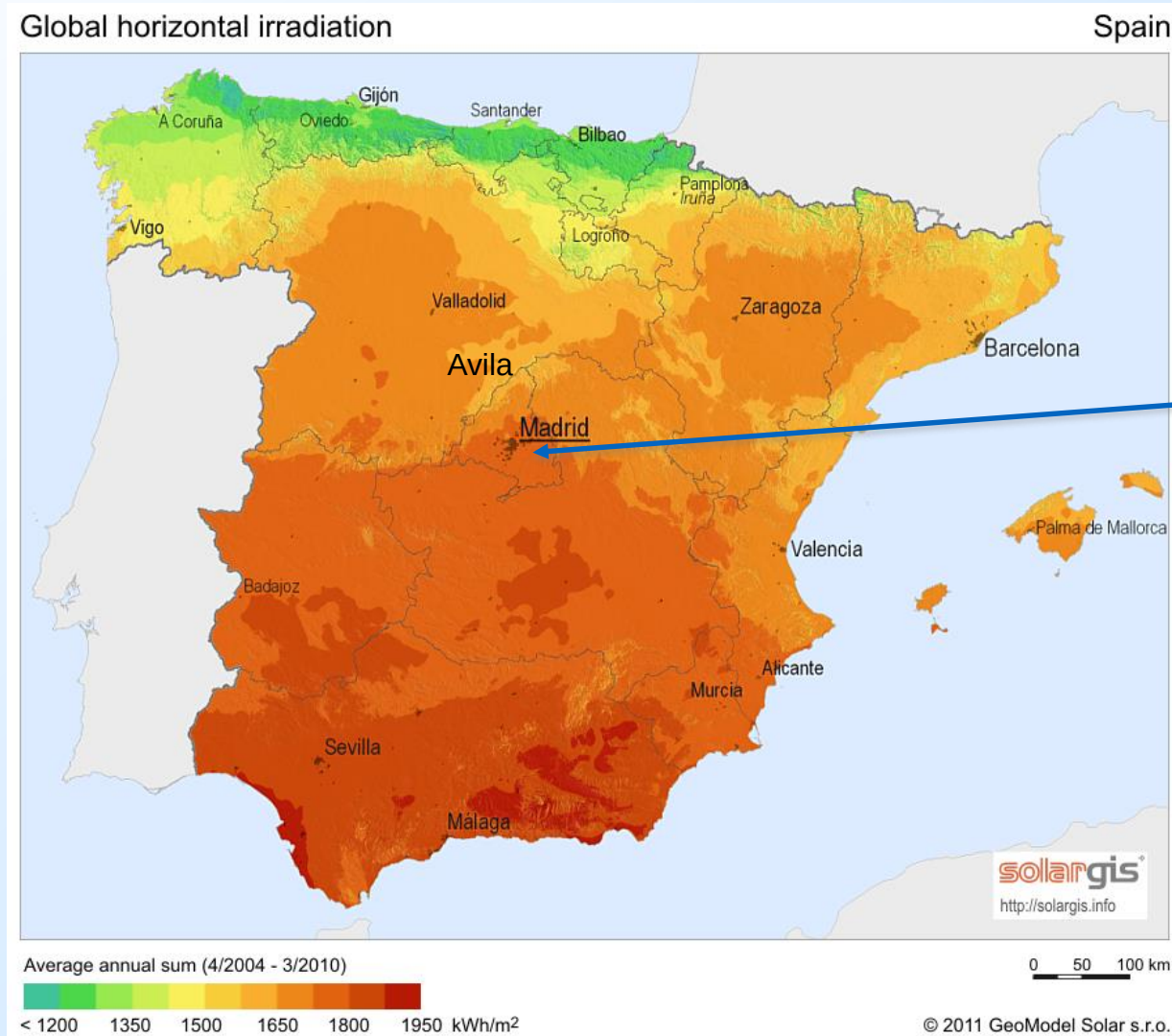
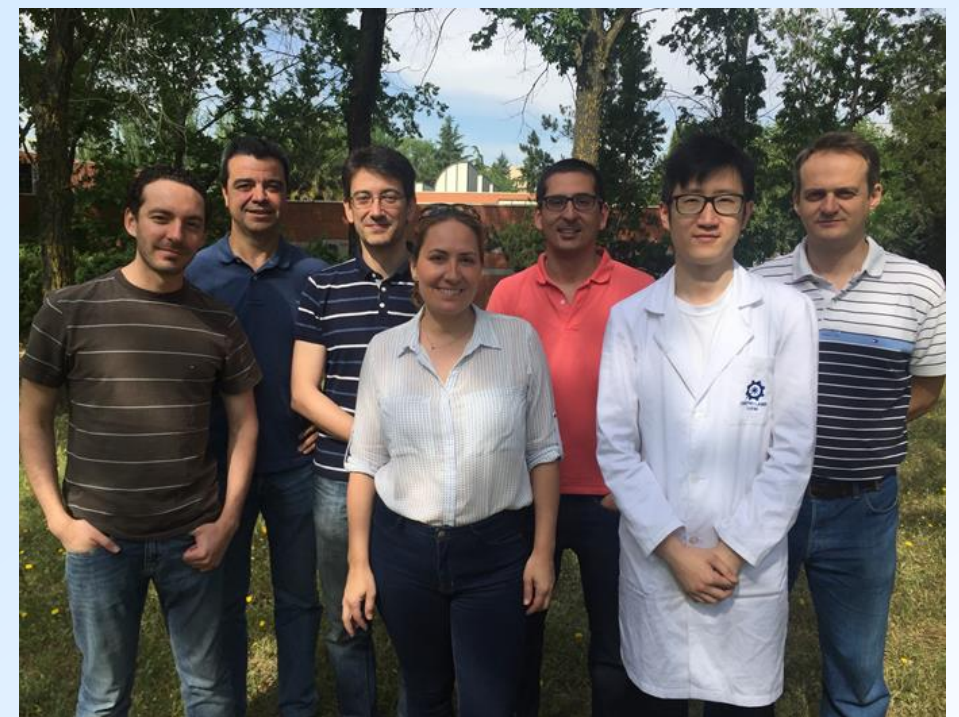




Laser based Processes for Product Customization in Building Integrated Photovoltaics

C. Molpeceres, D. Canteli, Y. Chen, D. Muñoz, M. Morales,
J.J. García-Ballesteros, S. Lauzurica





Activity in:

- Laser material processing
- Laser-matter interaction modelling
- Laser micro and nanoprocessing
- Laser processing for Solar Energy

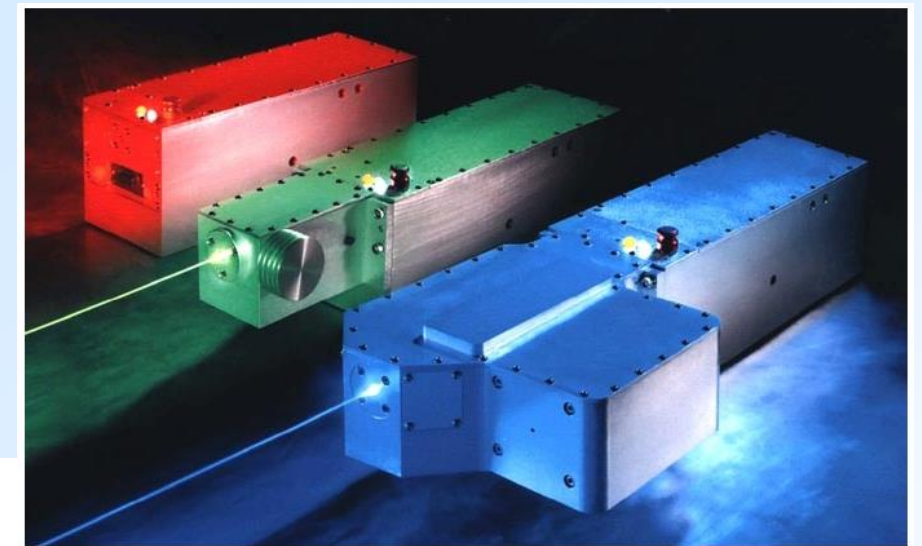
Lasers in PV ... then and now

Production Process	Production Status	
	C-Si Cells	
Laser Edge Isolation		
Laser Grooved Buried Contacts (LGBC)		
Cutting/ Singulation		
Emitter Wrap-Through (EWT) and Metal Wrap-Through (MWT) Interconnects		
Selective Emitters (SE) Ablation		
Selective Emitters (SE) Dopant Diffusion		
Laser Fired Contacts (LFC)		
Interconnection/ soldering		
Texturing		

Production Process	Production Status			
	Thin film silicon	Cd Te	CIS/ CIGS	Flexibles
P1 Patterning				
P2 Patterning				
P3 Patterning				
Laser Edge Isolation				
Crystallization				

 Mature technology in industrial production
  Partially adopted or pilot line
  In development

SSL technology



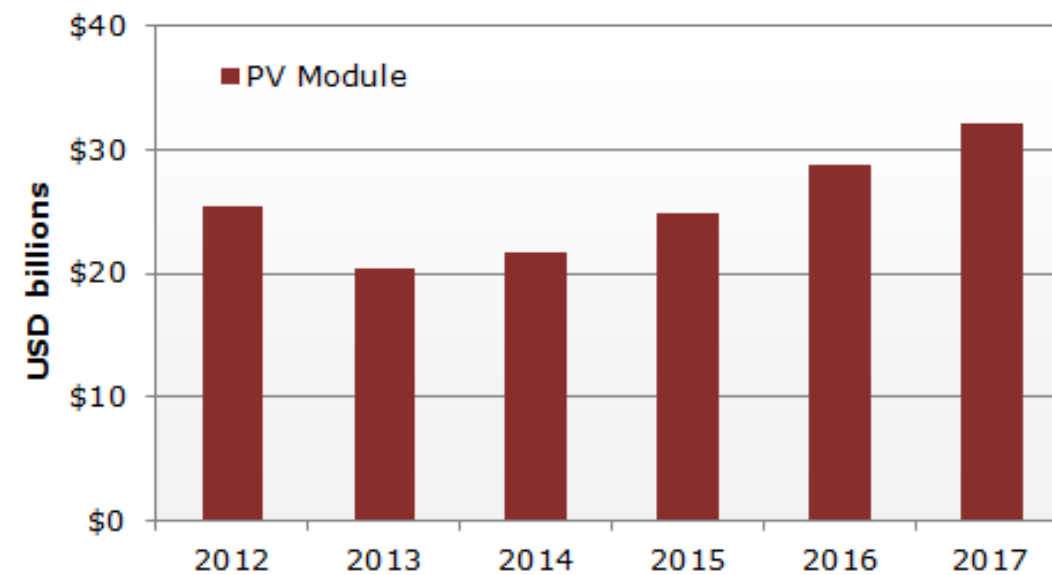


Lasers in PV..then and now

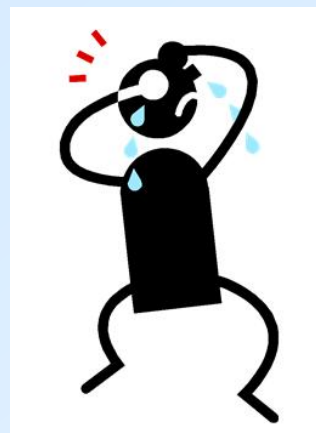
Production Process	Production Status	
	C-Si Cells	
Laser Edge Isolation		
Laser Grooved Buried Contacts (LCBC)		
Cutting/ Singulation		
Emitter Wrap-Through (EWT) and Metal Wrap-Through (MWT) Interconnects		
Selective Emitters (SE) Ablation		
Selective Emitters (SE) Dopant Diffusion		
Laser Fired Contacts (LFC)		
Interconnection/ soldering		
Texturing		

Production Process	Production Status			
	Thin Film	Cd Te	CIS/ CIGS	Flexibles
P1 Patterning				
P2 Patterning				
P3 Patterning				
Laser Edge Isolation				
Crystallization				
Mature technology in industrial production Partially adopted or pilot line In development				

Figure 1: Solar PV Module Supplier Revenues Forecast to 2017



Source: NPD Solarbuzz Marketbuzz 2013



New BIPV applications could help
to recover the market share of PV applications
In laser industry



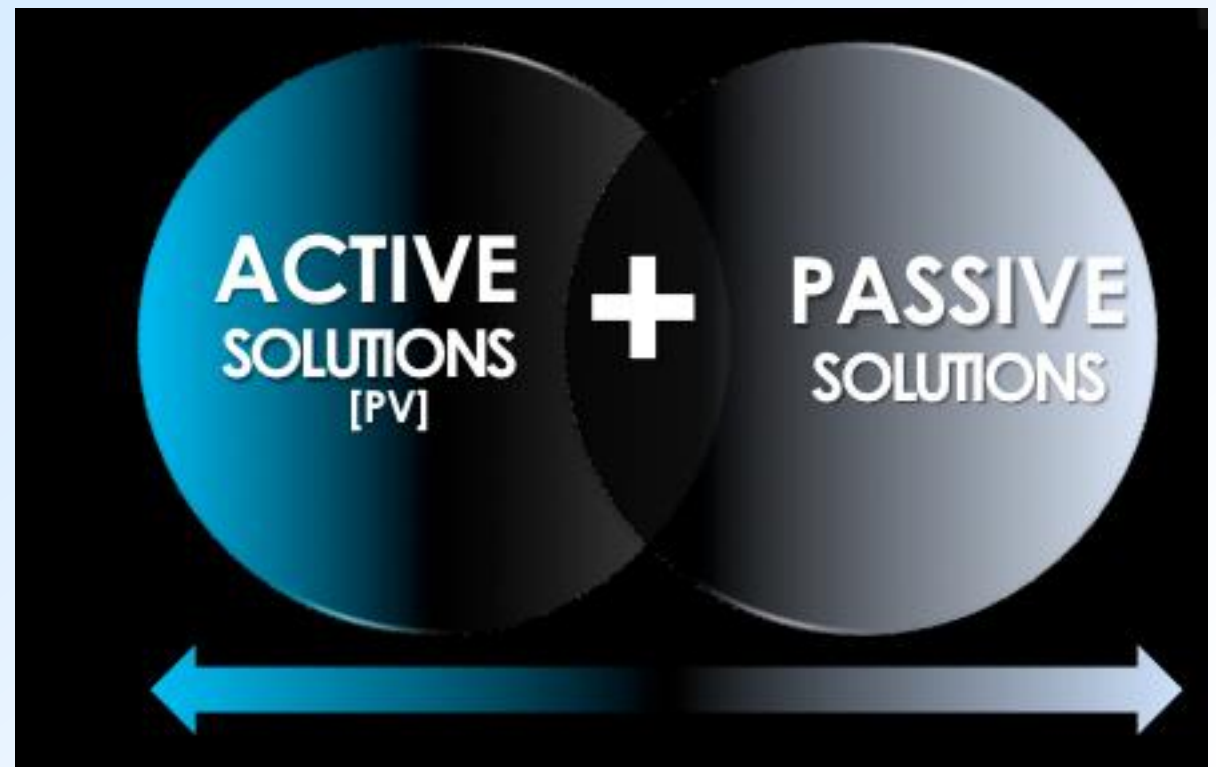
In Europe buildings use 40% of total EU energy consumption and are responsible of 38% of global energy demand

BIPV vs BAPV

BAPV (Building Applied Photovoltaics) main limitations:

- a) it requires an additional investment within the building budget
- b) aesthetical does not fulfill the requirements of most of the building stakeholders showing poor acceptability
- c) does not compile with key building codes limiting its application.

