



LASER PATTERNING OF CIGS THIN FILMS WITH 1550 NM NANOSECOND LASER PULSES

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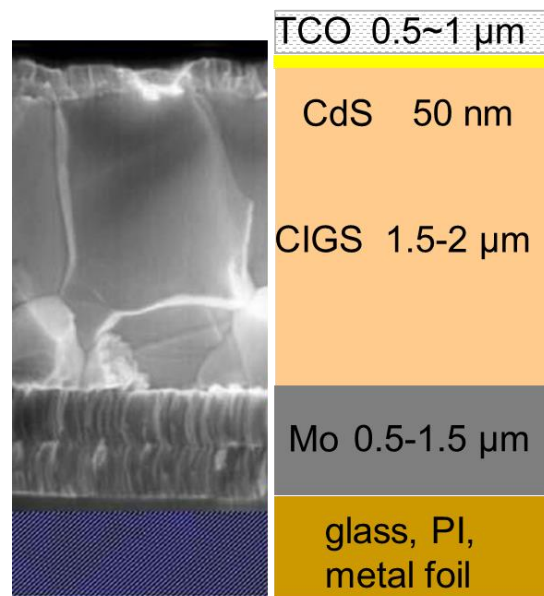
SP 1: Short pulse processes

September 19. – 22. 2016, Fürth, Germany

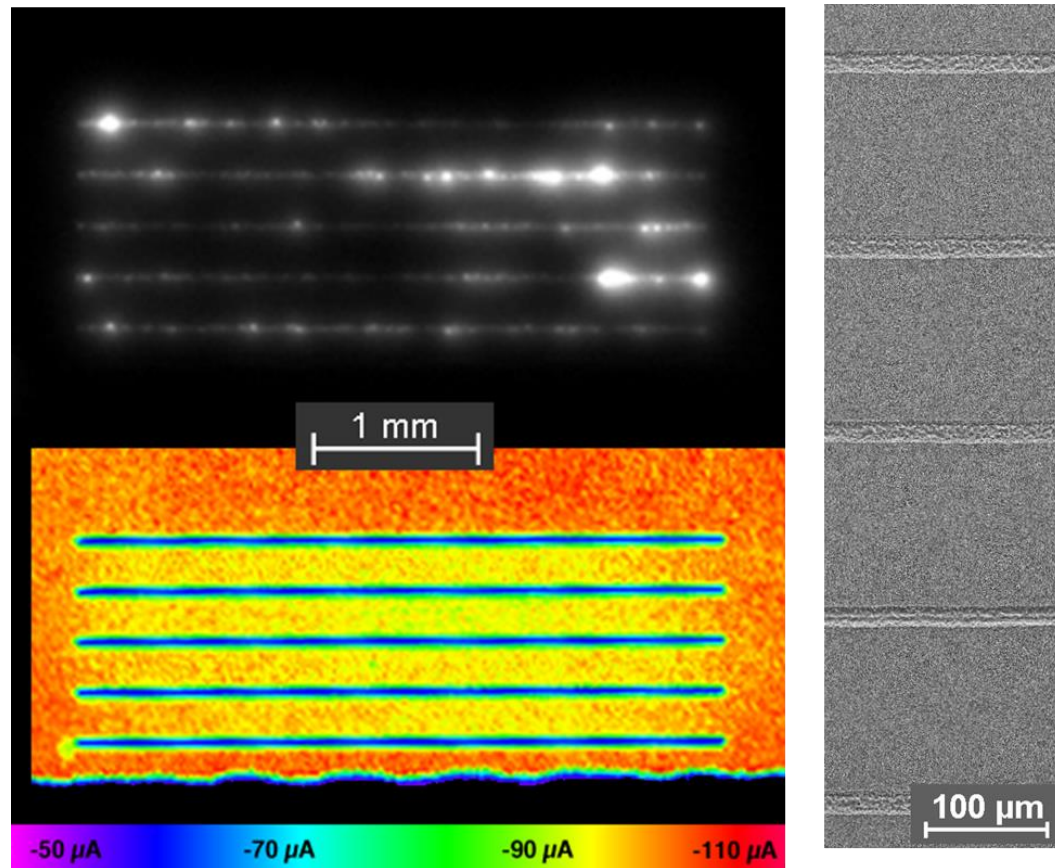
Laser patterning of CIGS thin films with 1550 nm nanosecond laser pulses

High-efficient, high-quality laser scribing is one key technology for efficient module fabrication.

Interface-related laser matter interactions are helpful for some material processing tasks



- Laser scribing for CIGS module fabrication
- Selected experimental results
- Mechanism of scribing
- Summary



DLIT and LBIC of laser P3
scribes with significant defects
reducing the photocurrent.

LASER SCRIBING FOR SERIAL INTERCONNECTION

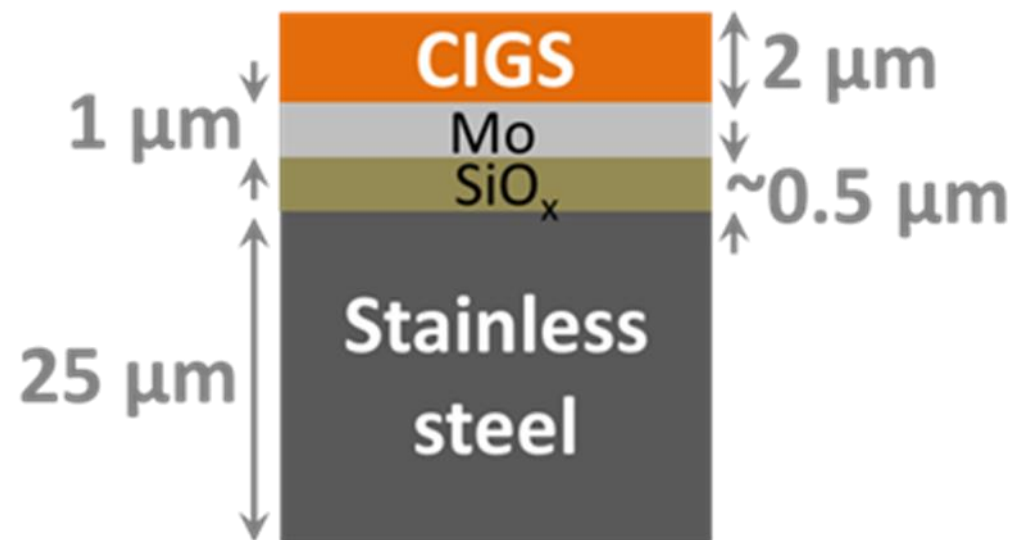
efficiency

narrow scribes → small dead zone
scribing with low defects e.g.
morphological, electrical
selective processing → material
selective / interface related

technical

fast scribing – high speed
reliable process
low cost process

High-efficient, high-quality laser scribing is one key technology.



Schematic cross section of the CIGS samples.

