Ablation properties of borosilicate glass under continous wave laser

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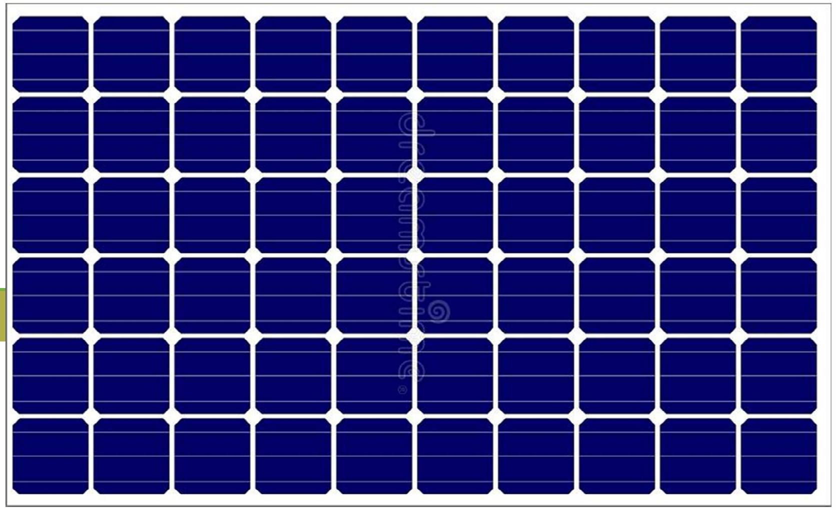
Motivation

Part of Implementation Phd
„Laminating processes of photovoltaic (PV) modules based on materials modified by laser surface treatment techniques”.

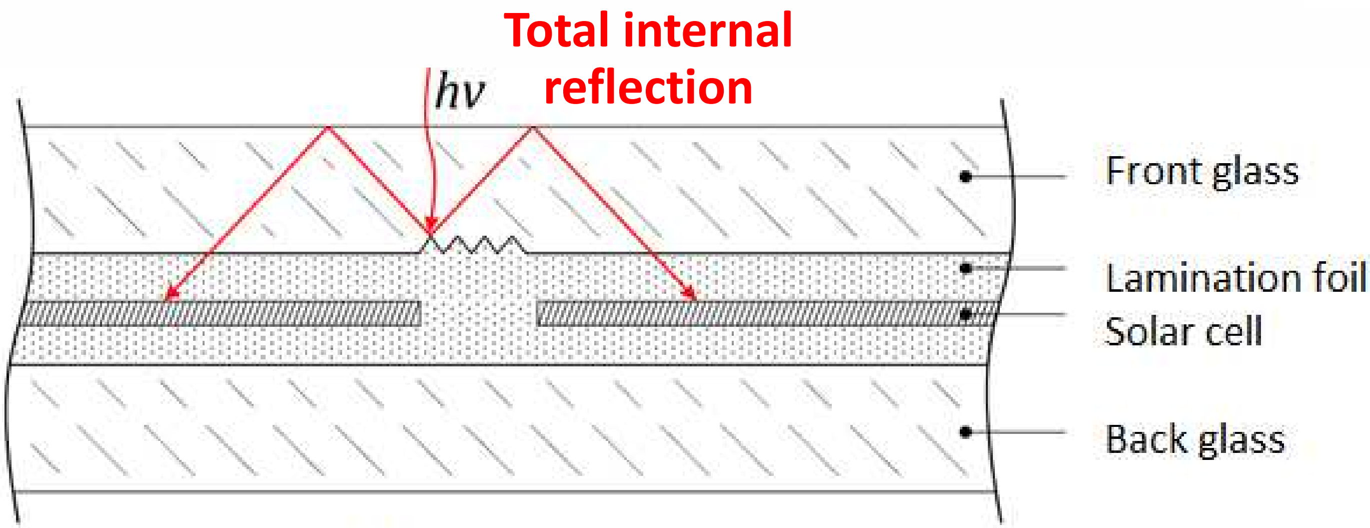
Supervisors:

- dr hab. inż. Kazimierz Drabczyk, IMIM PAN
- dr inż. Grażyna Kulesza-Matlak - IMIM PAN
- Wojciech Nikiel – Helioenergia Sp z o.o.



PV module area component	cm²	
total	19 820	
Total without frame	19 225	
Silicone cells only	17 691	
Left unused	1 535	7,7%