BIPV (building integrated photovoltaics) technology has already undertaken their journey to become the most attractive business model for PV technologies. This is based on the capacity of providing multifunctional solutions to buildings throughout active and passive properties allowing on-site Renewable Energy Sources energy production





BIPV vs BAPV

ADVANTAGES OF PV PRODUCTS FOR BUILDING APPLICATIONS	ADVANTAGES COMPARISON	
	BIPV System	BAPV System
ENERGY GENERATION IN-SITU		
UV & IR FILTER		
THERMAL & ACOUSTIC INSULATION		
NATURAL ILLUMINATION		
INNOVATIVE DESIGN		
REPLACEMENT OF CONSTRUCTIVE MATERIALS		
CUSTOMIZE CAPABILITY (SIZE, GEOMETRY)		
ATTRACTIVE DESIGN (SEMI-TRANSPARENCY AND COLORS)		





See-Through solutions are ideal for use in curtain walls, skylights, canopies, atriums



Source: Kaneka (www.kakena-solar.com)c

See-through modules can be used to replace a number of architectural elements commonly made with glass or similar materials



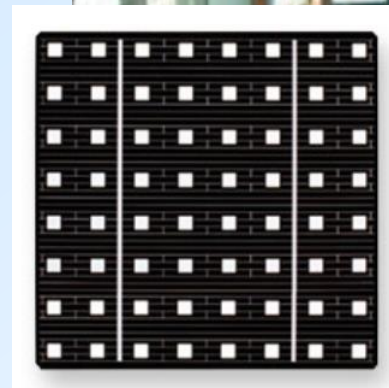
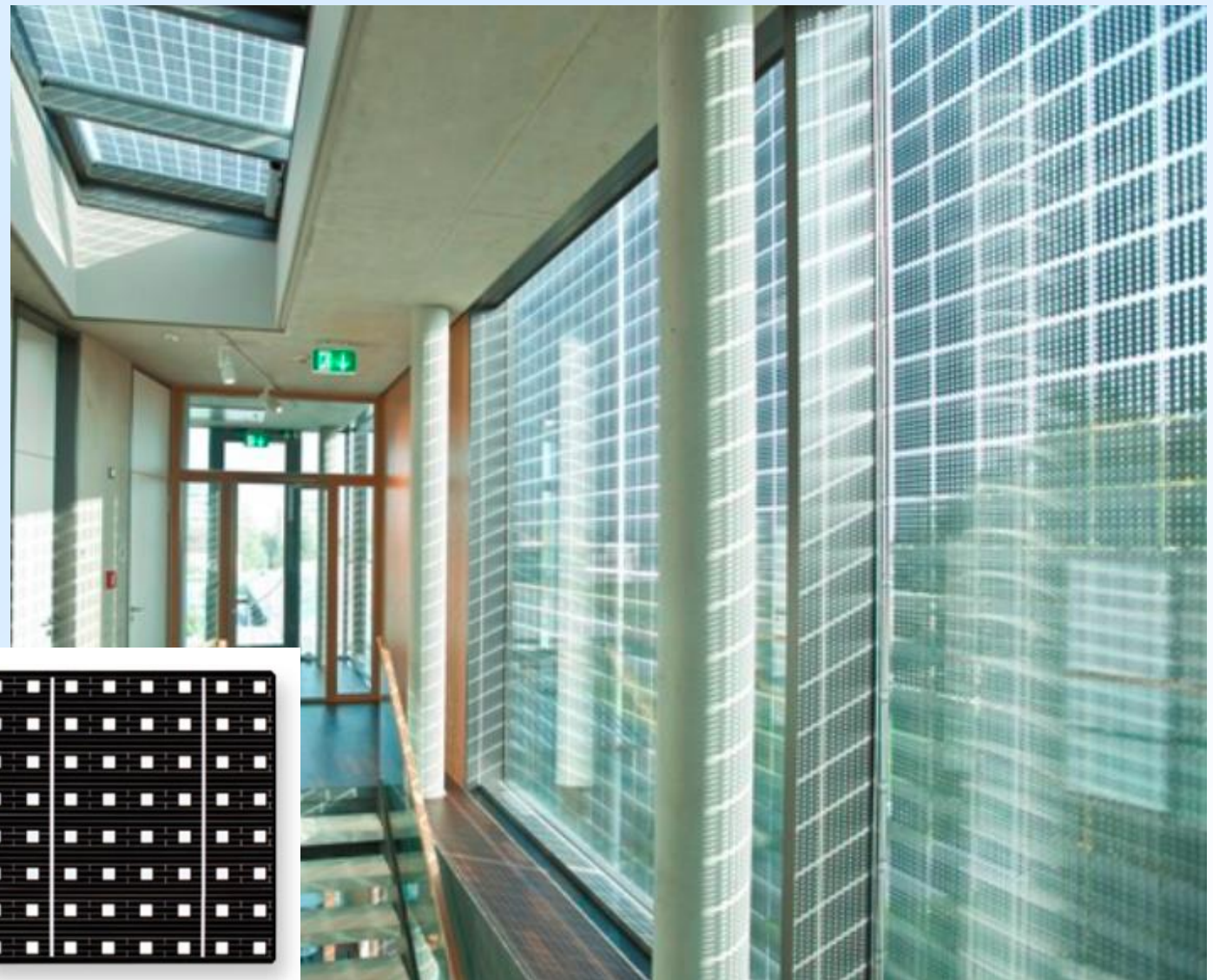
Customized see-through solutions in mono-Si and pc-Si

...or just cut the cell



Source: www.terrecielenergies.com

**Cell spacing adapted to lighting,
heating and cooling requirements**

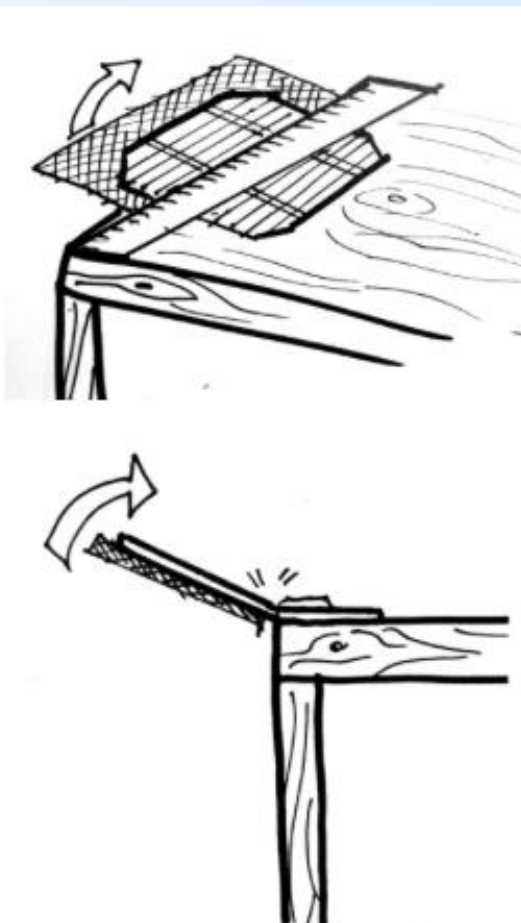


Source: www.sunways.com

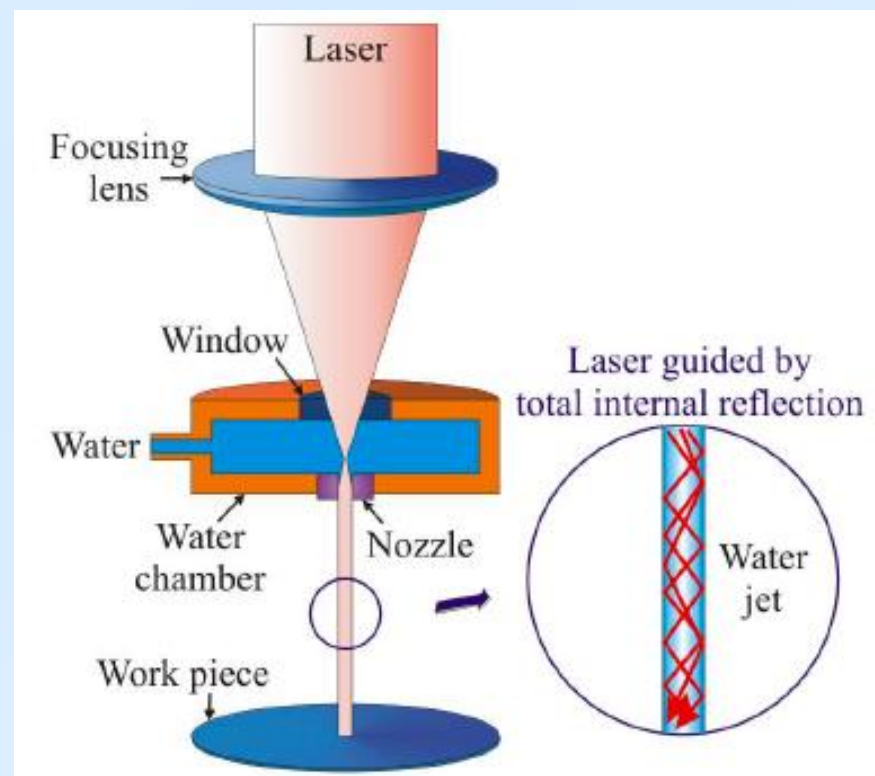


Customized see-through solutions in c-Si (m-Si and pc-SI)

For cell cutting some technologies are available



Source: www.mit.edu

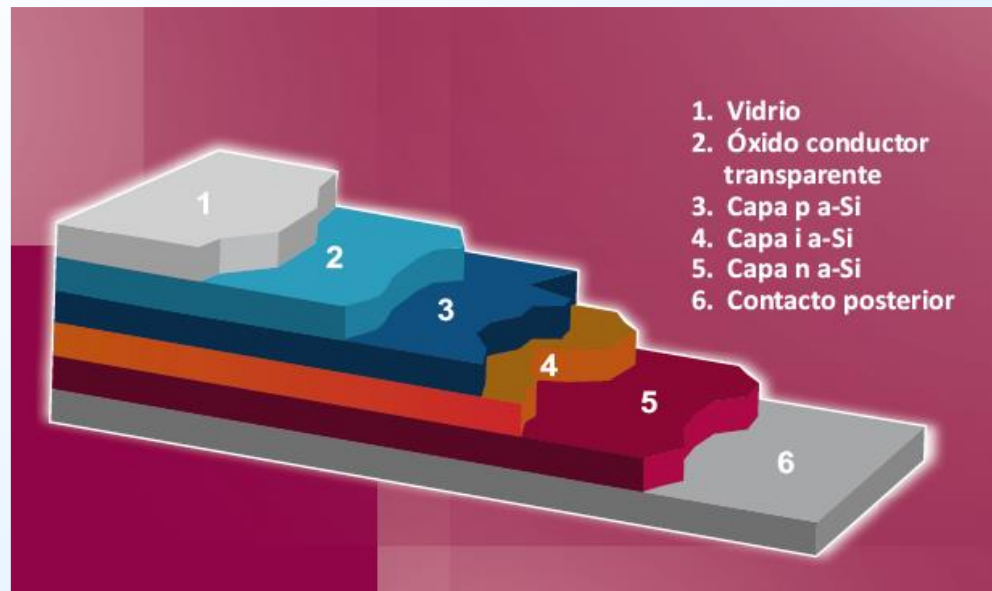
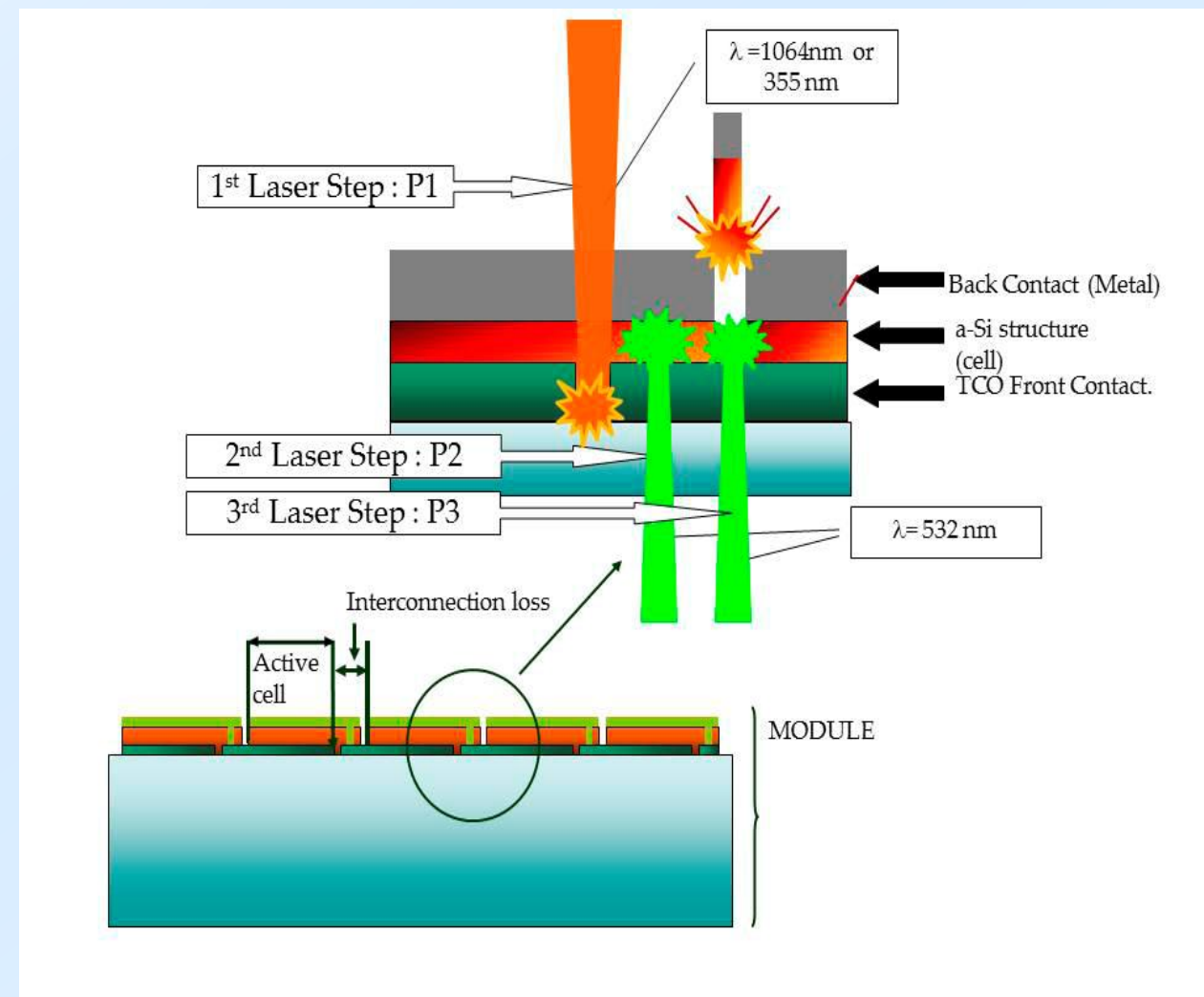