SAMPLES AND LASER

Source: Abengoa solar NT

CIGS ~ 2 μm

Molybdenum ~ 1 μm

Dielectric insulator ~0.5 μm

Stainless steel foil

Wavelength: 1550 nm

Pulse duration: 6 ns

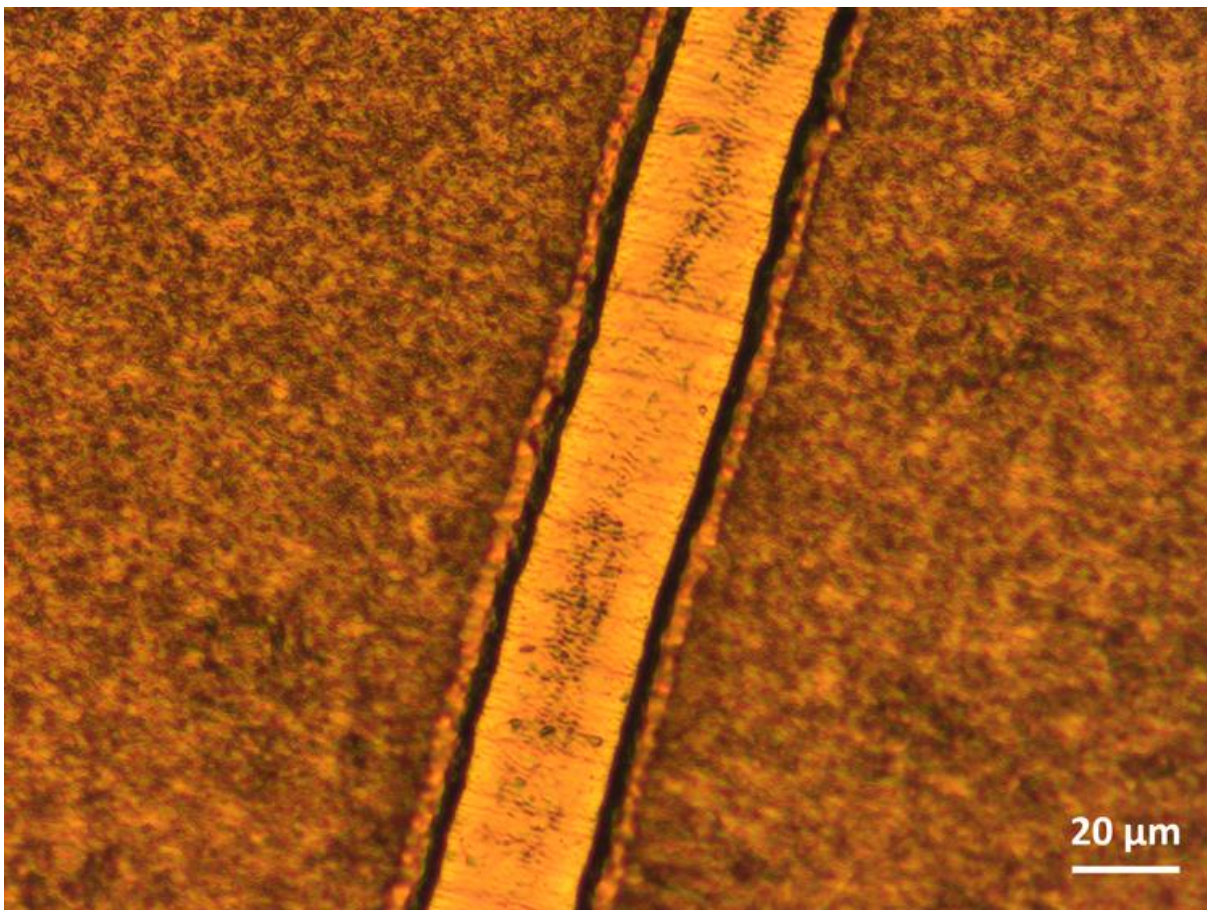
Repetition rate: 100 kHz

Scanning speed: 0.1 to 10 m/s

Pulse energy: 6 to 50 μJ

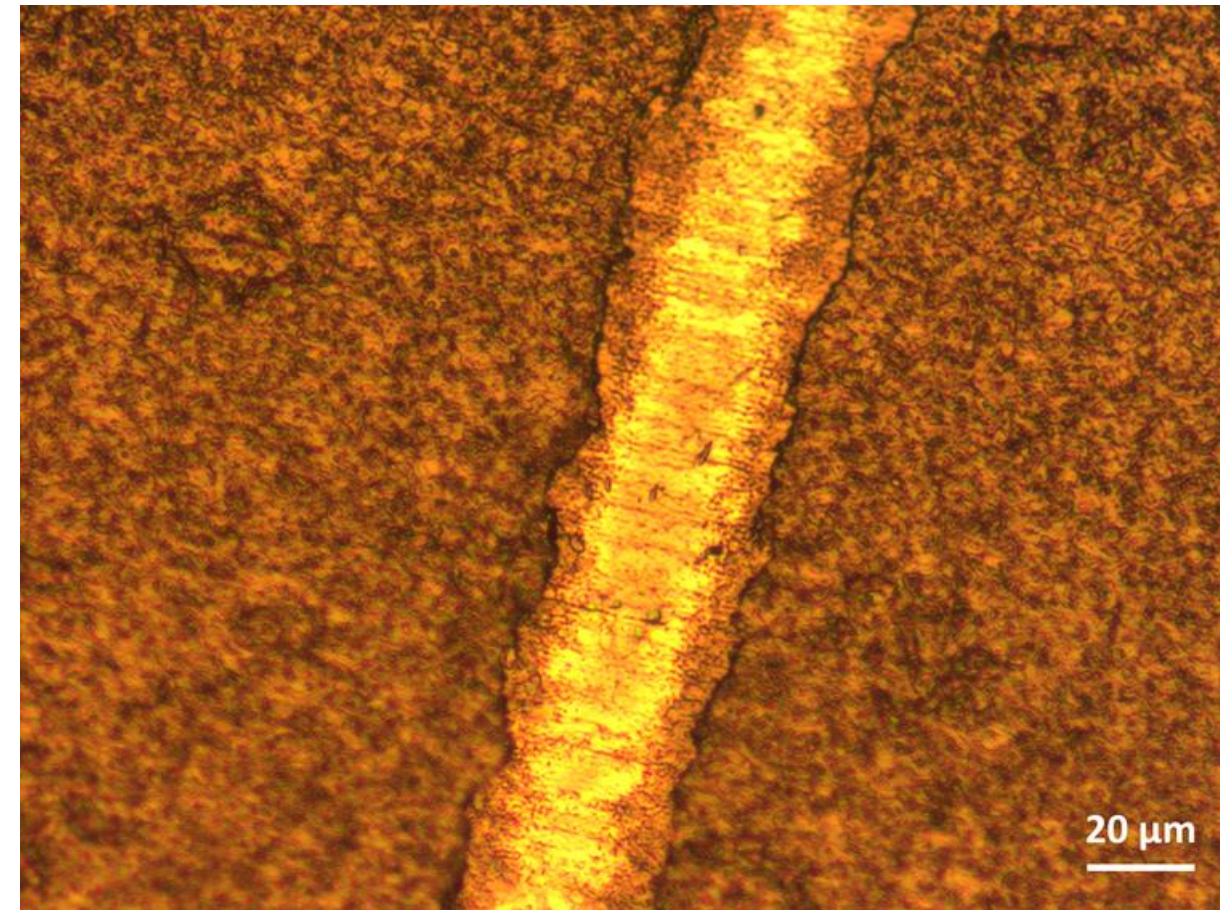
→ **Scribing of CIGS for P2 and P3 interconnection steps.**

