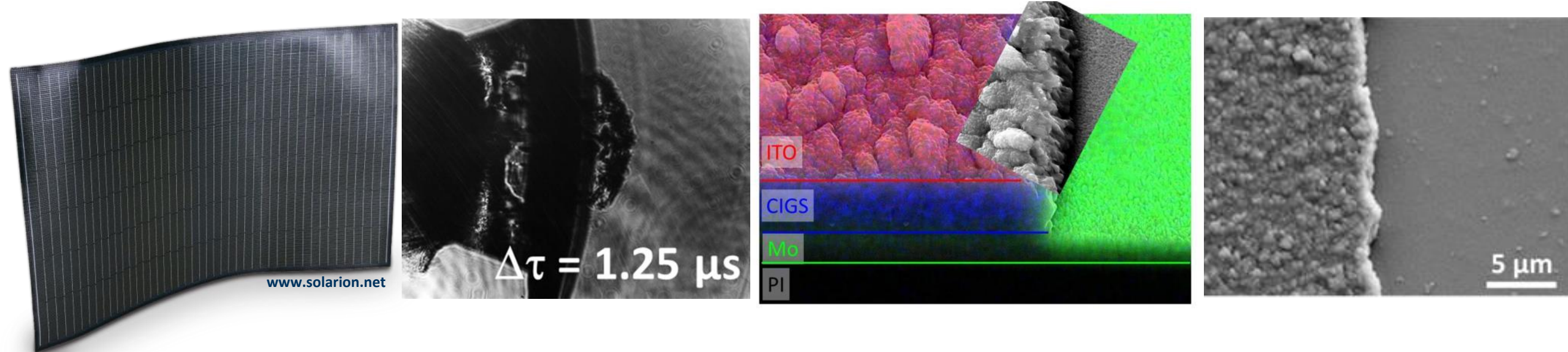




SHOCKWAVE INDUCED THIN FILM DELAMINATION (SWIFD): A NON-THERMAL STRUCTURING METHOD OF FUNCTIONAL LAYER

Pierre Lorenz, Martin Ehrhardt, Lukas Bayer, Klaus Zimmer

Leibniz-Institut für Oberflächenmodifizierung e. V., Permoserstr. 15, 04318 Leipzig, Germany

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SP 1: Short pulse processes

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Motivation

Set-up

Experimental results

Shockwave delamination of CIGS (SWIFD)

- CIGS on PI substrate

- CIGS on stainless steel

SWIFD of CIGS further dependency

- Additional tension force

- Confinement and laser spot size

- Temperature

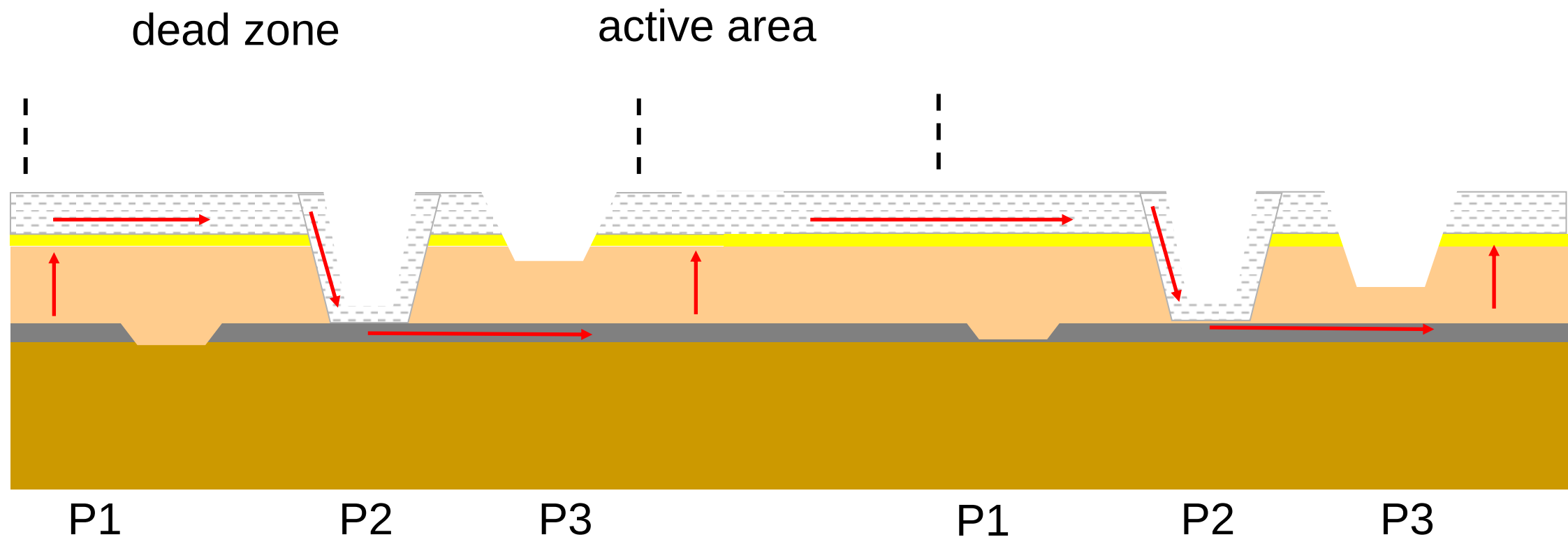
Conclusion and Outlook

Selective structuring of multi-layer functional thin films using a laser-induced shockwave delamination process

- The microstructuring of thin films especially for electronic applications without damaging the layers or the substrate is a challenge for conventional methods.
- Laser methods like laser ablation are on special interest.

Selective structuring of multi-layer functional thin films using a laser-induced shockwave delamination process

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Monolithic integrated interconnection

Selective structuring of multi-layer functional thin films using a laser-induced shockwave delamination process

- The microstructuring of thin films especially for electronic applications without damaging the layers or the substrate is a challenge for conventional methods.
- Laser methods like laser ablation are on special interest.

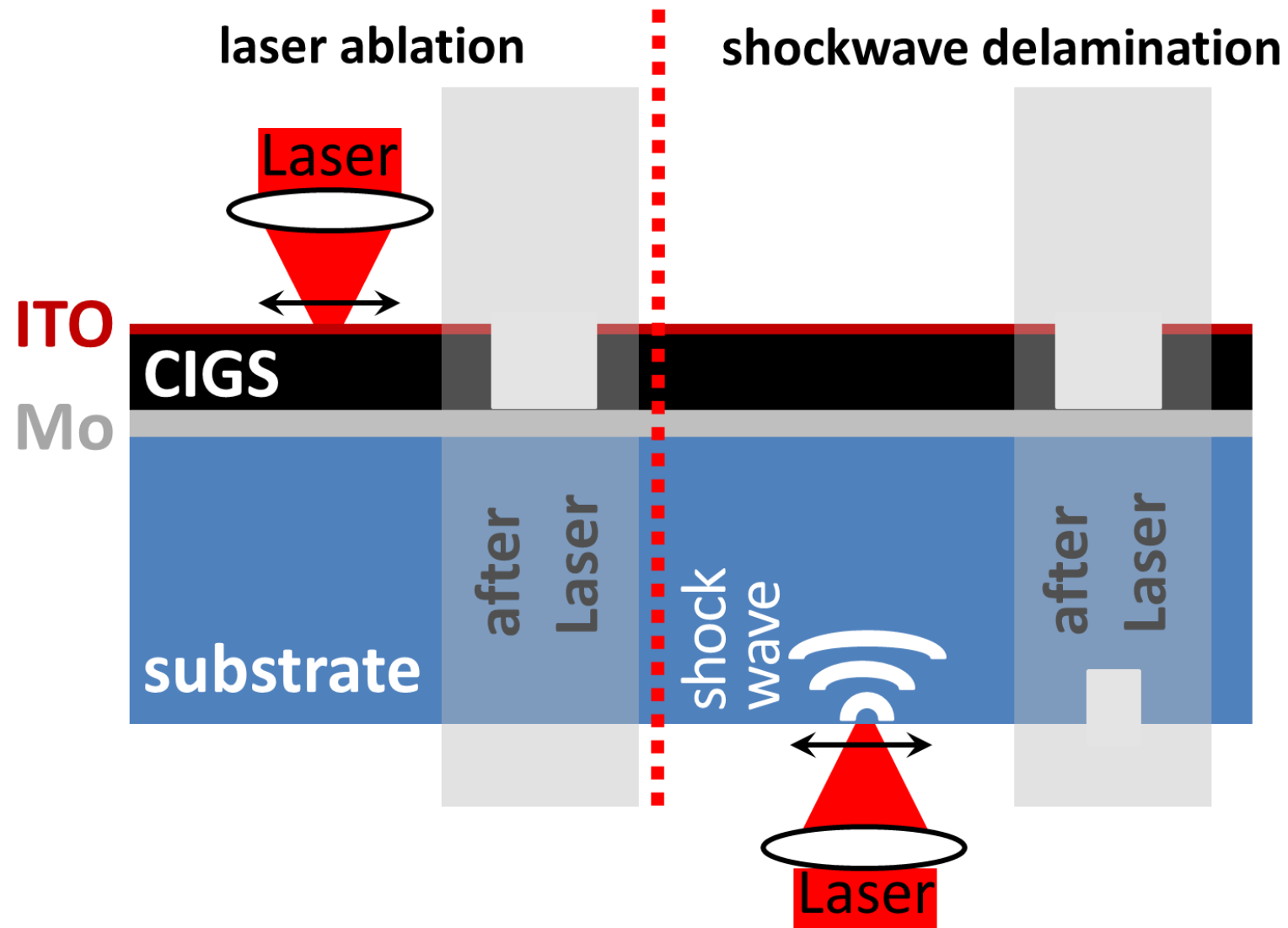
→ ADVANTAGE:

