cm2/(Vs)
μion = 4x10-9 cm2/(Vs)
Nions = 1x1023 m-3
-Z''(Ω·cm2)
Frequency (Hz)

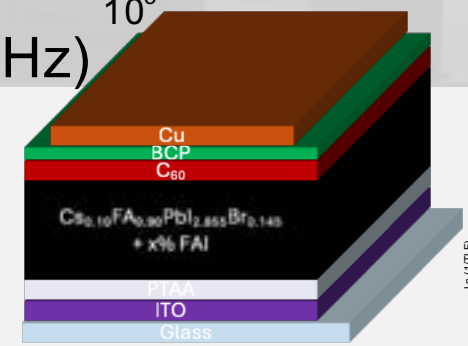

Cu
BCP
C60
Cs0.10FA0.90PbI2.855Br0.145
+ x% FAI
PTAA
ITO
Glass

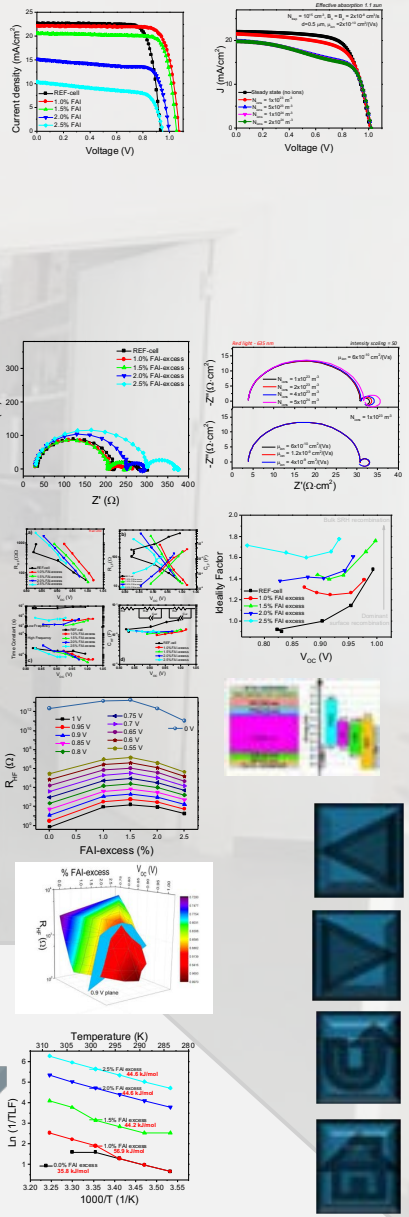

Voltage (V)
Frequency (Hz)
Z' (Ω)
FAI-excess (%)
Temperature (K)
1000/T (1/K)

Results

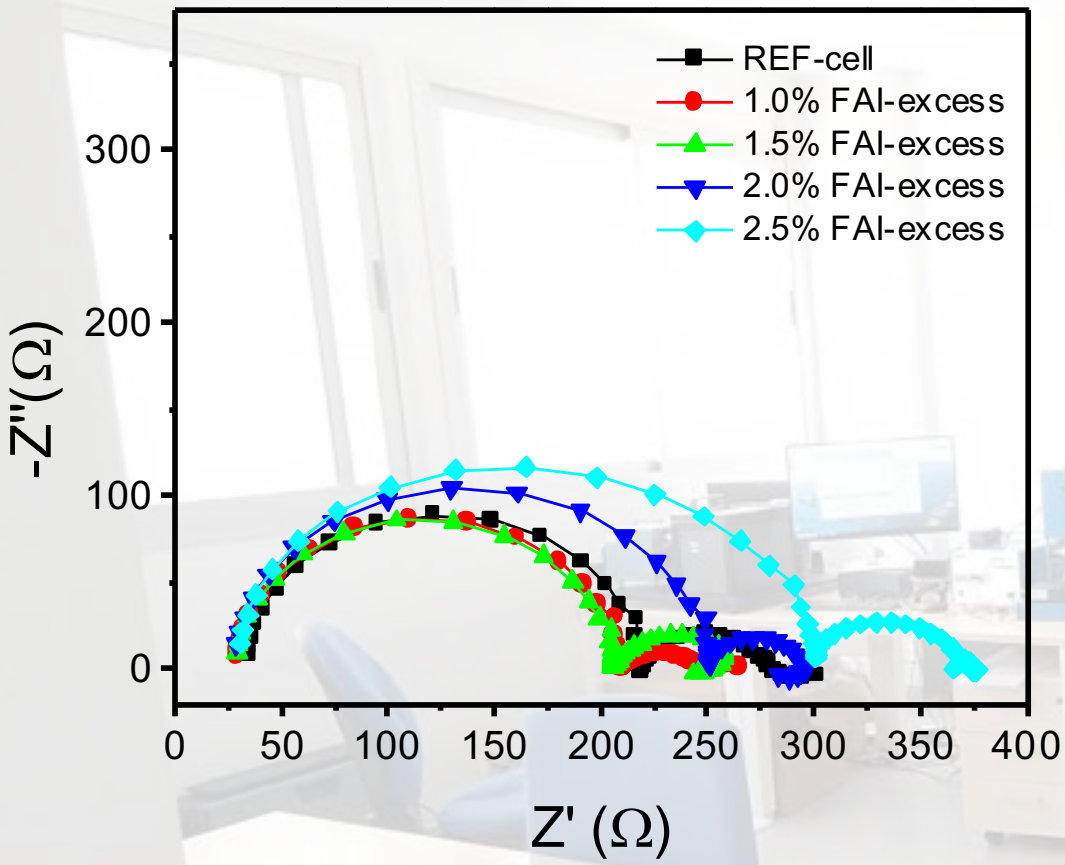

REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
-Z'' (Ω)
Frequency (Hz)
-Z'' (Ω)
Frequency (Hz)

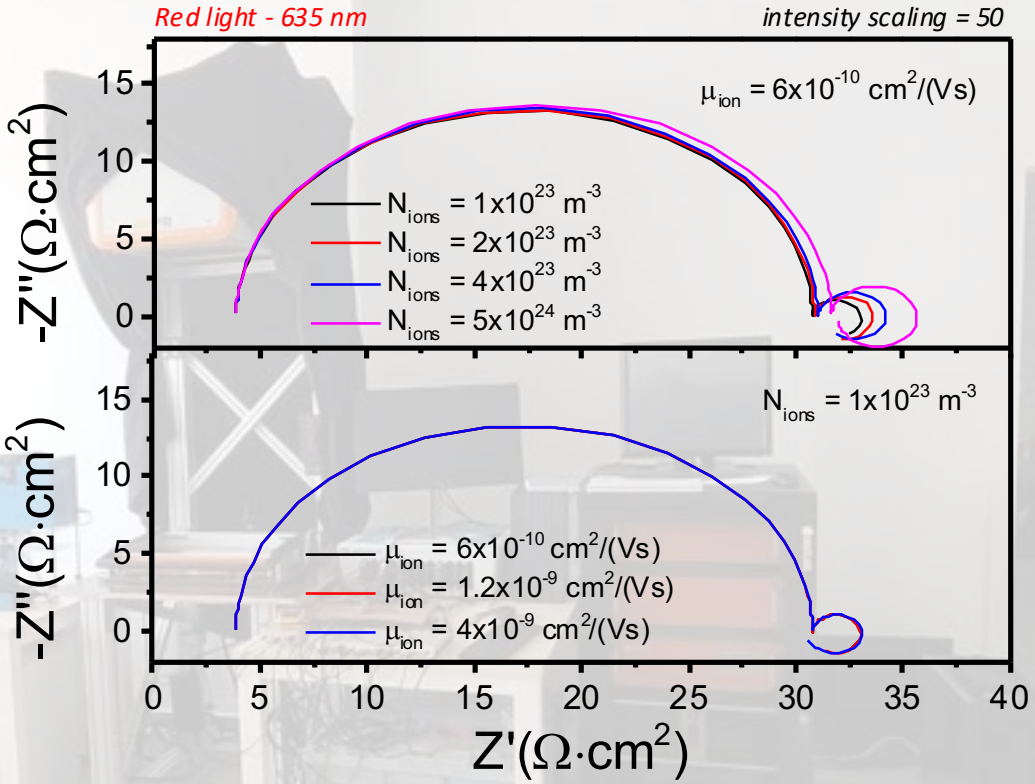

Red light - 635 nm
intensity scaling = 50
N_ions = 1x10^23 m^-3
N_ions = 2x10^23 m^-3
N_ions = 4x10^23 m^-3
N_ions = 5x10^24 m^-3
N_trap = 10^15 cm^-3
μ_ion = 6x10^-10 cm^2/(Vs)
-Z''(Ω·cm^2)
μ_ion = 6x10^-10 cm^2/(Vs)
μ_ion = 1.2x10^-9 cm^2/(Vs)
μ_ion = 4x10^-9 cm^2/(Vs)
N_ions = 1x10^23 m^-3
-Z''(Ω·cm^2)
Frequency (Hz)

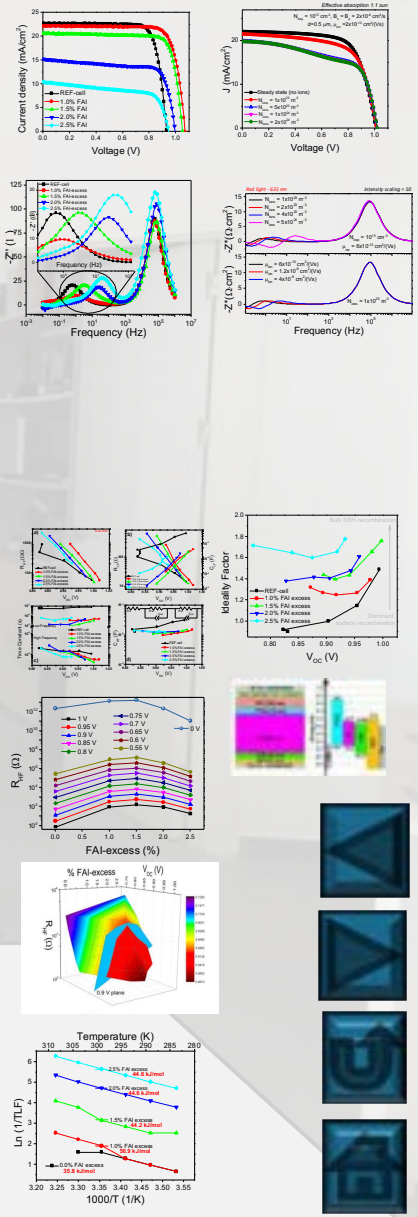

Cu
BCP
C60
Cs0.10FA0.90PbI2.855Br0.145
+ x% FAI
PTAA
ITO
Glass



Results


REF-cell
1.0% FAI-excess
1.5% FAI-excess
2.0% FAI-excess
2.5% FAI-excess
-Z''(Ω)
Z' (Ω)
0
100
200
300
0
50
100
150
200
250
300
350
400


Red light - 635 nm
intensity scaling = 50
μion = 6x10-10 cm2/(Vs)
Nions = 1x1023 m-3
Nions = 2x1023 m-3
Nions = 4x1023 m-3
Nions = 5x1024 m-3
Nions = 1x1023 m-3
μion = 6x10-10 cm2/(Vs)
μion = 1.2x10-9 cm2/(Vs)
μion = 4x10-9 cm2/(Vs)
-Z''(Ω·cm2)
Z'(Ω·cm2)



Dr. Juan Anta
Dr. Paul Pistor
Dr. Gerko Oskam
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Dr. Renán Escalante Quijano
M. Beatriz Heredia Cervera
M. Patricia Sánchez Fernández
M. Juan Carlos Expósito Gálvez
M. Mahmoud Nabil Mahmoud
M. Pablo Romero

Thank you for your attention

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AI-based process monitoring for achieving zero-defect manufacturing in the PV industry (Platform ZERO)

Victor Izquierdo-Roca

Platform-ZERO

ACHIEVING ZERO DEFECT MANUFACTURING FOR THE PHOTOVOLTAIC INDUSTRY

Monday 9th September 2024

Special session:

From Laboratory to Industry

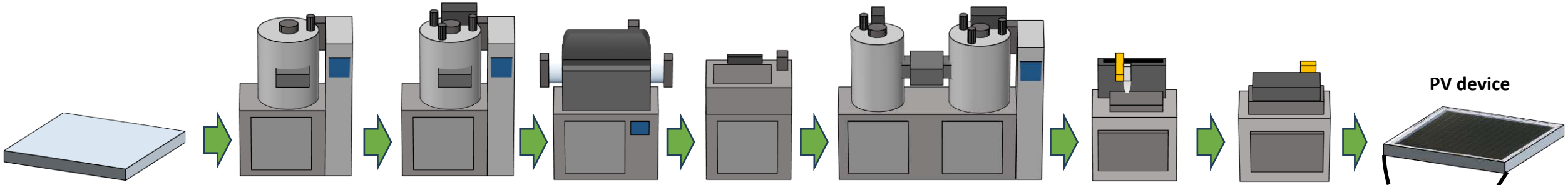
Revolutionizing Photovoltaics with New Advanced Monitoring Approaches

NEXT GEN
International School and Workshop

Co-funded by the European Union

EXEMPLE KESTERIE CASE

Motivation: Complex fabrication of TF-PV devices



Glass Substrate

Sputtering: Metallic Back contact

Sputtering: Absorber precursor

Annealing: Light Absorber synthesis

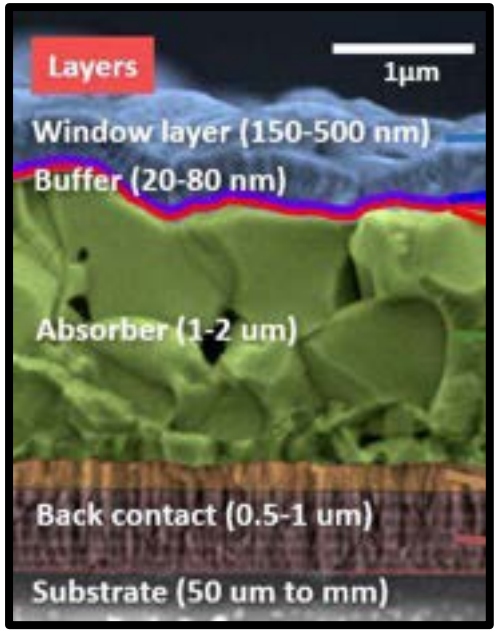
CBD: Carriers separation stack

Sputtering: Front Transparent contact stack

Annealing: System stabilization

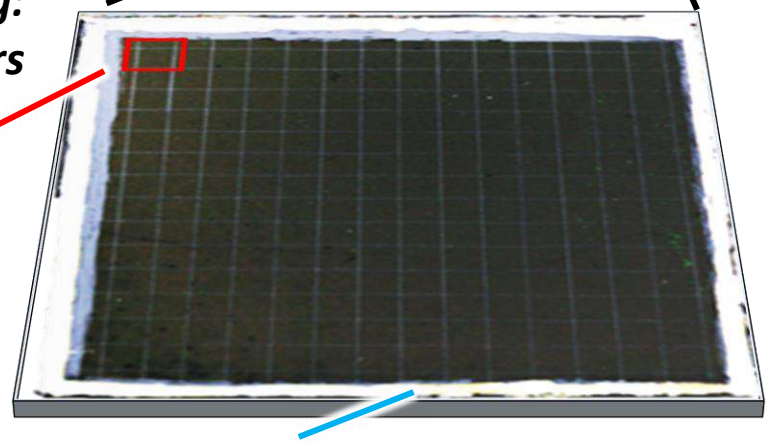
Scribing: Devices discretization

PV device



Complex device (6 layers) with strong interaction between them

Complex fabrication process involving:
7 processes with >100 controllable parameters