$v_s = 0.1 \text{ m/s}$



ablation

$v_s = 3 \text{ m/s}$



delamination

The optical images show differences at the bottom and the edges of the scribe ($E_{\text{puls}} = 18 \text{ μJ}$)

straight

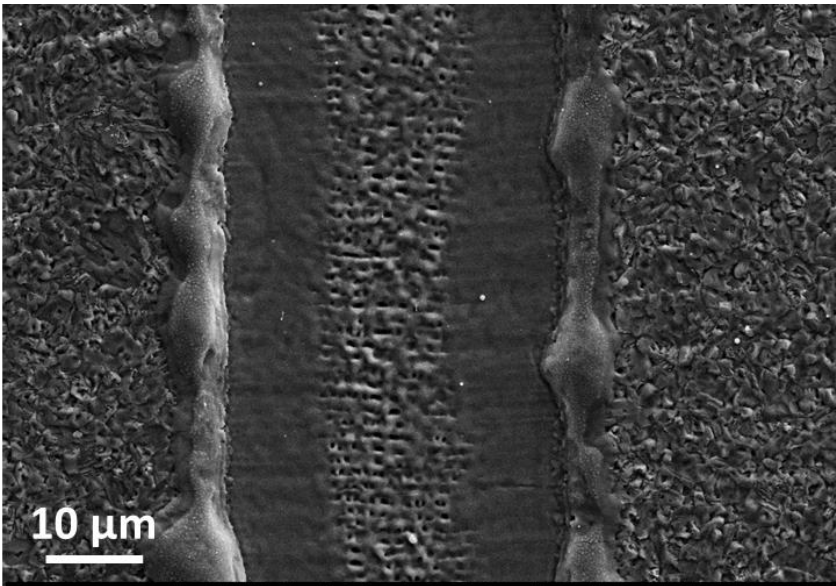
edges

jagged

homogeneous, cleared

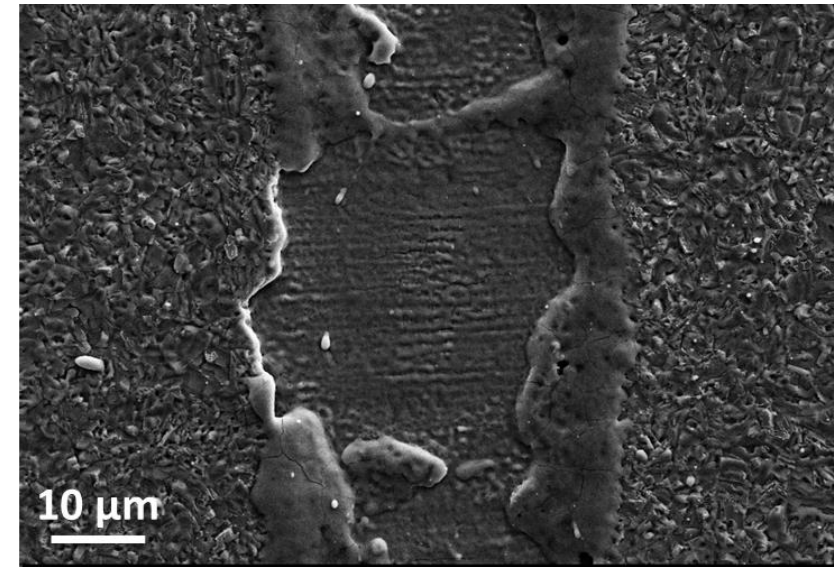
bottom

sectioned, scattering / shiny

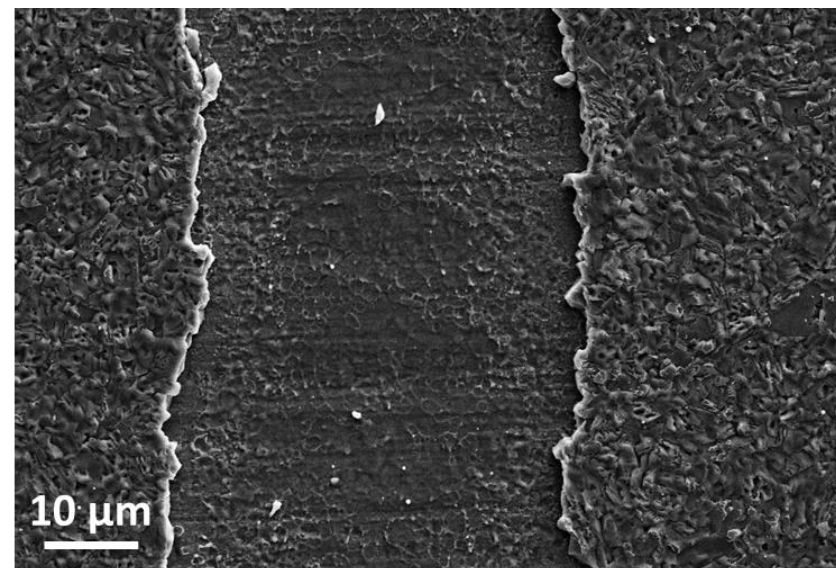


$v_s = 0.05 \text{ m/s}$

melting
&
ablation

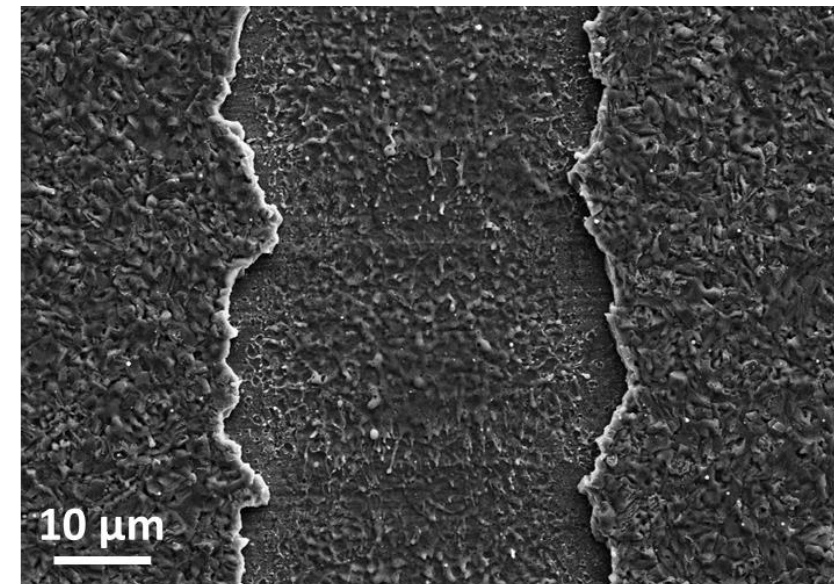


$v_s = 0.15 \text{ m/s}$,



$v_s = 1.5 \text{ m/s}$

film cracking
&
delamination



$v_s = 3 \text{ m/s}$