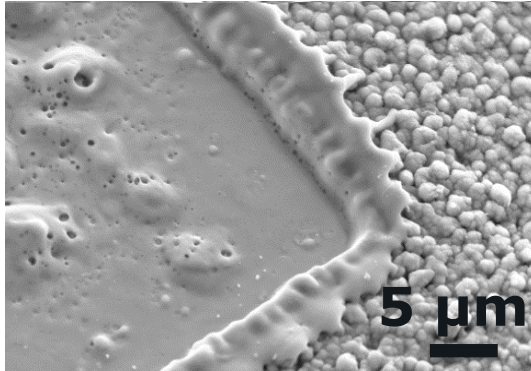
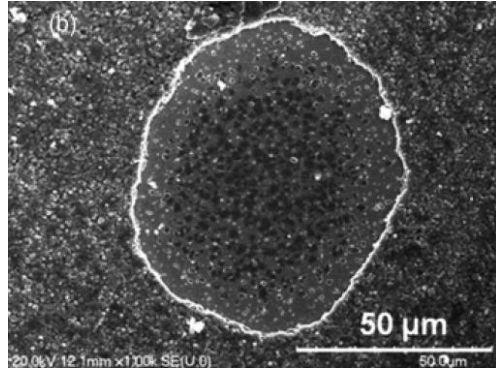
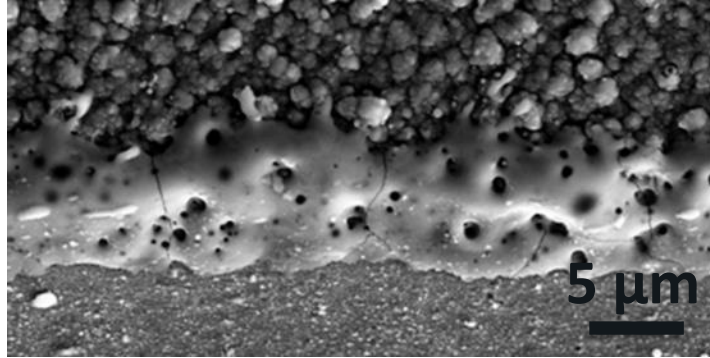
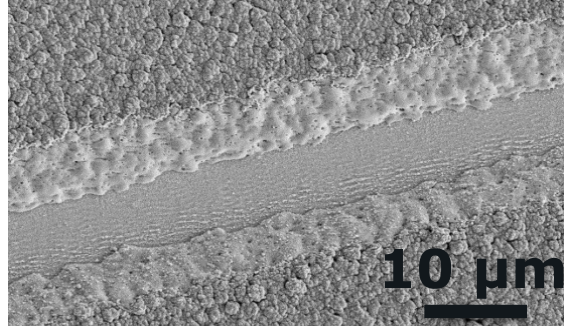
fast, flexible, easy, and large area structuring

→ DISADVANTAGE:

laser-induced material modifications mostly due to the released heat; can be observed already at ultra short laser pulses

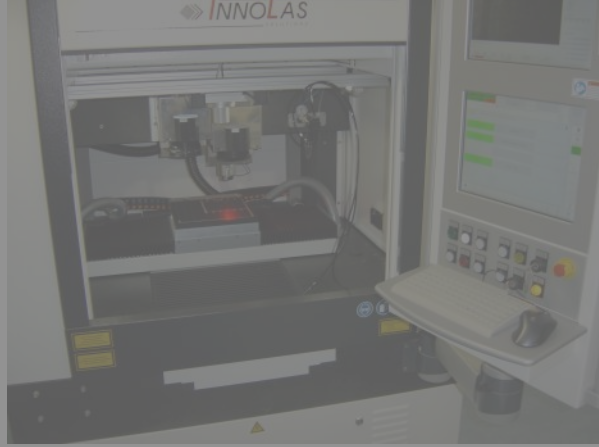
- Alternative:
mechanically scribing
SWIFD: shock-wave-induced thin-film delamination



nanosecond		picosecond	femtosecond
$\lambda = 248 \text{ nm}, \Delta t_p = 25 \text{ ns}$ 	$\lambda = 1550 \text{ nm}, \Delta t_p = 5 \text{ ns}$  (B)	$\lambda = 1064 \text{ nm}, \Delta t_p = 10 \text{ ps}$ 	$\lambda = 775 \text{ nm}, \Delta t_p = 150 \text{ fs}$ 
<ul style="list-style-type: none">• high ablation rate• strong molten modification	<ul style="list-style-type: none">• Stress-assisted laser lift-off delamination^{B)}	<ul style="list-style-type: none">• moderate ablation rate• molten edge modification	<ul style="list-style-type: none">• small ablation rate• molten edge mod.
			

Summary of laser structuring at different pulse duration inclusive exemplary SEM images based on the CIGS sample produced at Solarion AG

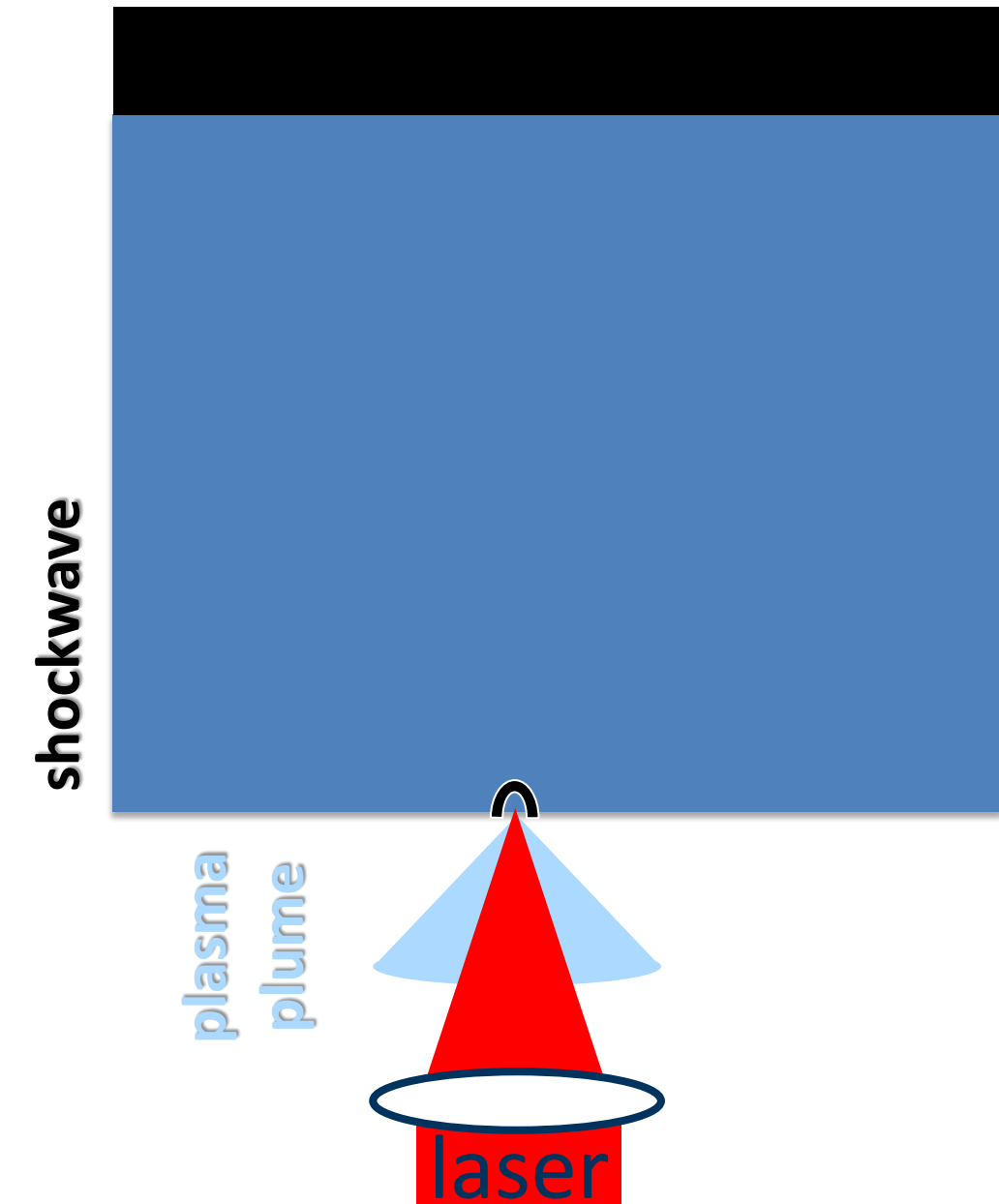
- available Laser

nanosecond		picosecond		femtosecond
Excimer Laser		Fiber laser	Nd:YVO4	Ti:Al ₂ O ₃
				
λ [nm]	193, 248, 351	1064, 1550	355, 532, 1064	780
Δt_p	25 ns	1-600 ns	10 ps	150 fs
	top hat profile	Gaussian profile	Gaussian profile	Gaussian profile

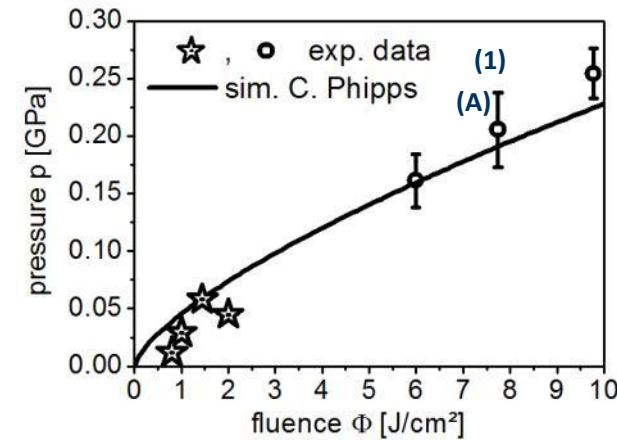
laser-induced shockwave delamination

laser ablation

N = 1

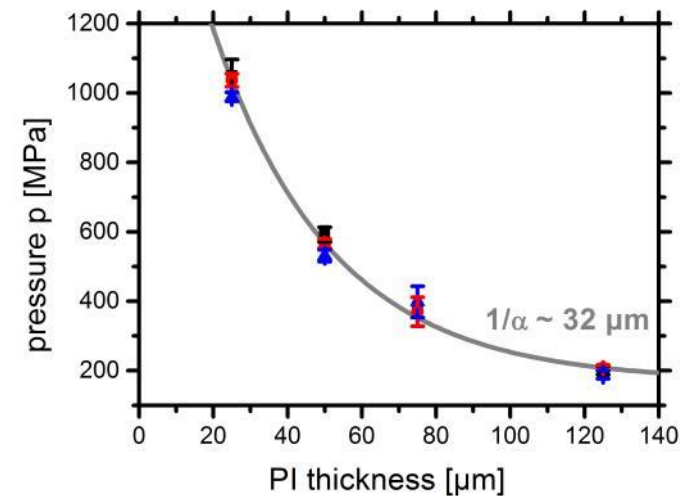
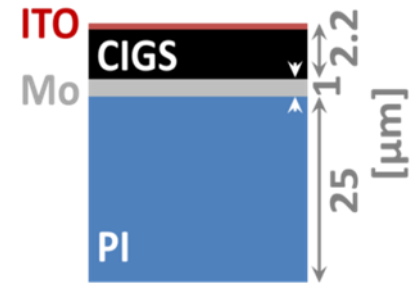


Polyimide



$$p(\Phi) \approx 4 \cdot 10^{-5} \cdot b \cdot \lambda^{-0.3} \cdot \tau^{-0.15} \cdot \Phi^{0.7}$$

$$p(\Phi) \approx 37.8 \frac{\text{MPa} \cdot \text{cm}^{1.4}}{J^{0.7}} \cdot \Phi^{0.7}$$