Idea

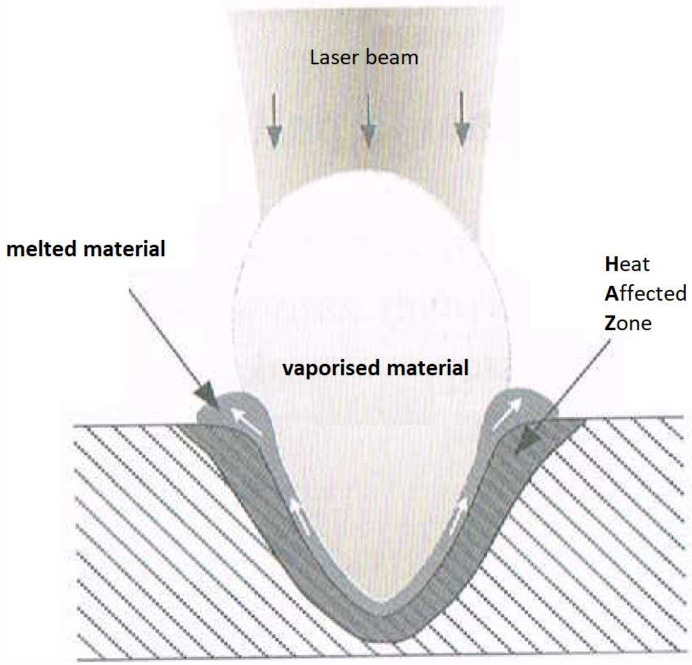


PV module cross section

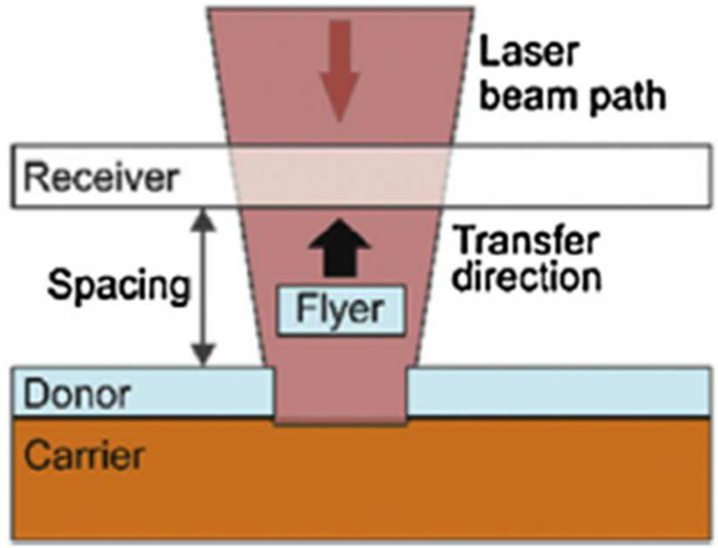
Aim:
Re-direct solar radiation from inter-cell space to increase module efficiency at low cost

Key aspects:
- **Printing + Laser = laser print**

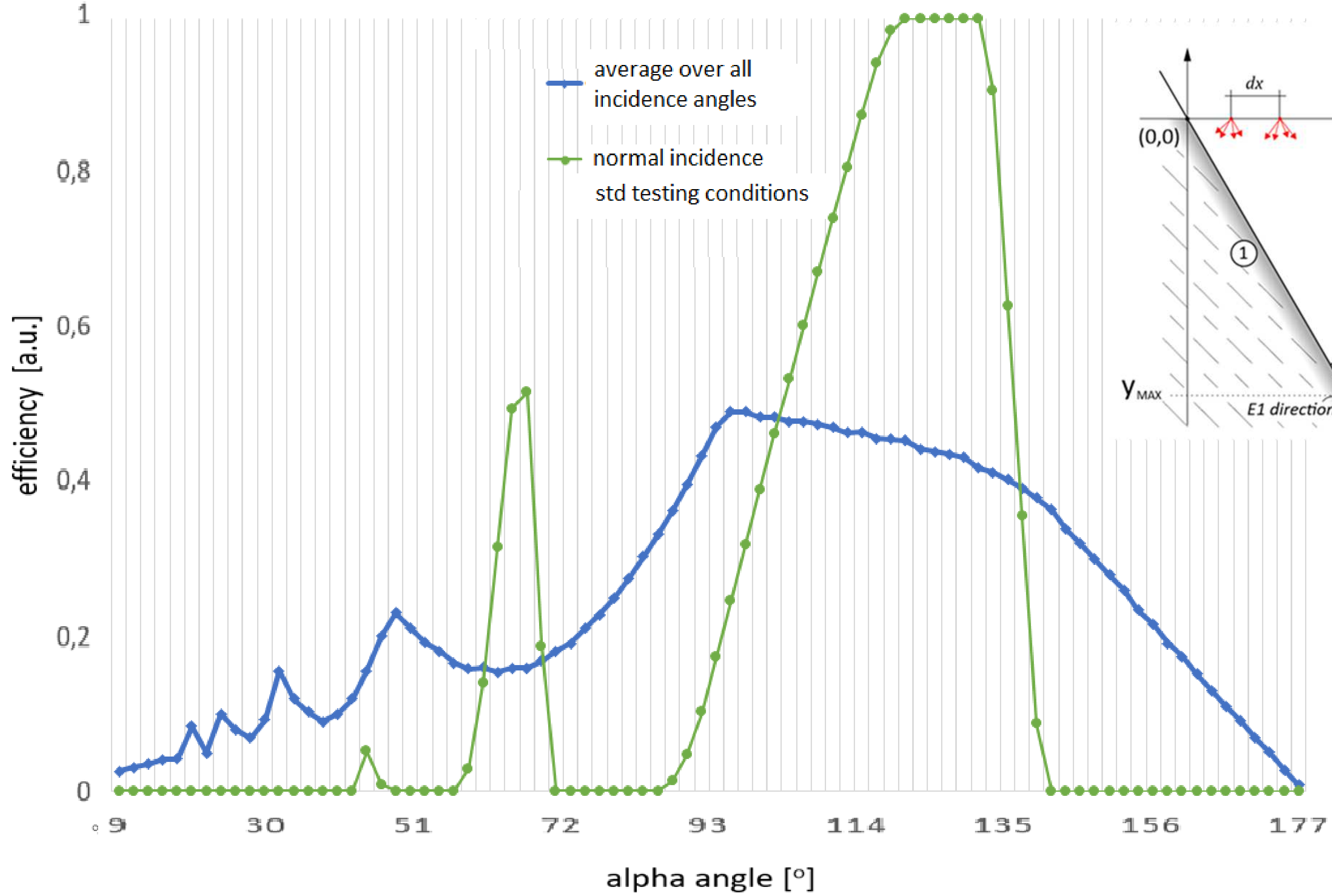
Laser printing step 1:
mid infrared CO_2 laser to
engrave glass