Source: www.synova.ch

Problems:
Cost
Throughput
Cell degradation
Cell fragilization



TF a-Si technologies are specially well suited to be used in BIPV

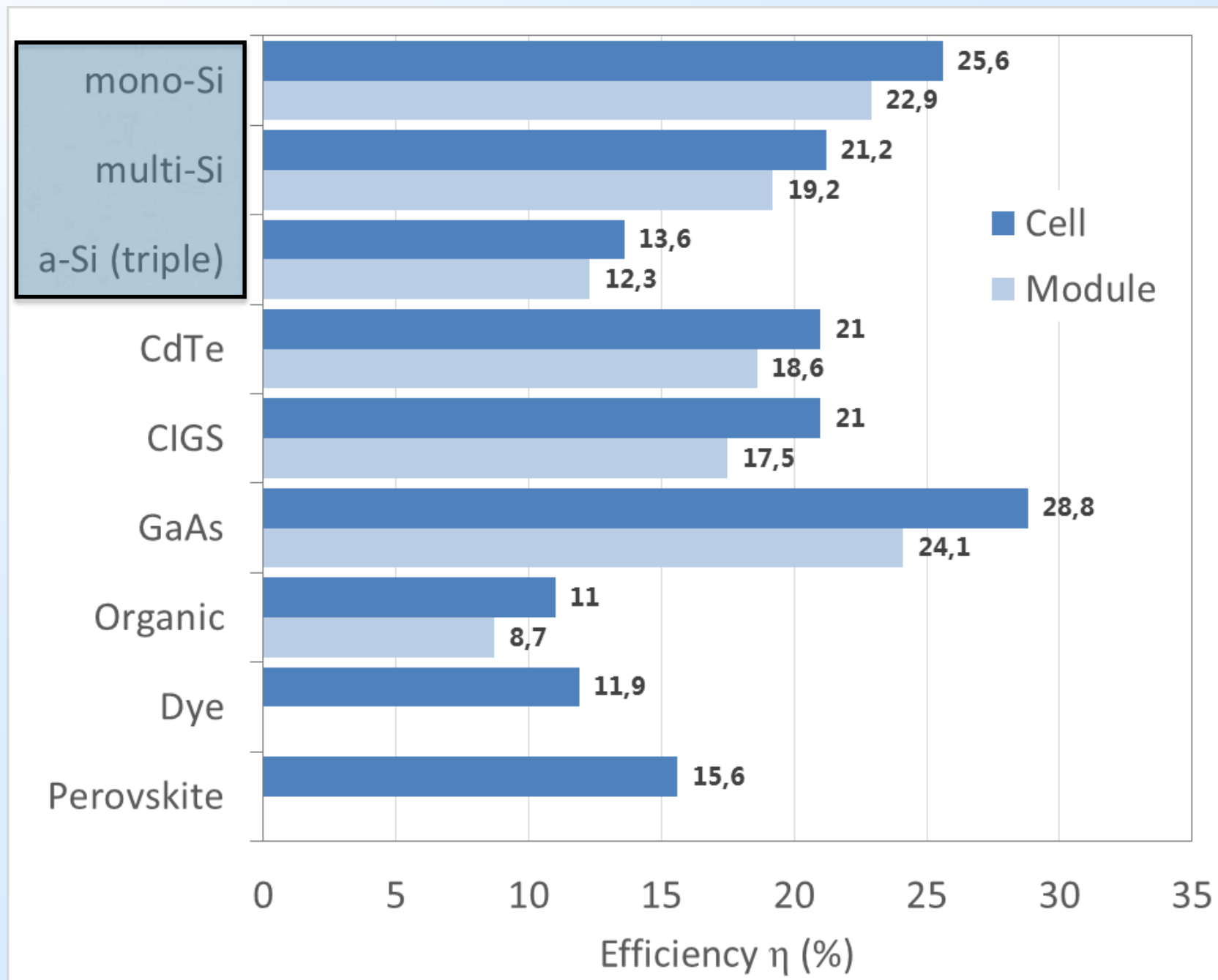


In addition P4 processes in which all layers are removed can be considered

Use standard well-known laser processes to obtain products with an added value for BIPV applications



Source: Kaneka (www.kaneka-solar.com)

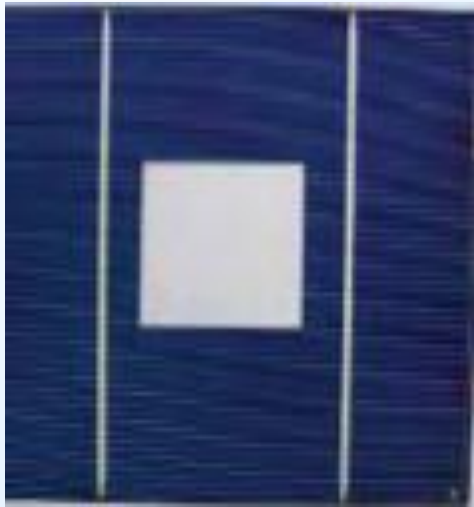


Source: Green et al. Solar Cell Efficiency Tables (Version 47), Progress in PV: Research and Applications 2016

In this work we present examples of see-through BIPV devices
with a high degree of customization



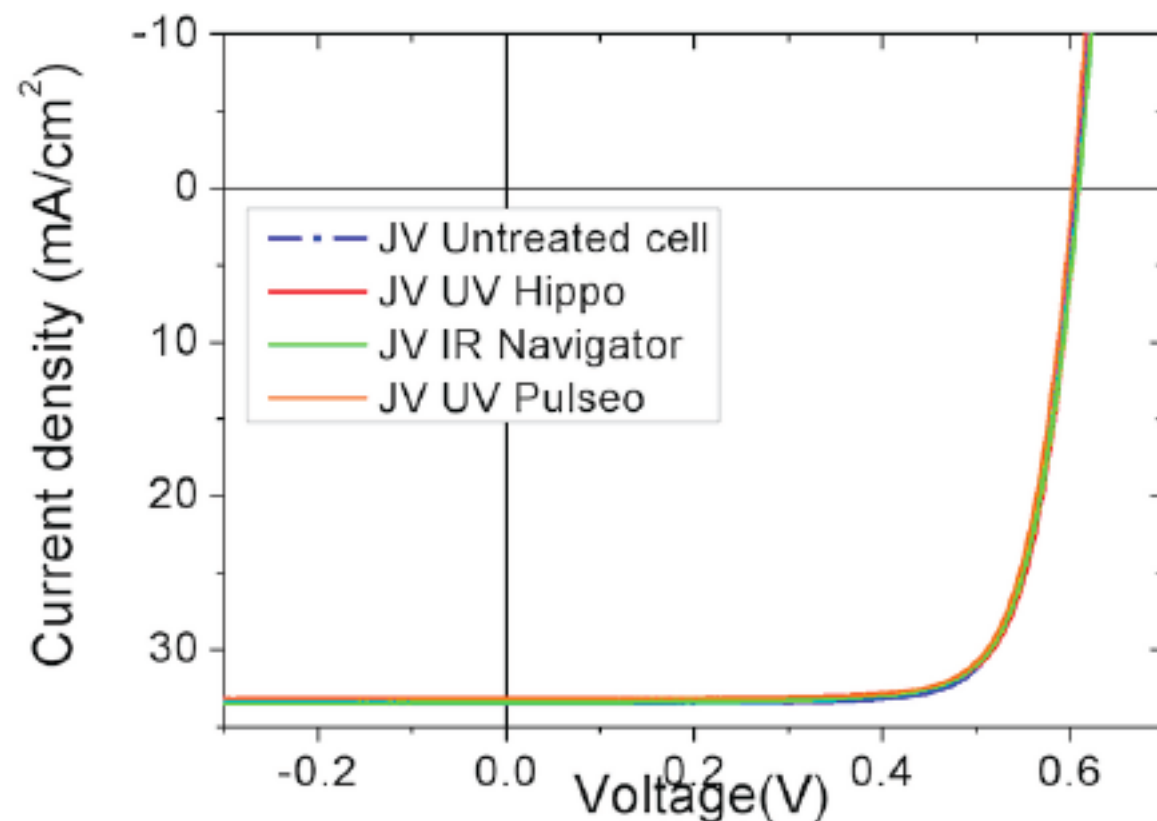
50 mm x 50 mm
square in 6" cells



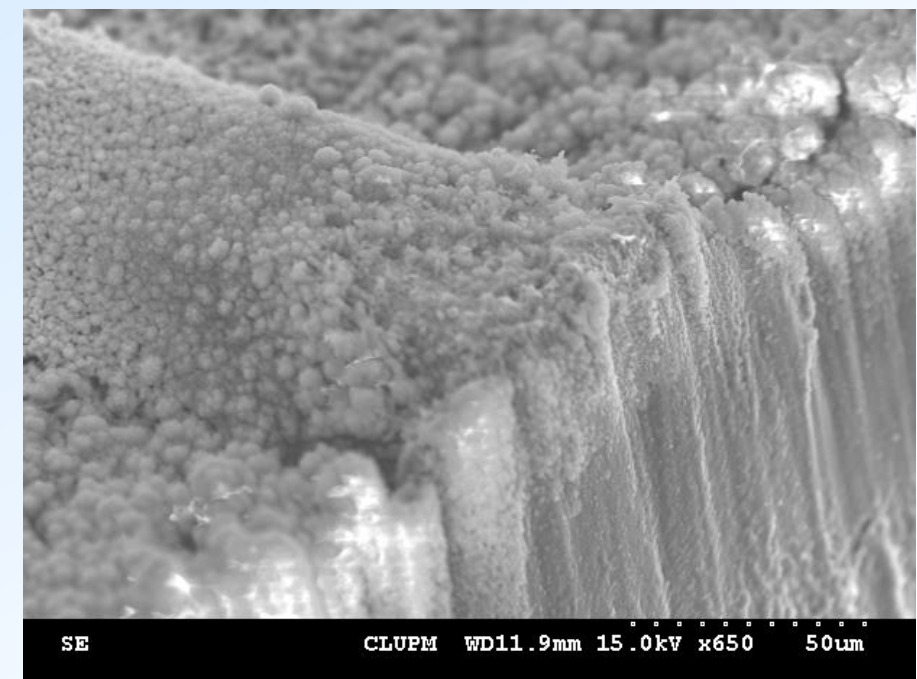
Laser and Optics	λ (nm)	Pulse width (ns)	Spot Size in sample (mm)	Scanner field
Spectra Physics X15 Navigator + Ray Laser SuperScan 2	1064	15	45	150 mm x 150 mm
Spectra Physics Hippo + ScanLab HurryScan	355	15	30	120 mm x 120 mm
Spectra Physics Pulseo + fix optics	355	38	28	-

λ (nm)	Rep. Rate (Hz)	Spot Size (mm)	Pulse Energy (mJ)	Process Speed (mm/s)	Number of Repetitions
1064	20000	45	235	6	7
355 (scanner)	50000	28	90	30	25
355 (fix opt.)	50000	30	200	3	3

Results: c-Si customized modules

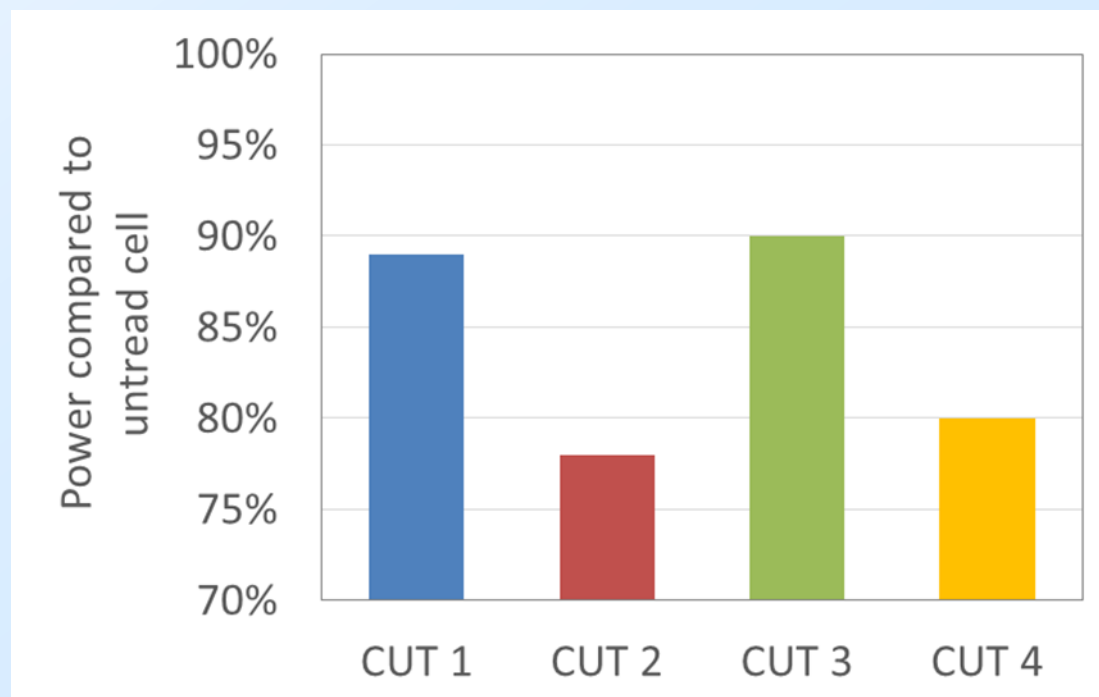
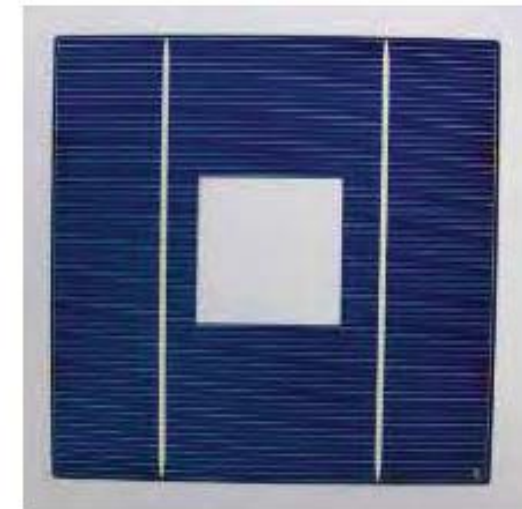


Thicknnes 230 μ m (m-Si and pc-Si)



A battery of experiments were run to select the appropriate geometry.

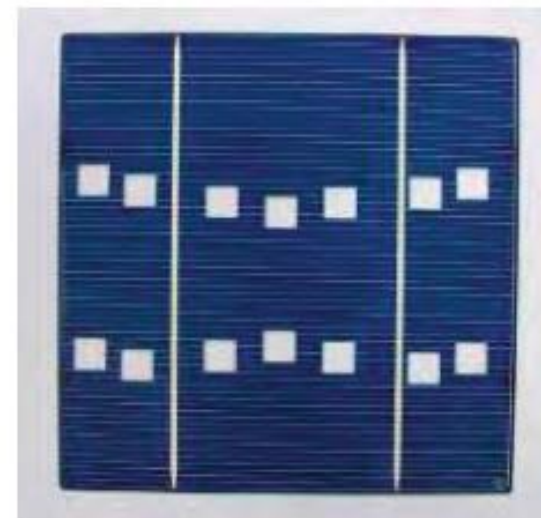
Different designs affect in a different way to the final power of the solar cell.