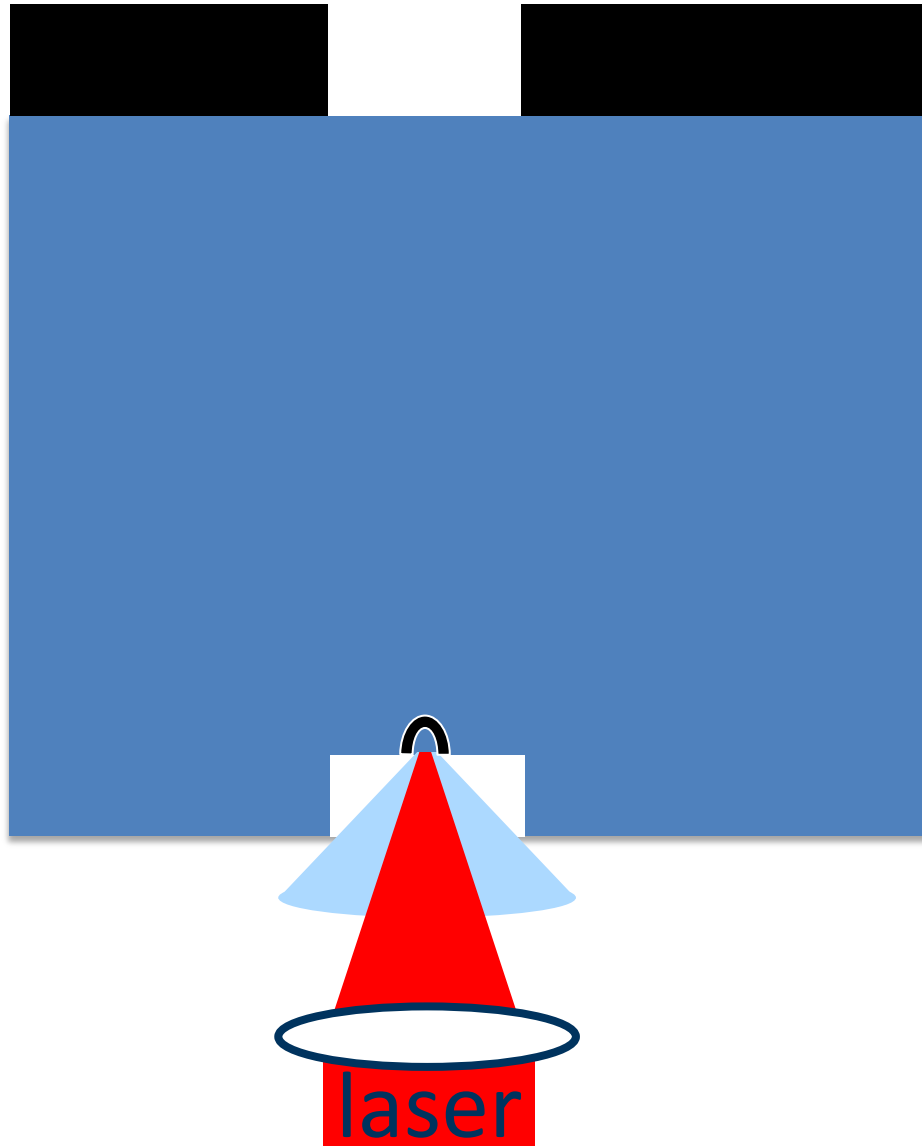
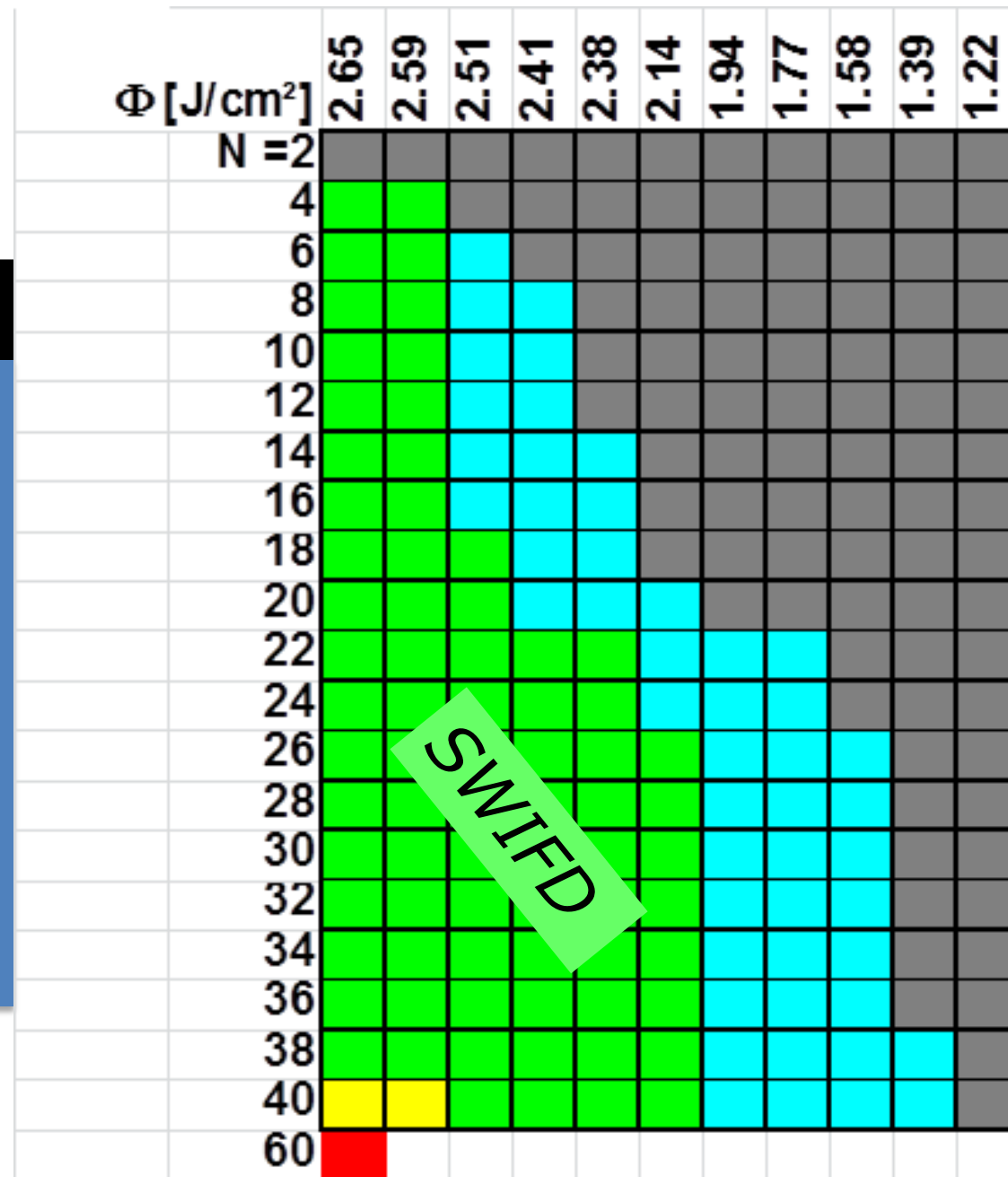
pressure of the shockwave

damping of the shockwave

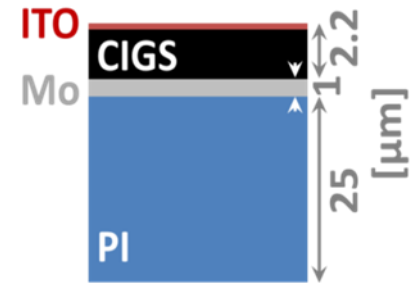
Schematic illustration of the SWIFD process

4. SWIFD – CIGS on PI

N = 4



10



Summary SWIFD - CIGS solar cells on PI:

grey: no effect on the front side;

turquoise: instable region: unspecific delamination;

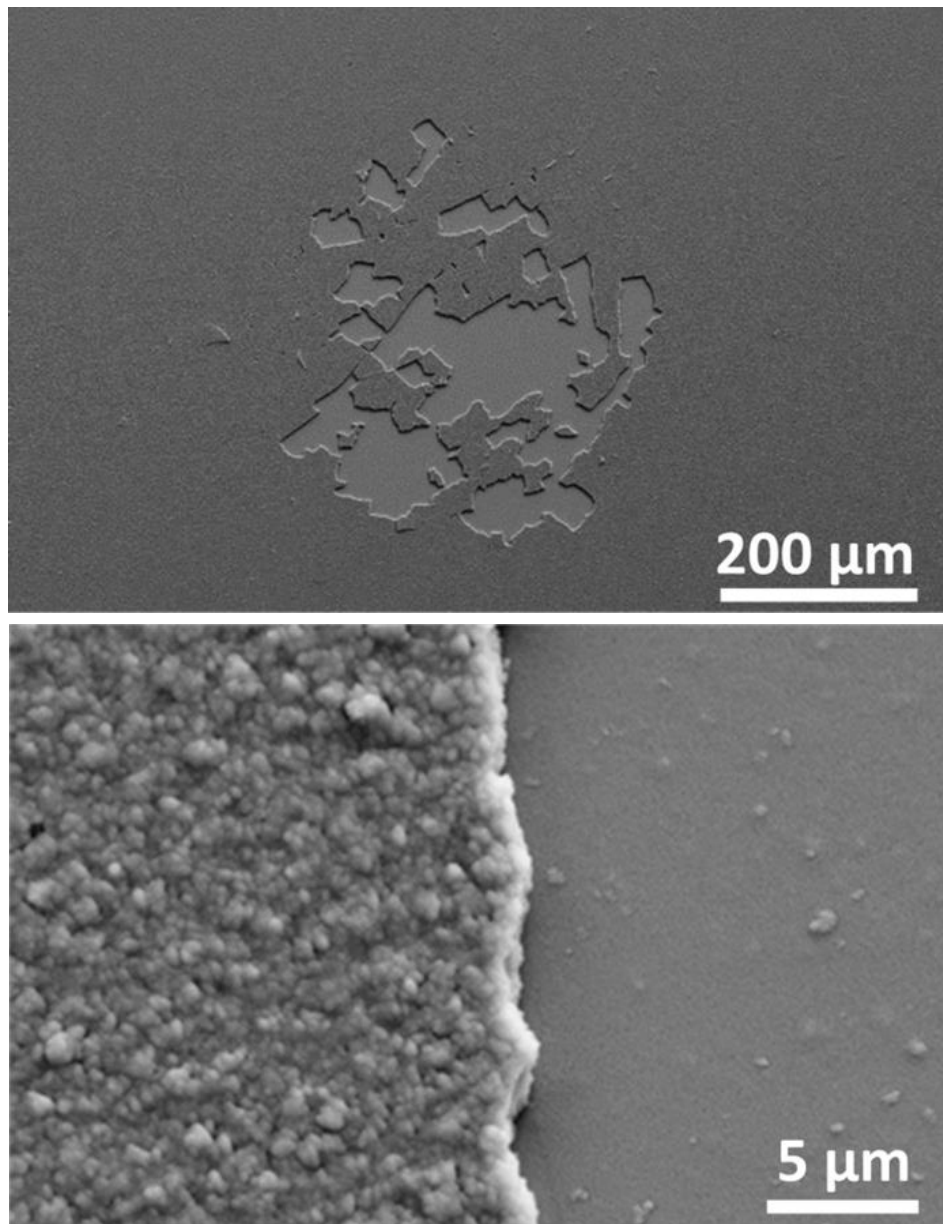
green: delamination of CIGS including the ITO;

yellow: delamination of the CIGS with damage of Mo;