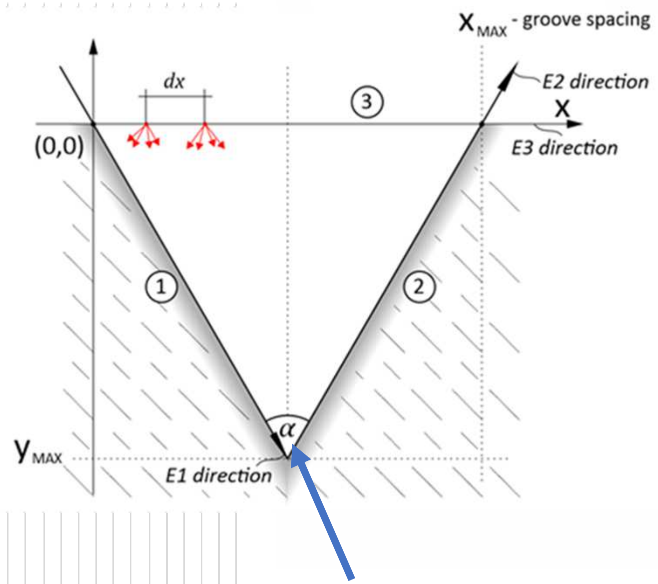


Laser printing step 2:
Laser Induced Backward
Transfer (LIBT) to print light
reflecting coating