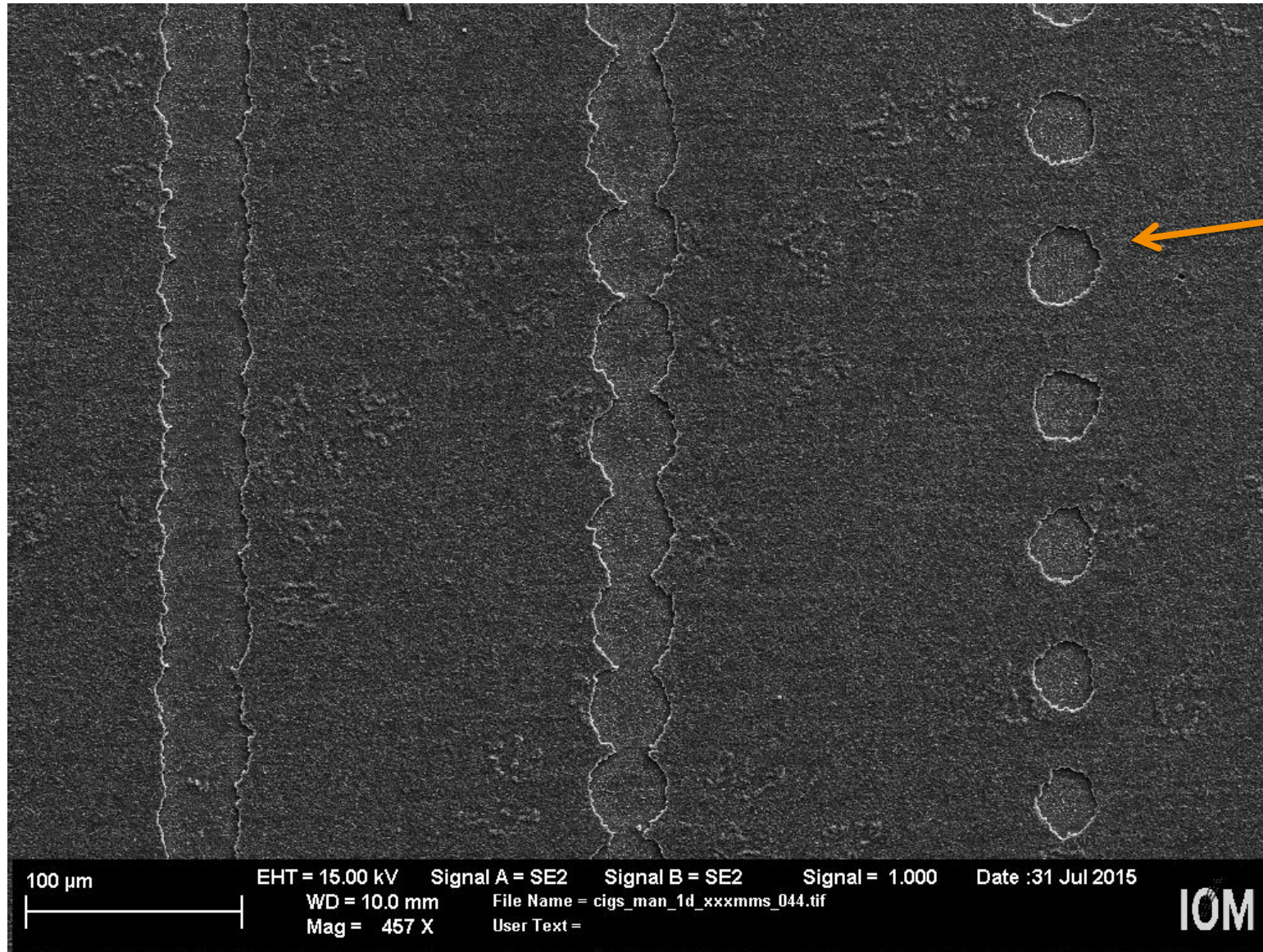
		E [μ J]										
		5,8	9	14	18	22	25	29	34	39	43	49
v [m/s]	0,01	a	a	a	s	s	s	s	s	s	s	s
	0,02	a	a	a	a	s	s	s	s	s	s	s
	0,05	a	a	a	a	a	a	s	s	s	s	s
	0,08	ü	a	a	a	a	a	a	a	s	s	s
	0,1	ü	a	a	a	a	a	a	a	a	a	s
	0,12	ü	a	a	a	a	a	a	a	a	a	a
	0,15	ü	a	a	a	a	a	a	a	a	a	a
	0,2	ü	ü	a	a	a	a	a	a	a	a	a
	0,3	ü	ü	ü	ü	a	a	a	a	a	a	a
	0,5	l	l	l	l	ü	ü	ü	ü	a	a	a
	0,8	l	l	l	l	l	l	l	l	ü	ü	a
	1	l	l	l	l	l	l	l	l	l	l	ü
	1,5	l	l	l	l	l	l	l	l	l	l	l
	2	l	l	l	l	l	l	l	l	l	l	l
	2,5	n	l	l	l	l	l	l	l	l	l	l
	3	n	l	l	l	l	l	l	l	l	l	l
	5	n	n	n	n	l	l	l	l	l	l	l
	10	n	n	n	n	n	n	n	n	n	n	n