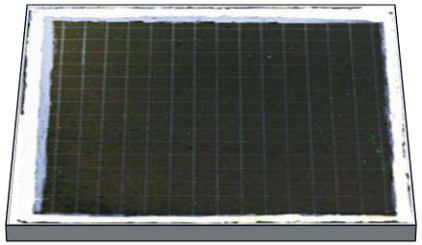
5x5 cm^2 sample
#196 3x3mm^2 Test-cell

Back Contact terminal

EXEMPLE KESTERIE CASE

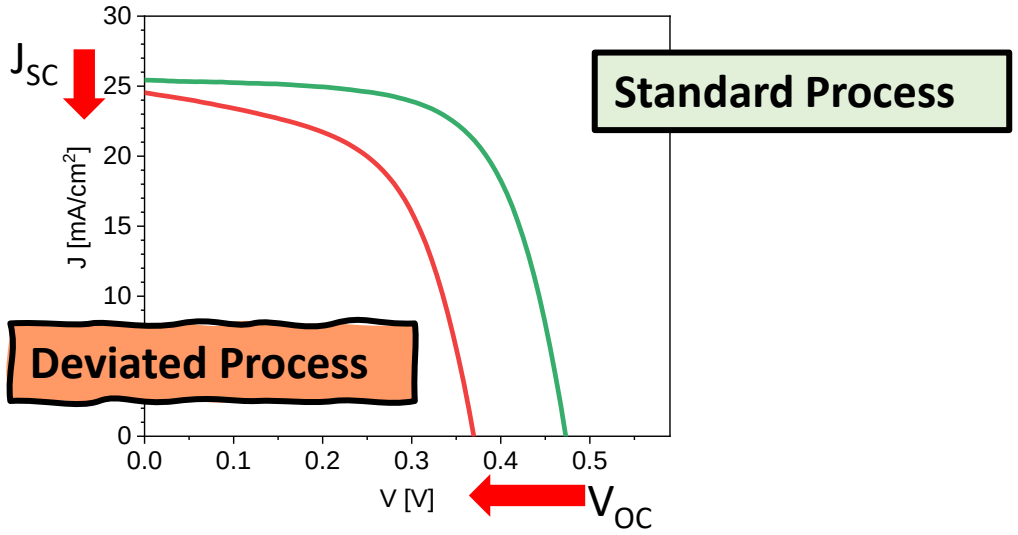
Motivation: Complex fabrication of TF-PV devices

The performance of PV devices is defined as…

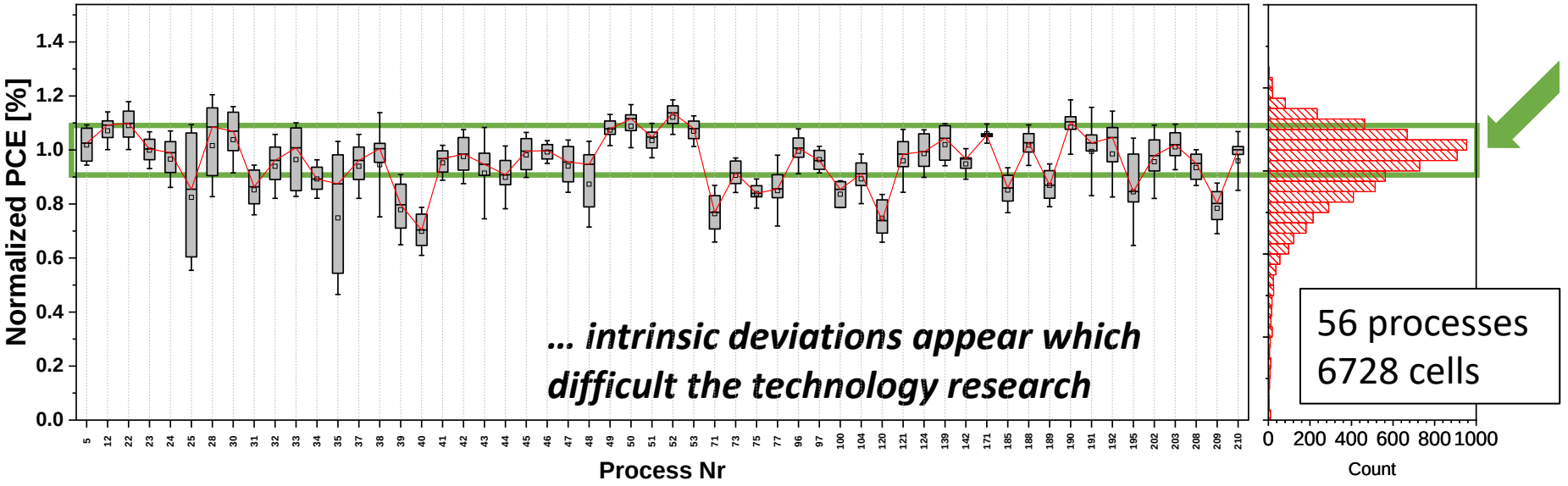


$$PCE = \frac{Photogenerated\ power}{Irradiated\ power}$$

$$PCE = \frac{J_{sc} \cdot Voc \cdot FF}{Light\ irradiation}$$



When reproducing the fabrication process…..



… intrinsic deviations appear which difficult the technology research

PCE dispersion 10%
➔ ≈ 50% population

56 processes
6728 cells

QUESTION:

Which is the origin of the fluctuations?
Can we do something?

EXEMPLE KESTERIE CASE

Motivation: Complex fabrication of TF-PV devices

Descriptors (data signal)

Characterization techniques → Data acquisition Automatization

Structured database

Data conditioning → Data fusion → Database splitting

Labels (Target)

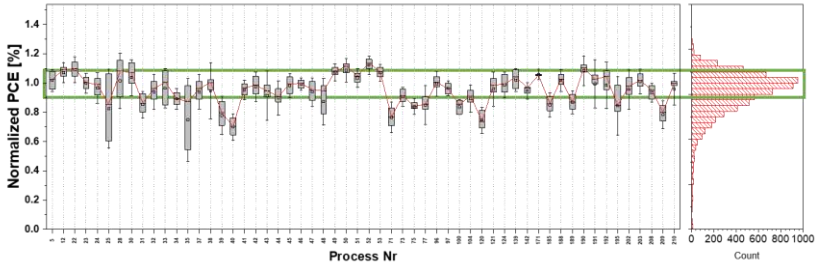
Relevant device parameters → Creation of classification criterion

ML Training data 70%

ML Model Testing data 30%

Which is the technological limitation?

Enric Grau-Luque, et al
Accelerating the Development of Thin Film Photovoltaic Technologies: An Artificial Intelligence Assisted Methodology Using Spectroscopic and Optoelectronic Techniques, Small Methods (2024) 2301573/17.



AI semi-supervised classification algorithm

PCA Algorithm
Unsupervised dimension reduction

≈10000D → 20D

LDA Algorithm
Supervised dimension reduction

20D → 2D

PV Technology limitation

Technology Optimization strategies

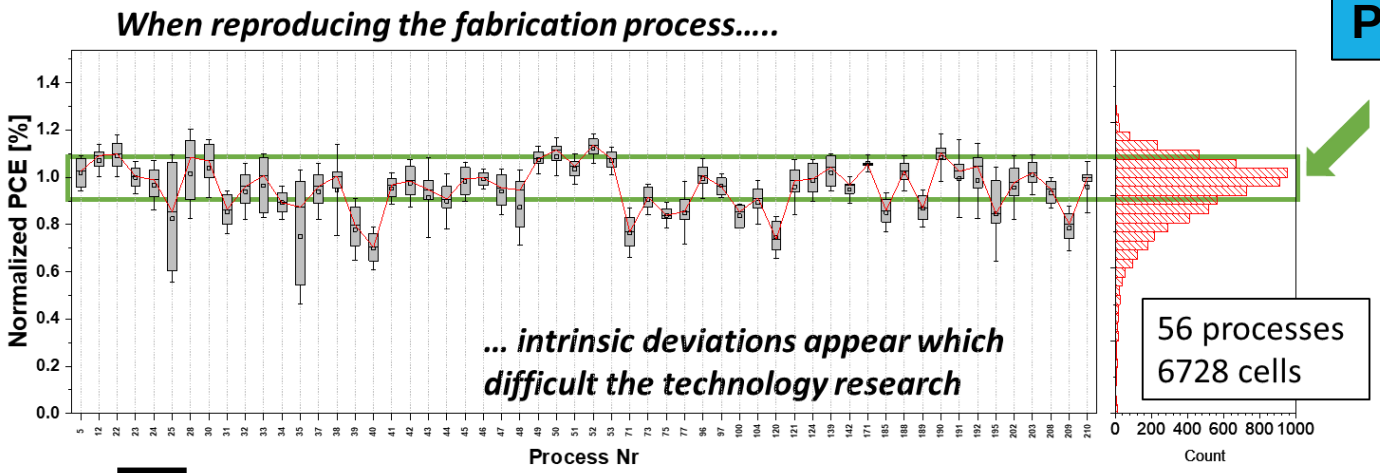
Research and knowledge generation

descriptors validation → Identification of significant features → research in relevant properties / process steps

EXEMPLE KESTERIE CASE

Motivation: Complex fabrication of TF-PV devices

PROBLEM



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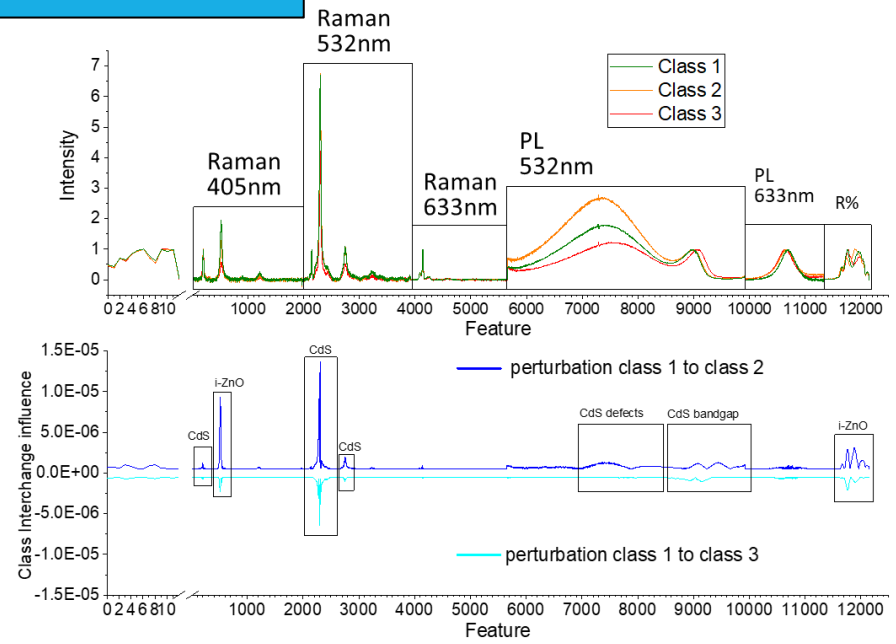
RESEARCH



CONCLUSION

Deviation managed by lack of control over the TCO and CdS deposition.

Use it to find more details

Motivation: High tech materials Industry

Batteries, PV, electrodes, optoelectronics, smart/functionalization coatings, plastics, etc…

Complex products: multi-process manufacturing, multi layers, with complex compounds materials with low tolerance to deviations

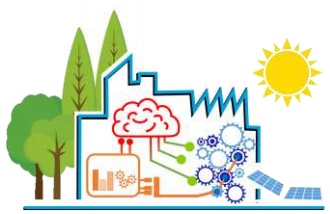
Productions involves
- Highly complex technology equipment
- High value materials

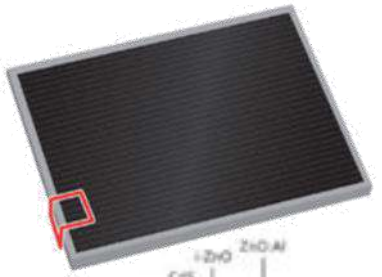
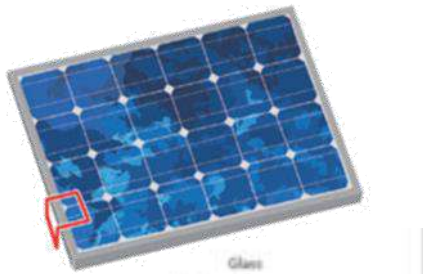
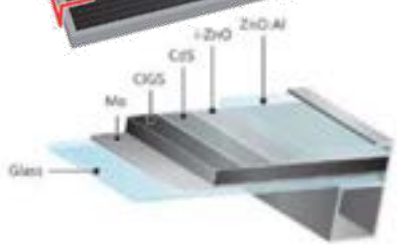
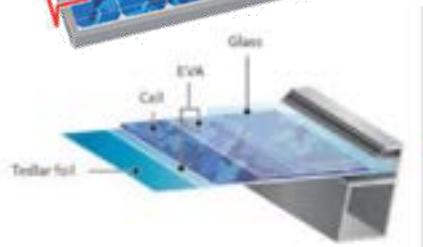
PV production can be highly automated and is Industry 4.0 ready.

Product competitiveness requires
- High yield and quality production

This pushes the industry to high levels of automation compatible with Industry 4.0

PV industry



	Thin films (I.e. CIGS)	Crystalline Silicon
Module technology		
Multi-nano layers device structure		
Main properties	High integrability	High performance
Market size	BIPV (16.6 B$)	Solar farms (61.4 B$)

Motivation: High tech materials Industry

Issues

Production efficiency	**Product quality**	**Identification of process deviations origin**	**R&D actions for product and process development and optimization**

Challenges

Move to *first-time-right* production model	**Minimize production deviations & improve production parameters**	**Advanced production control beyond standard process parameters monitoring**	**Fast development without impact on production**

Solve these issues

Environmental: reduction of production waste and reduction of high value materials use and energy consumption.
Economic: increase the production eff (cost reduction) and improve the materials/devices quality.