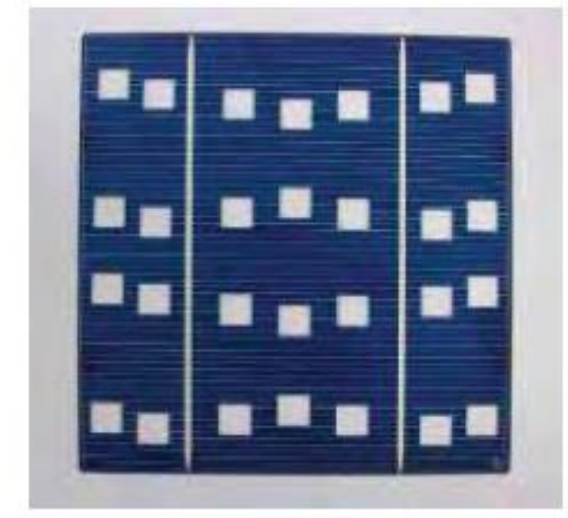
CUT 1
Square size 50 mm x 50 mm



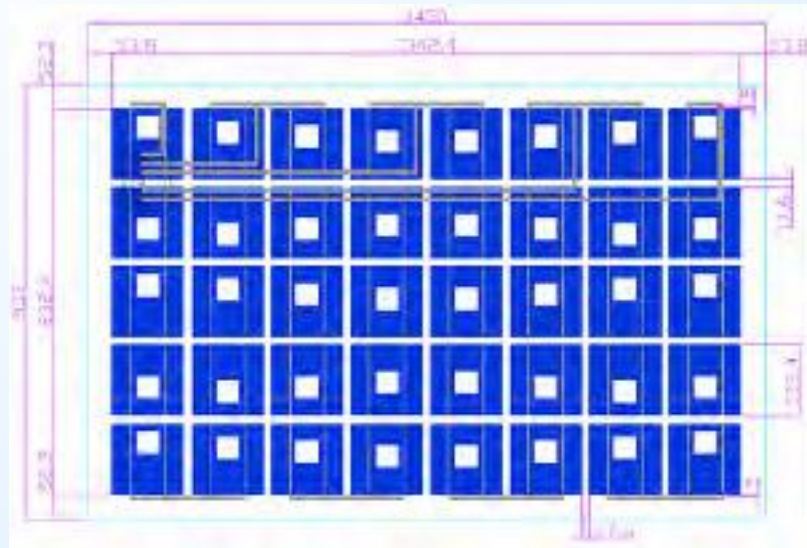
CUT 2
Rectangle size 96 mm x 50 mm



CUT 3
Squares size 11mm x 11mm



CUT 4
Squares size 11mm x 11mm



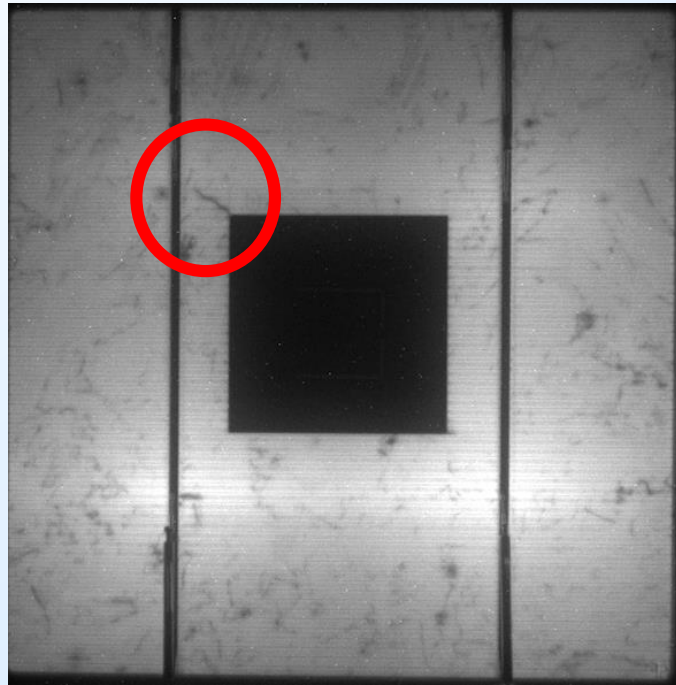
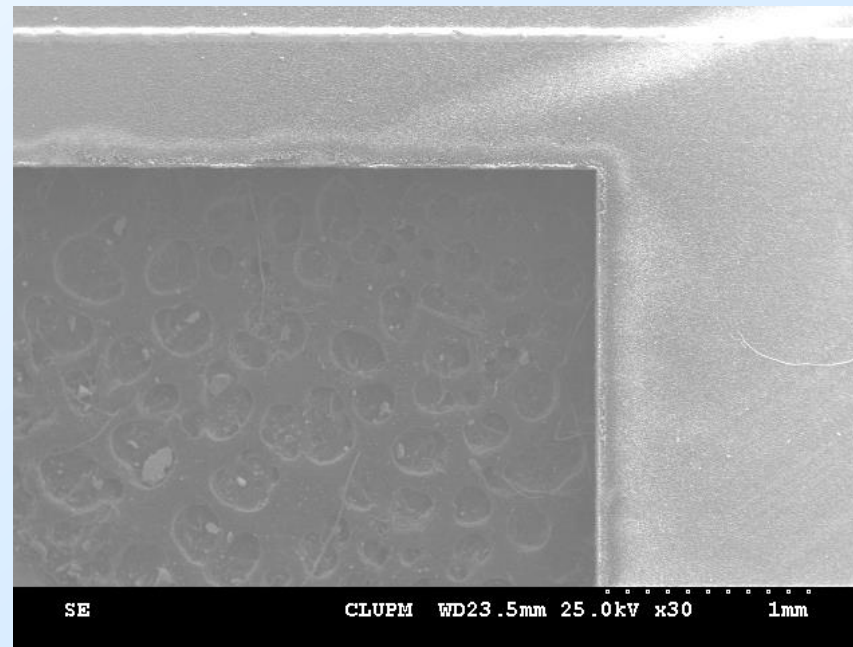
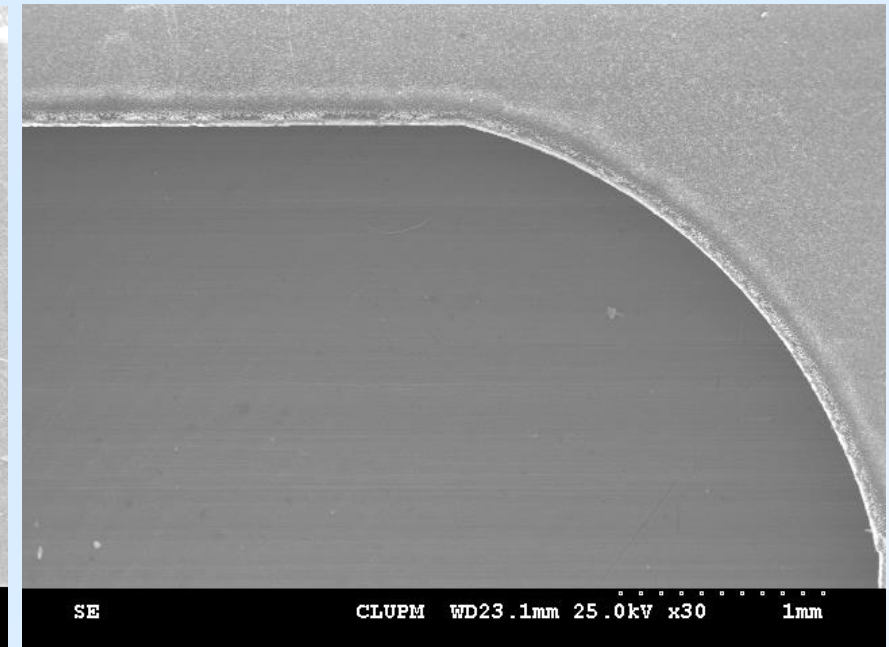
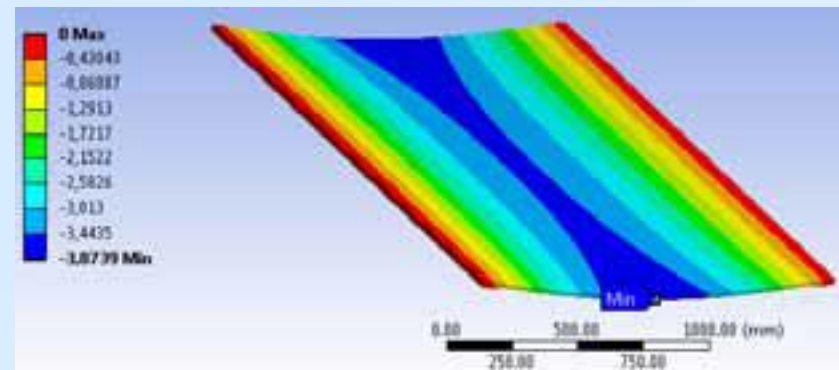
MODULE DATA

$$\begin{aligned} I_{sc}/I_{mp} [A] &= 7.26/6.70 \\ V_{oc}/V_{mp} [V] &= 25.62/19.16 \\ F.F. &= 0.718 \\ \text{Cell eff. [\%]} &= 8.79 \\ \text{Module eff. [\%]} &= 7.91 \end{aligned}$$

For measurements a standard 6" pc-Si module was used as reference

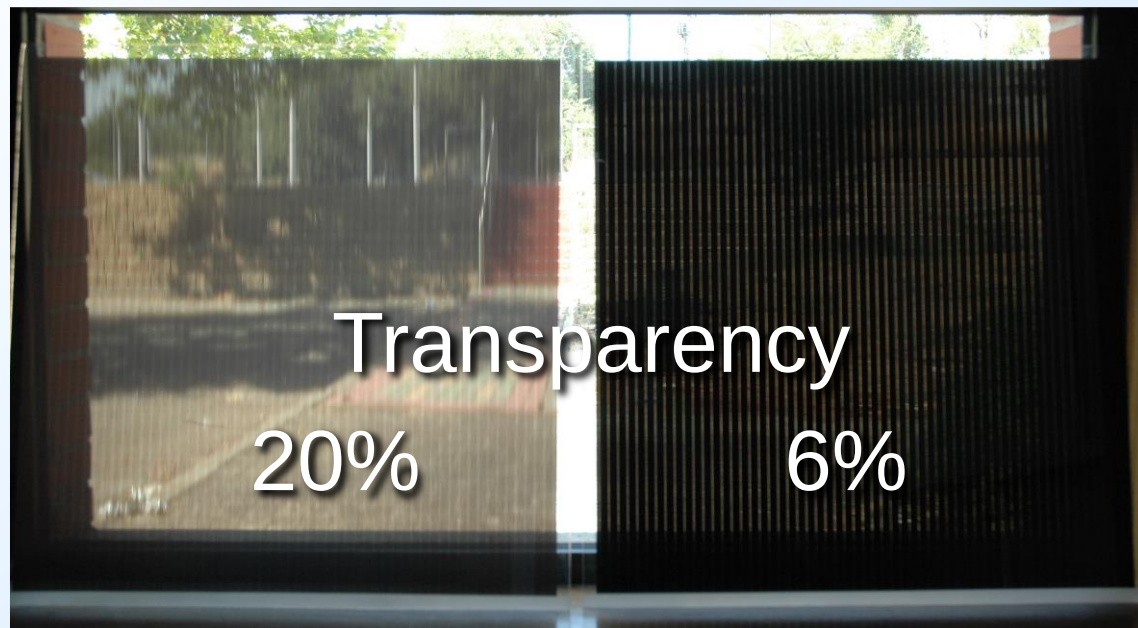
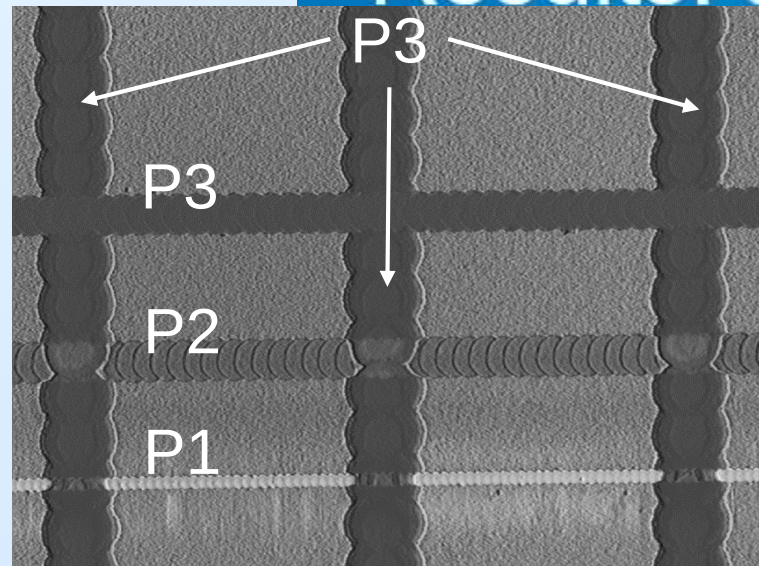
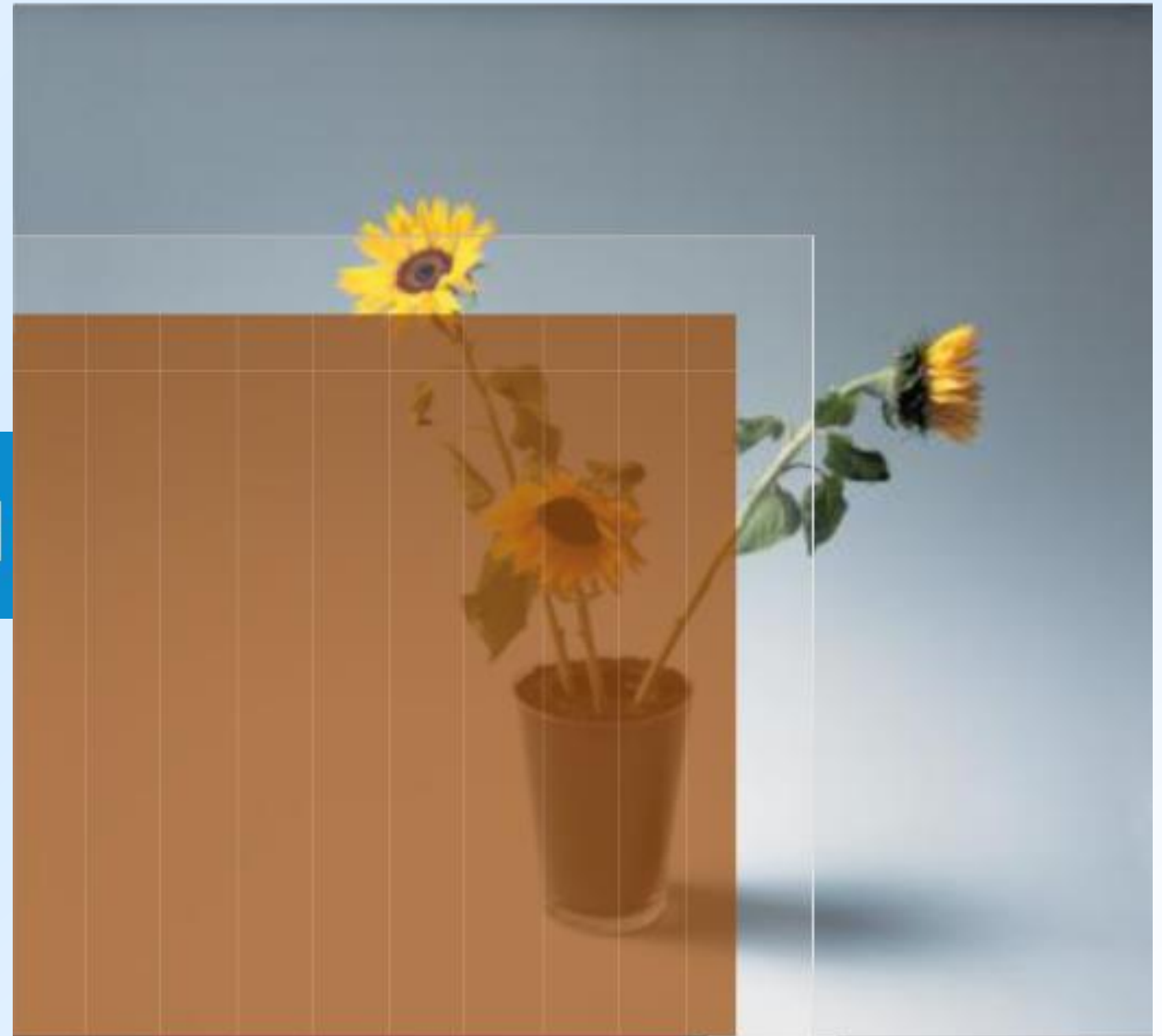