Damage

Laser ablation

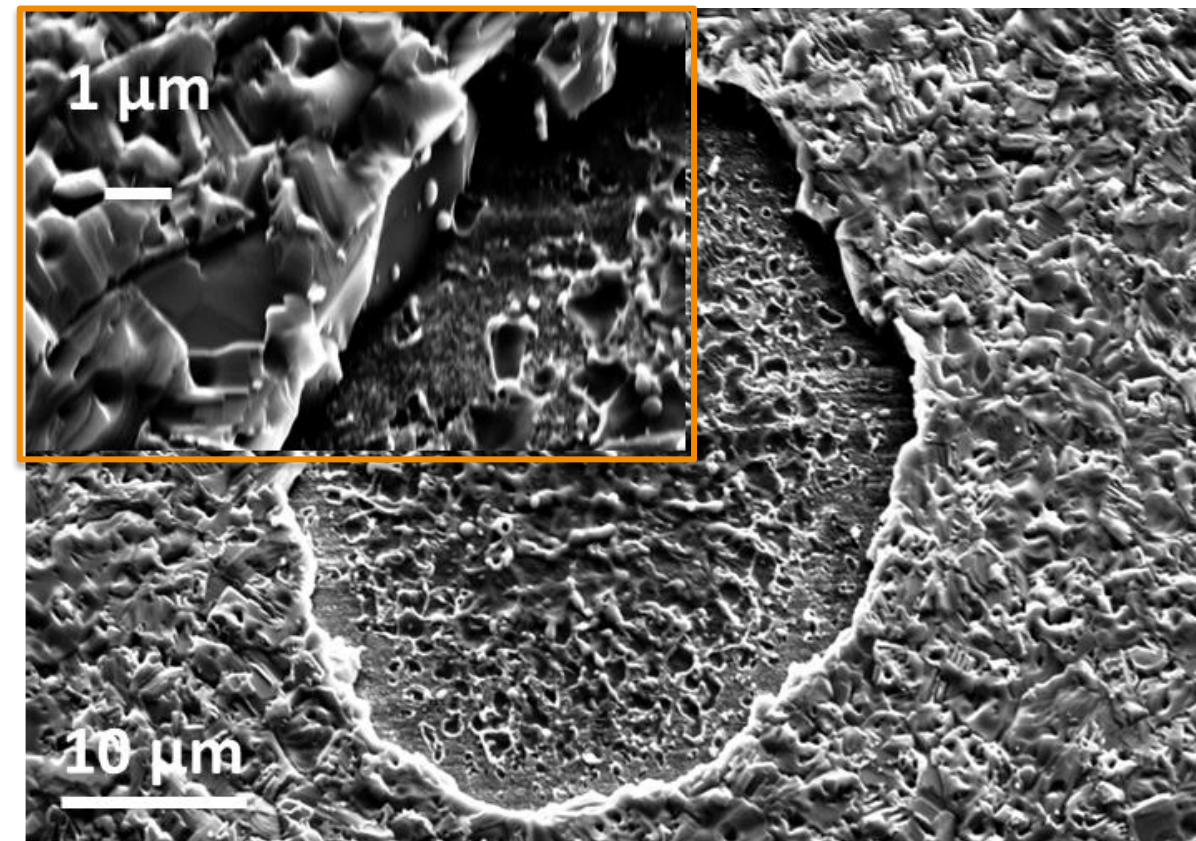
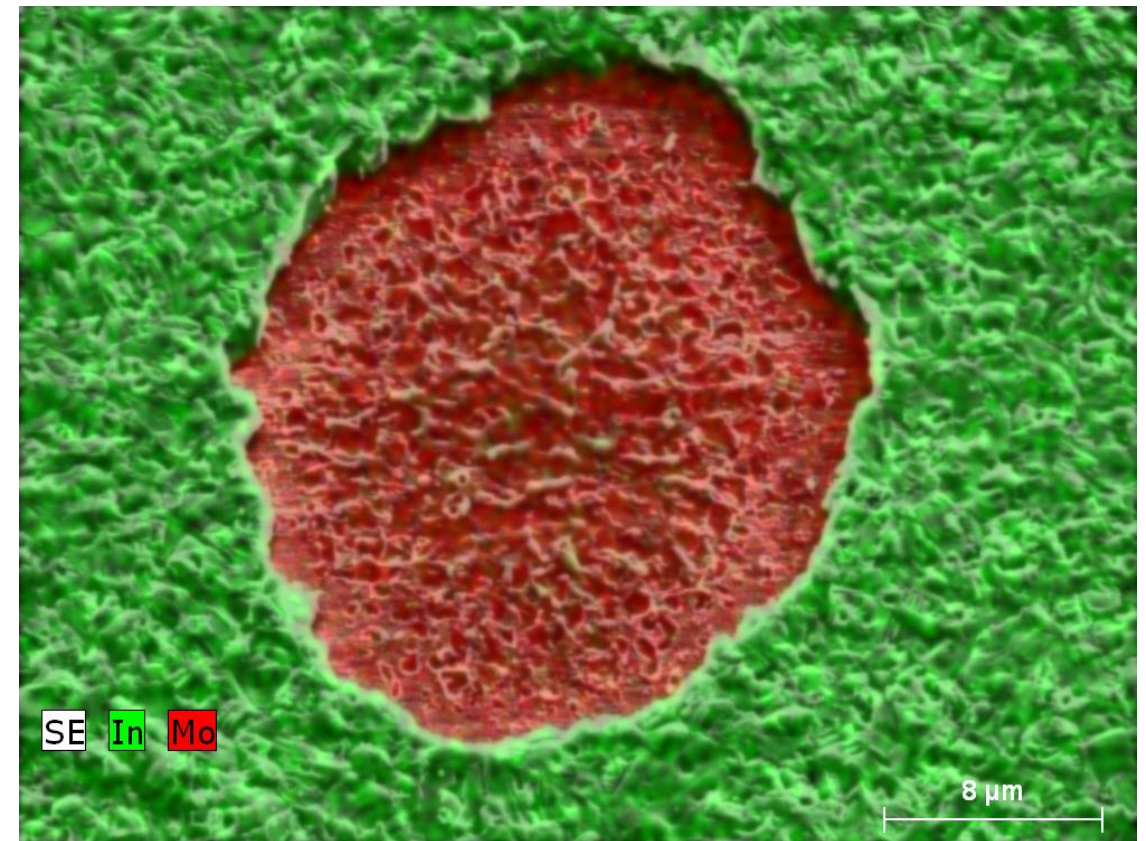
Lift-off / delamination

green: laser ablation
 dark green: laser lift-off
 yellow: transition from ablation to lift-off;
 red: Mo film damaged
 blue: separated pulses



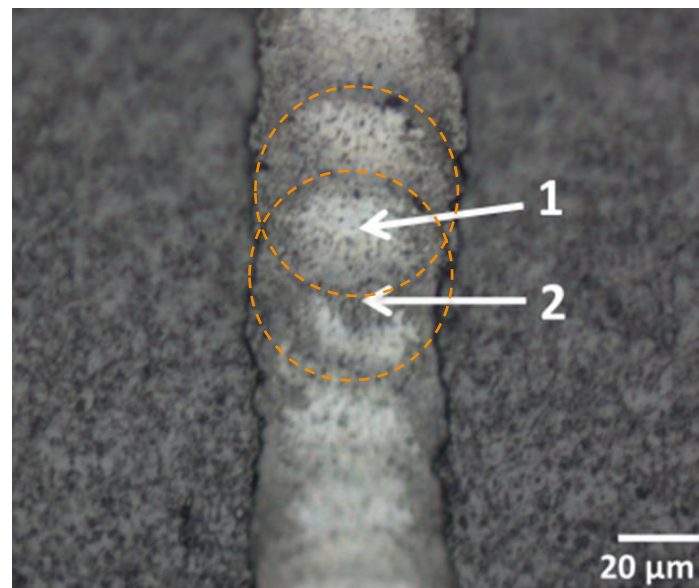
Single pulse ablation to study the mechanism

SEM image of CIGS scribes with different scribing speeds (3, 5, and 10 m/s)..