How

Process monitoring and control helps surpass these challenges

Motivation: Transference From Laboratory to Industry

Descriptors (data signal)

Characterization techniques

Full characterization by automatized In-Line Sensors

Structured database

Data conditioning

Data fusi

Structuration of Big-Data data information

Labels (T

Rele… paran… …on of …classification criterion

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…Luque, et al

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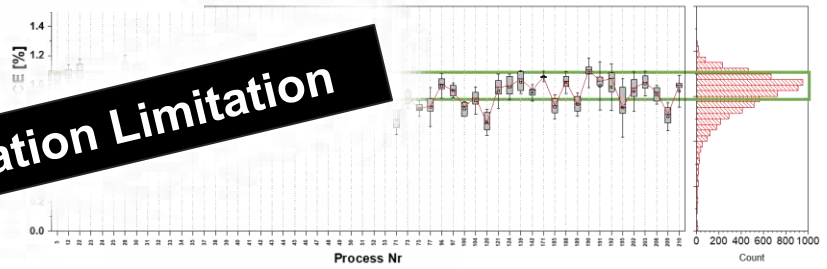
PV Technology

PV Fabrication Limitation



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PCA Algorithm
Unsupervised …duction

≈10000D

Automatized data analysis

20D

LDA Algorithm
Supervised dimension reduction

2D

Technology Optimization strategies

Research and knowledge …ration

research in relevant prope… / process ste…

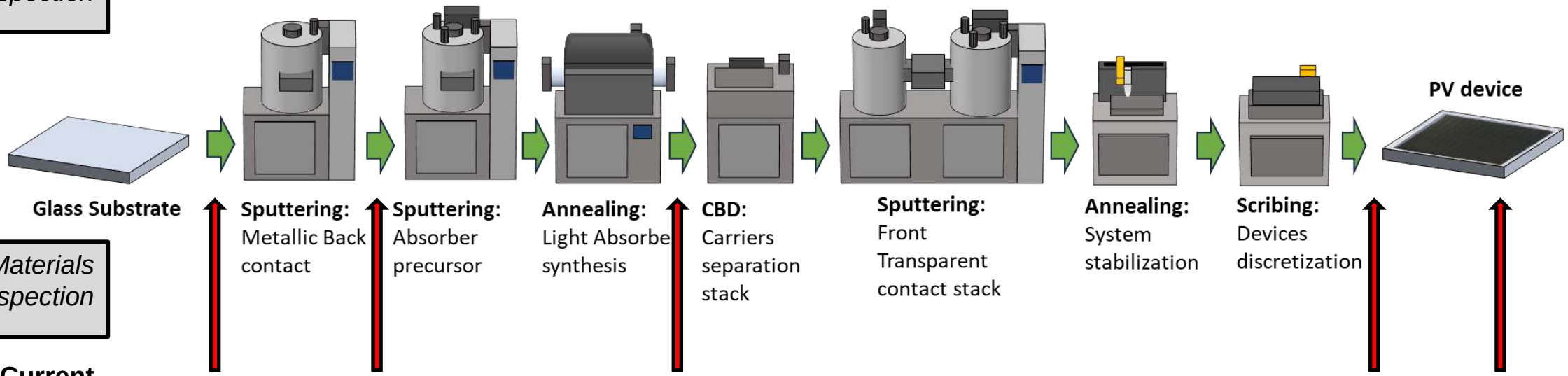
Identification, prediction and reaction

descriptors validation

Project concept

Process inspection

Fabrication parameters: pressure, temperature, process times, concentration, atmosferes, etc…



Materials inspection

Current implemented In-line

Vision inspection

Composition

Composition reflectance

Vision inspection

Device performance

No complete inspection of the fabricated materials.

Current implemented at-line

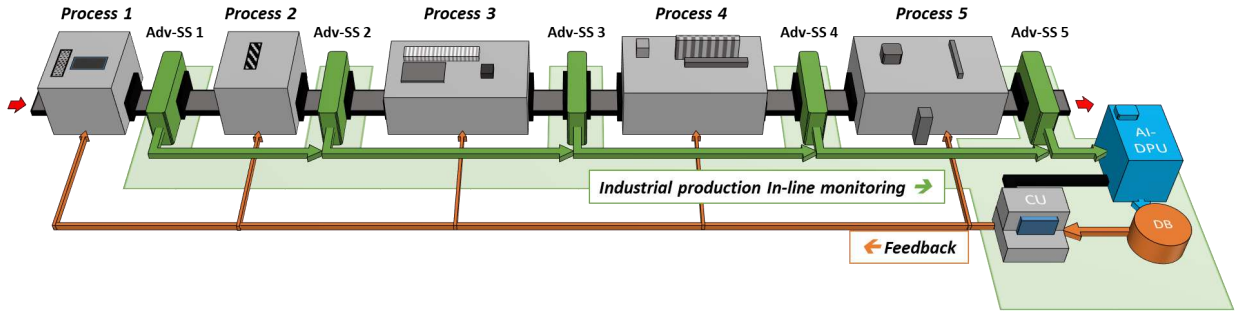
Laboratory characterization: detailed materials morphology and performance characterization

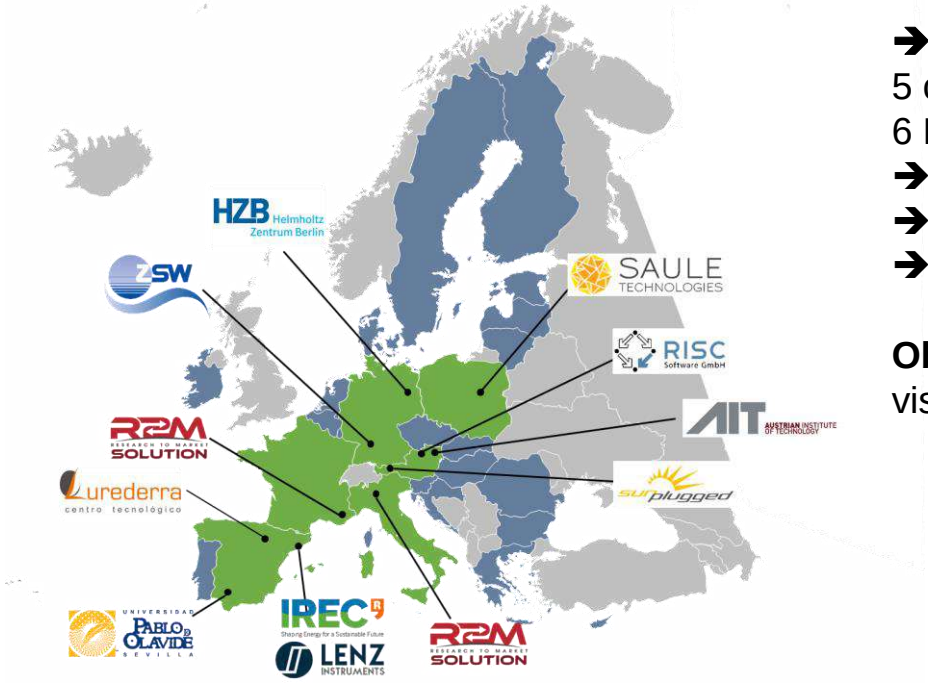
Significant delays lead to slow feedback to the production line.

Project concept

2023 start a HE project focused on developing this platform

Customizable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in the PV industry (Platform-ZERO)





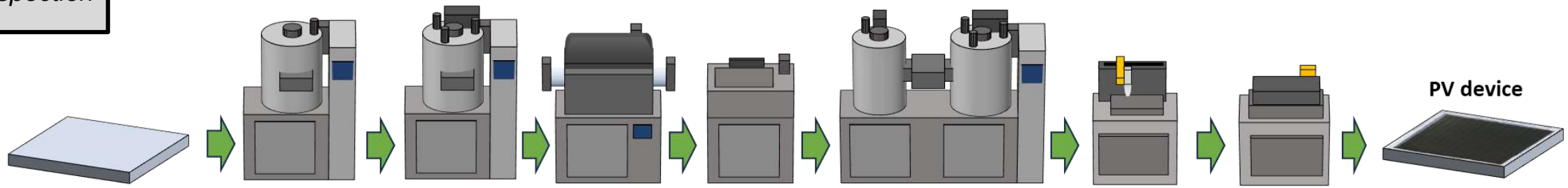
➔ **Consortium:** 11 partners (6 counties)
5 companies (metrology, Inovation and PV industry)
6 Research centers
➔ **Budget:** 10M€ budget
➔ **Duration:** 4 years 1st January 2023 – 31st December 2027
➔ **Validations (TRL 7):** 4 demosites in industrial environment

Objective: develop and validate in real conditions a customizable spectroscopic and vision based process monitoring platform for PV industry

Project concept

Process inspection

Fabrication parameters: pressure, temperature, process times, concentration, atmosferes, etc…



Materials inspection

In-line

Adaptation and Integration of laboratory at-line inspection in-line
(spectroscopic, imaging, optoelectronic characterization)

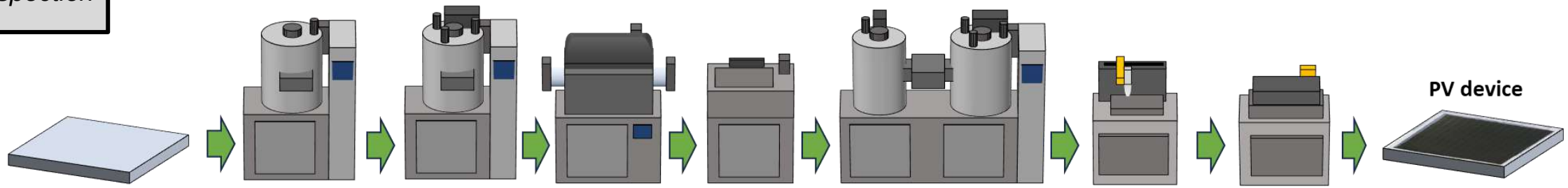
Current implemented at-line

Laboratory characterization: detailed materials morphology and performance inspection

Project concept

Process inspection

Fabrication parameters: pressure, temperature, process times, concentration, atmosferes, etc…



Materials inspection

In-line

Adaptation and Integration of laboratory at-line inspection in-line (spectroscopic, imaging, optoelectronic characterization)

Automatization of sensors operation and manufacturing the ADV-SS

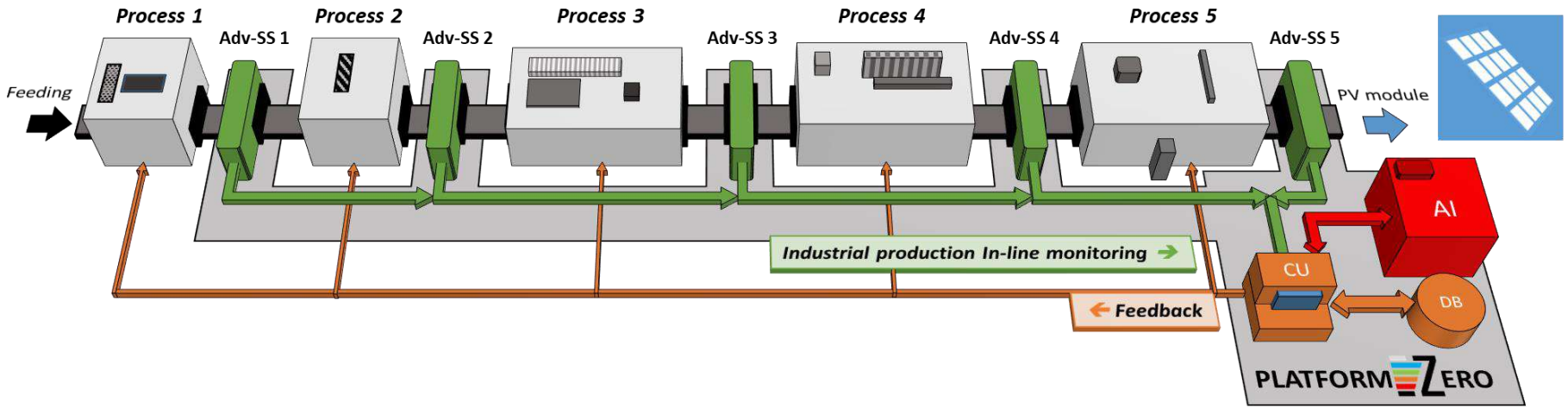
Manage and storage the data, and system control

Data processing a prediction ➔ interaction with the production

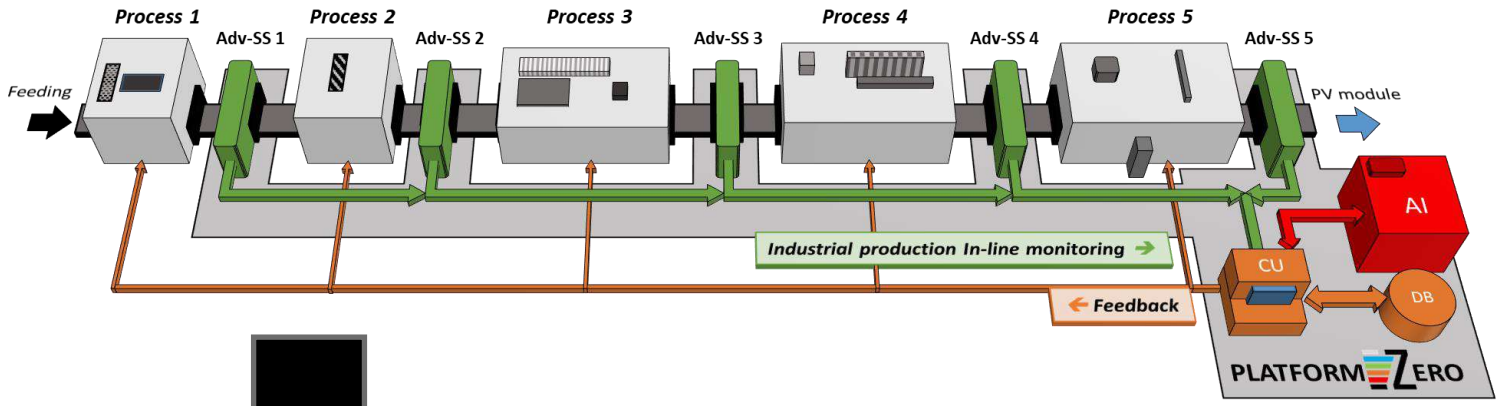
Project concept

Sensor Stations

Platform-ZERO will develop advanced sensor stations compatible with customizable sensor arrays for morphological, physicochemical and/or optoelectronic in-line inspection of PV industrial production.