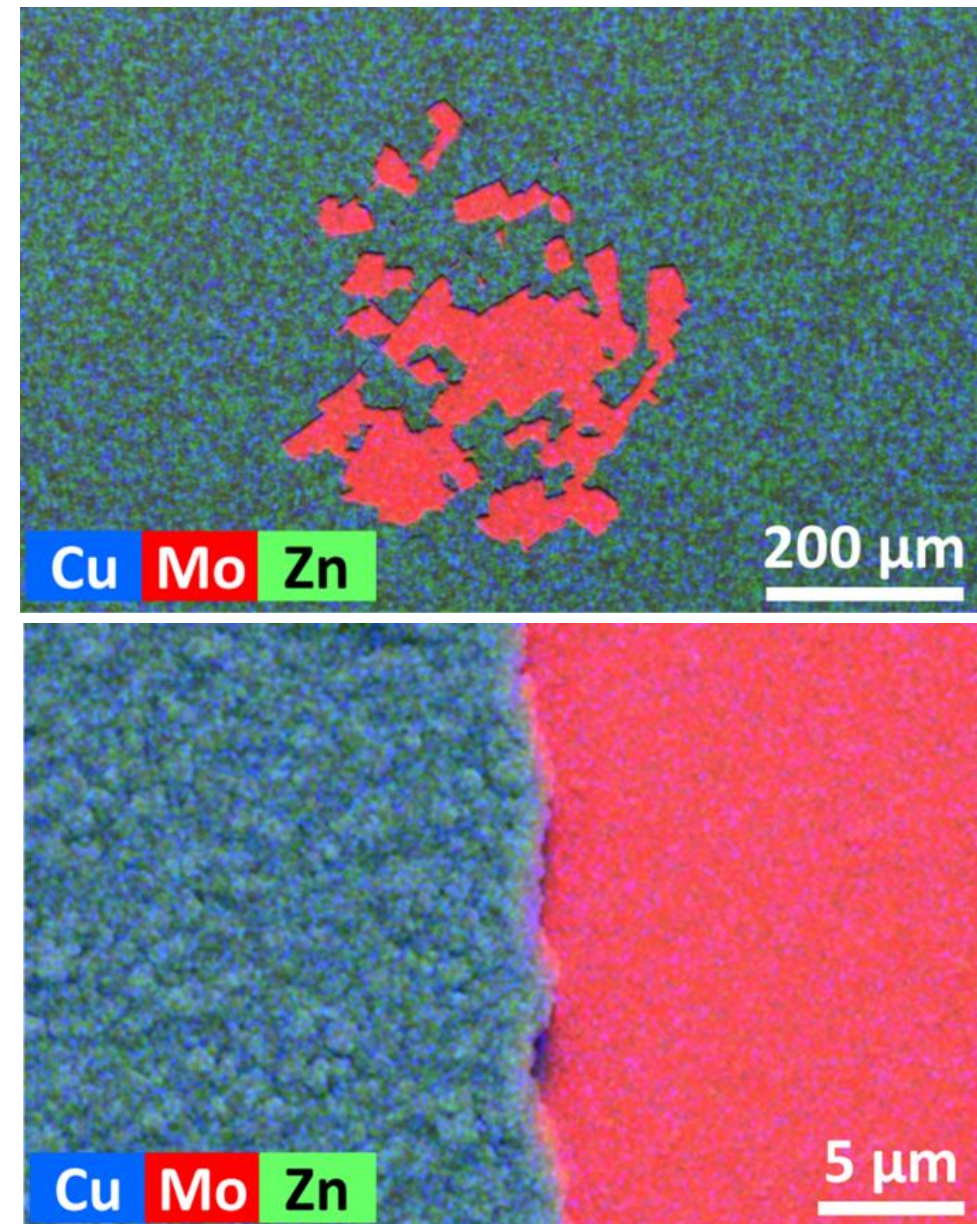
red: full penetration of the PI

Schematic illustration of the SWIFD process

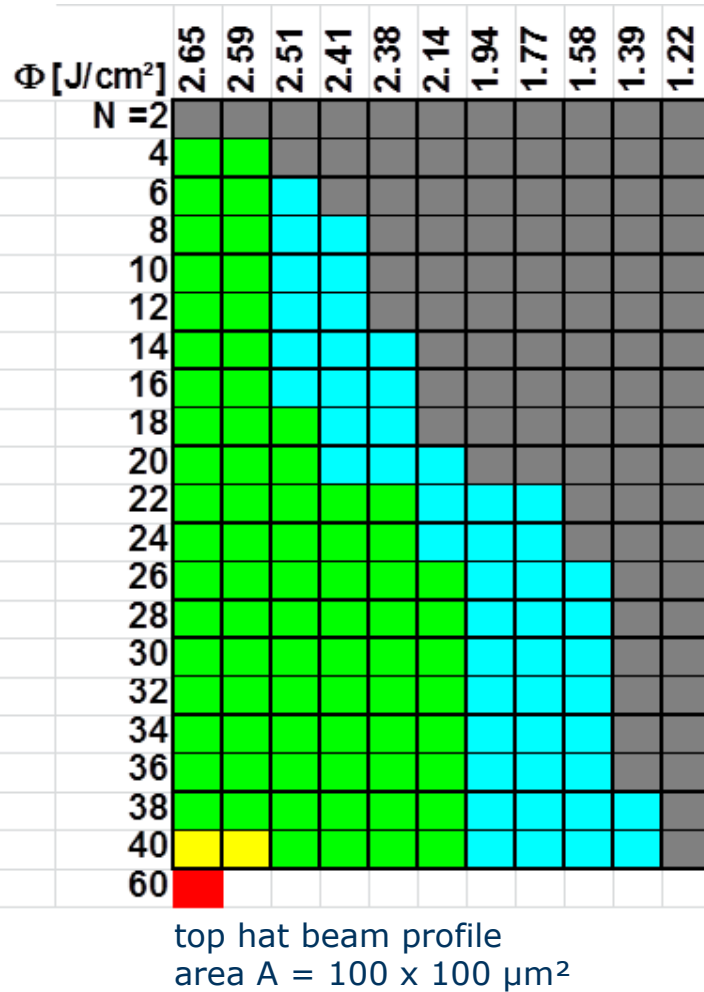
SEM



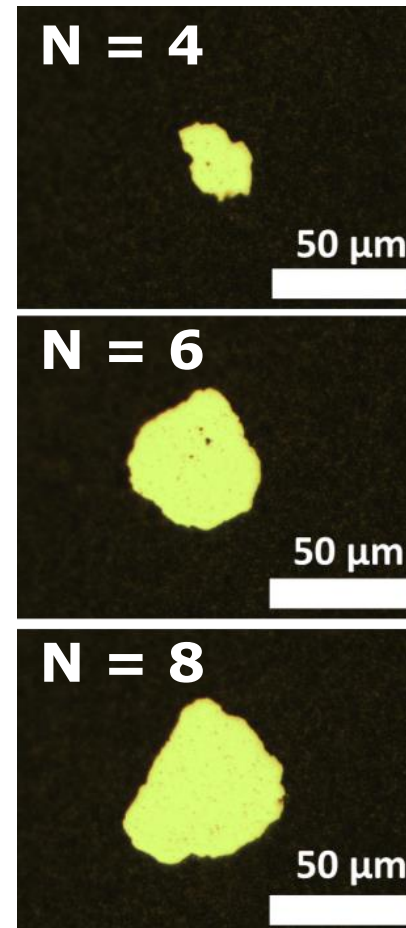
EDX



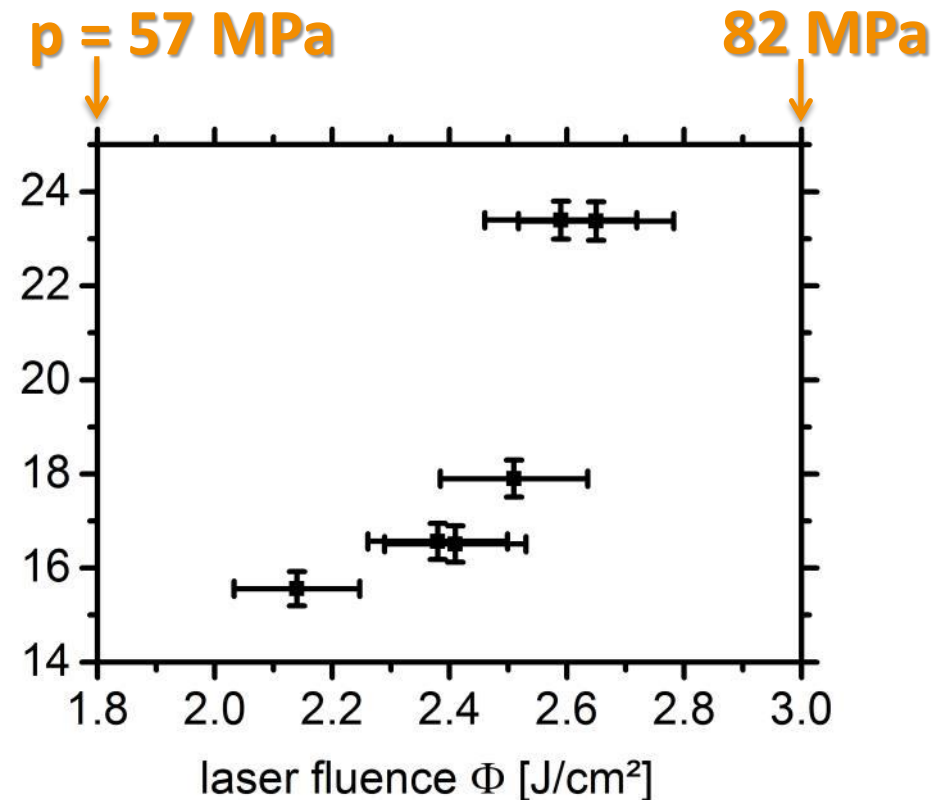
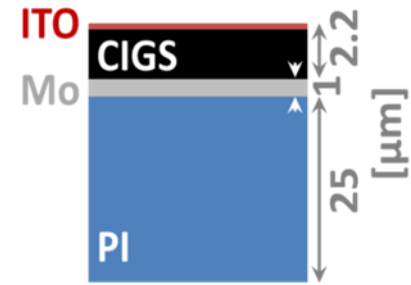
SEM and EDX images after the laser treatment ($\Phi \sim 2.8 \text{ J/cm}^2$, $N = 1$, $A \sim 0.8 \text{ mm}^2$)