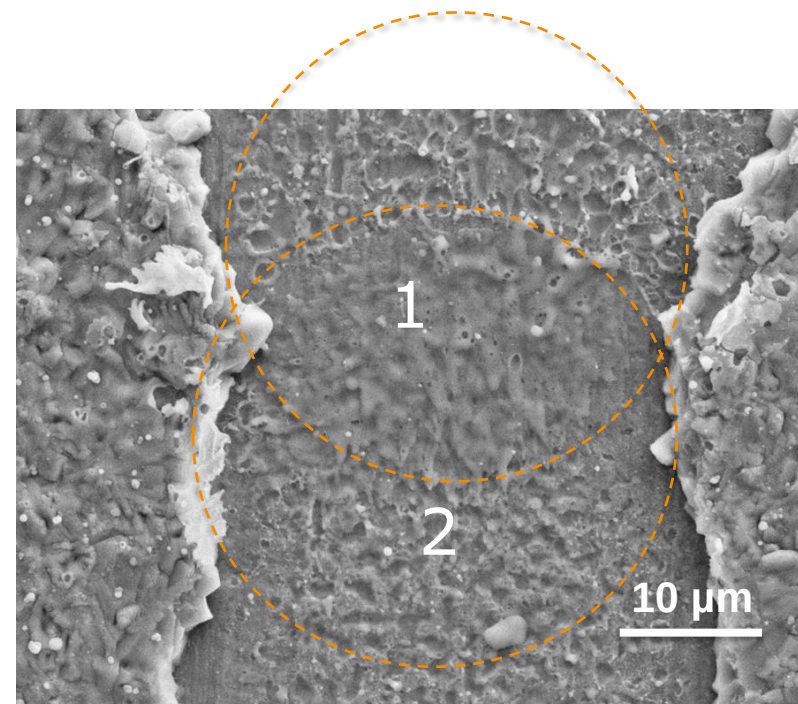


SEM: green: indium signal
 red: molybdenum signal

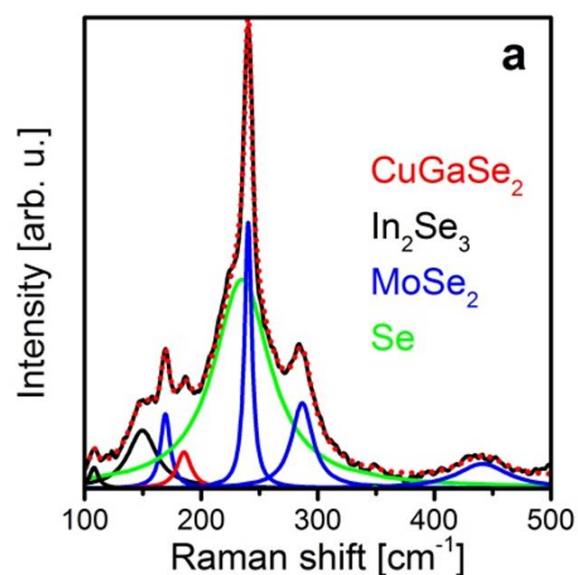
EDX: green: indium signal
 red: molybdenum signal



Optical image:
Scribe with a
pulse overlap of $\sim$
50%

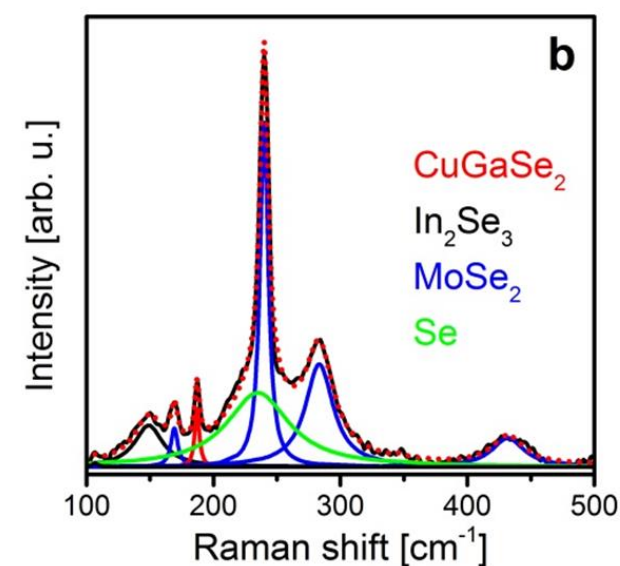


**SEM image of a
similar scribe**



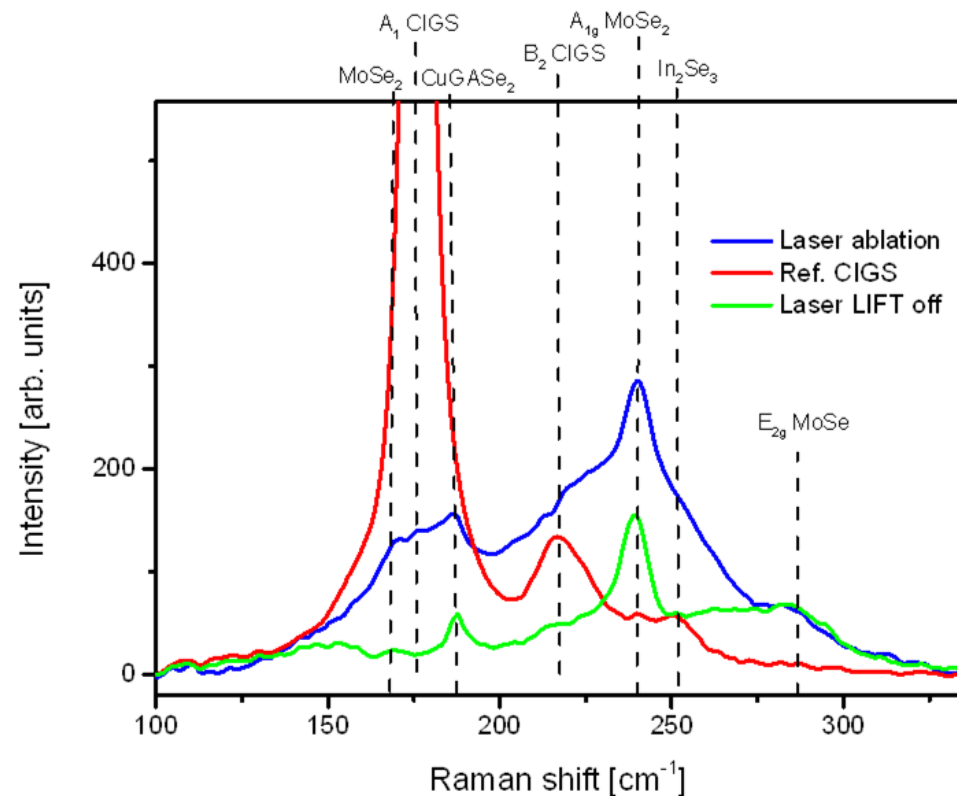
**Dark region,
see arrow 2**

**2ed pulse high
fluence**



**Bright region,
see arrow 1**

**2ed pulse low
fluence**



Raman spectra of different scribed areas:

CIGS

laser ablation scribe

lift-off delamination scribe

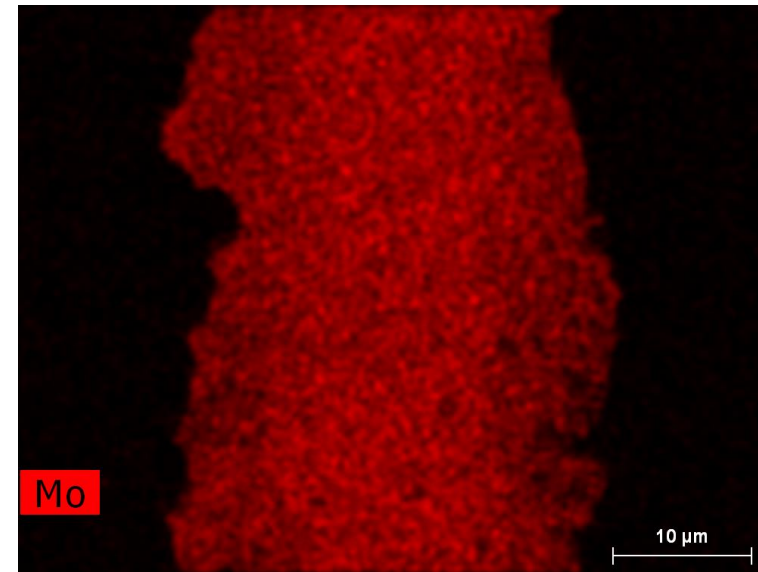
MECHANISM DETERMINES THE SURFACE COMPOSITION

- The laser-induced ablation mechanism influences the characteristics of the exposed surface of the molybdenum.
- MoS₂ is the main component on top of the scribed Mo back contact
- Ablation and lift-off cause removing of the main amount of CIGS
- The laser-ablated surface show more remaining components of the CIGS absorber film because the multi-pulse ablation process is accompanied with induced sequential melting

Composition of CIGS scribe at laser lift-off delamination

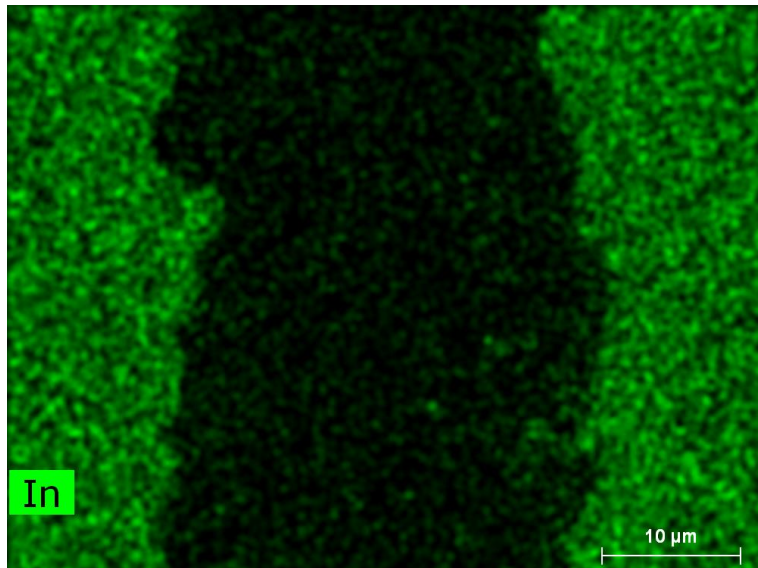
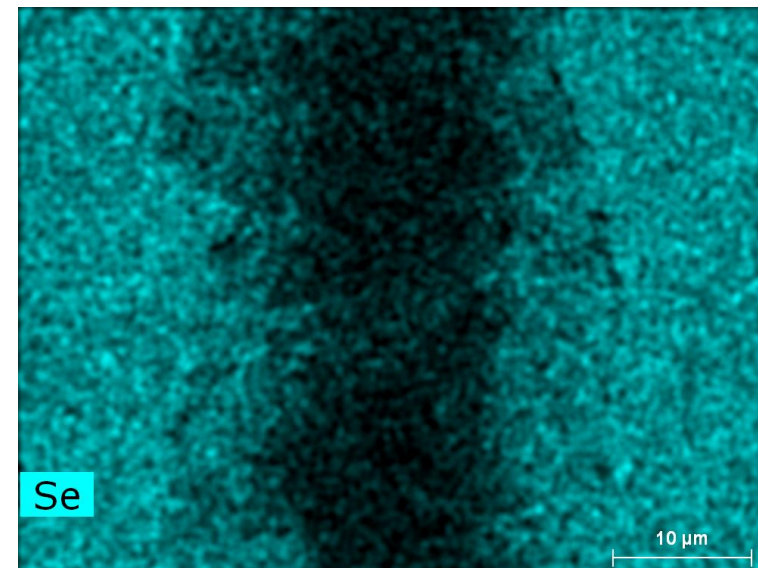
SEM