Electroluminescent measurements shows good cutting quality but some micro crack formation



Deformation without rupture: 0.1 mm/mm
Max. deformation amplitude in cell 12 mm

Amorphous silicon (a-Si) modules use lasers as standard tools for module fabrication

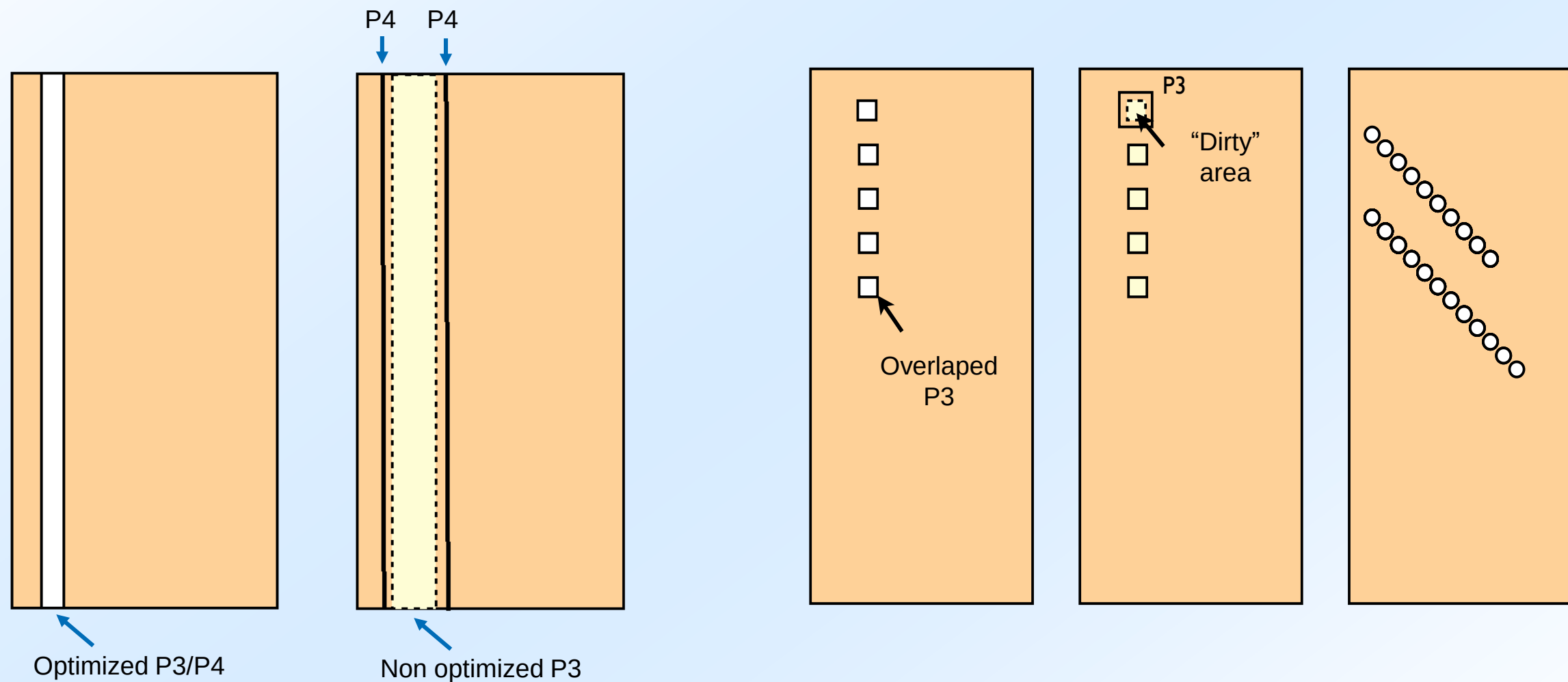


Usually semitransparencies are achieved doing P3 processes perpendicular to the interconnection processes.

The accumulation of P3 degrades the module. For that reason the degree of transparency is usually $< 10 \%$.



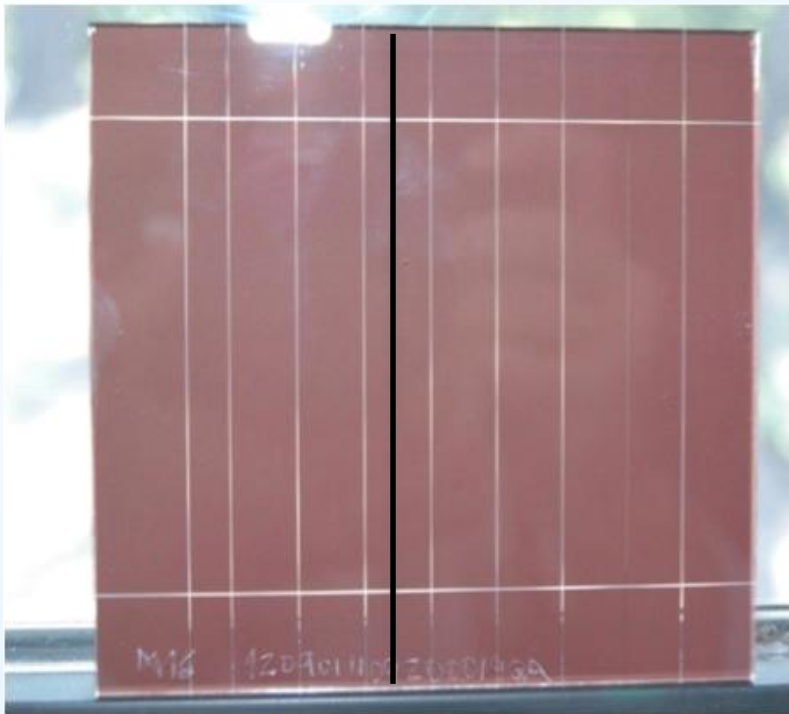
New approaches try to find solution for higher throughput and/or customized designs:



The use of optimized P3 or P4 processes allows the possibility of isolate areas cleaned using non optimized processes

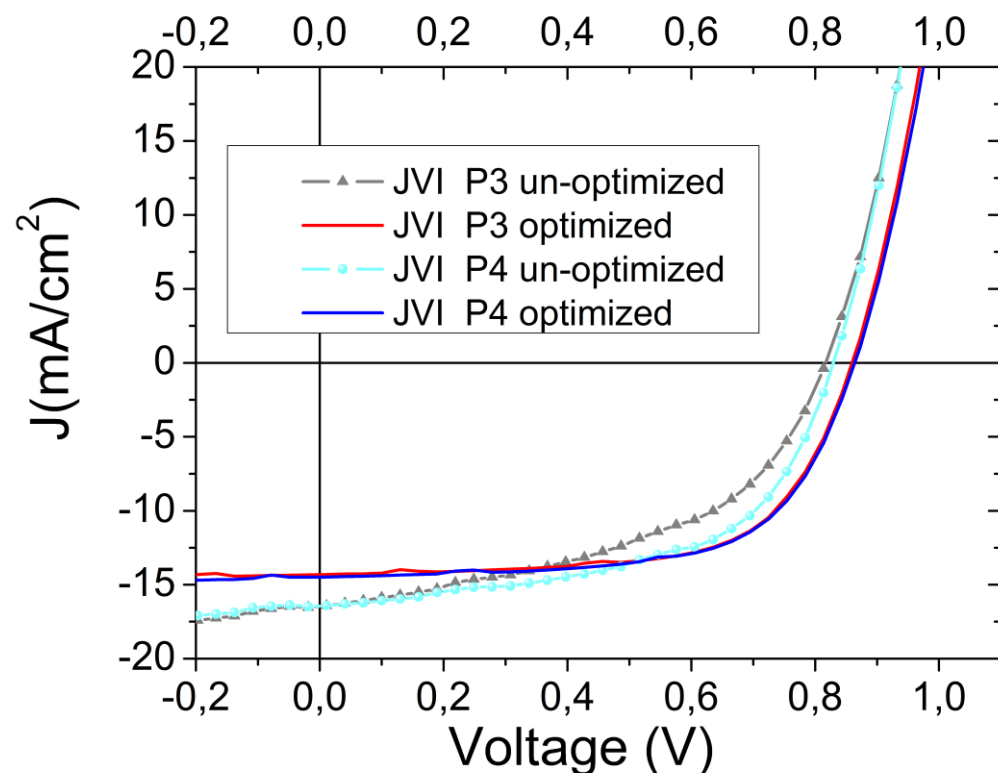
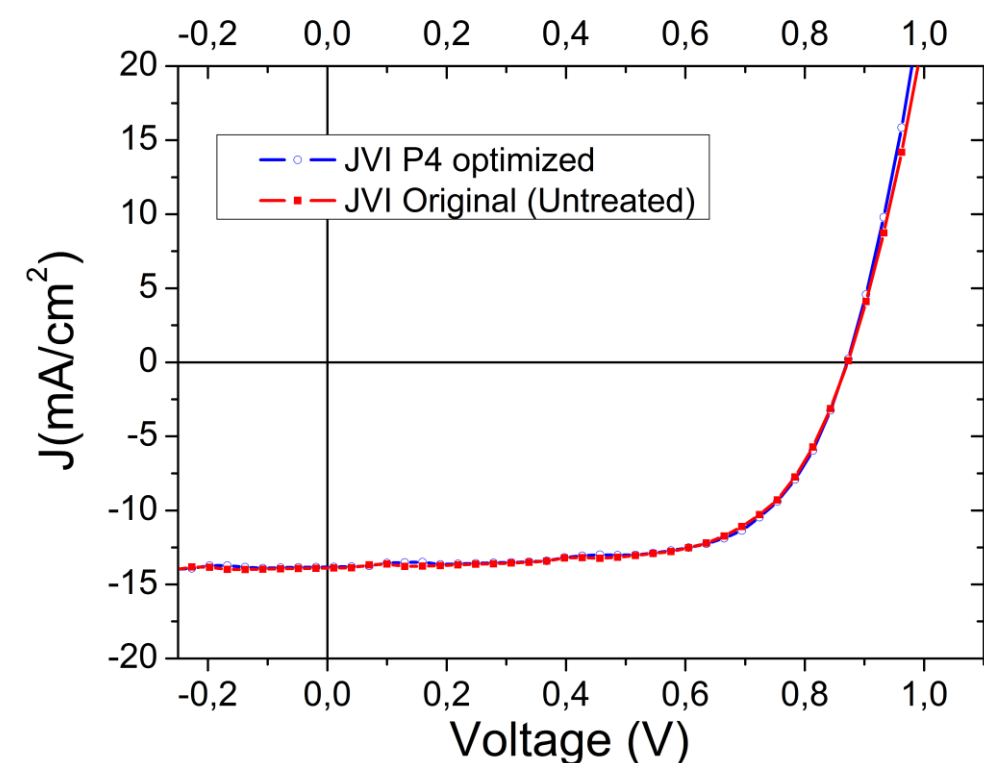