Ray tracing simulation results

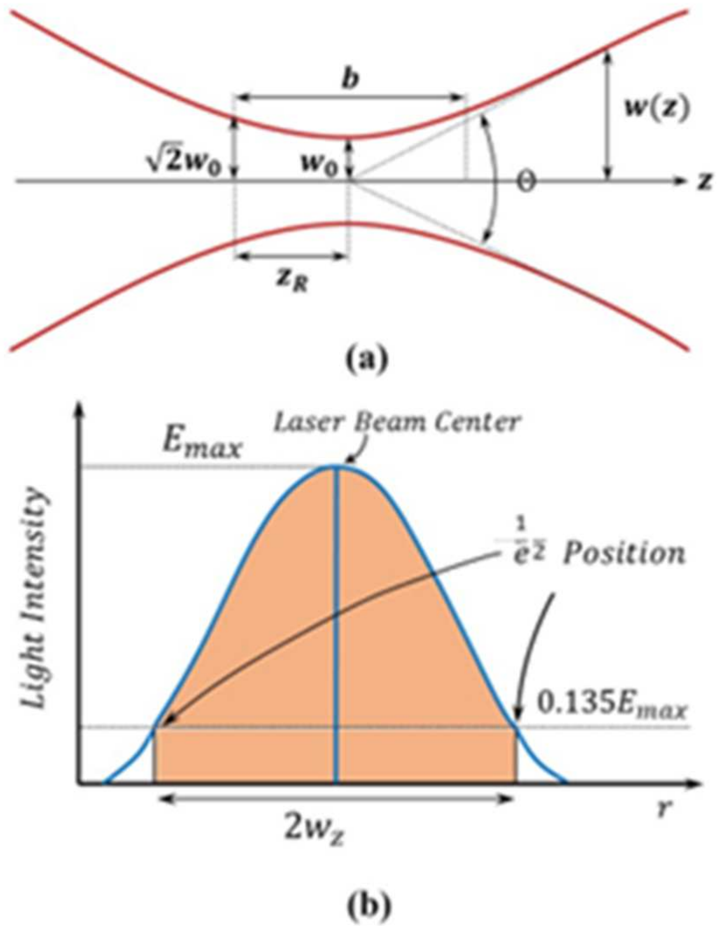




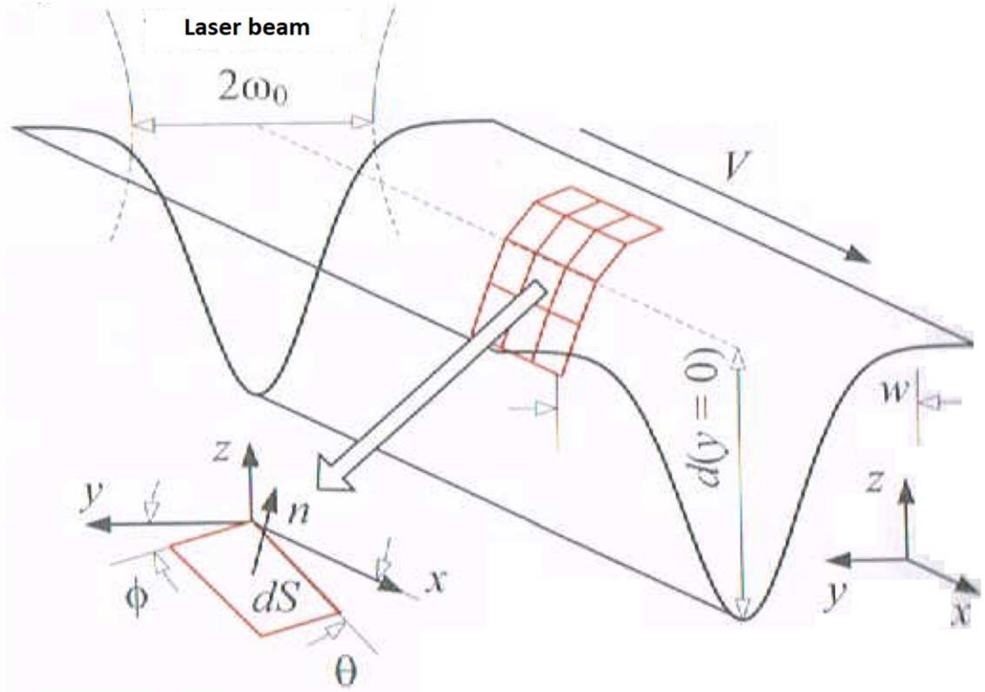
Angle to achieve:
122° to 132°

Gaussian energy distribution across the beam

$$E(r) = E_0^{max} \exp\left(-\frac{2r^2}{w_0^2}\right)$$



Diffuser– step 1 modeling



Groove width formula

$$W = \sqrt{2}w_0 \sqrt{ln \frac{4P}{\Pi w_0 F_{th} V}}$$

W – groove width
P – laser power
F_{th} – ablation treshold of the material
V- scan speed

Groove depth formula

$$d = \sqrt{\frac{2}{\Pi} \frac{A\ P}{w_0 Q \rho\ V}}$$

d – groove maximum depth
P – laser power
A – total absorption (1 less Reflection less Transmission)
Q – specific enthalpy of material
ρ - density of material
V- scan speed

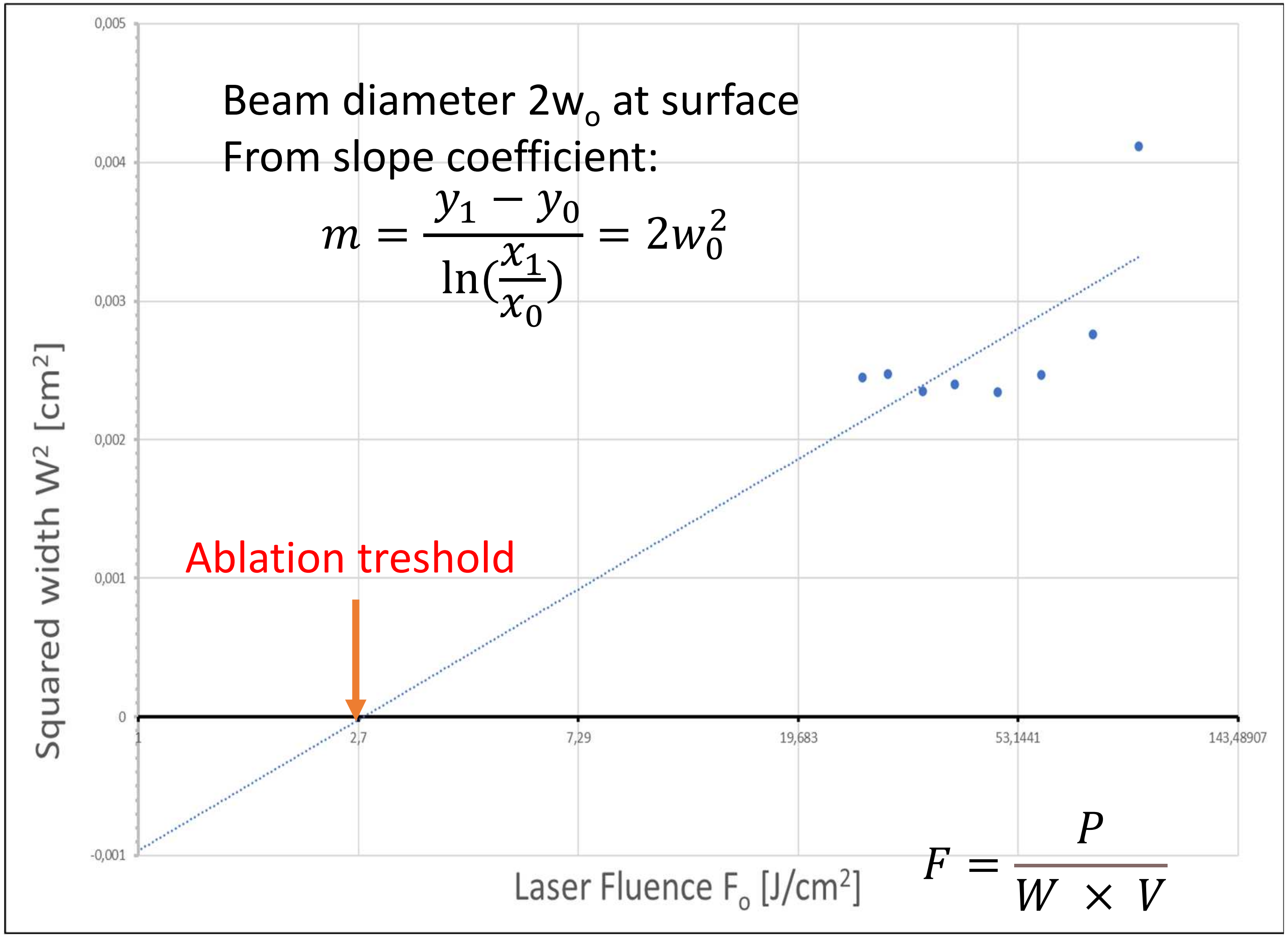
Ablation treshold and beam diameter determination