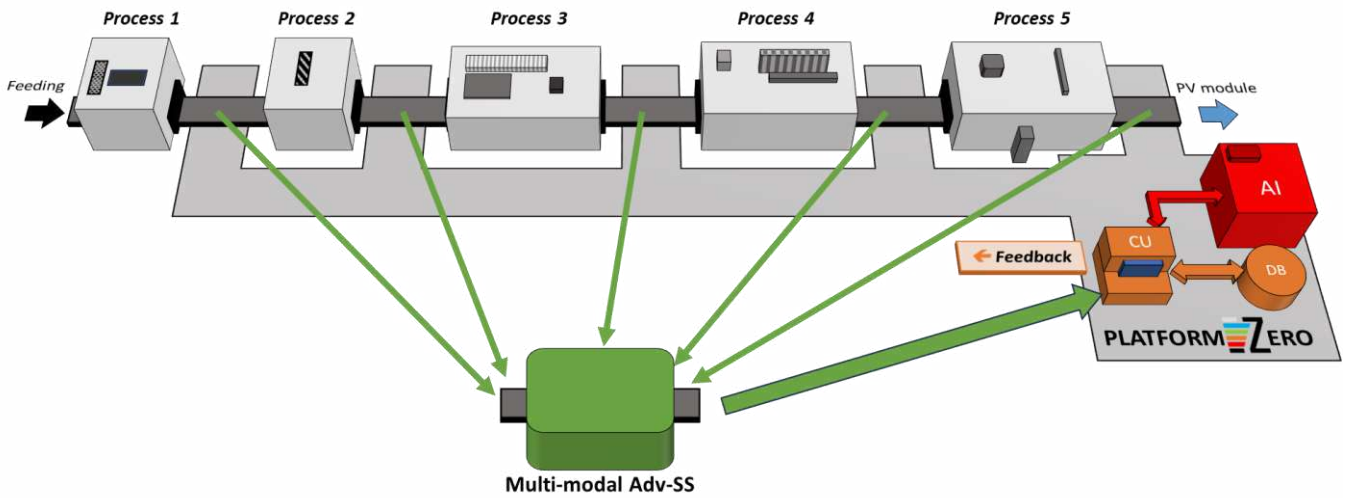
Platform development

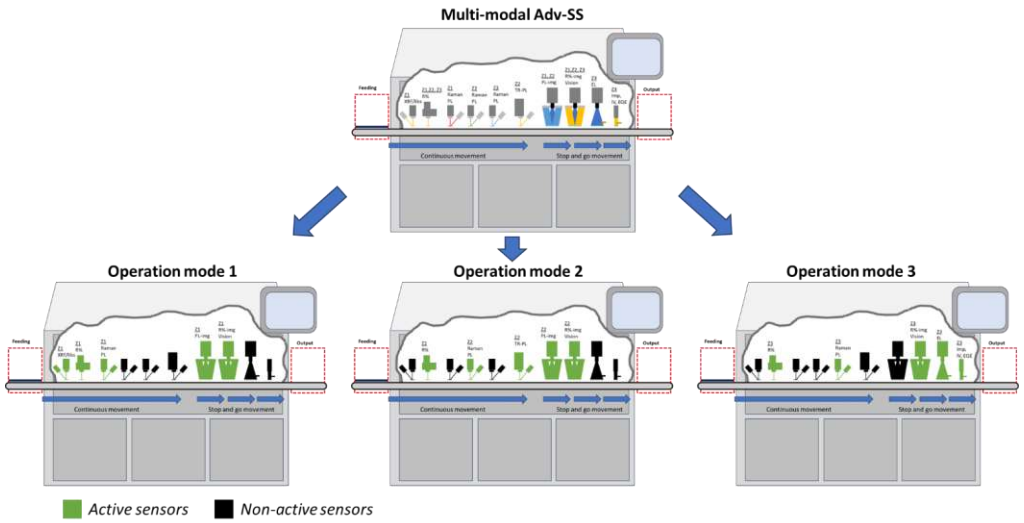


Future full Integration in production

(Commercial exploitation)

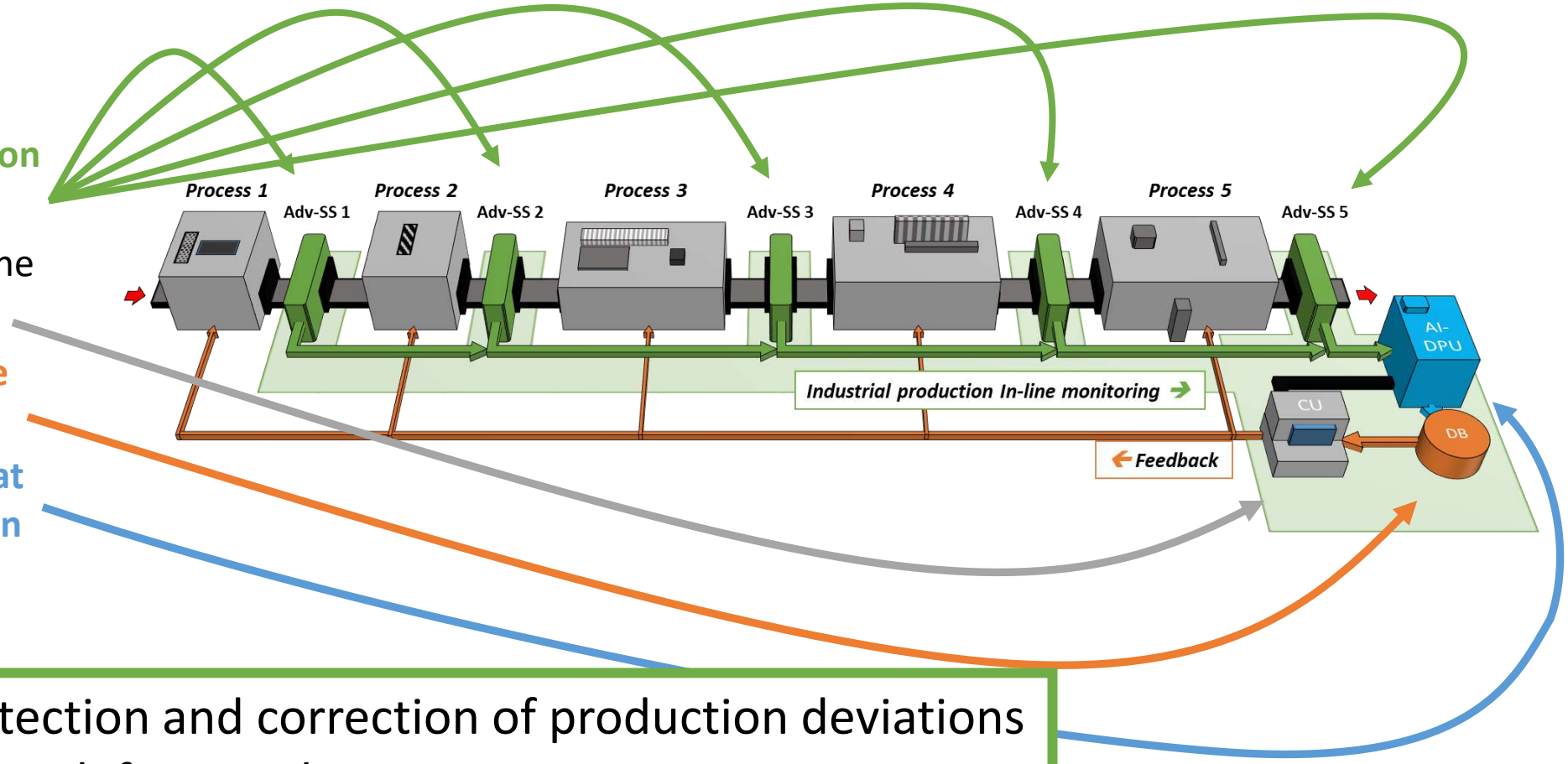
Development and validation in the project





Based in:

- ➔ **Multiples multisensory station after each production steps**
- ➔ Control unit that centralize the information
- ➔ **Big data-base to manage the information**
- ➔ **And artificial intelligence that process and propose decision making**



This allow the fast detection and correction of production deviations
➔ reducing production defects and waste

Flexible holistic process monitoring and control platform

FUTURE industrial transference

Full integration in Platform-Zero pilot lines

Extension to other PV technologies

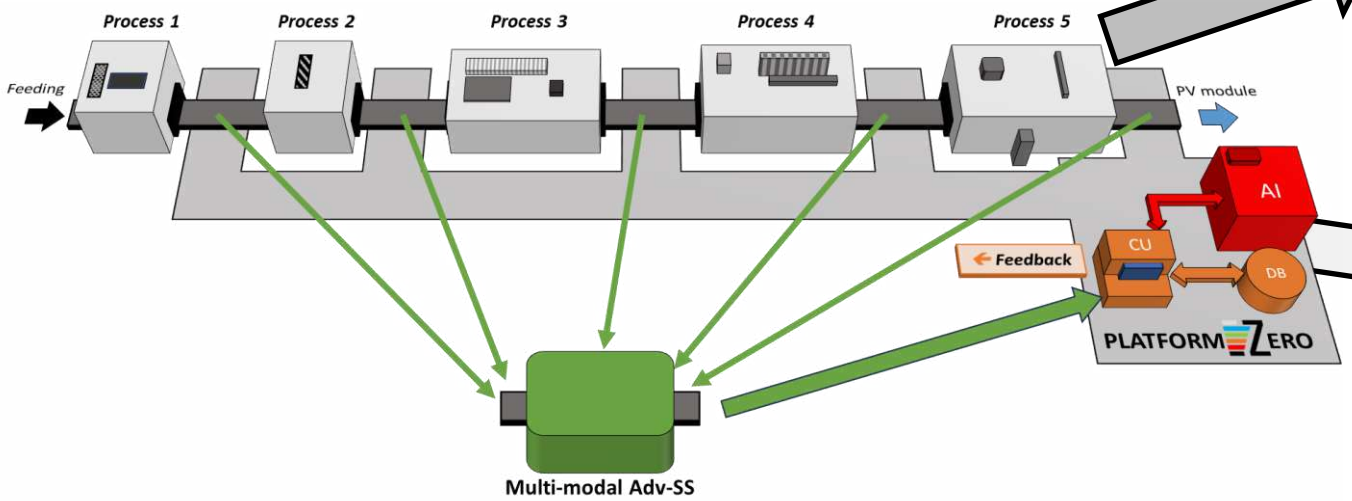
New PV technologies
Silicon
Organics
Etc.

Extension to other semiconductors technologies

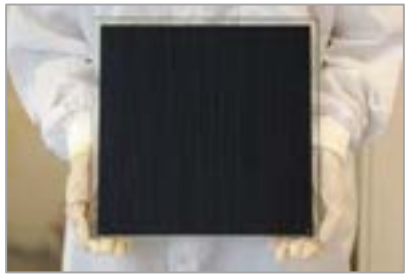
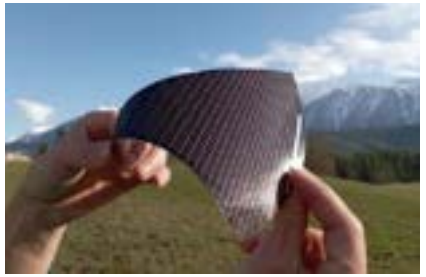
Batteries
General Smart coatings
Functional materials
Etc.

Extension to other applications

Smart sorting in recycling



Project concept
Pilot-lines where demonstrate the process monitoring platform

	Lurederra centro tecnológico	ZSW	sunplugged	SAULE TECHNOLOGIES
Pilot Line				
Pilot line objective	Technology Demonstration / optimization	Technology Demonstration/ optimization	Production	Production
Products	Oxide based smart coating	High eff CIGSe PV	Customizable CIGSe PV	Customizable Perovskite PV
Product Image				
Production process	Discontinued (batch)	Sheet-to-Sheet (StS)	Roll-To-Roll (RtR)	Front end of Line (FEOL)

Research Pilot-line (Laboratory to Industry)

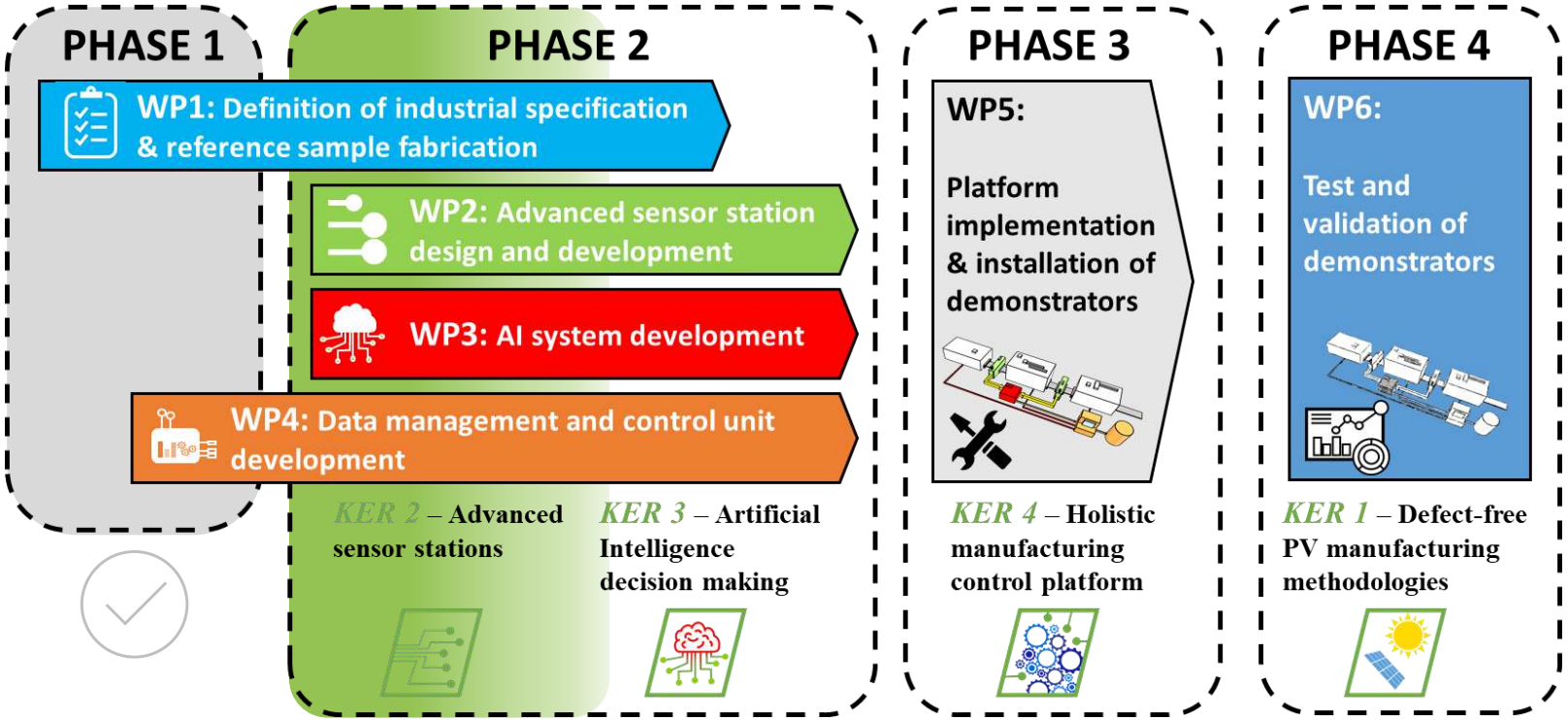
Industrial Pilot-line

Different type of industries in terms of:
PV products, Production methods, materials fabrication, and samples transference