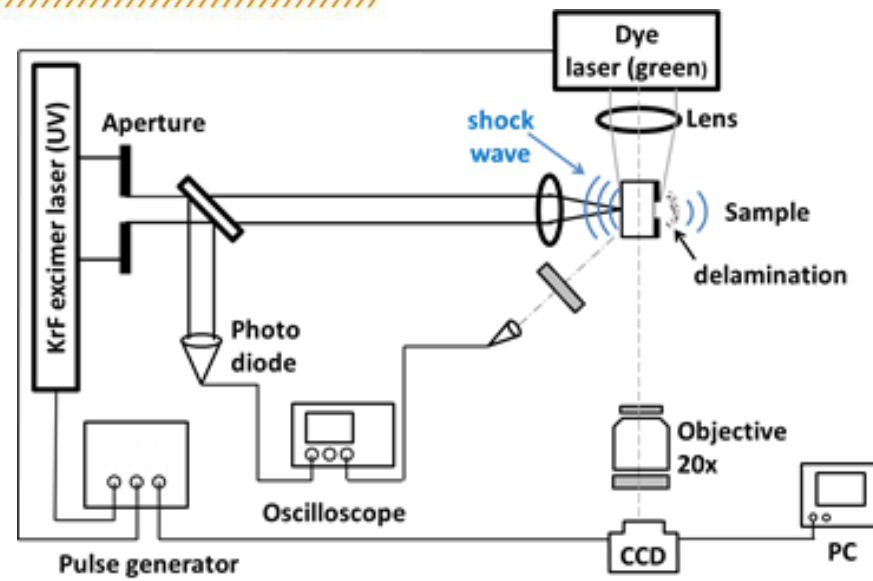
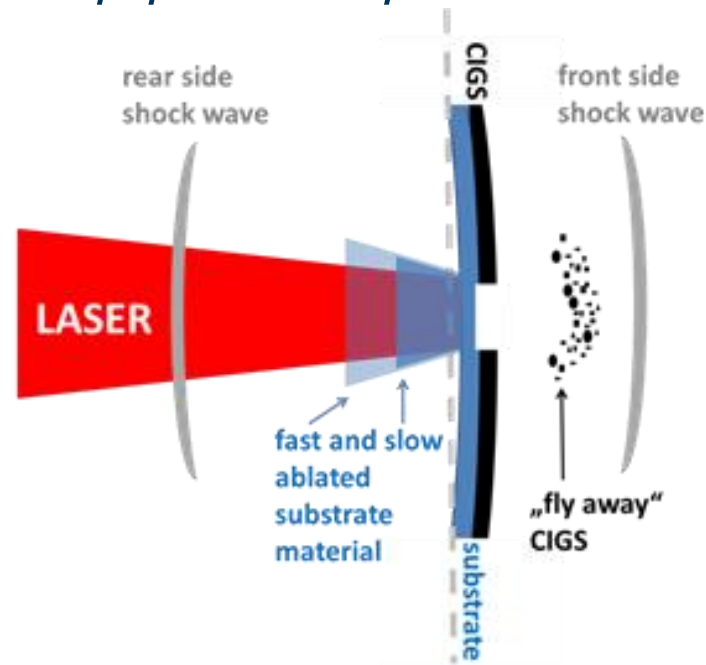
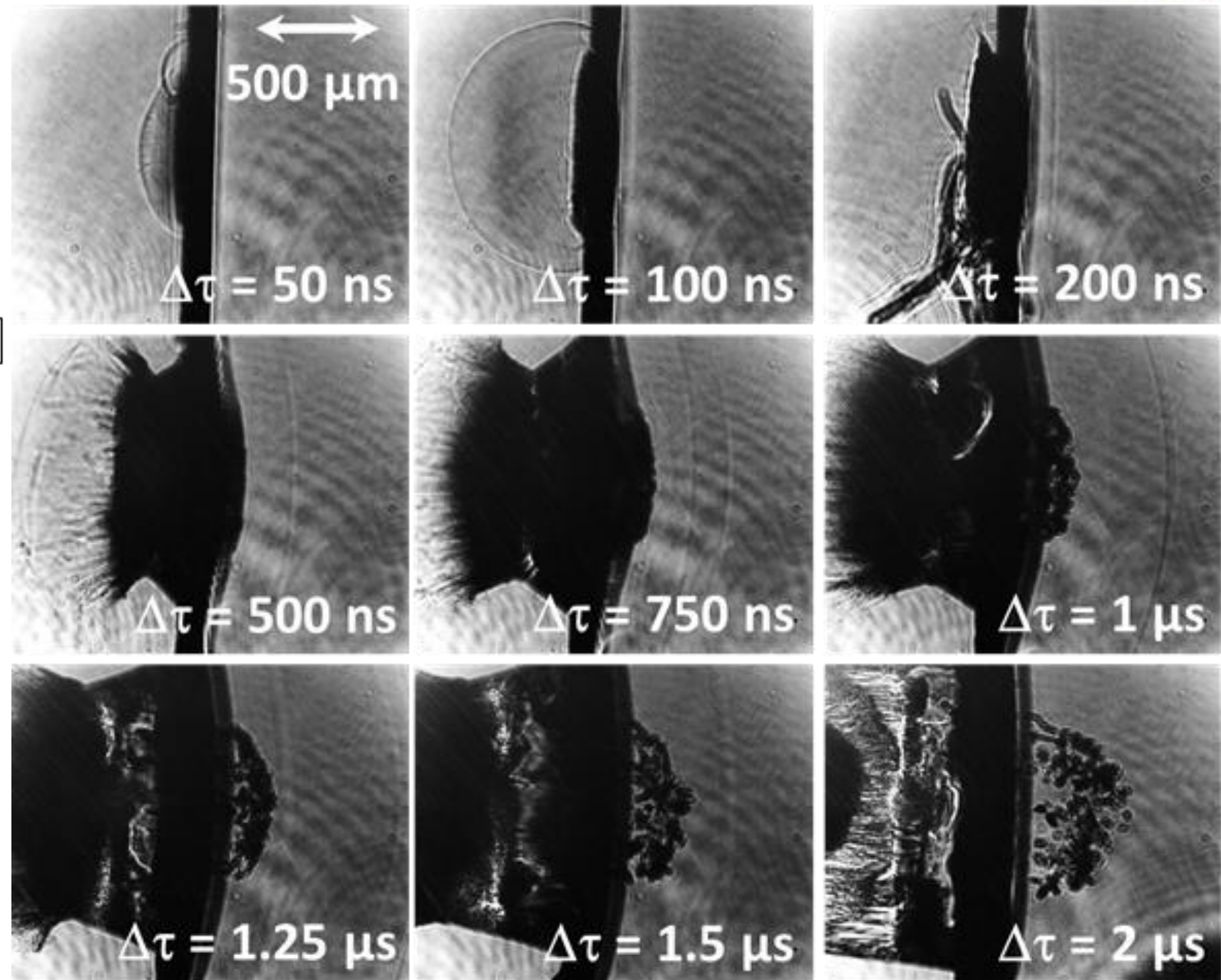
Optical microscopic image

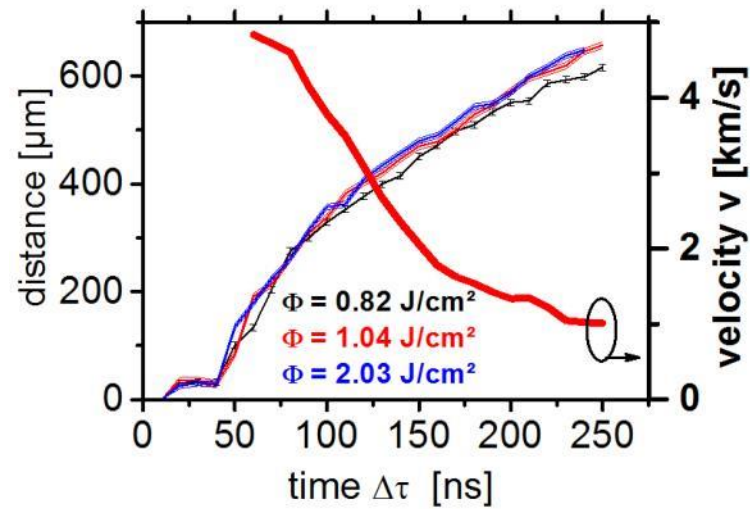


$\Phi \sim 2.65 \text{ J/cm}^2$
remaining thickness d [μm]

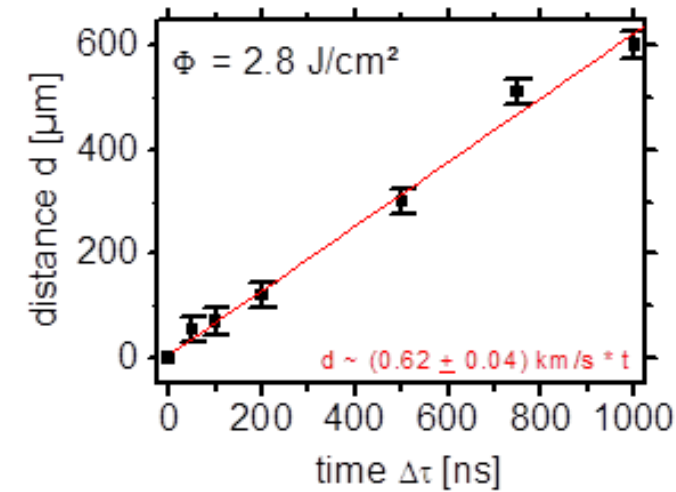


- (left) Summary of the irradiation results of the CIGS solar cells on PI (grey: no effect on the front side; turquoise: instable region: unspecific delamination; green: delamination of CIGS including the ITO front contact; yellow: delamination of the CIGS with damage of molybdenum back contact; red: full penetration of the PI).
- (middle) Optical microscopic image of the laser-treated CIGS solar cell at $\Phi \sim 2.65 \text{ J/cm}^2$, N=4-8, (dark region: non-modified CIGS solar cell, bright region: uncovered Mo back contact)
- (right) Necessary remaining PI thickness d dependent on the laser fluence Φ