$$F_0^{av} = \frac{E_{pulse}}{\Pi\ w_0^2}$$

Solving Gauss with $r = \frac{W}{2}$ and recognizing that W=0 at threshold laser fluence

$$W^2 = 2w_0^2 \ln\left(\frac{F_0^{av}}{F_{th}}\right)$$

F_{th} = 2,7 J/cm^2
2w_0 = 434 µm

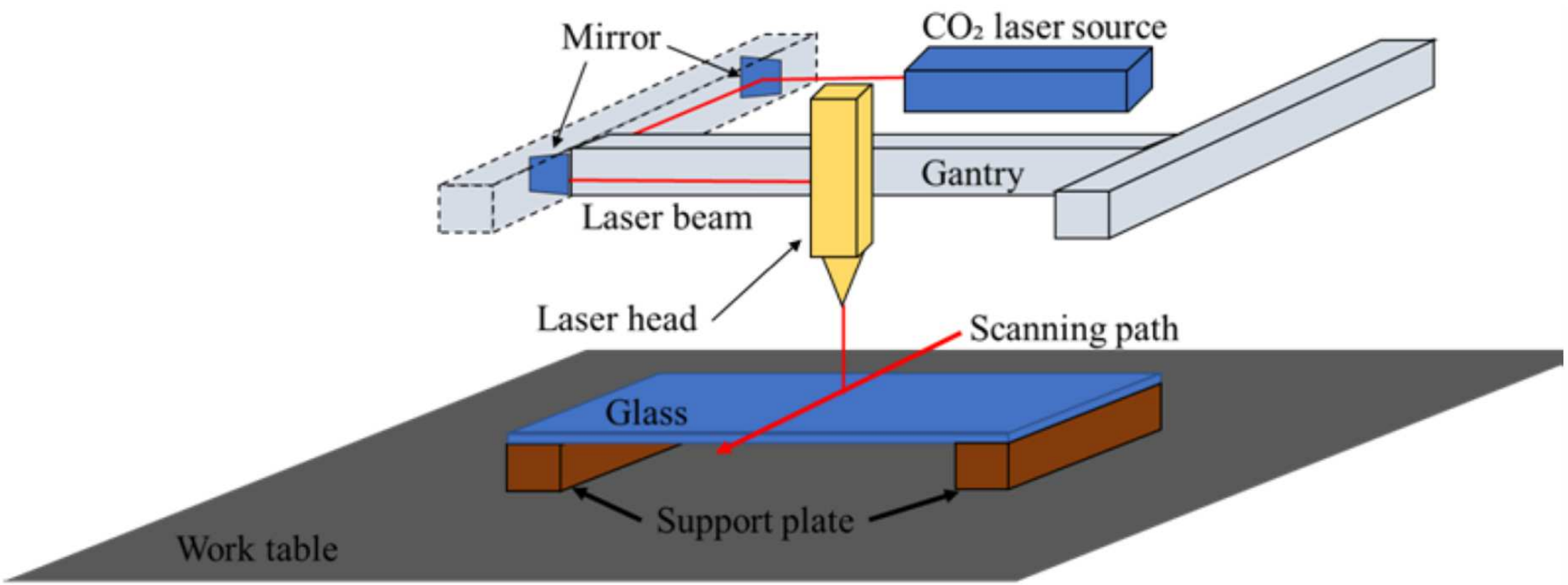


Challenges ablation treshold and beam diameter measurement experiment

- Accuracy of Scan speed (V) nad Power (P) measurement – V is set up in machine. $F=P/(W \times V)$

- Float glass has 2 sides which differ in many physical properties
  - Ablation treshold is supposed to be lower at „Tin side”.

Challenges so far



- By experiment - focusing is most important parameter
- By experiment - accuracy needed: ±0.3mm
- Beam delivery system not precise enough,
- Work table leveling,
- Laser power fluctuates – warm up needed but anyway fluctuates ±4%
- Beam delivery system is subject to contamination.
- Control driver <-> stepper motors limitations, accuracy vs. speed.