→ Demonstration of suitability of Platform-Zero process monitoring platform

Methodology

The methodology successfully achieve the S&T objectives is based on four project development phases:

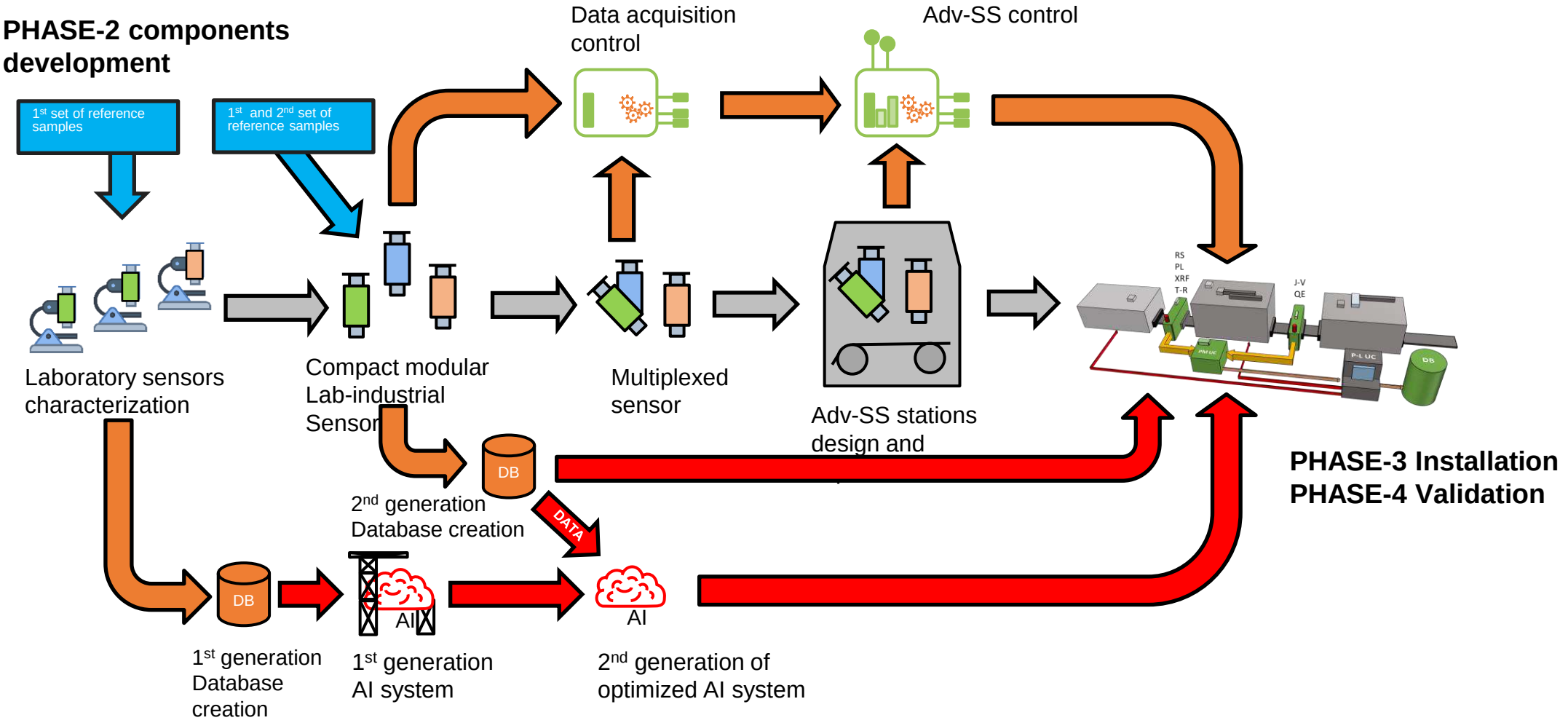


Identification of requirement	Development of the components	Implementation of the PMC systems	PMC Testing and validation TRL7	Intermediate Objective

Methodology

Specifications (PHASE-1)

PHASE-2 components development



First operative system

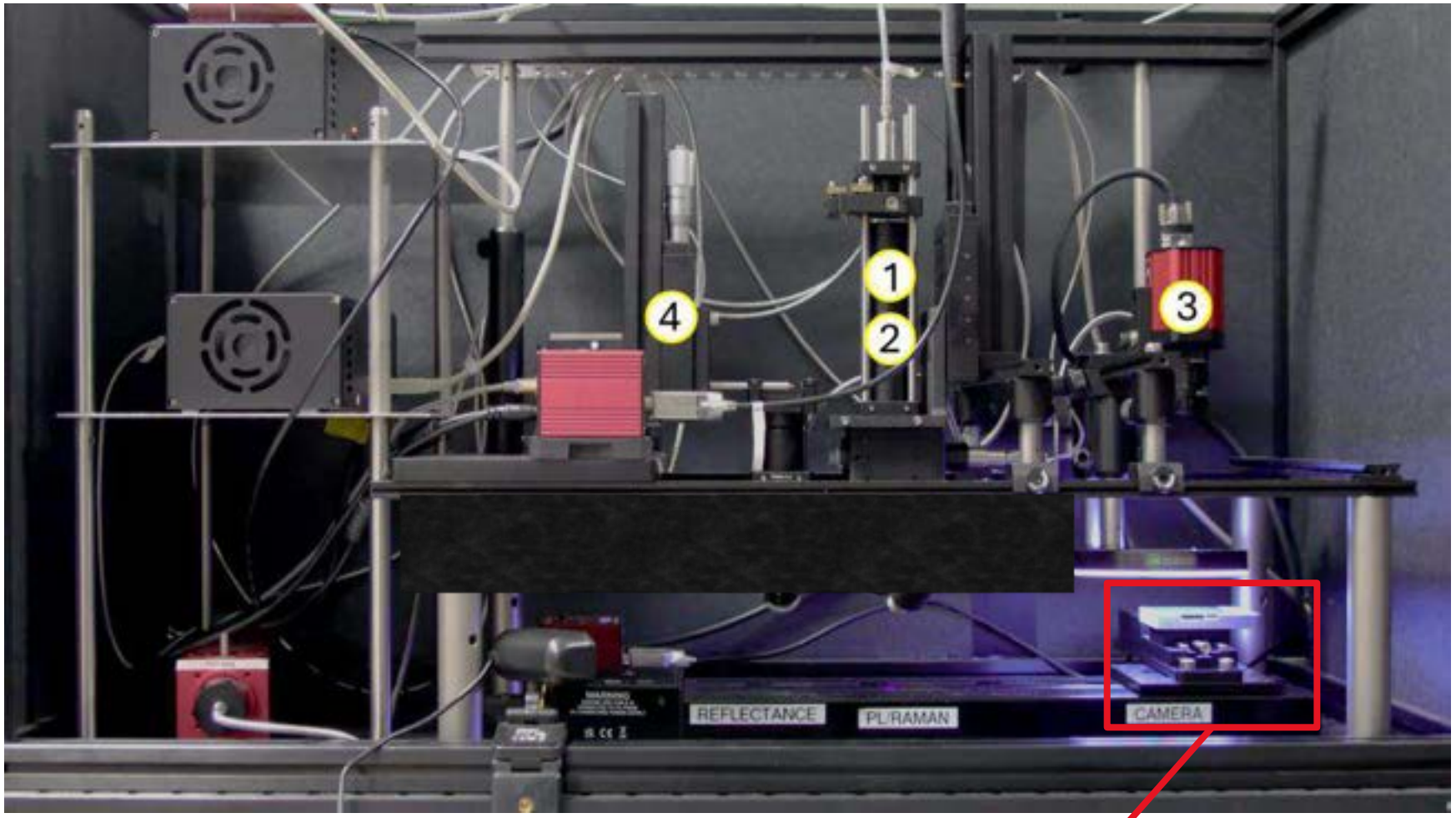
TEST system for 5x5 cm^2:

1. **RAMAN 633nm**
2. **SPECTRAL PHOTOLUMIISCENCE**
3. **VISION/ REFLECTANCE IMAGING**
4. **SPECTRAL REFLECTANCE**

Update for December

- **Electrolumincence**
- **IV**
- **Discret EQE**
- **Raman/PL 405 and 532 nm**

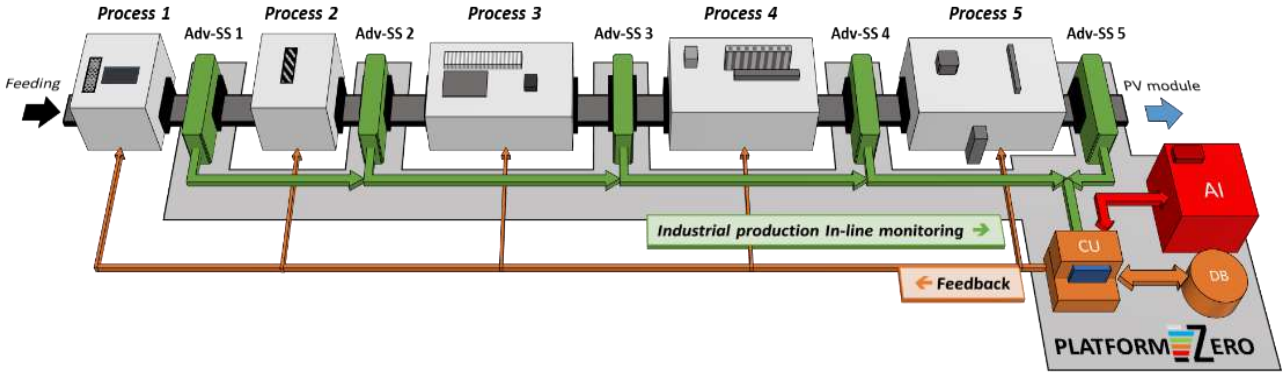
Upscale to 15x15 cm^2 samples



Automatic X-Y Sample Translation System"

Validation of Industrial Sensors ➔ Application to Accelerated Research

THANK YOU



Customizable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in the PV industry (Platform-ZERO)

January 2023 – December 2026

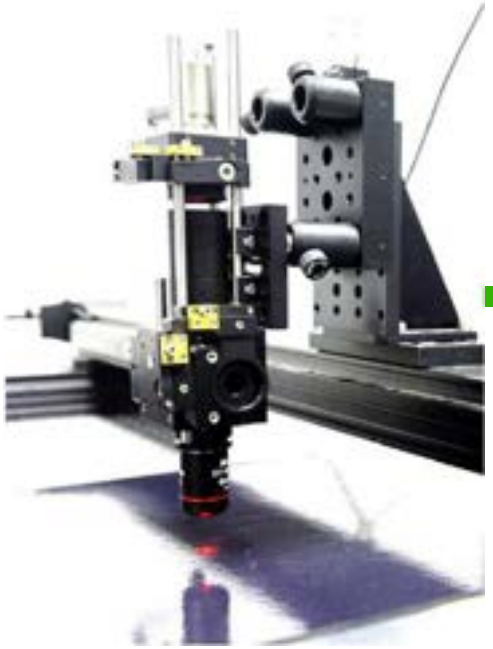
Co-funded by the European Union

Contacts for additional information and collaboration

Steven Ortiz jsortiz@irec.cat Maxim Guc mguc@irec.cat Victor Izquierdo vizquierdo@irec.cat

PLATFORM-ZERO @PLATFORMZERO_EU WWW.PLATFORM-ZERO-PROJECT.EU

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them.



Reading Photons – Spectroscopic Characterization for Process Monitoring Methodologies Development

Dr. Maxim Guc

Ramón y Cajal 2022

Co-funded by the European Union

Cofinanciado por la Unión Europea

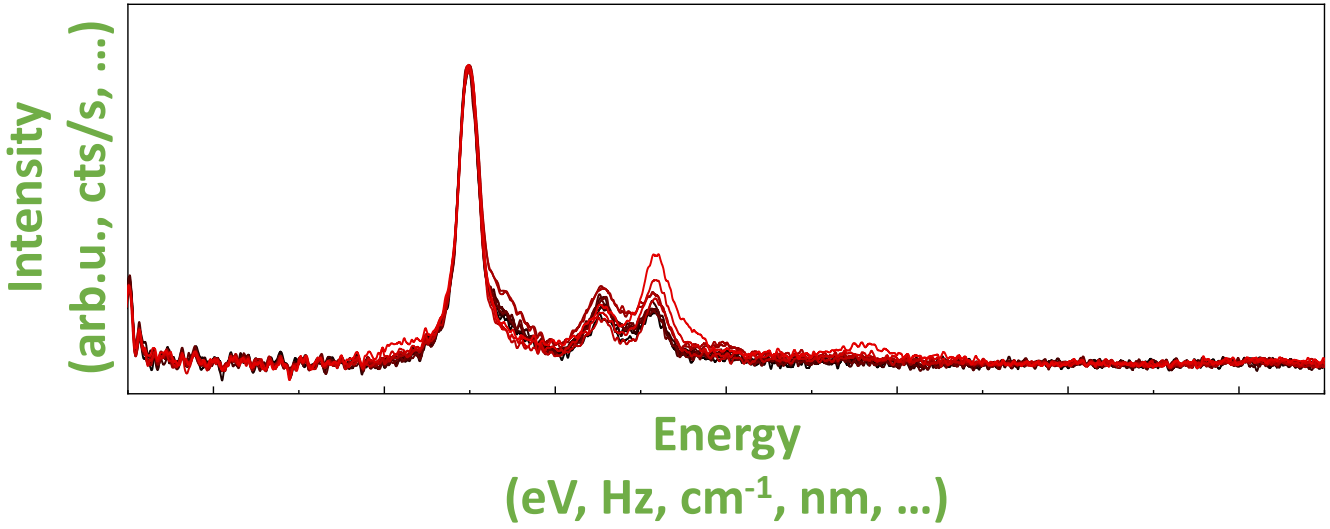
OUTLINE

- **Introduction**
  - Nomenclature
  - Type of spectroscopies
  - Parameters of a spectroscopic signal
  - Parameters of a measured sample
- **Development of a process monitoring methodology**
  - General approach
  - Examples
- **Conclusions**

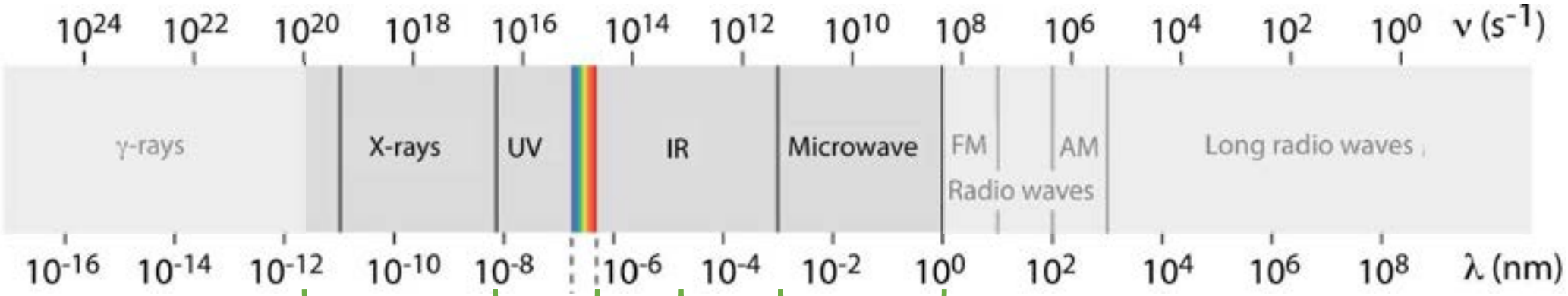
What is spectroscopy?