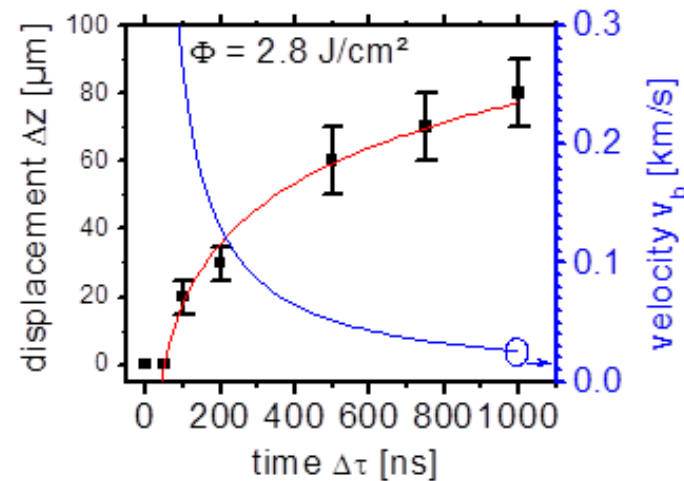




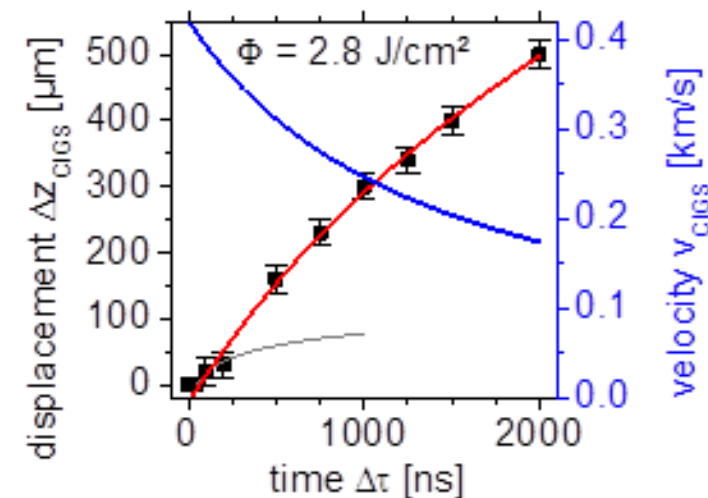
rear side shock wave formation process



removal of material from the rear side of PI substrate



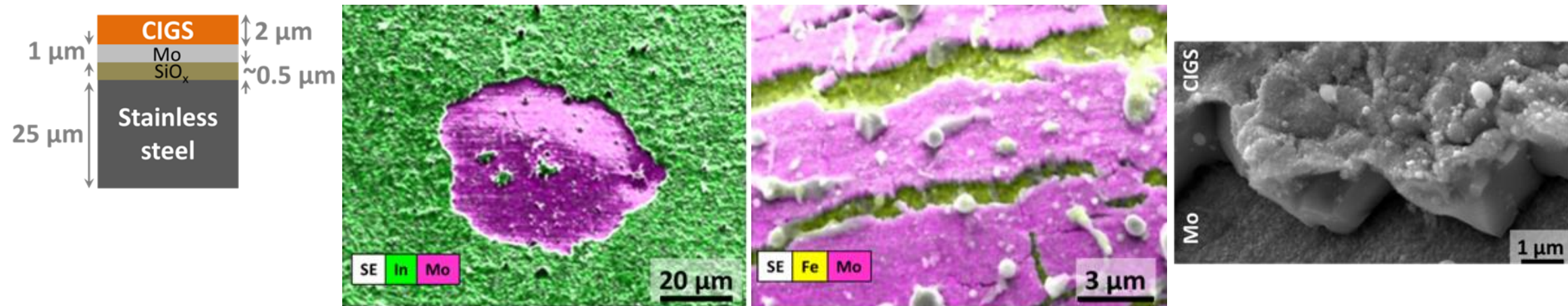
bending of the substrate



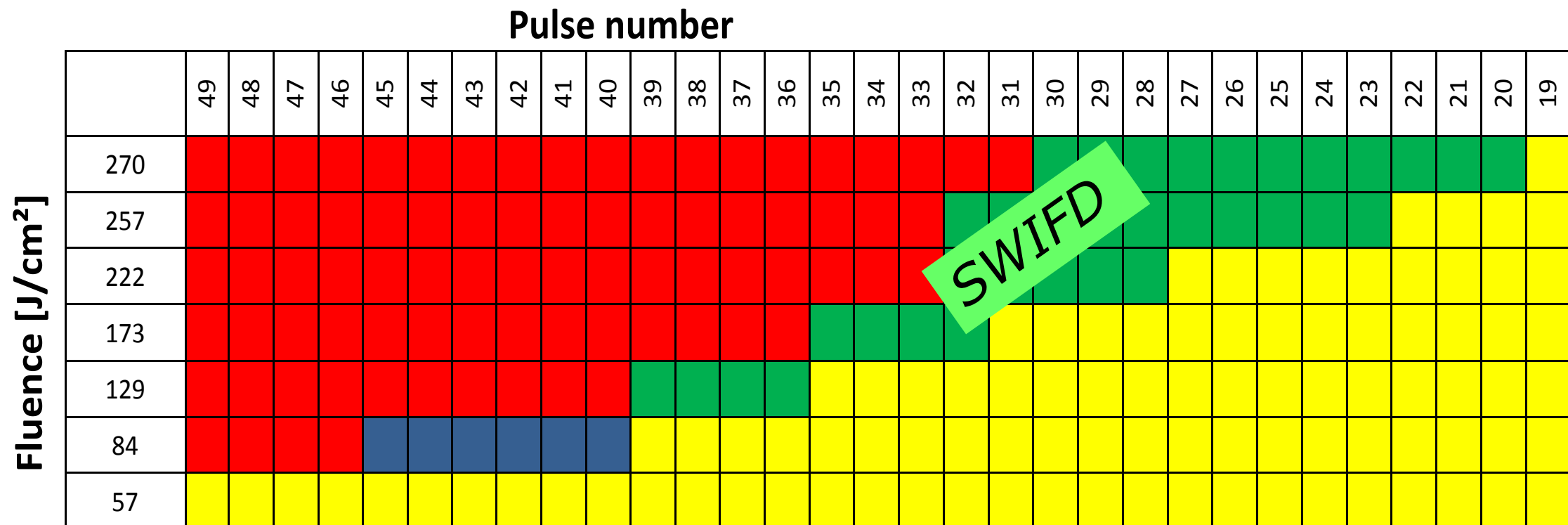
delamination and "fly away" of the CIGS material

4. SWIFD – CIGS on stainless steel

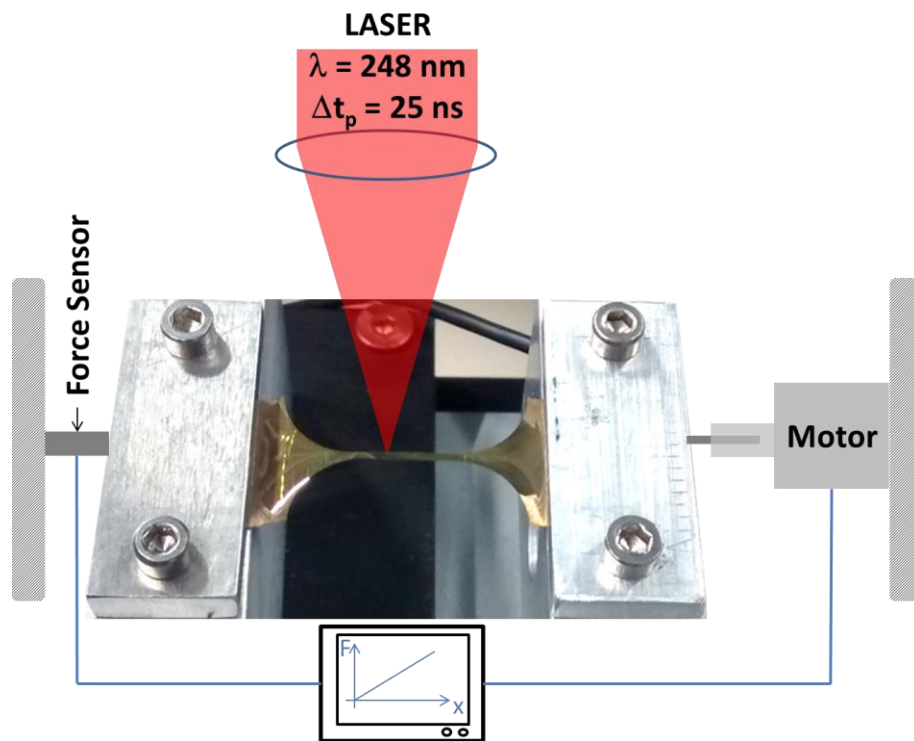
15



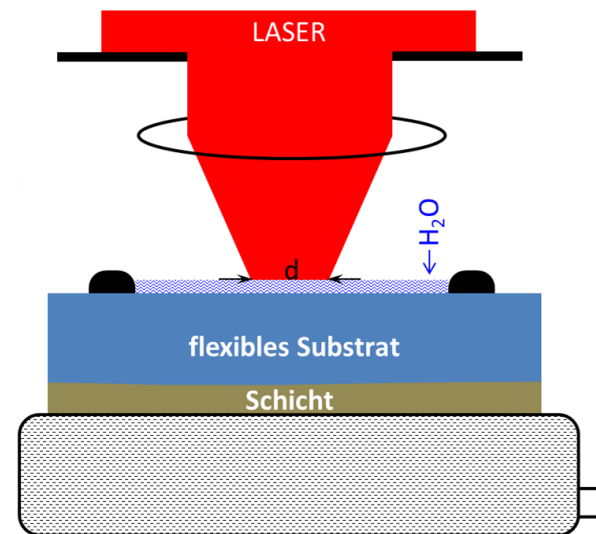
(left) EDX images of the front side of a sample after the SWIFD process.
 (middle) magnified view of the delaminated area shown in the left images.
 (right) High resolution SEM image of the broken CIGS edge.