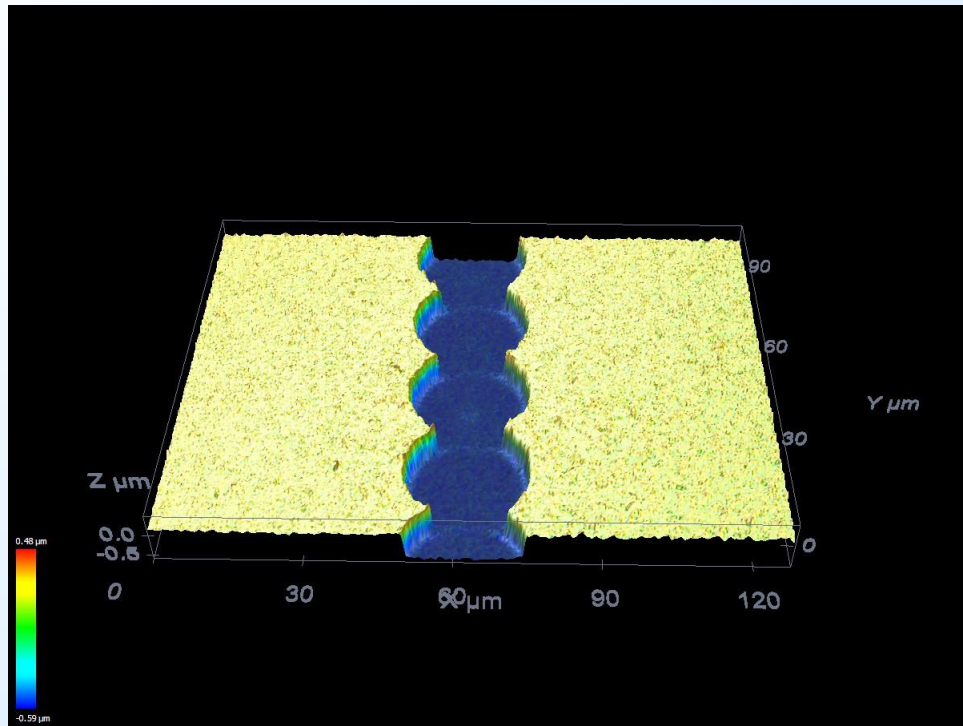
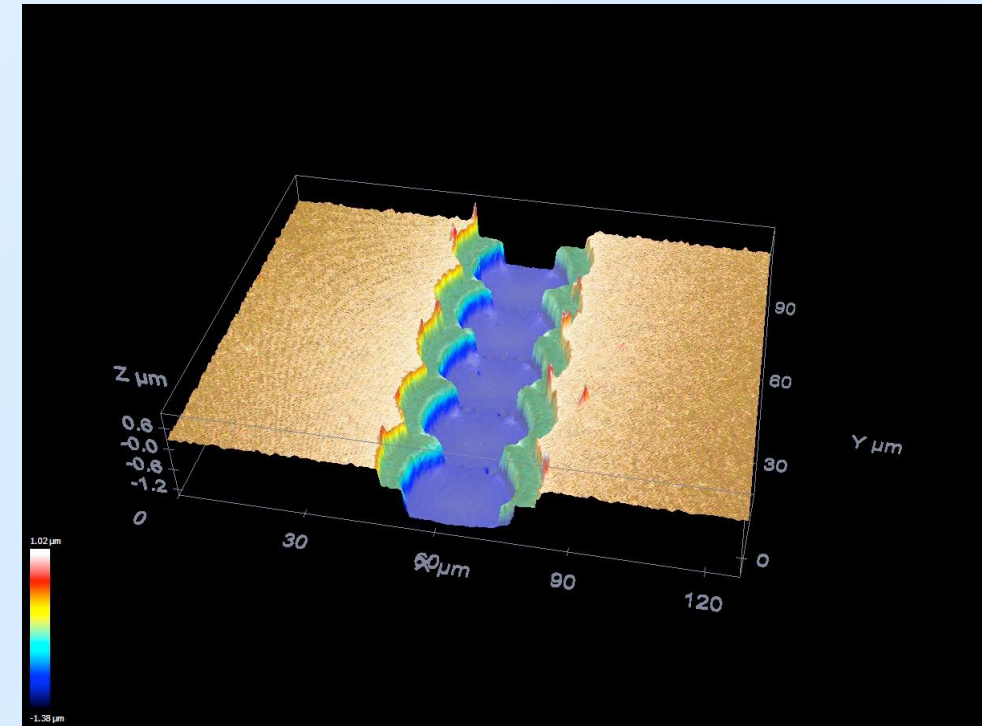
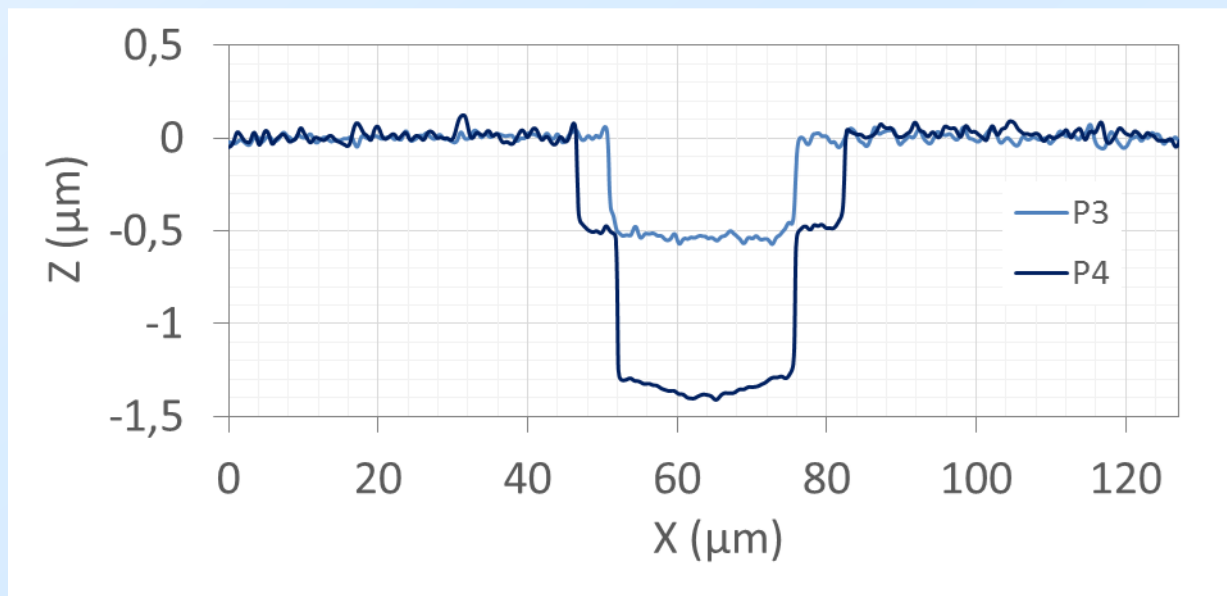
Minimodules 100 mm x 100 mm



Lasers and Optics	Wavelength	Pulse width	Spot Size in sample	Scanner field
	nm	ns	μm	
Spectra Physics Explorer + ScanLab HurryScan	532	15	25-48	150 mm $\times$ 150 mm
Powerlaser Naos i20-M + Raylase AXIALSCAN-30-Y	1064	50	50-80	600 mm $\times$ 600 mm

Layer	Material	Thickness (μm)
Front contact	Asahi-U ($\text{SnO}_2\text{:F}$)	800
Absorbent	<i>p-i-n</i> a-Si	300
Back contact	Aluminium	150





Process parameters (532 nm)

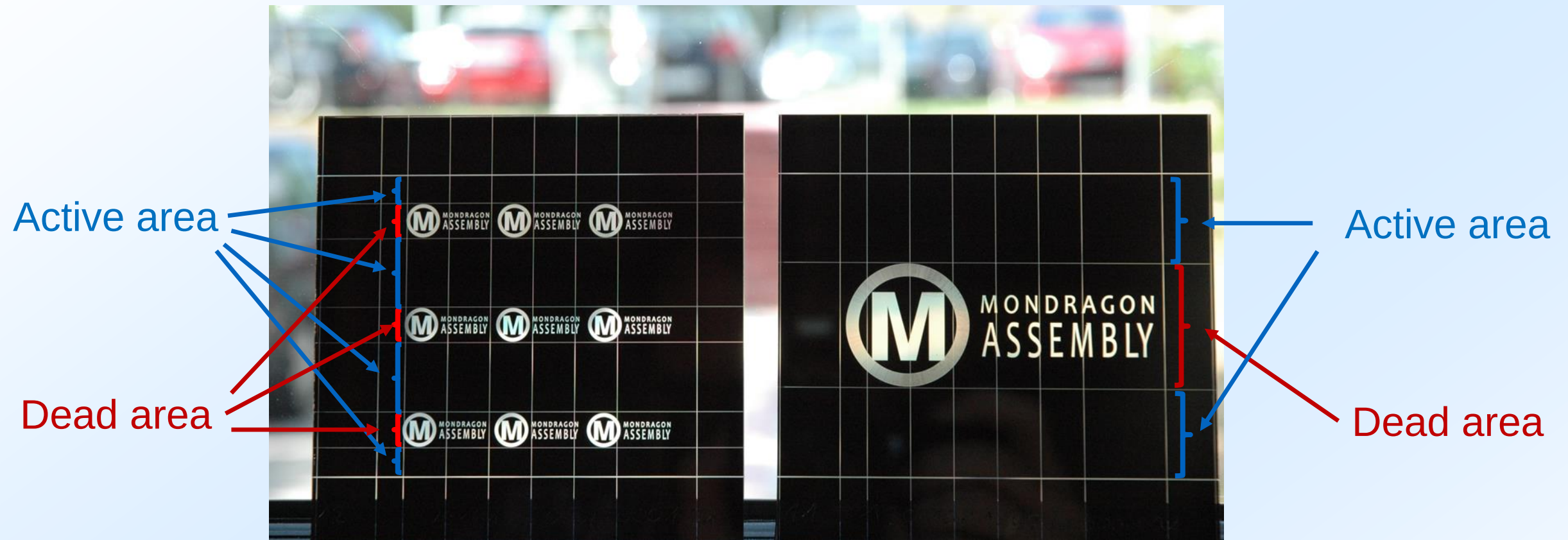
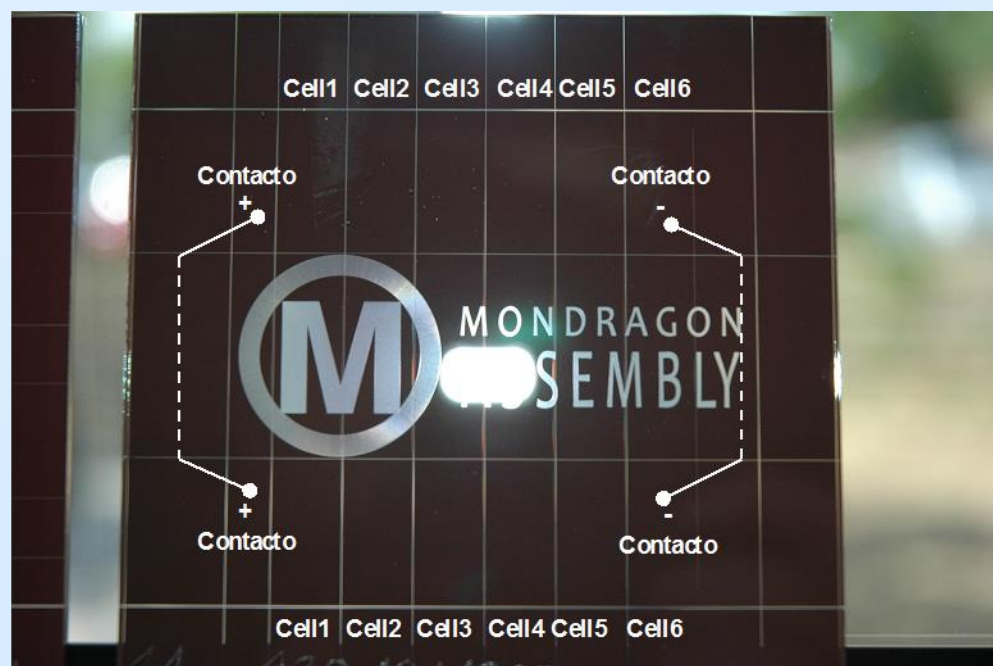
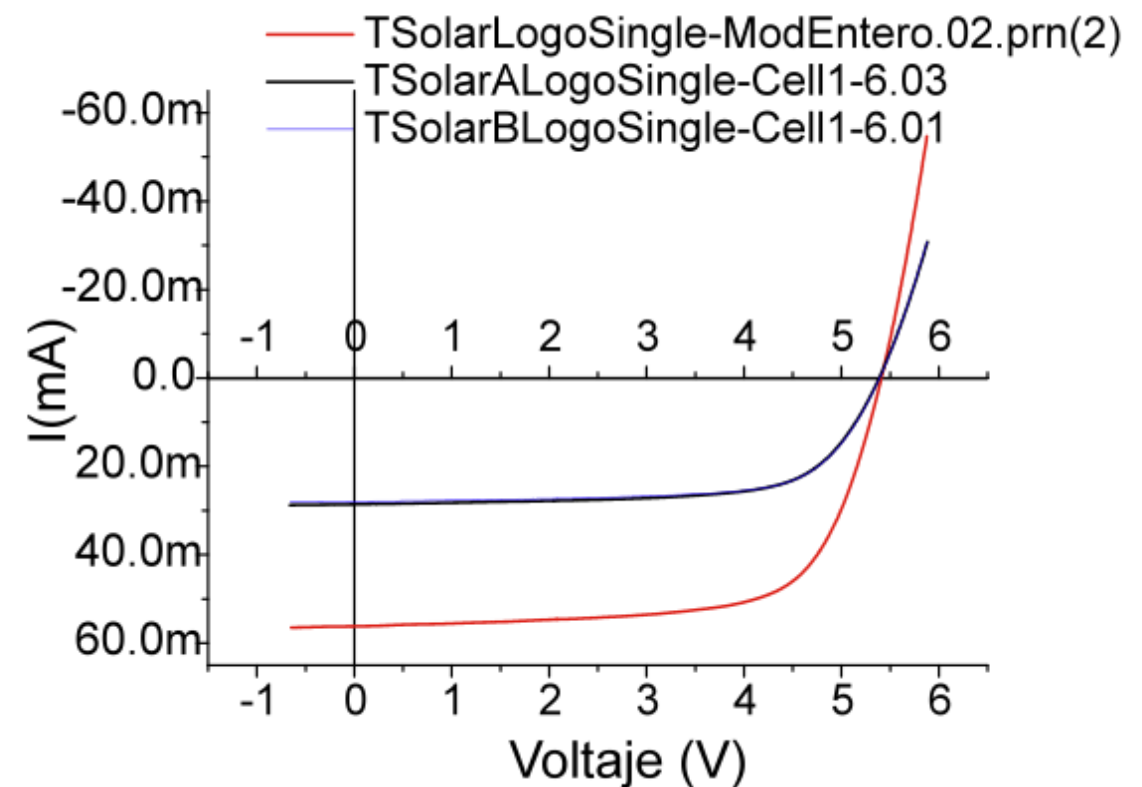
P3:

Spot size: 25 μm
Repetition rate: 50 kHz
Process velocity: 1.16 m/s
Pulse energy: 4 μJ

P4:

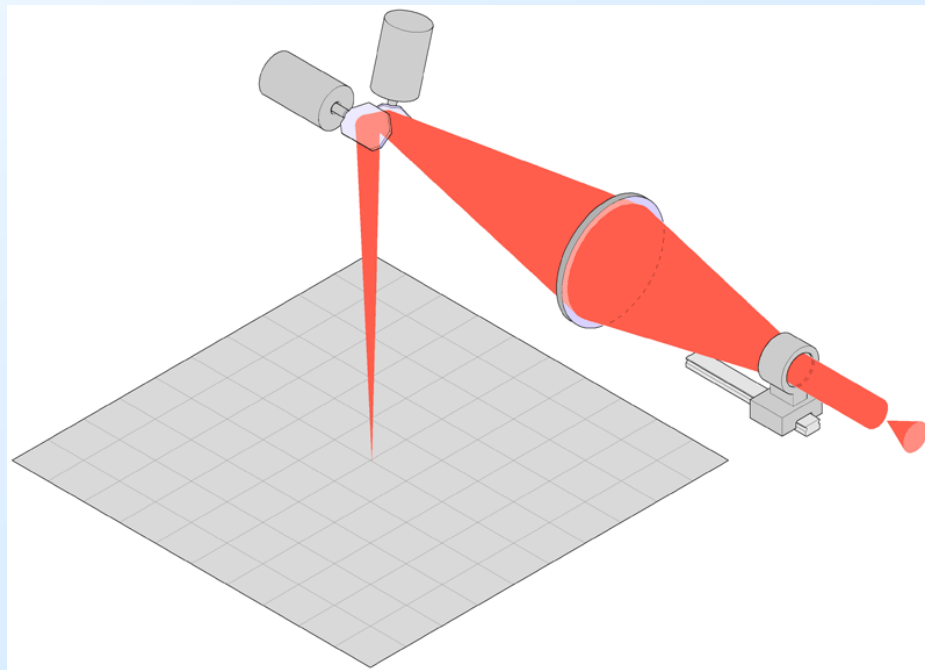
Spot size: 25 μm
Repetition rate: 50 kHz
Process velocity: 1.00 m/s
Pulse energy: 20 μJ

Optimized P3 and P4 processes





New 3D digitally controlled galvo scanners offer large processing areas, offering the possibility of applying our concept to full size modules.