Spectroscopy is the field of study that measures and interprets electromagnetic spectra.

The main result is dependence of intensity of an electromagnetic wave from energy (mostly).



Type of spectroscopies



Elemental analysis

Reactivity analysis

Chemical bond type

Molecular orientation

Molecular connectivity

Mossbauer
X-ray absorption
X-ray fluorescence
X-ray photoelectron
Auger electron

UV/Vis absorption
UV/Vis transmission
UV/Vis reflection
Luminescence
Raman

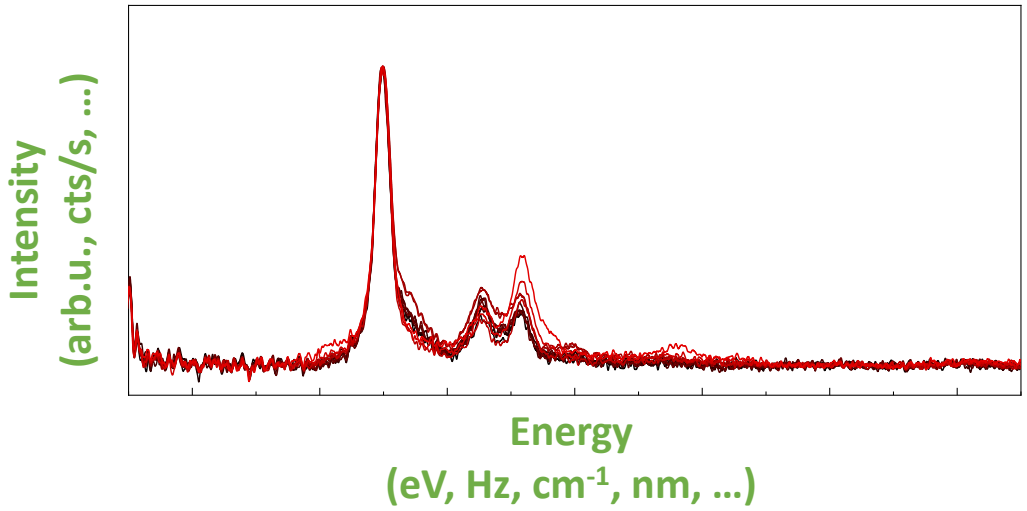
IR transmission
IR reflection
Electron spin resonance
Nuclear magnetic resonance
Raman

Type of spectroscopies

IREC's standard techniques:

- X-ray fluorescence
  mapping
- Multiwavelength Raman
  mapping, low temperature, anti-Stokes, polarized
- Multiwavelength Photoluminescence
  steady-state, mapping, low temperature
- UV/Vis Transmittance
  mapping spectral, imaging
- UV/Vis Reflectance
  mapping spectral, imaging
- Electroluminescence
  spectral, imaging
- Thermography
  imaging

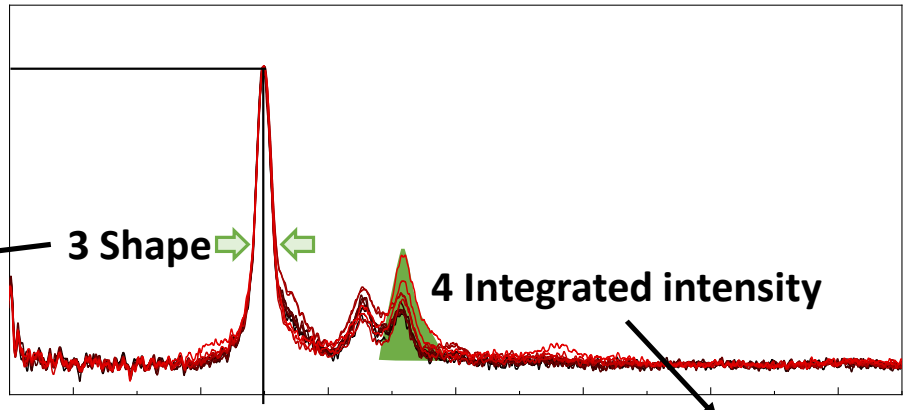
Spectrally resolved signal



Parameters of a spectroscopic signal

Spectrally resolved signal

WHAT:



How much signal of the light with the specific energy we get

- Absolute
- Relative

How signal looks like

- FWHM
- Asymmetry
- Slope

What spectral range defines the signal

Intensity * Shape

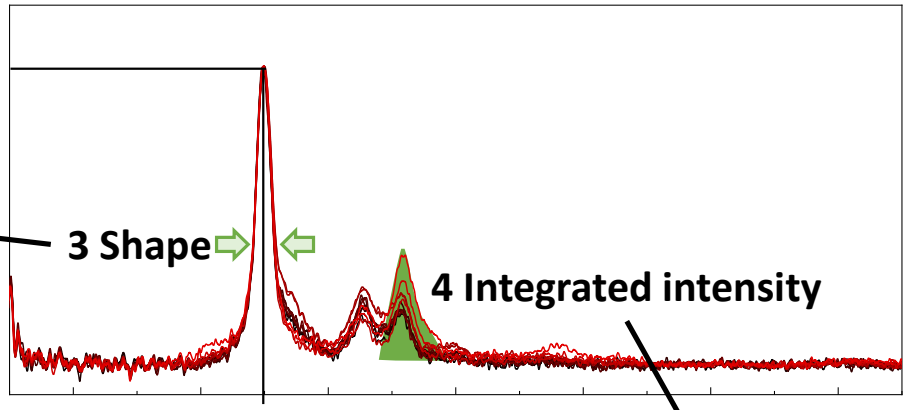
At which energy the signal was detected

Parameters of a spectroscopic signal

Spectrally resolved signal
HOW:

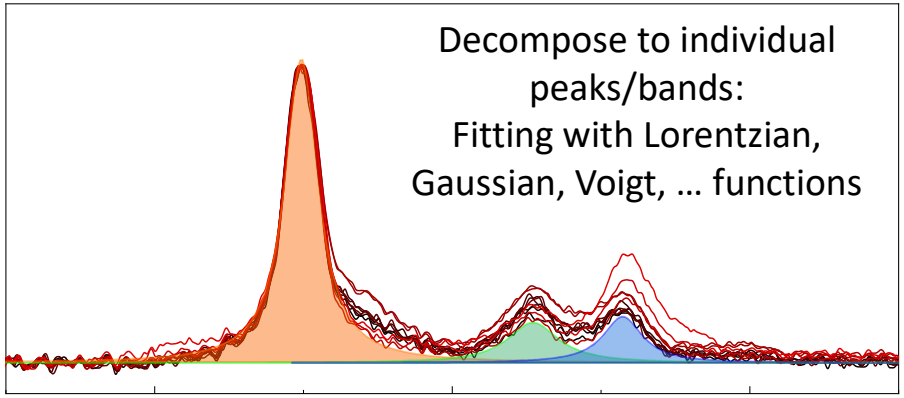
Calculating global/local maximum ← **1 Intensity**

Calculating difference between positions at X% of the global/local maximum ← **3 Shape**



Integrating intensity in the defined spectral range

Calculating position of global/local maximum

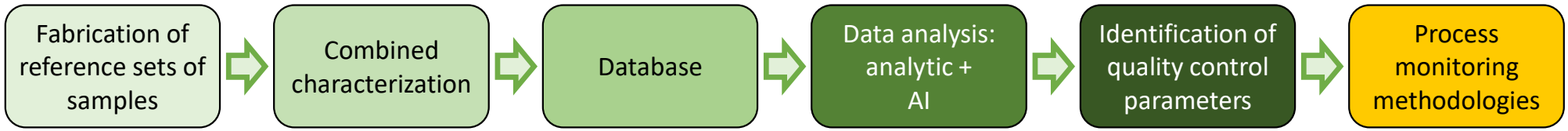


OUTLINE

- Introduction
  - Nomenclature
  - Type of spectroscopies
  - Parameters of a spectroscopic signal
  - Parameters of a measured sample
- **Development of a process monitoring methodology**
  - General approach
  - Examples
- **Conclusions**

Development of a process monitoring methodology

General approach



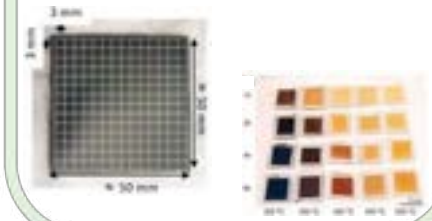
Development of a process monitoring methodology

General approach

Fabrication of reference sets of samples → Combined characterization → Database → Data analysis: analytic + AI → Identification of quality control parameters → Process monitoring methodologies

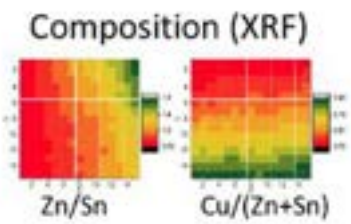
Clear variation of a property

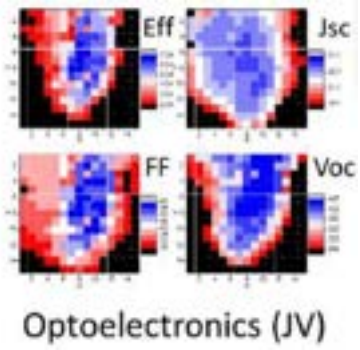
1) Combinatorial samples
2) Samples with non-desired variations
3) Samples with standard fabrication conditions and with controlled deviations
4) Complete devices or stopped after specific process

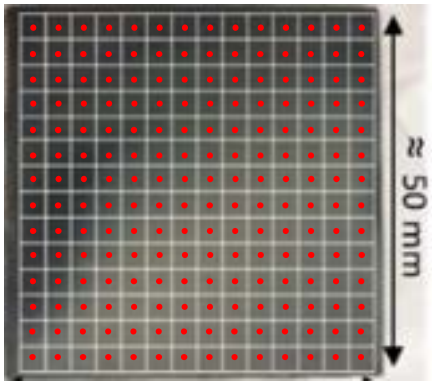


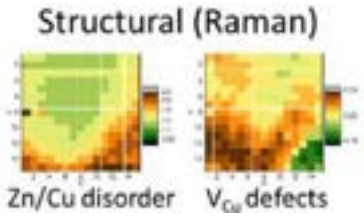
**R. Fonoll-Rubio et.al., Solar RRL 6 (2022) 2200235.*

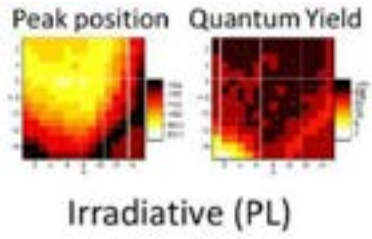
Combination of different measurement techniques











Requirements for combined techniques:

- ➔ Non-destructive
- ➔ Mappings by robotization and/or XYZ stages
- ➔ Reasonable measurement time
- ➔ Compatible measurement area
- ➔ Automation of data processing

Development of a process monitoring methodology

General approach

Fabrication of reference sets of samples → Combined characterization → Database → Data analysis: analytic + AI → Identification of quality control parameters → Process monitoring methodologies

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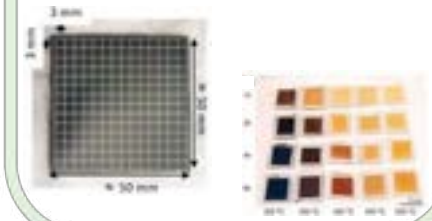

**R. Fonoll-Rubio et.al., Solar RRL 6 (2022) 2200235.*

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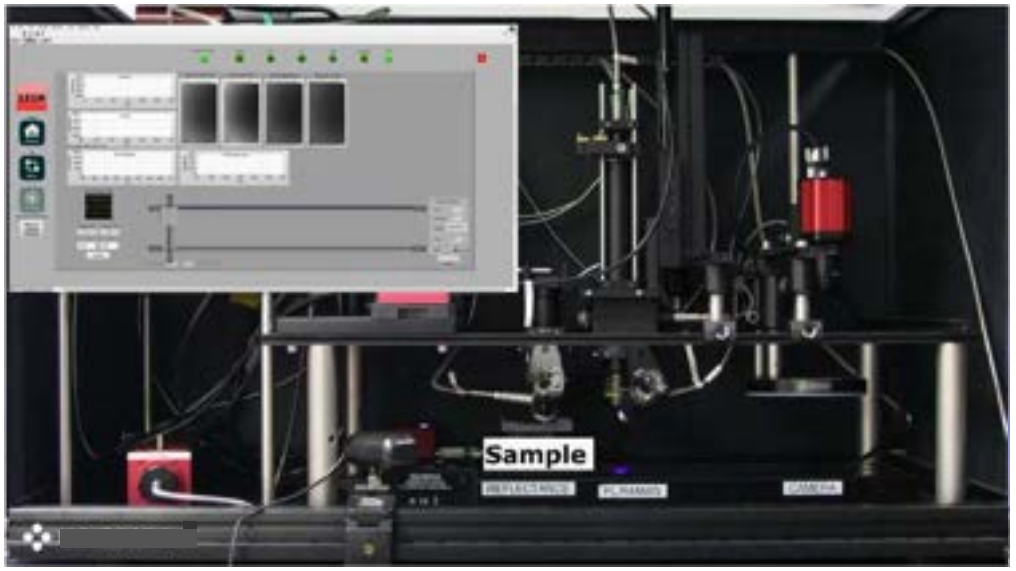


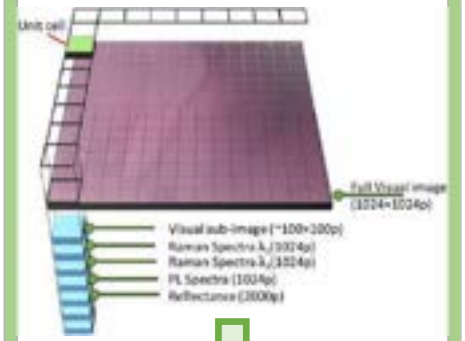
IREC's combined characterization platform

Development of a process monitoring methodology

General approach

Fabrication of reference sets of samples → Combined characterization → Database → Data analysis: analytic + AI → Identification of quality control parameters → Process monitoring methodologies

Coherent database

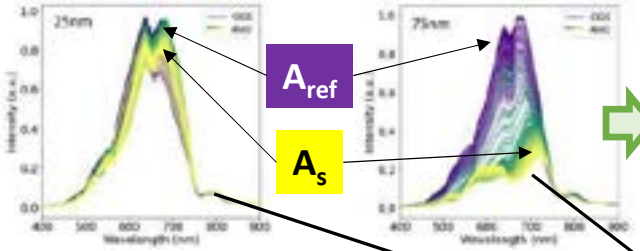


Object in data file
Sample[X].Position[x,y].Technique[t].Pixel[xp,yp]

t=0 - Visual sub-image
t=1 – Raman spectra
t=2 – Reflectance spectra
….