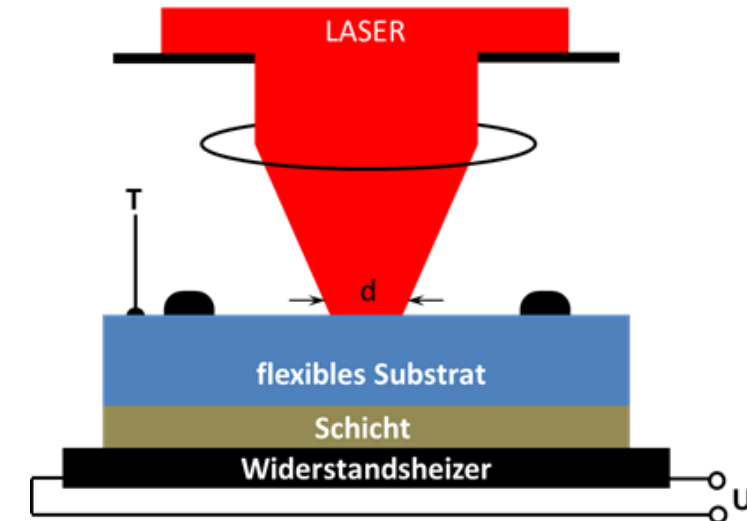
5.1 additional tension force



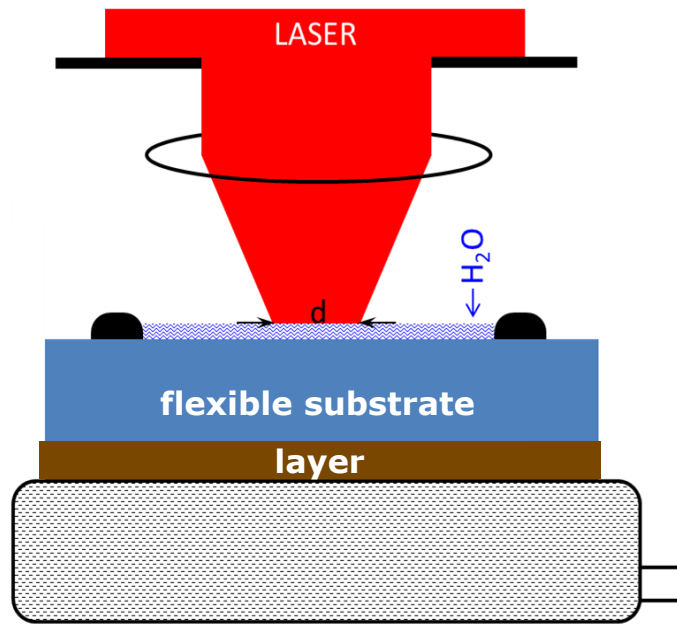
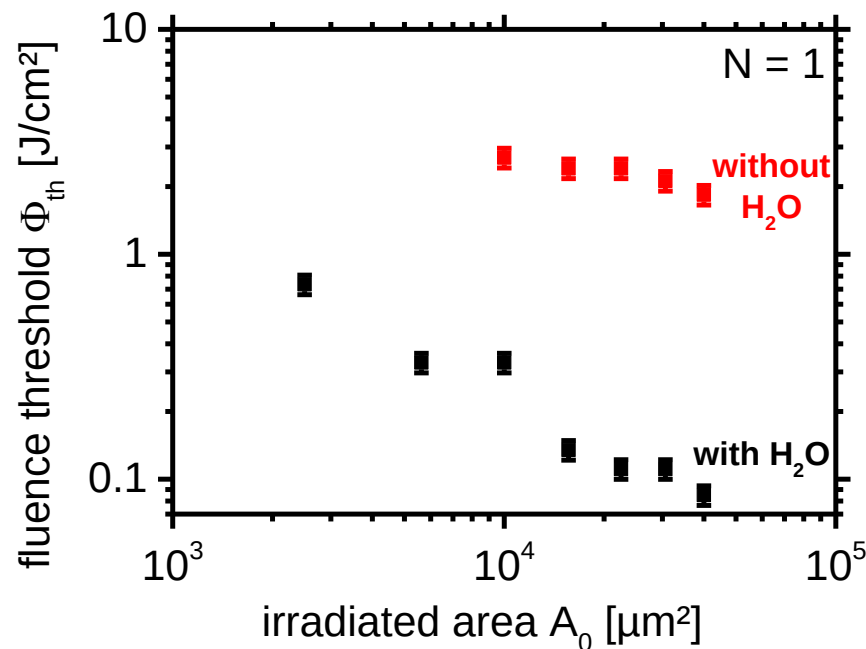
5.2 Confinement and laser spot size



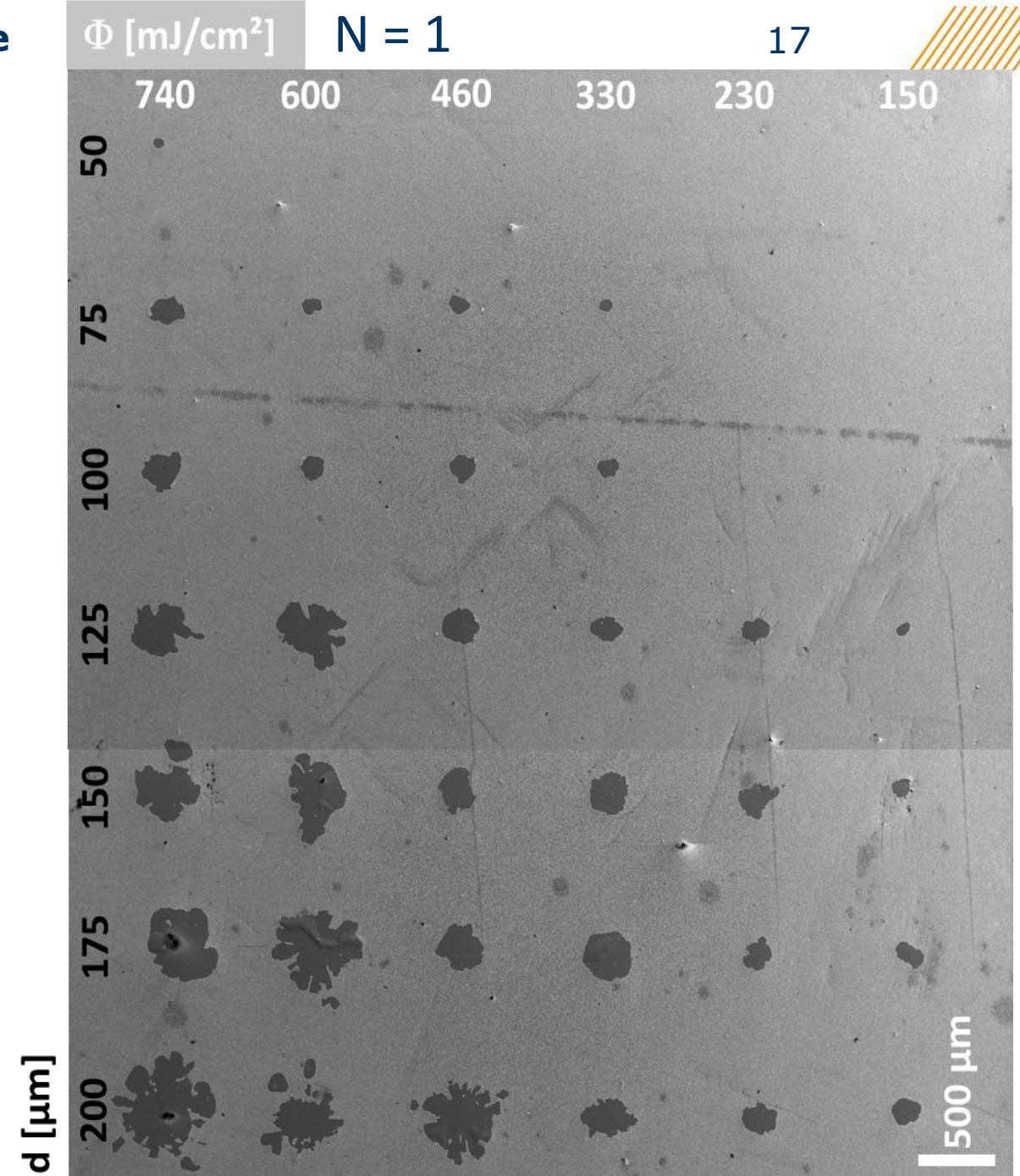
5.3 temperature



5.2 Confinement and laser spot size

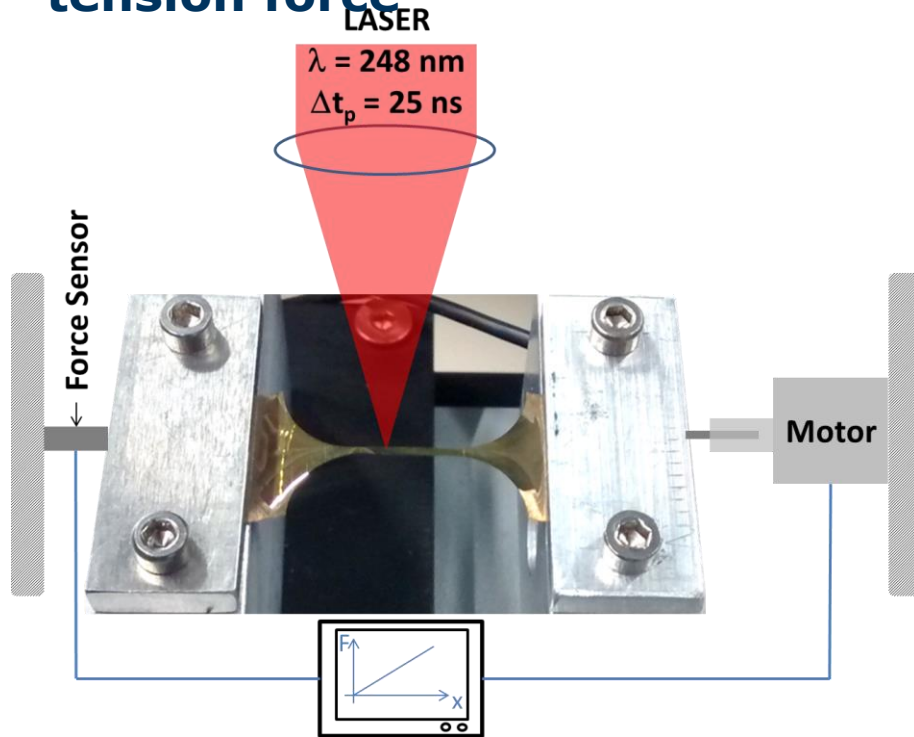


CIGS delamination threshold Φ_{th} dependence on irradiated area A_0 with and without confinement

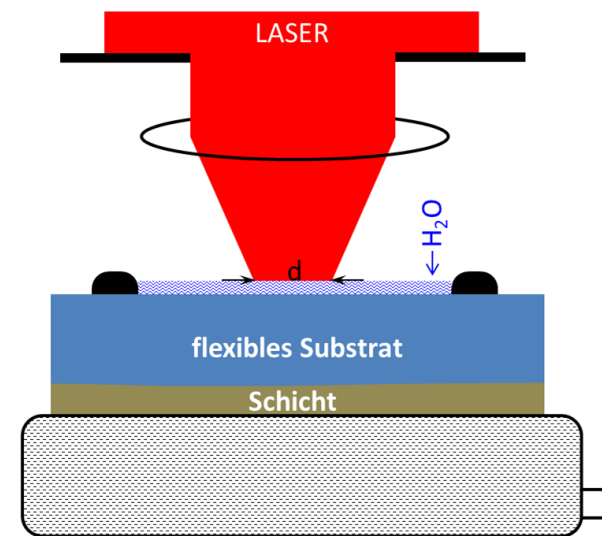


SEM images of the front side of a rear side irradiated CIGS solar cell at different laser fluences Φ and irradiated area $A_0 = d^2$.