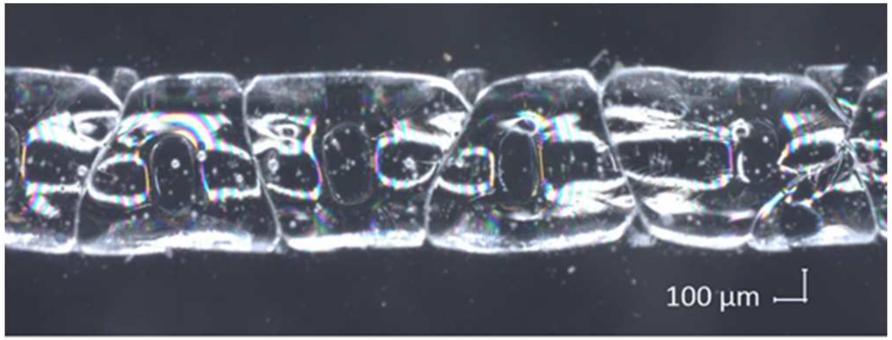
Challenges glass engraving

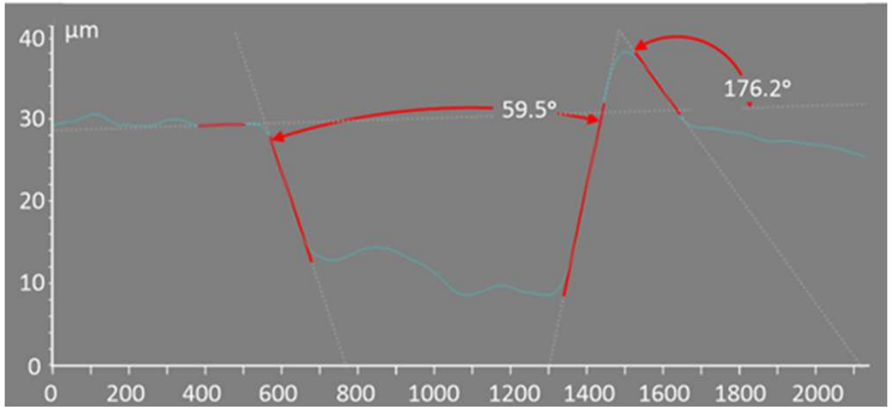
Laser beam – focusing:

Minimum 76.2mm focal length is needed to protect both: the lens and the processing zone
F= 76.2mm results in too large laser spot diameter.
Solved by beam expander in beam delivery system.

Laser beam <–> glass physics:

Expansion followed by compression creates stress leading to cracking. (HAZ)
Debris and HAZ affected material is to be removed mechanically.
Repeatability of this proces.
Solved by high pressure water cleaning – non mechanical.



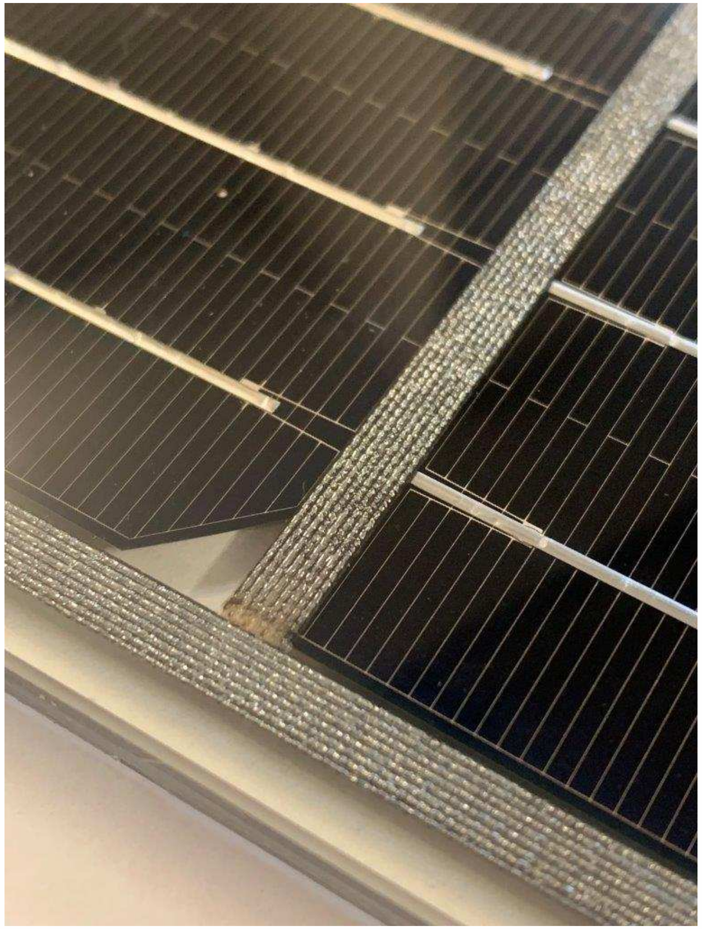


Groove efficiency evaluation:

Solved by digital evaluation of groove geometry

Diffuser– step 2

LIBT printing

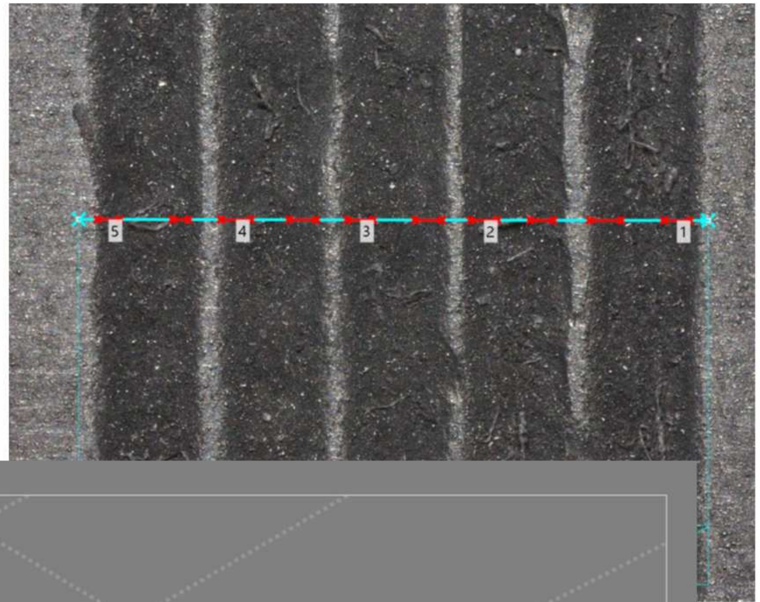


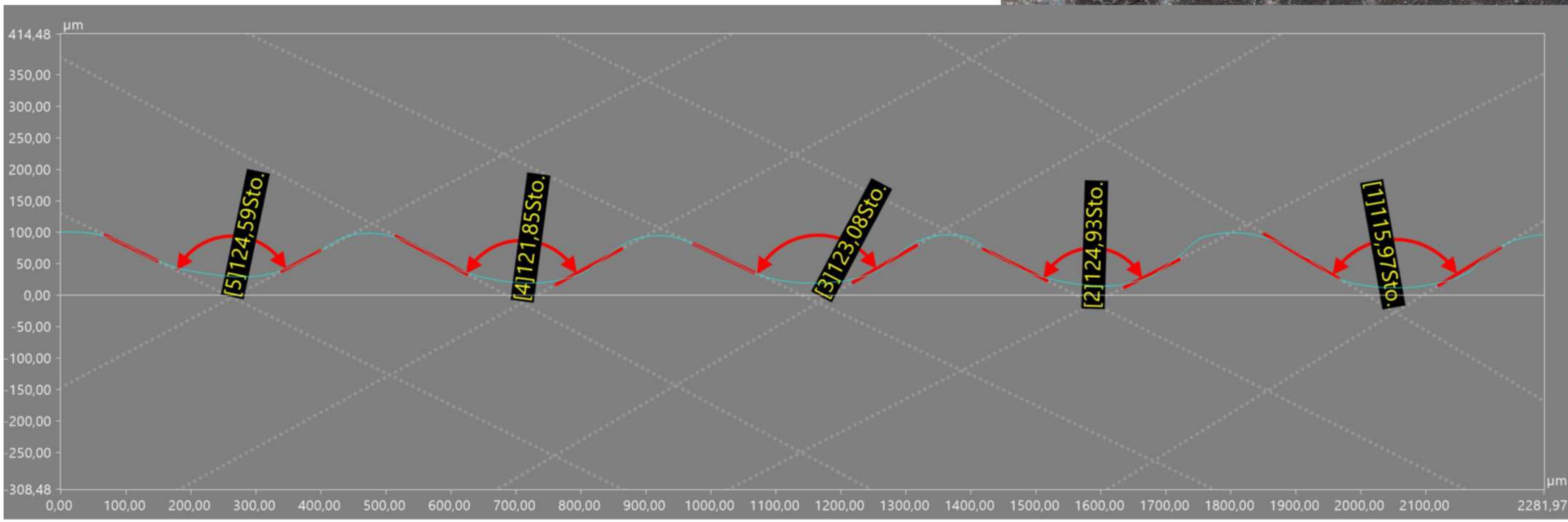
Finished Diffusor step1 + step 2 + lamination

Material of choice for LIBT:
Zinc – 99%
Very low cohesive energy
Results in high ablation yield

PV modules tech scale

- Lab scale (200x200mm) groove efficiency: 45%
- Tech scale (1000x500mm) groove efficiency: 35%.





PV module 1000x500mm

- Lamination ok
- Mechanical withstand ok
- Electrical safety ok

But ….

PV modules tech scale challenges

1. Diffusor overlaping

Creates PV cell shadow multiplied by number of cells in series

Mitigation:

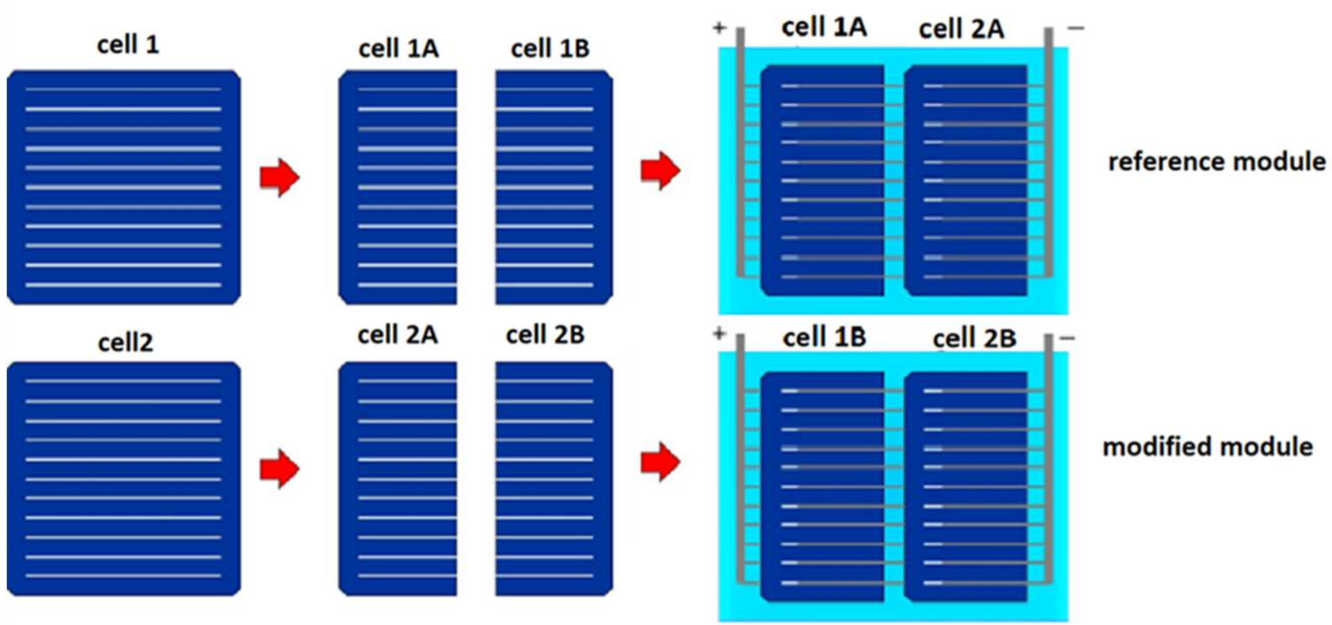
- Allow more margin,
- Increase precision.