Find specific spectra features or use AI for data classification

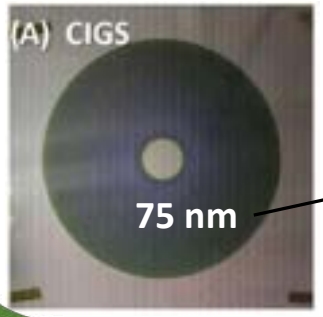
Analytical



$$q_t = \sum_x |A_s(x) - A_{ref}(x)|$$

Descriptors - spectra

AI-based

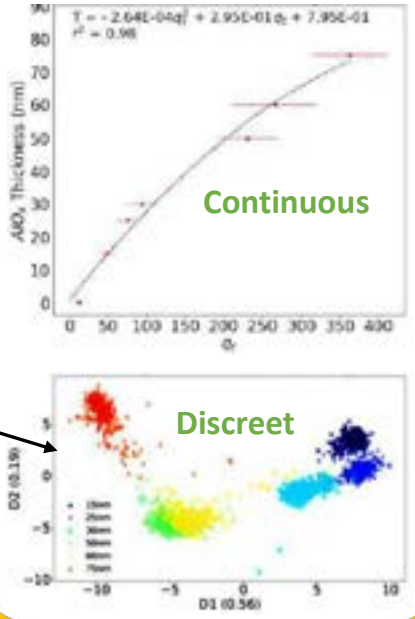


Target - thickness

Machine learning

*E. Grau-Luque et.al., Small Methods (2024) 2301573.

Methodologies



*E. Grau-Luque et.al., Progress in Photovoltaics 30 (2022) 229

Development of a process monitoring methodology

Examples

Monitoring the RbF-PDT on the surface of $Cu(In,Ga)Se_2$

No RbF-treatment

RbF-treatment at 490°C

RbF-treatment at 520°C

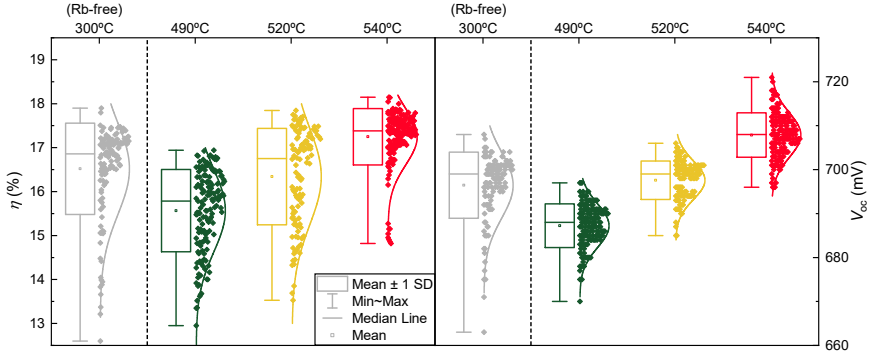
RbF-treatment at 540°C

~150 × 4 solar cells

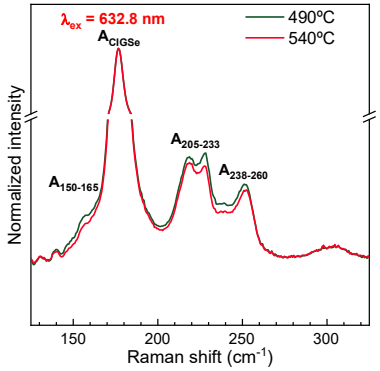
DATABASE

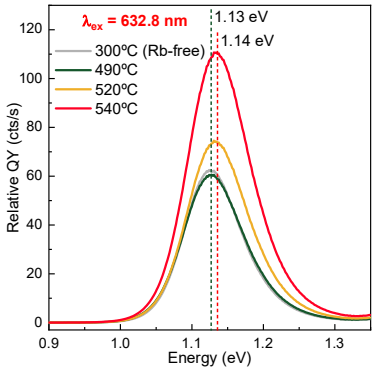
~600 IV data
+
~2400 Raman spectra
+
~2400 PL spectra

IV of each cell



Raman and PL under 632.8 nm





**R. Fonoll-Rubio et al., Adv. Energy Mater. 12 (2022) 2103163*

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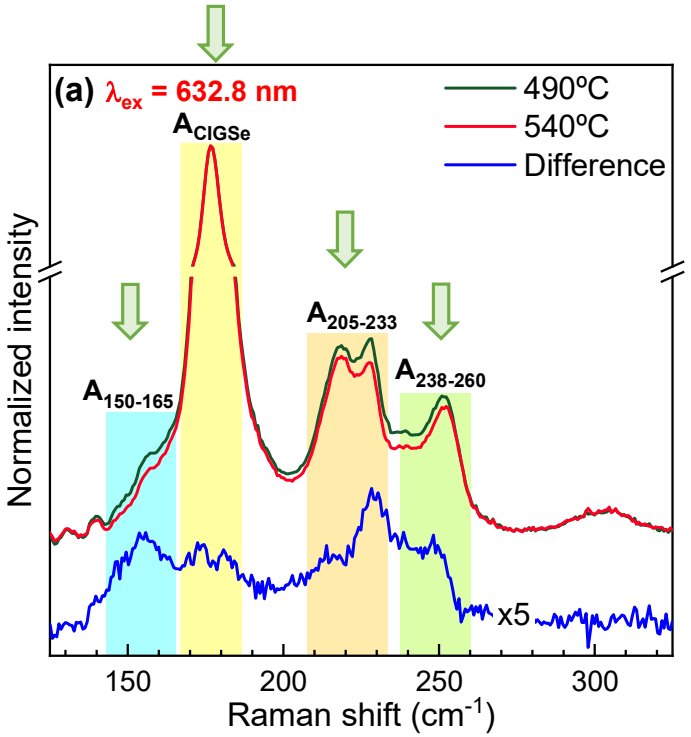
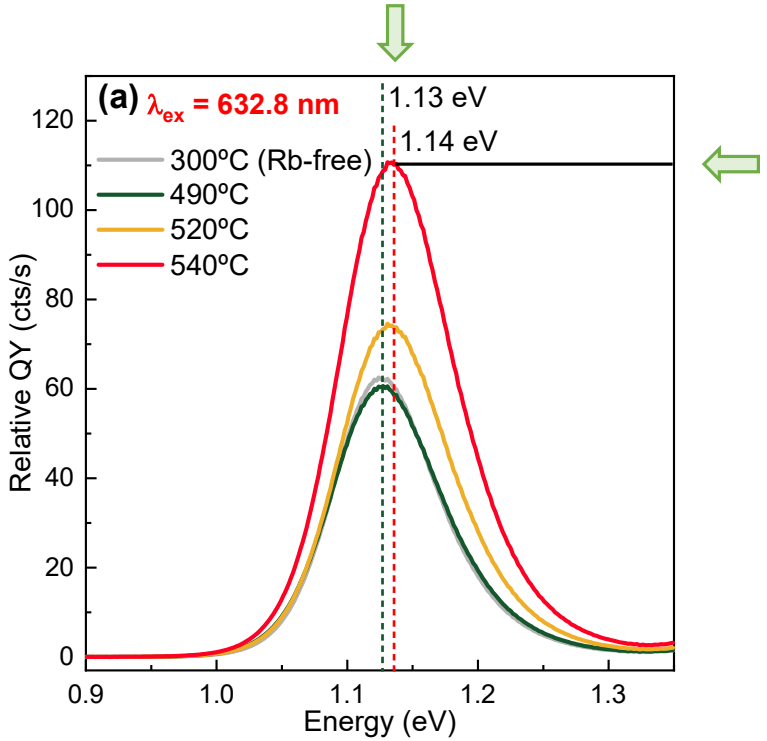
Monitoring the RbF-PDT on the surface of $Cu(In,Ga)Se_2$





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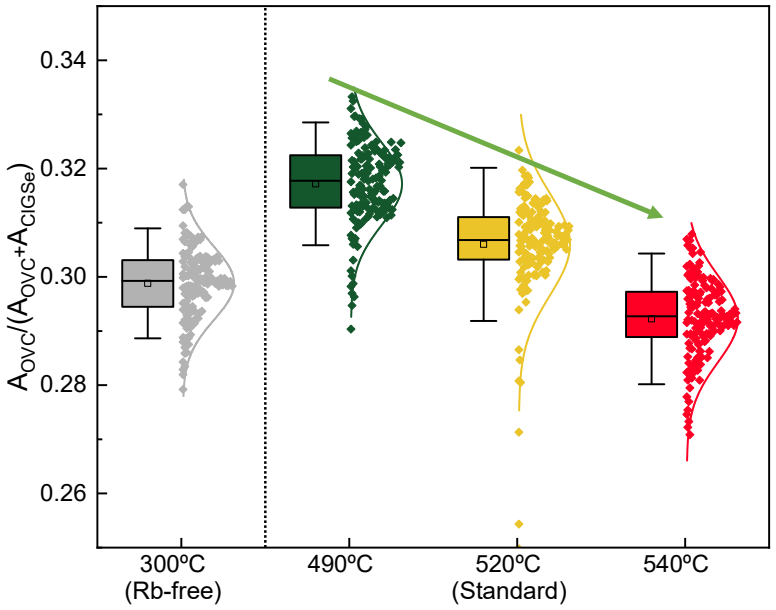
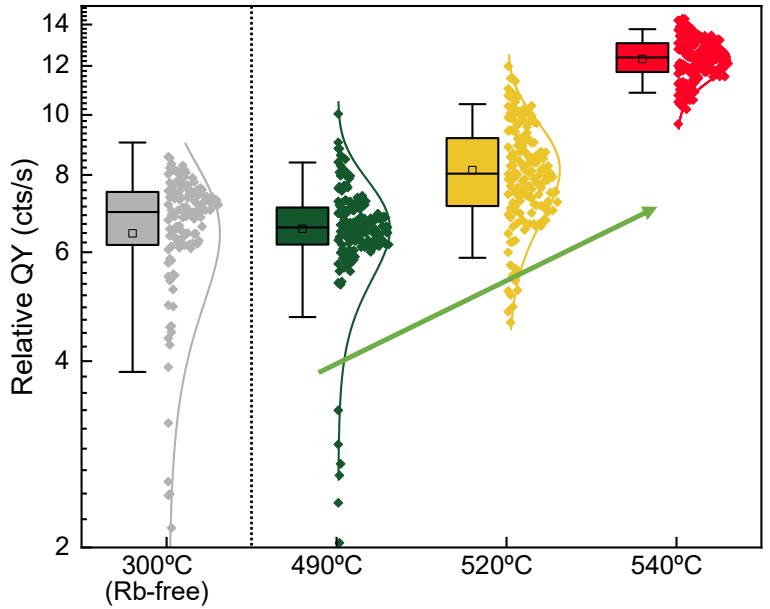


Raman vs PDT temperature

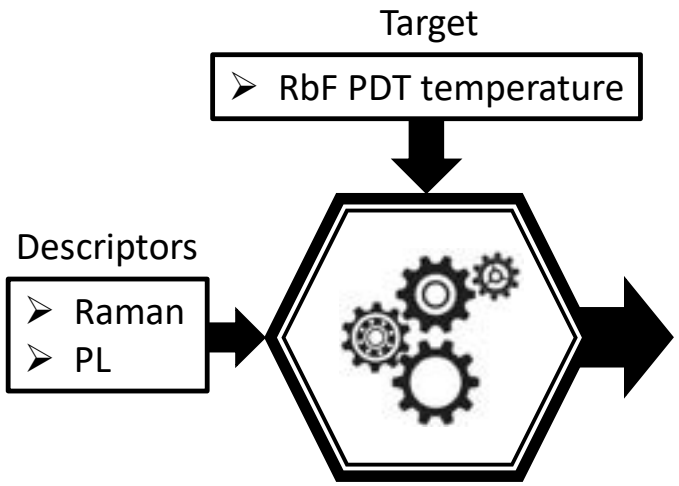


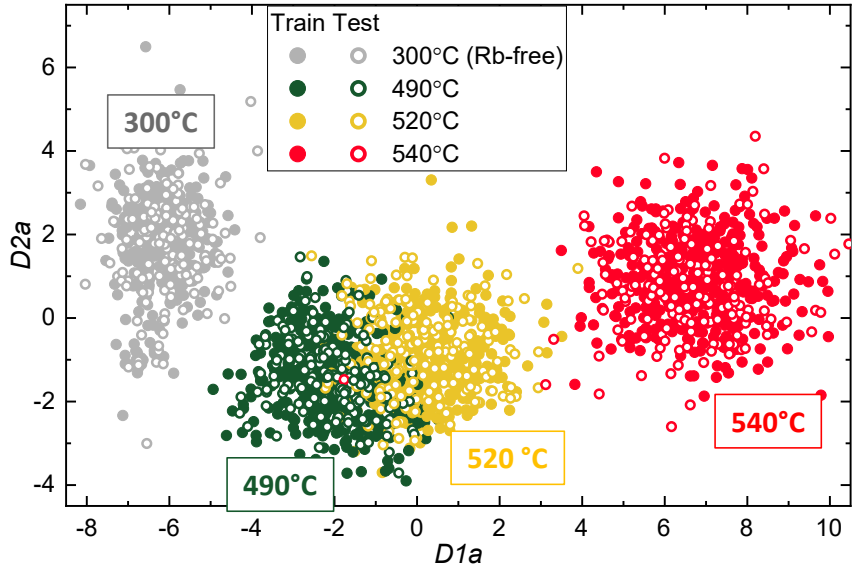
PL vs PDT temperature

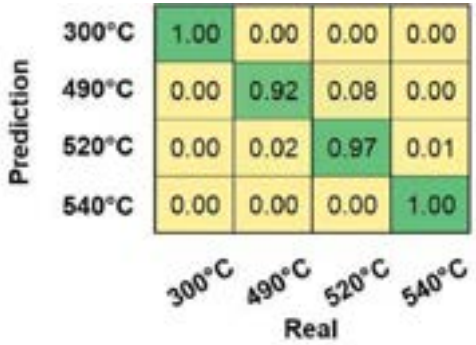
**R. Fonoll-Rubio et al., Adv. Energy Mater. 12 (2022) 2103163*