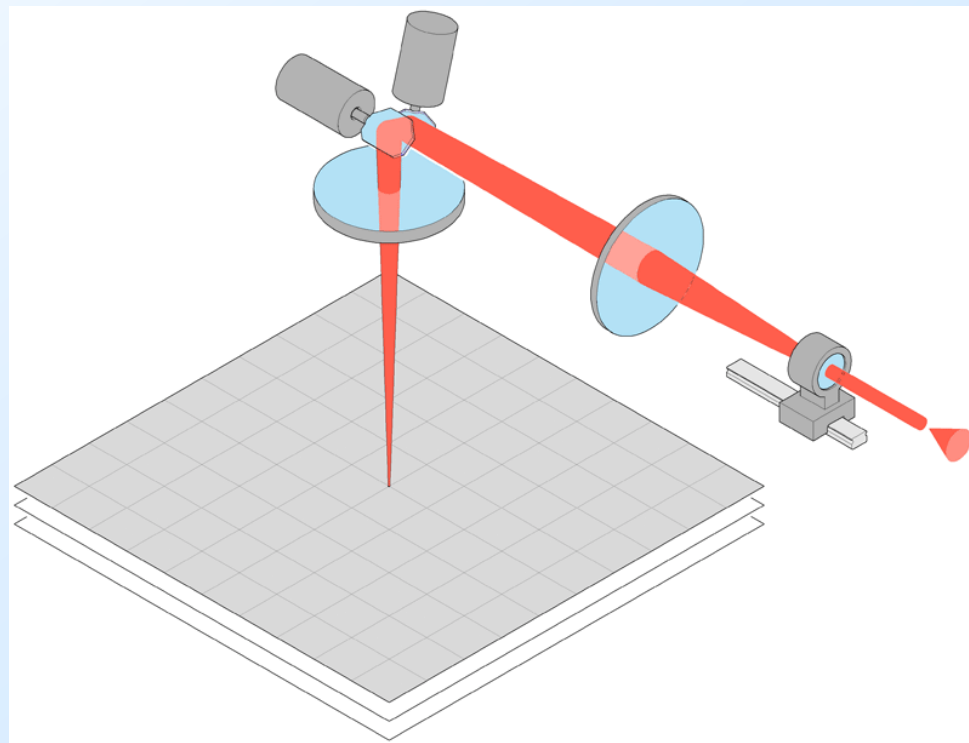
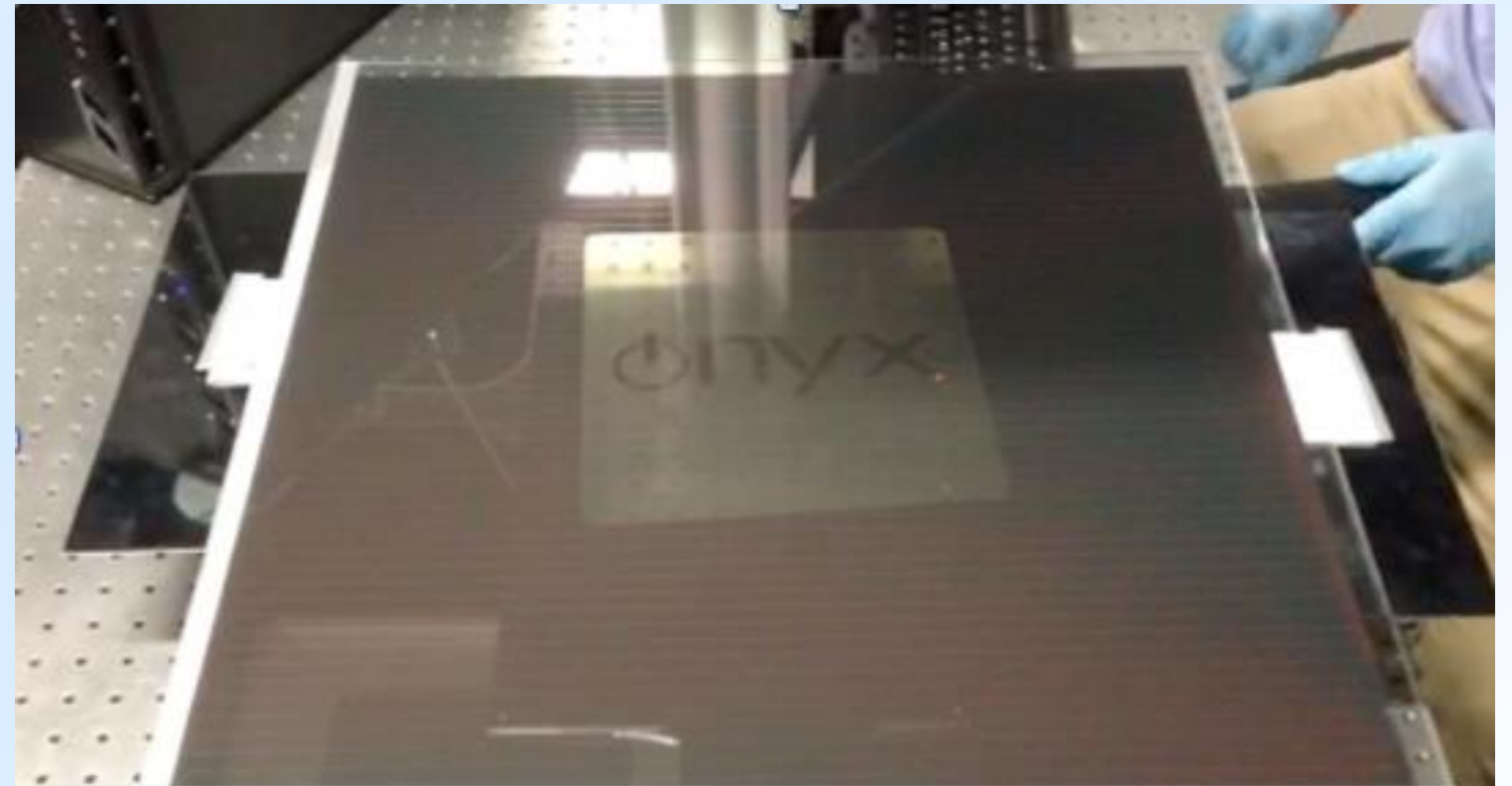


Source: www.raylase.de





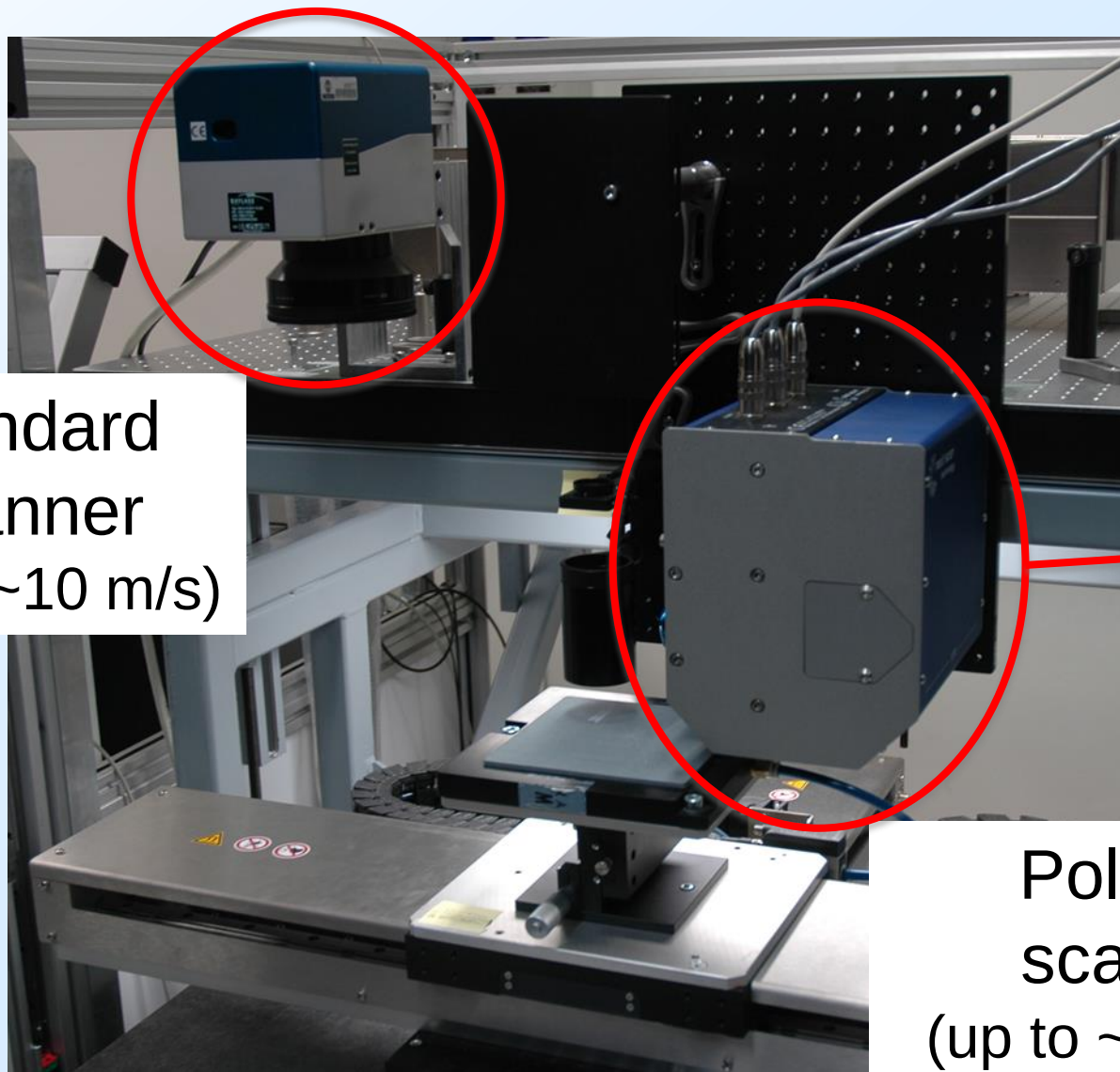
After logo scanning with not optimized laser processes we isolated this part with optimized ones.





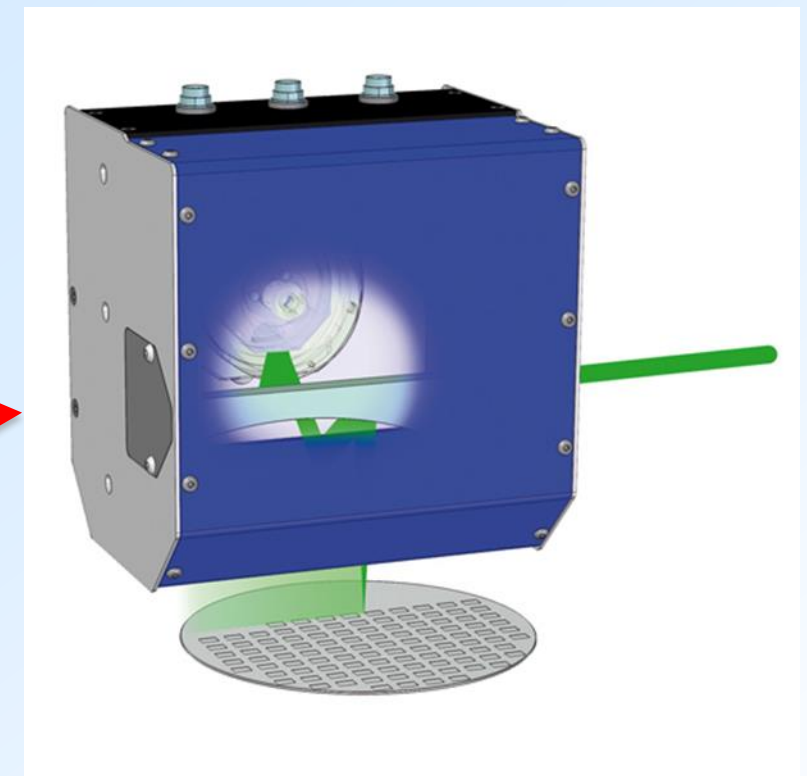


New technologies advances, as the use of polygon scanners, can make a laser process profitable for the industry.



Standard
scanner
(up to ~10 m/s)

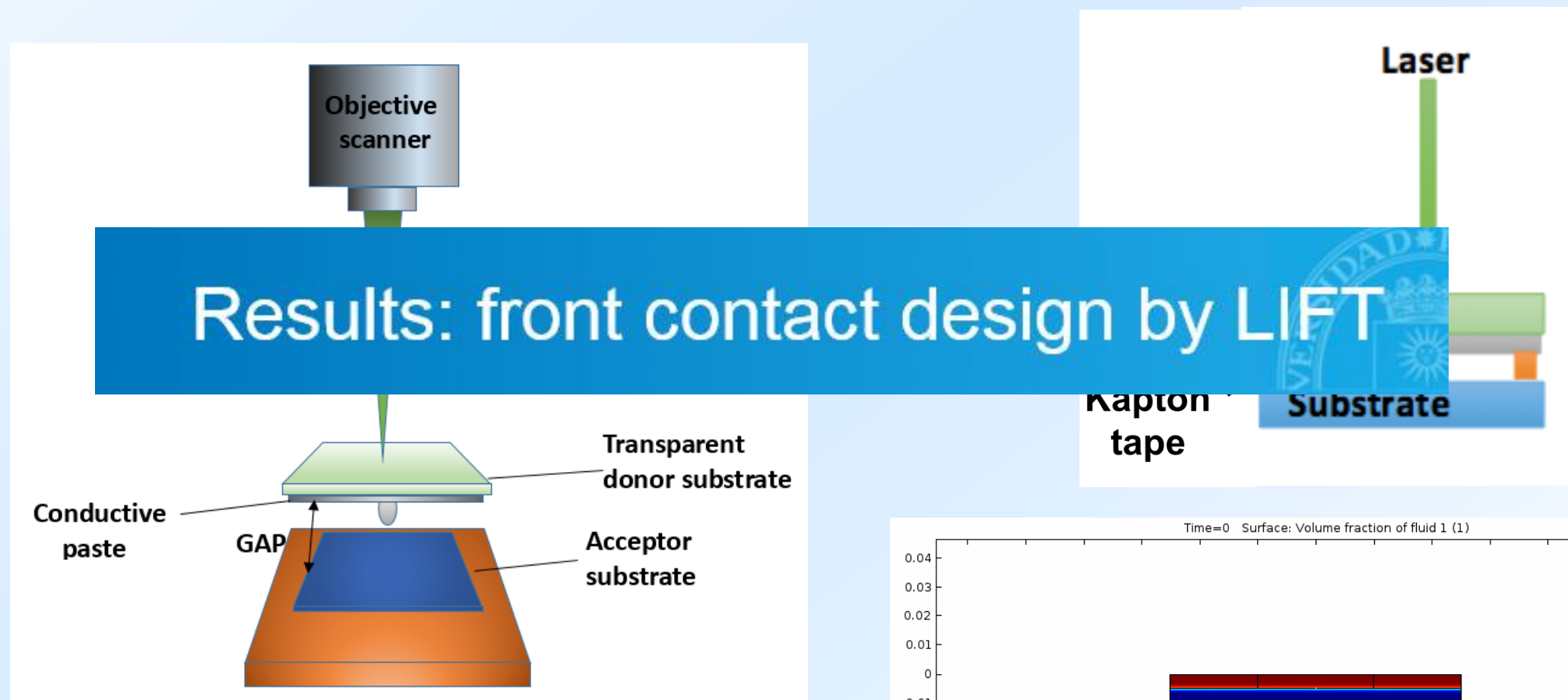
Polygon
scanner
(up to ~100 m/s)