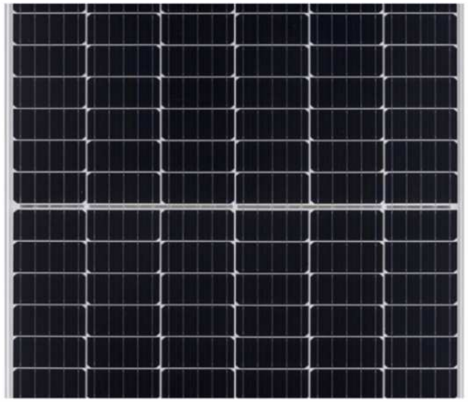
2. Comparability of 2 modules

We look for 2% difference. Production standard is ± 2%. Measurement accuracy is ± 2%.

Mitigation:

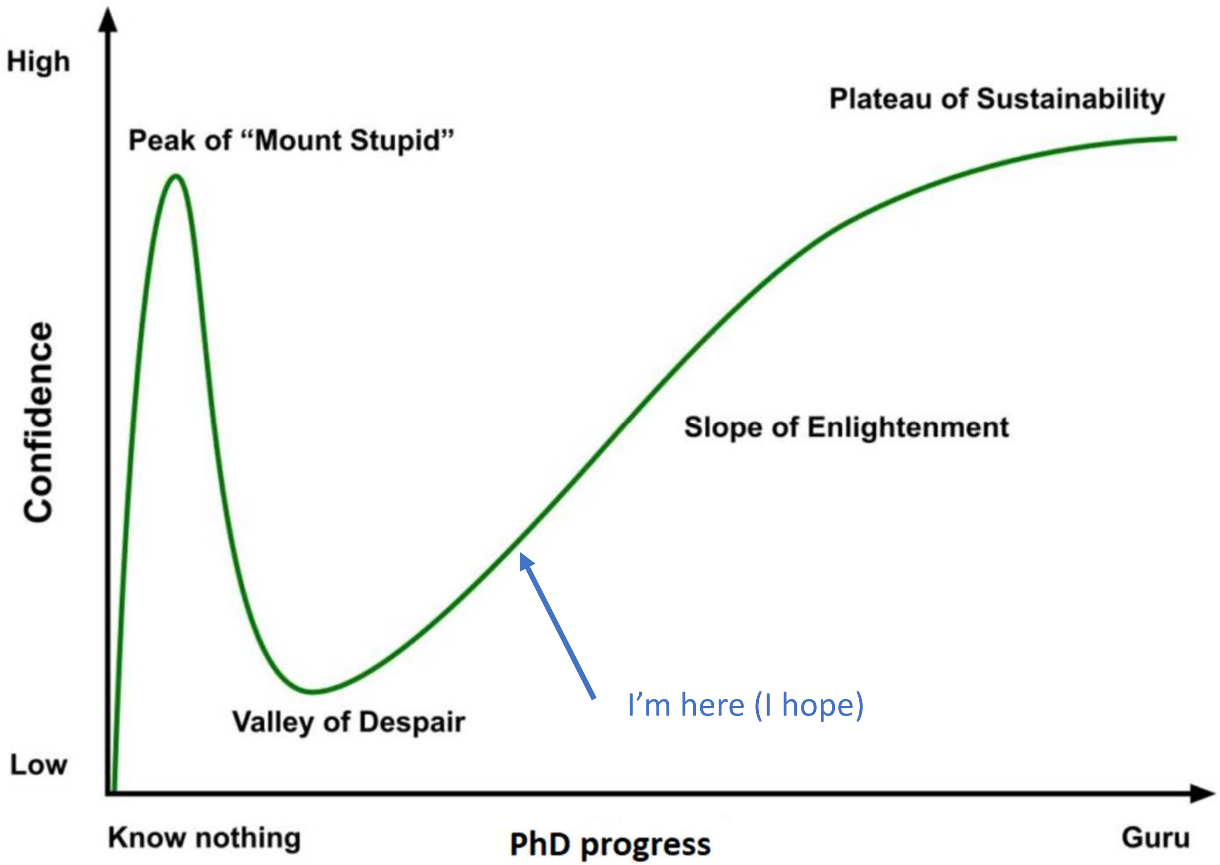
- Cell shuffle
- Make reference and test modules at the same time.





Cost of modification: below 1,00 PLN

Value of modification: 6,00 PLN



Thank you!

Ministerstwo
Edukacji i Nauki

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