Examples

Monitoring the RbF-PDT on the surface of $Cu(In,Ga)Se_2$







*R. Fonoll-Rubio et al., Adv. Energy Mater. 12 (2022) 2103163

Examples

Monitoring the RbF-PDT on the surface of $Cu(In,Ga)Se_2$

Device structure

SLG (3mm)/Mo/CIGS/CdS/i-ZnO/AZO/Ni-Al Grid

Device fabrication

- 30x30 cm^2 STS In-line Co-evaporation of $Cu(In,Ga)Se_2$ on Molybdenum Glass substrates
- in-situ PDT with RbF (controlled by RbF-PDT source temperature)

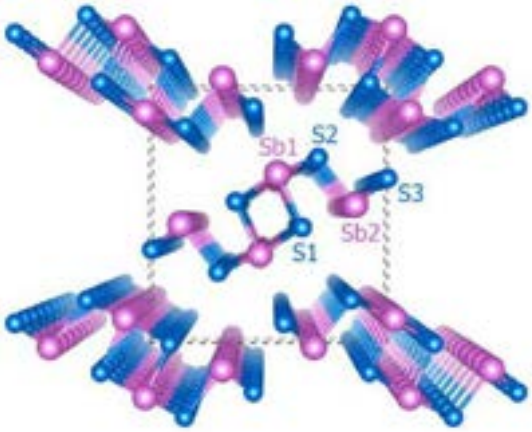
Measurement conditions

- Concomitant measurement of Raman and PL spectra
- Assessment of PDT quality in 30x30 cm^2 sample in 5 min

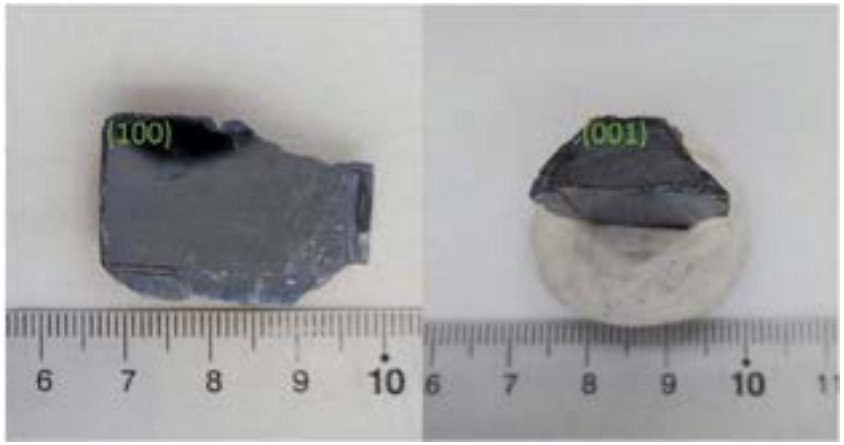
Examples

Assessment of crystallographic orientation in Sb_2S_3

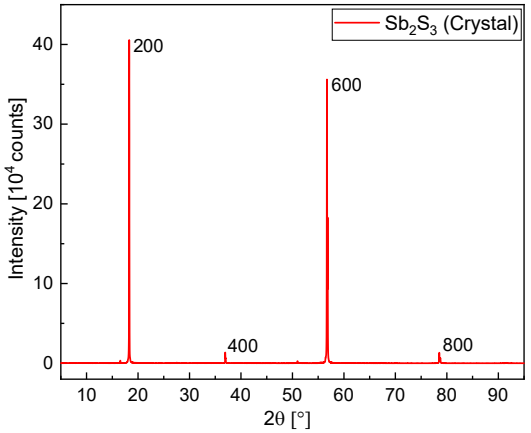
Materials properties are different along and cross to ribbons orientation



Sb_2S_3 single crystalline mineral



XRD diffractogram of the biggest surface



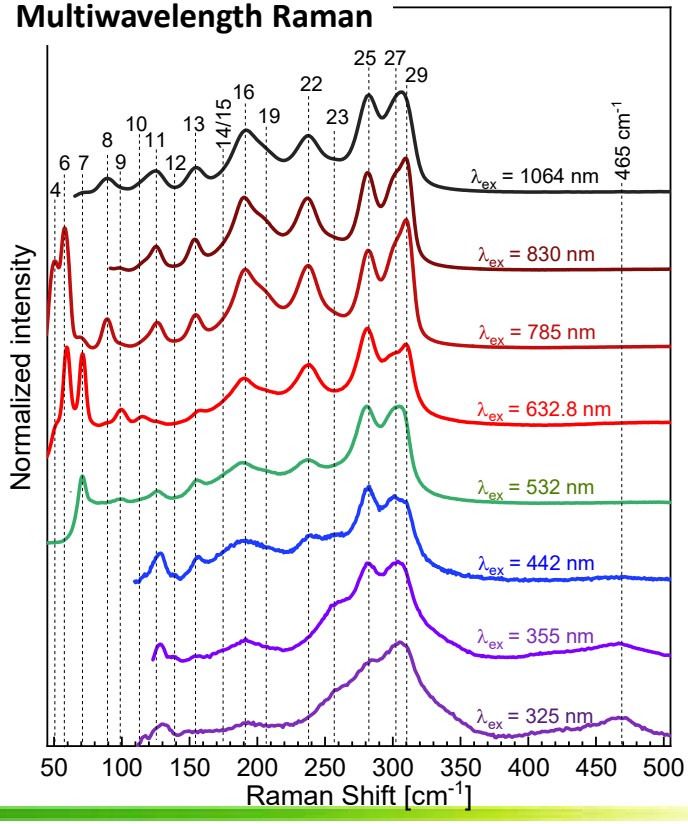
*V. Rotaru et al., iScience 27 (2024) 109619

Development of a process monitoring methodology

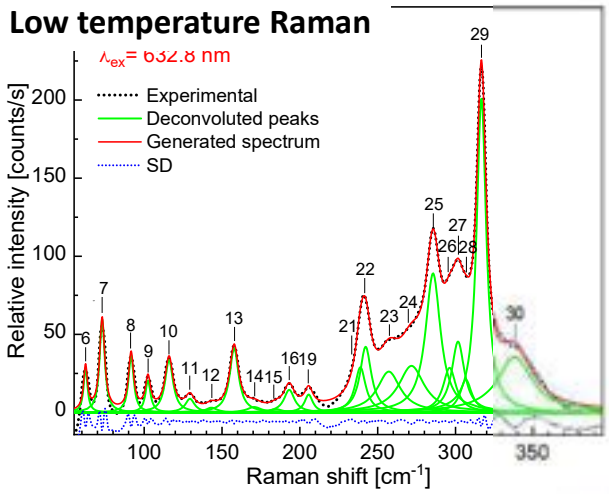
Examples

Assessment of crystallographic orientation in Sb_2S_3

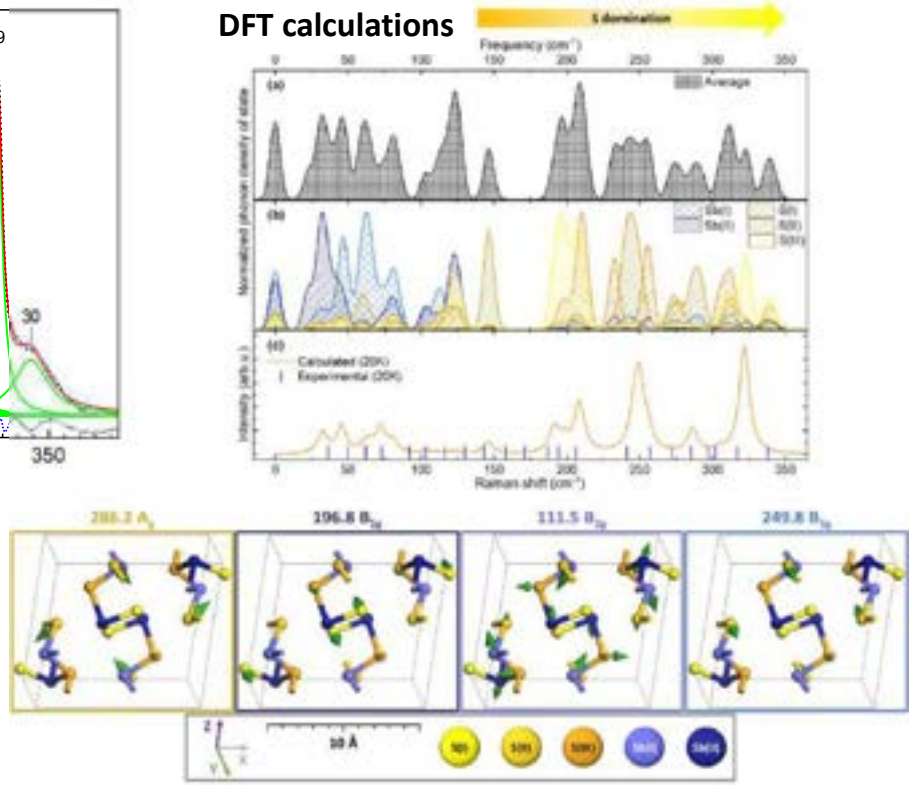
Multiwavelength Raman



Low temperature Raman



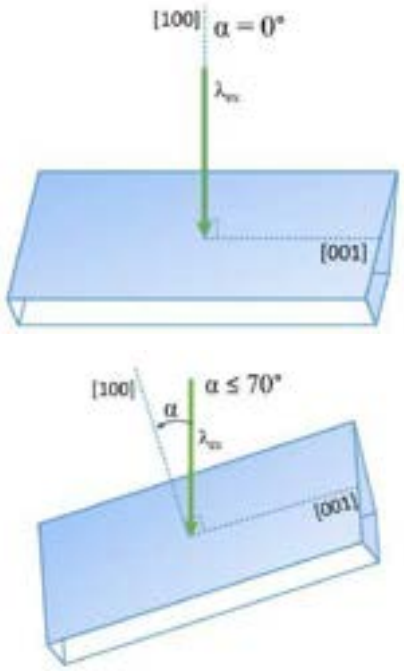
DFT calculations

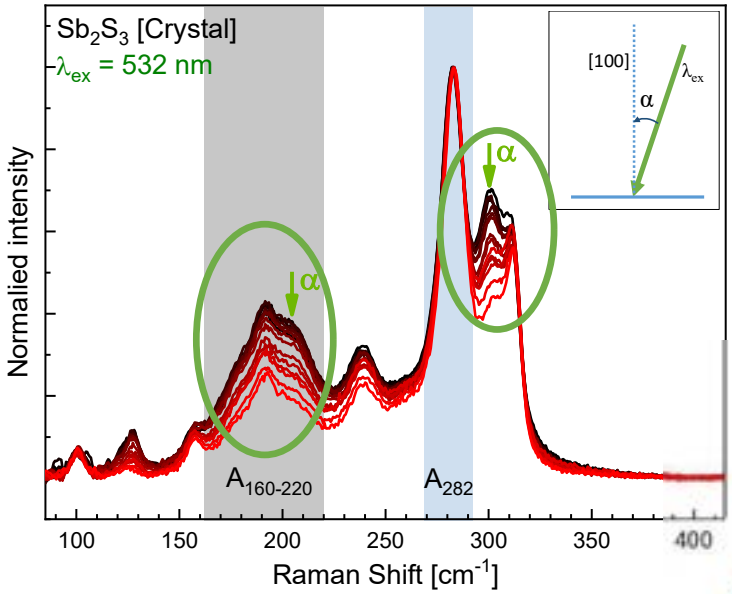


*V. Rotaru et al., iScience 27 (2024) 109619

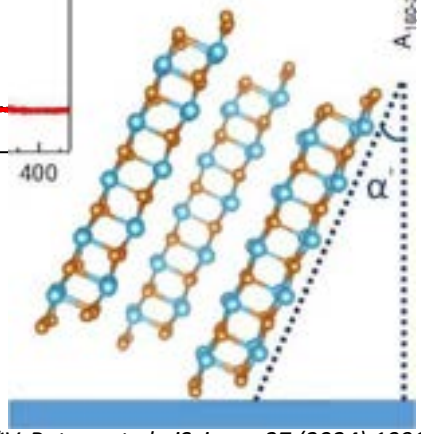
Examples

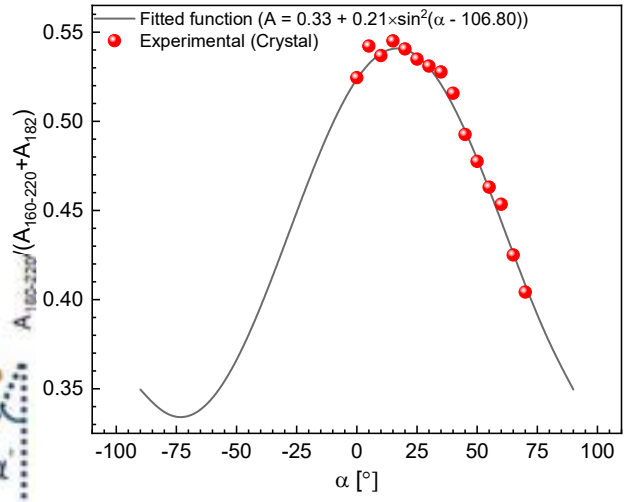
Assessment of crystallographic orientation in Sb_2S_3





$$\alpha' = -16.80 + \sin^{-1}(0.97 \times \sqrt{5.00 \times A - 1.66})$$





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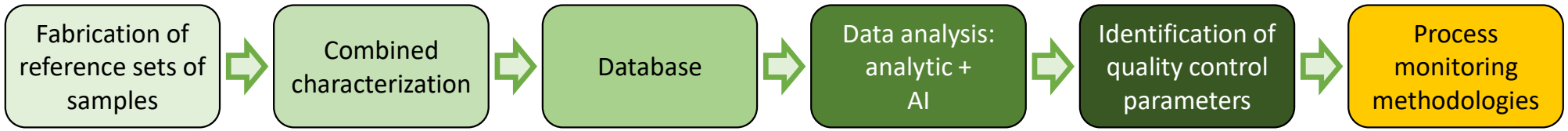
Conclusions



Clear variation of a property

Combination of different measurement techniques

Coherent database

Find specific spectra features that correlates with the varied property or use AI for data classification

Thank you for your attention!!

Maxim Guc mguc@irec.cat

Ramón y Cajal 2022 fellowship

Customizable AI-based in-line process monitoring platform for achieving zero-defect manufacturing in the PV industry (Platform-ZERO)
January 2023 – December 2026 **http://www.platform-zero-project.eu/**

Co-funded by the European Union

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