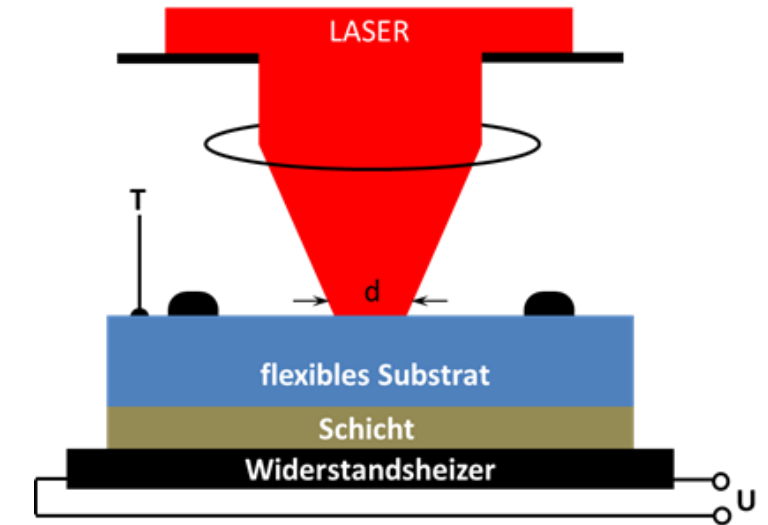
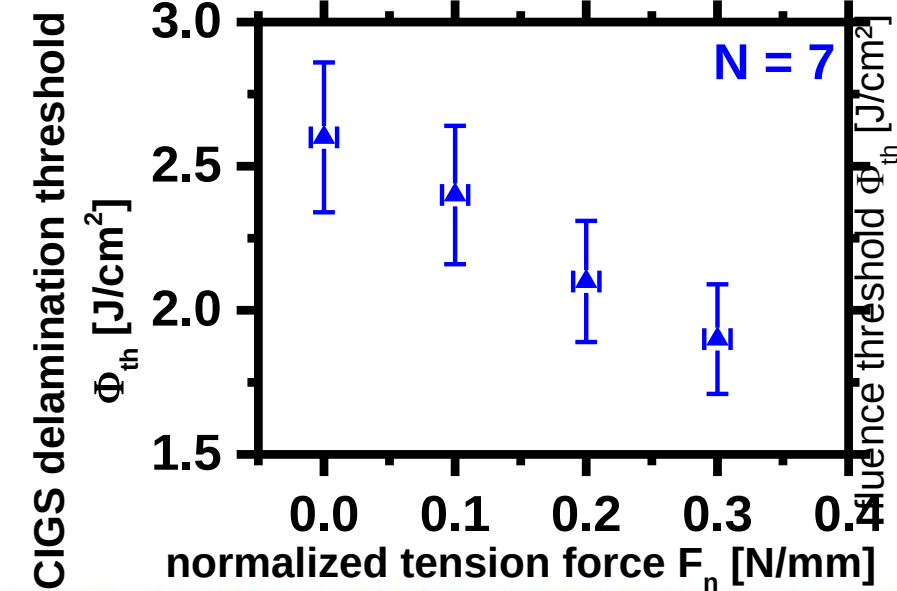
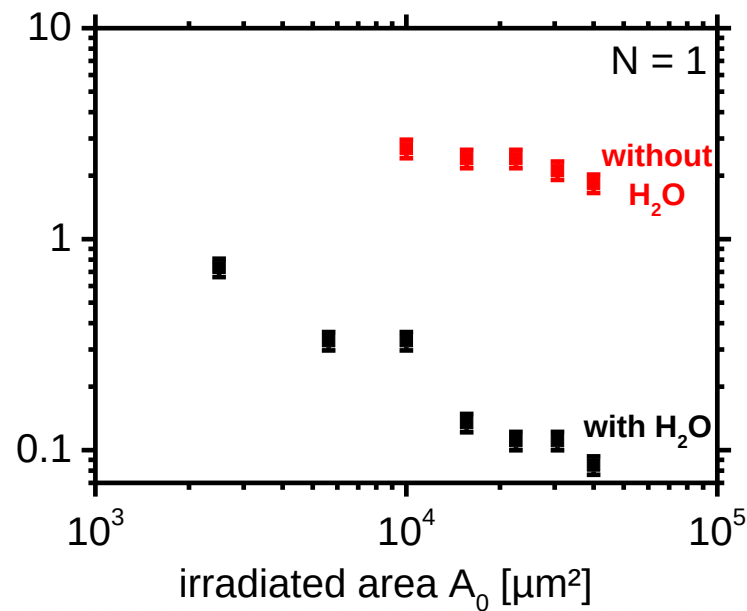
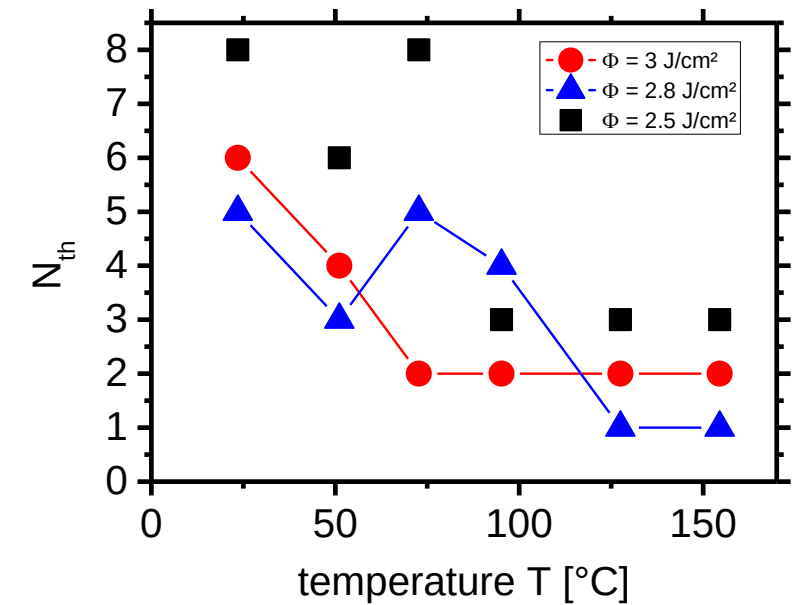
tension force



Confinement

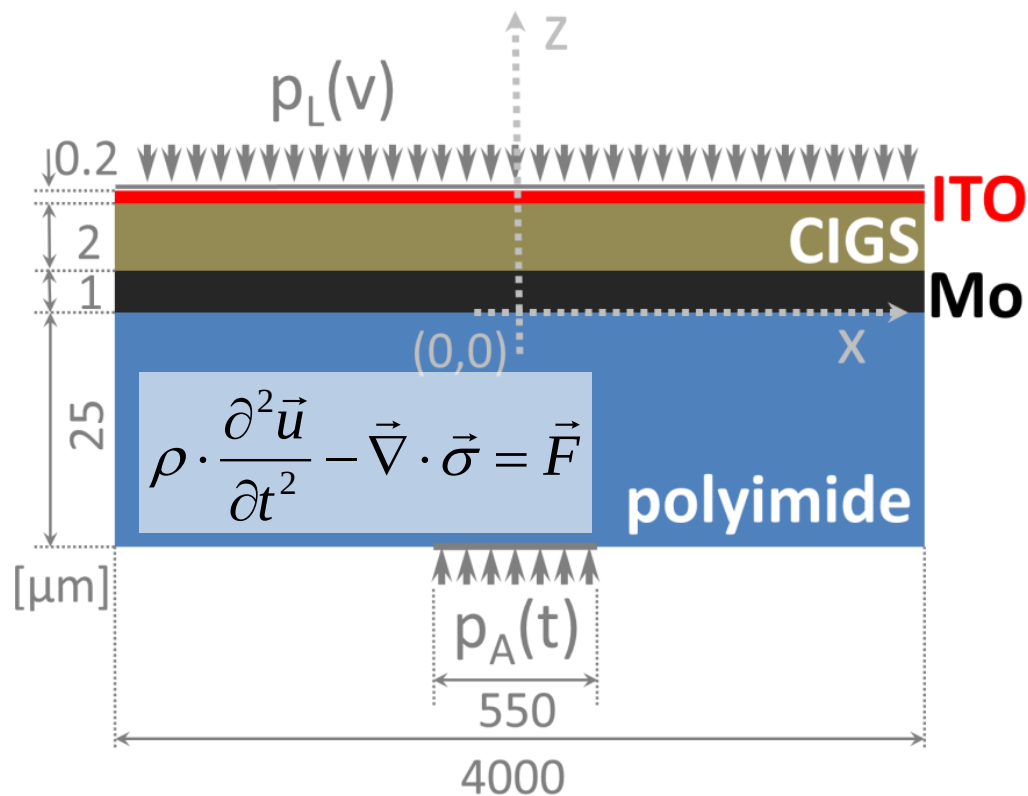


temperature



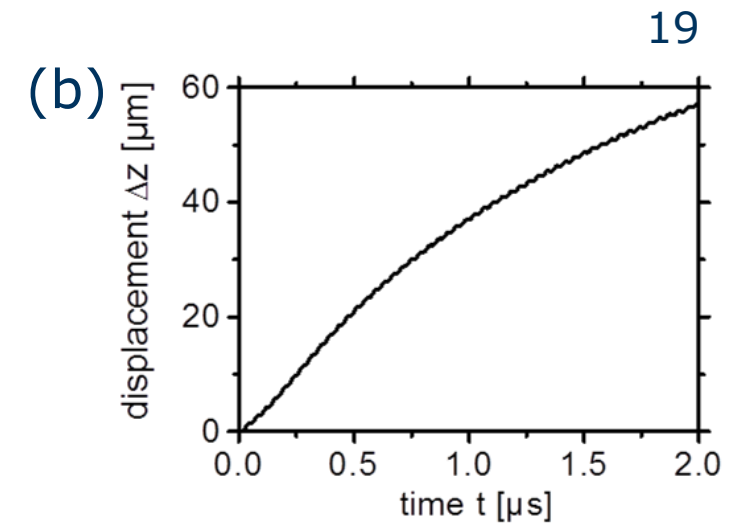
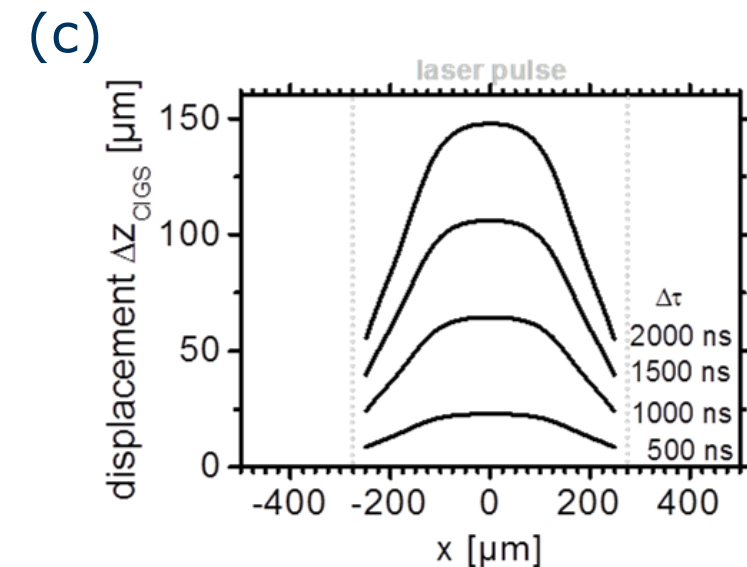
7. SWIFD – Theory

$$p_L(v) = p_0 \cdot \left[1 + \frac{k-1}{2} \cdot \frac{v(t)}{c_0} \right]^{2k/k-1}$$



$$p_A(t) = \begin{cases} b \cdot \frac{\Delta t_p}{\Phi} \cdot \left(\frac{\Phi \cdot \lambda}{\sqrt{\Delta t_p}} \right)^n & 0 \leq t \leq \Delta t_p \\ 0 & t < 0, t > \Delta t_p \end{cases} \approx 95 \text{ MPa} \quad \Phi = 2.8 \text{ J/cm}^2$$

Schematic illustration of the used model



- (a) Calculated deformation of the CIGS solar cells
- (b) Calculated bending-induced displacement Δz at (0,0)
- (c) Displacement of the "fly away" CIGS

The shockwave delamination process allows the selective removal of the CIGS material from the Mo back contact at different substrates.

shockwave delamination	laser ablation
 no thermal edge modification	 thermal edge modification
 fast structuring method	 fast structuring method
 low lateral precision	
 fabrication of high efficient solar modules	 fabrication of high efficient solar modules

The SWIFD process is especially suitable for thermal sensitive materials like OLED and organic solar cells.

Thank you for your attention!

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