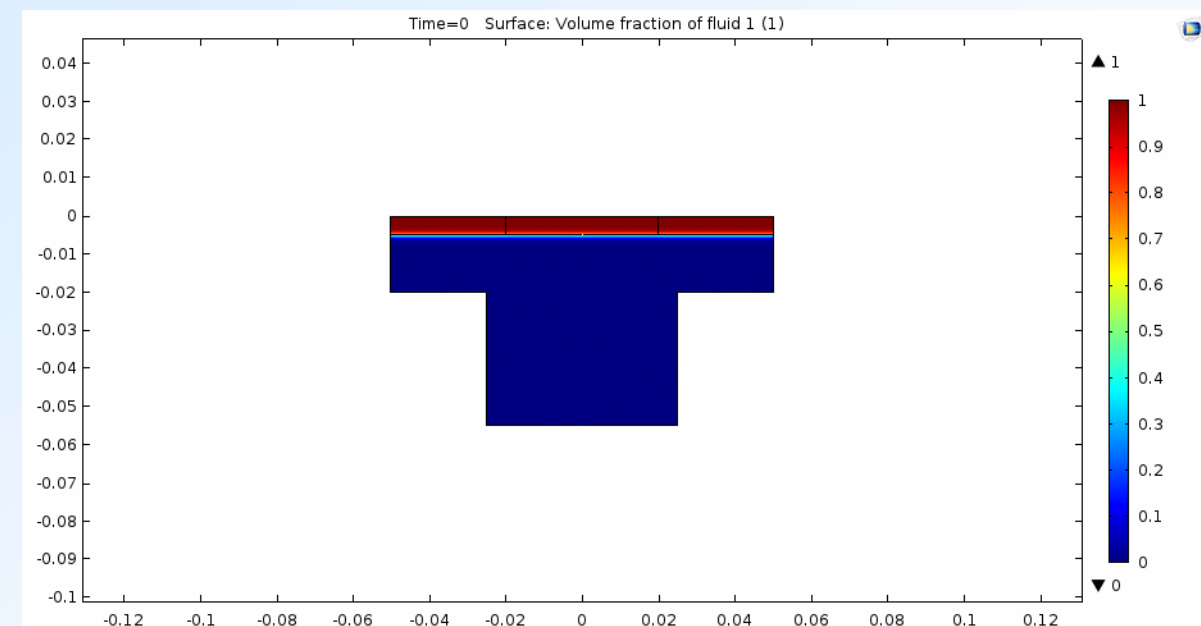
Source: <http://nextscantechnology.com/>

We are right now studying laser processes with this kind of systems.

Laser-induced forward transfer (LIFT) is a direct-write laser technique capable of transferring a number of materials (solid materials, conductive inks, biomaterials, living cells,...)



Easy setup, high flexibility in choice of printing contents and cost-effectiveness.

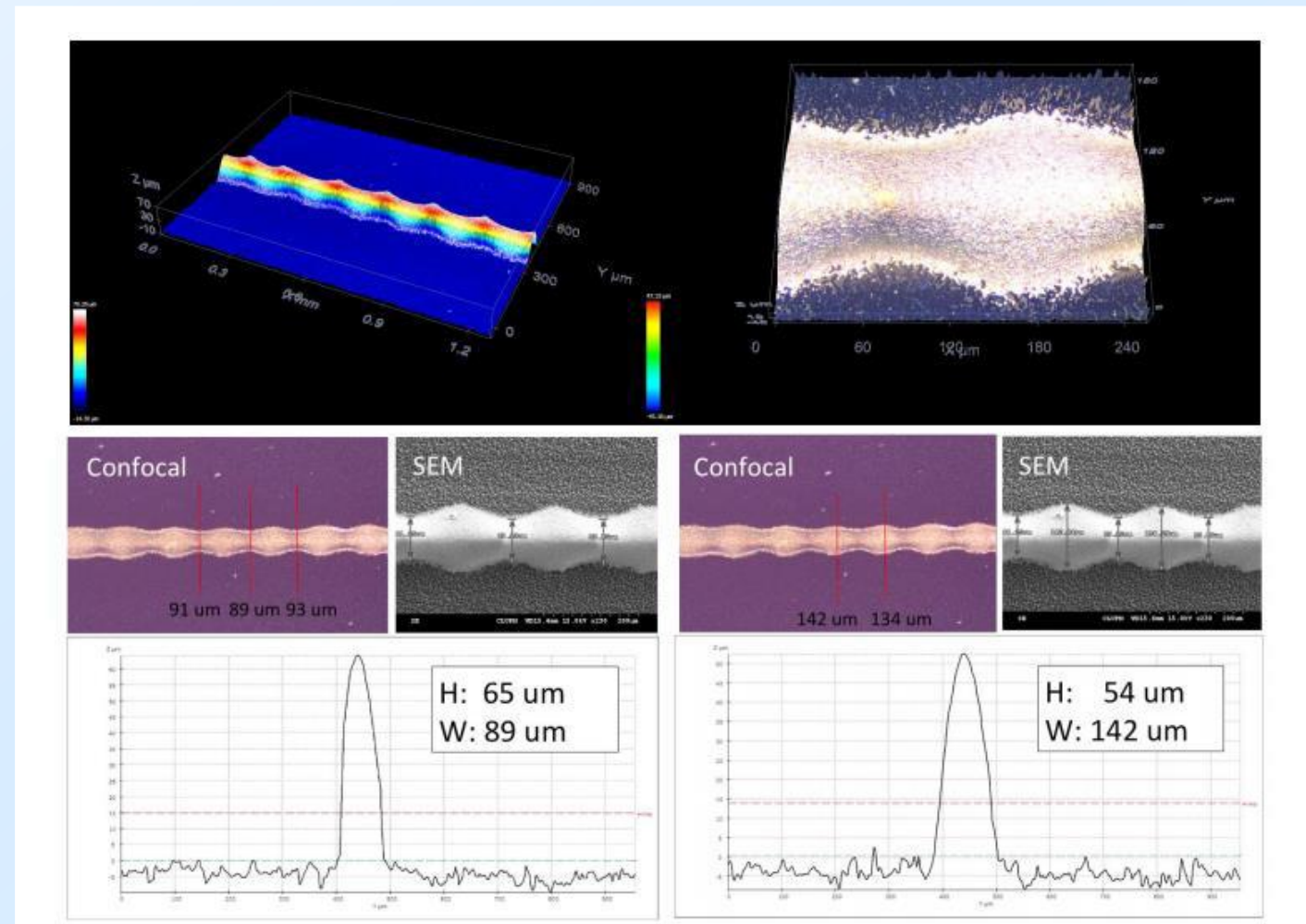
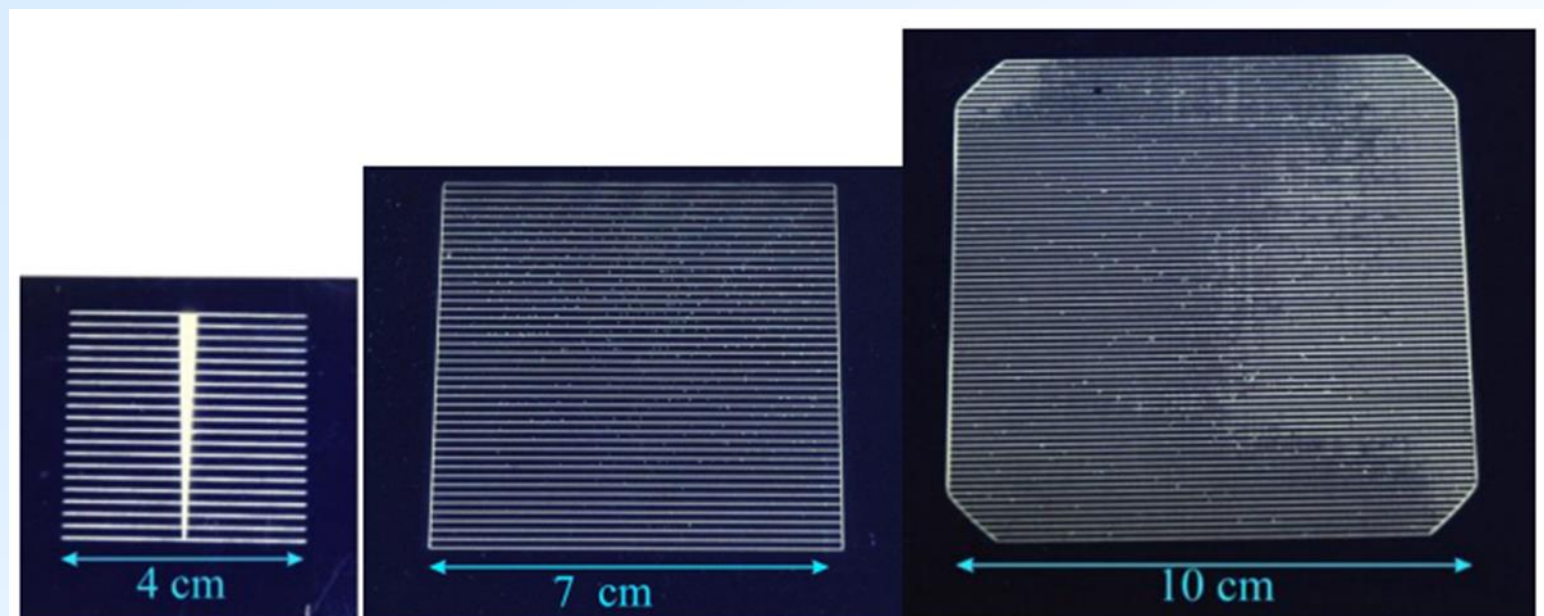




We have obtained long lines with high aspect ratio.

And make designs for the complete front contact metallization of solar cells.

Wavelength	532 nm
Pulse duration	14 ns
Frequency	20 kHz
Pulse energy	8-40 μJ
Spot size	25 μm
Silver paste thickness	30-80 μm
Gap	15-100 μm
Speed	0.05-2 m/s



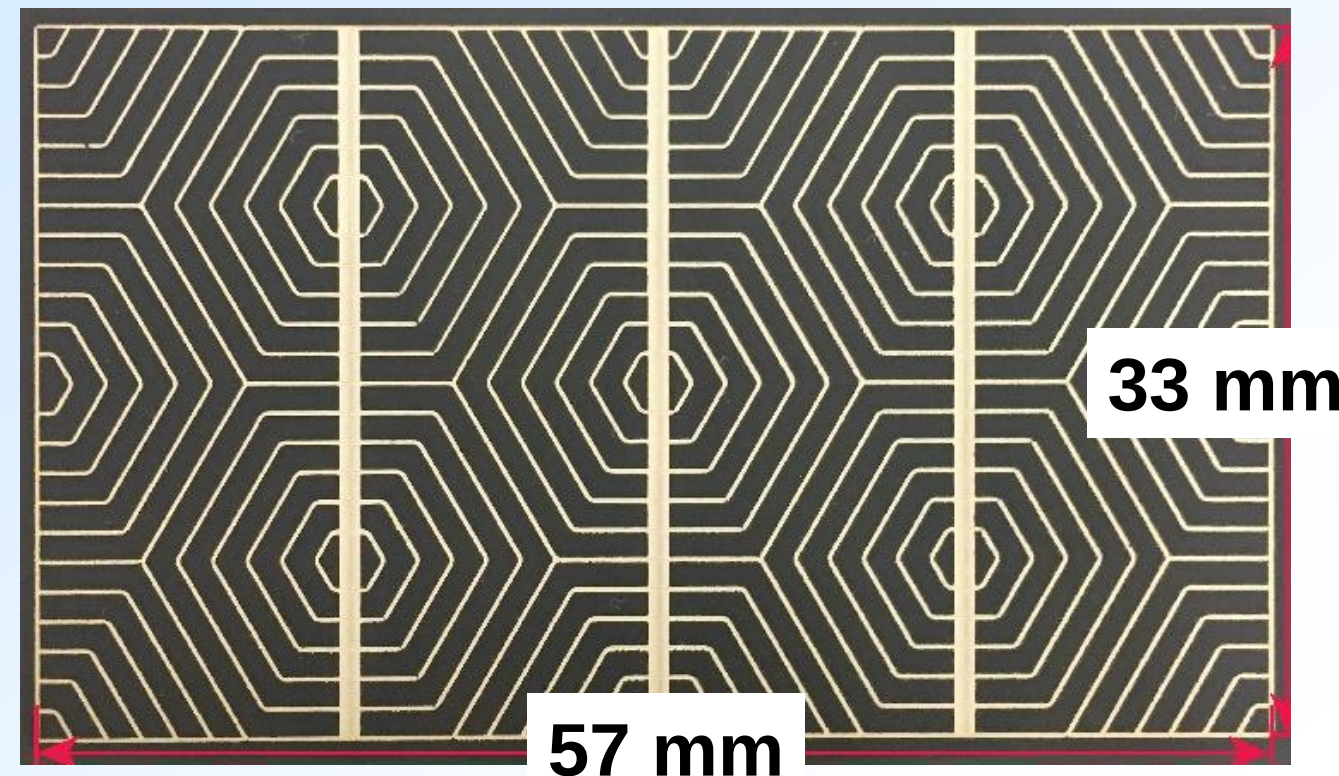


Results: front contact design by LIFT

Very versatile, allowing any
freeform design to be supplied to the solar
cells for personalization



Allow the use of complex
metallization patterns that can be
directly printed on the solar cell with
large velocity.





- We have shown that customized see-through modules using laser technology can be done in both wafer based and thin-film based PV technologies
- Two fundamental requirements in BIPV: cost and aesthetical customized effects can be obtained using approaches learned in other laser-material processing applications.
- With the appropriate process approximation, free-form geometries in full size modules can be obtained with throughputs fully compatible with the requirements of the BIPV industry.
- We have developed a LIFT method to deposit metallic front contacts with commercial silver pastes that allow a customization of the devices aspects with freeform designs.
- **Laser technology can play a fundamental role in the development of new BIPV products.**



This work has been supported by the Spanish Ministry of Economy and Competitiveness under project INNDISOL (IPT-420000-2010-6), HELLO (ENE2013-48629-C4-3-R), SIMLASPV (ENE2011-23359) and EC FP7 APPOLO FP7-2013 -NMP-ICT-FOF. 609355



appolo

Hub of Application Laboratories for Equipment
Assessment in Laser Based Manufacturing



תודה
Dankie Gracias
Спасибо شكريا
Merci Takk
Köszönjük Terima kasih
Grazie Dziękujemy Děkojame
Ďakujeme Vielen Dank Paldies
Kiitos Tänname teid 谢谢
Thank You Tak
感謝您 Obrigado Teşekkür Ederiz
Σας ευχαριστούμε 감사합니다
Bedankt Дěkujeme vám
ありがとうございます
Tack

“Solar architecture is not about fashion,
it is about survival”

Sir Norman Foster