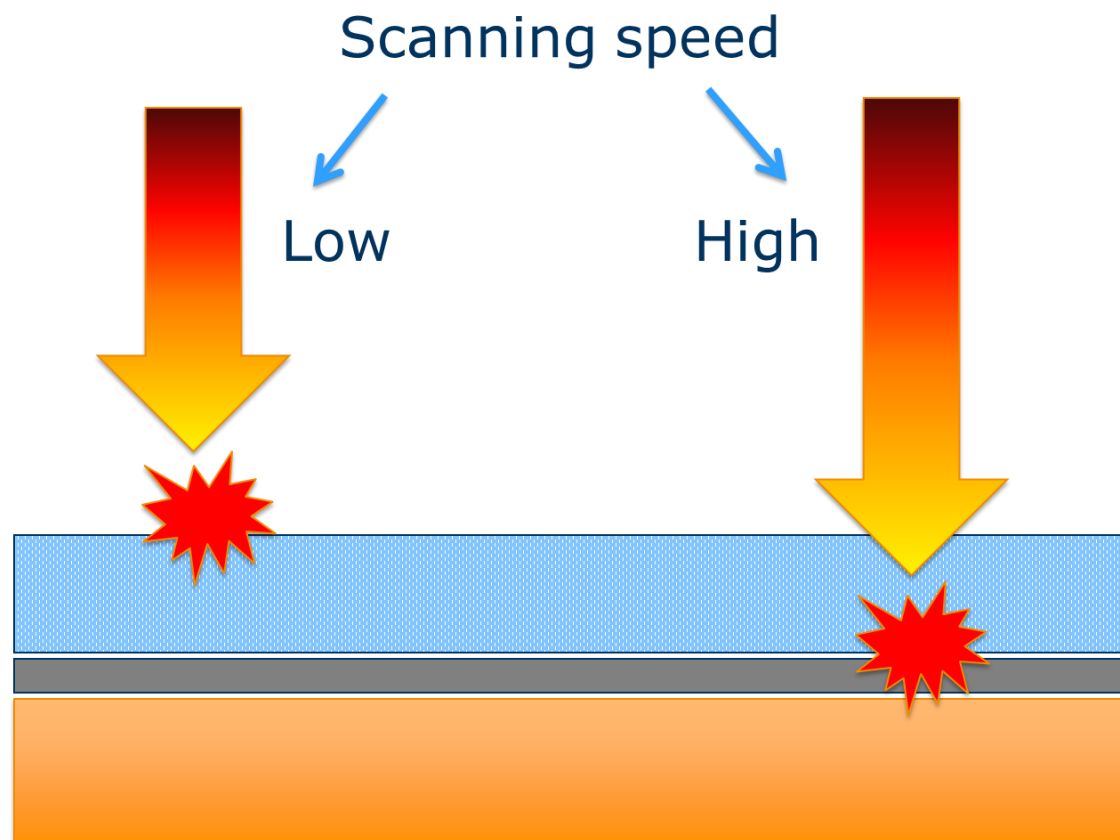
EDX: Mo



EDX: In

EDX: Se





Sketch of the laser absorption driven subsequent processes of scribing

SUGGESTED MECHANISM

High pulse overlap

- heat accumulation
- increasing of the absorption in the CIGS



Laser ablation

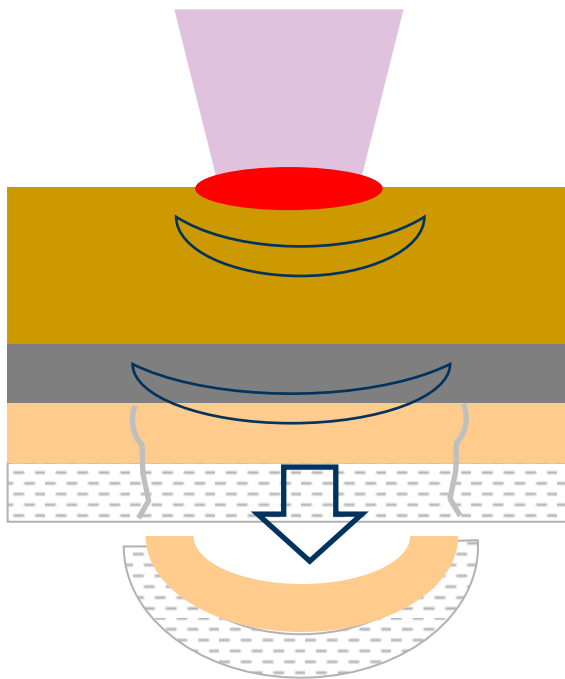
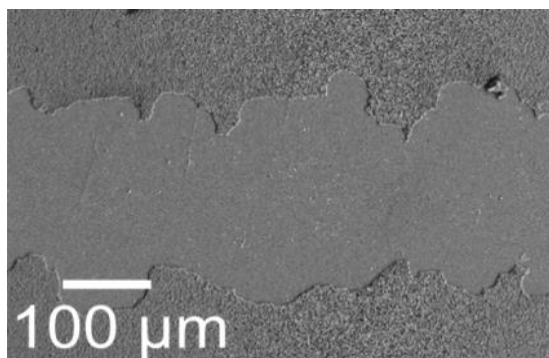
Low pulse overlap

- little heating of the CIGS
- keeping the low CIGS absorption
- laser energy absorption near the CIGS / Mo interface

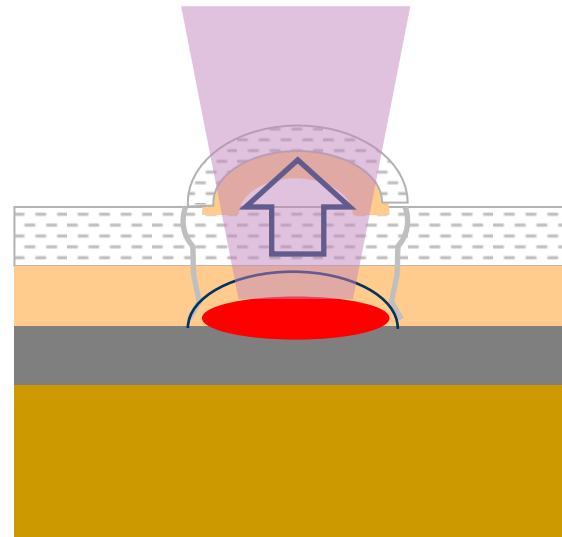
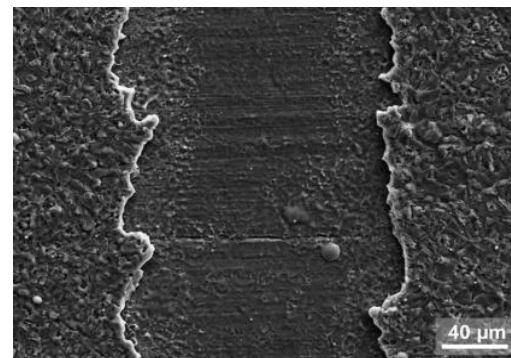


Laser lift-off, delamination

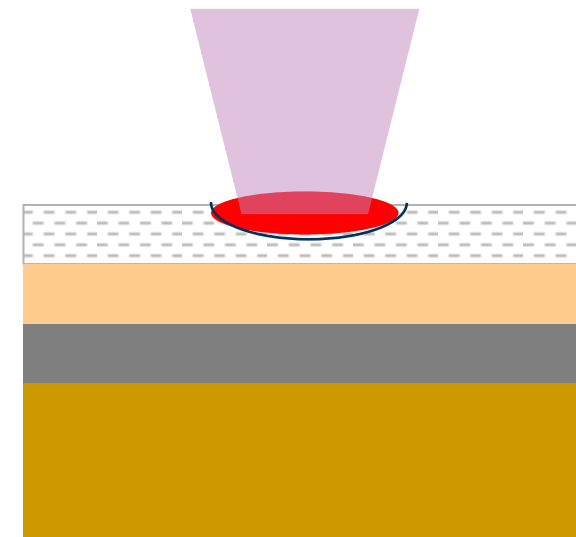
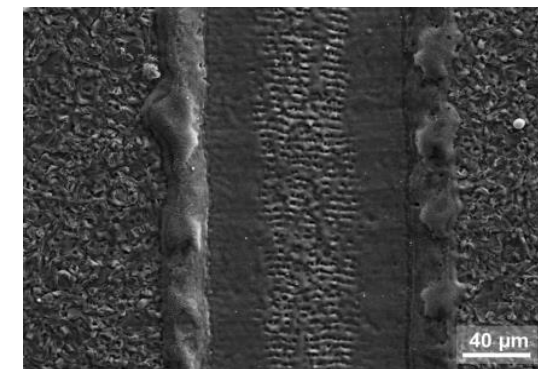
shock wave induced
thin film
delamination



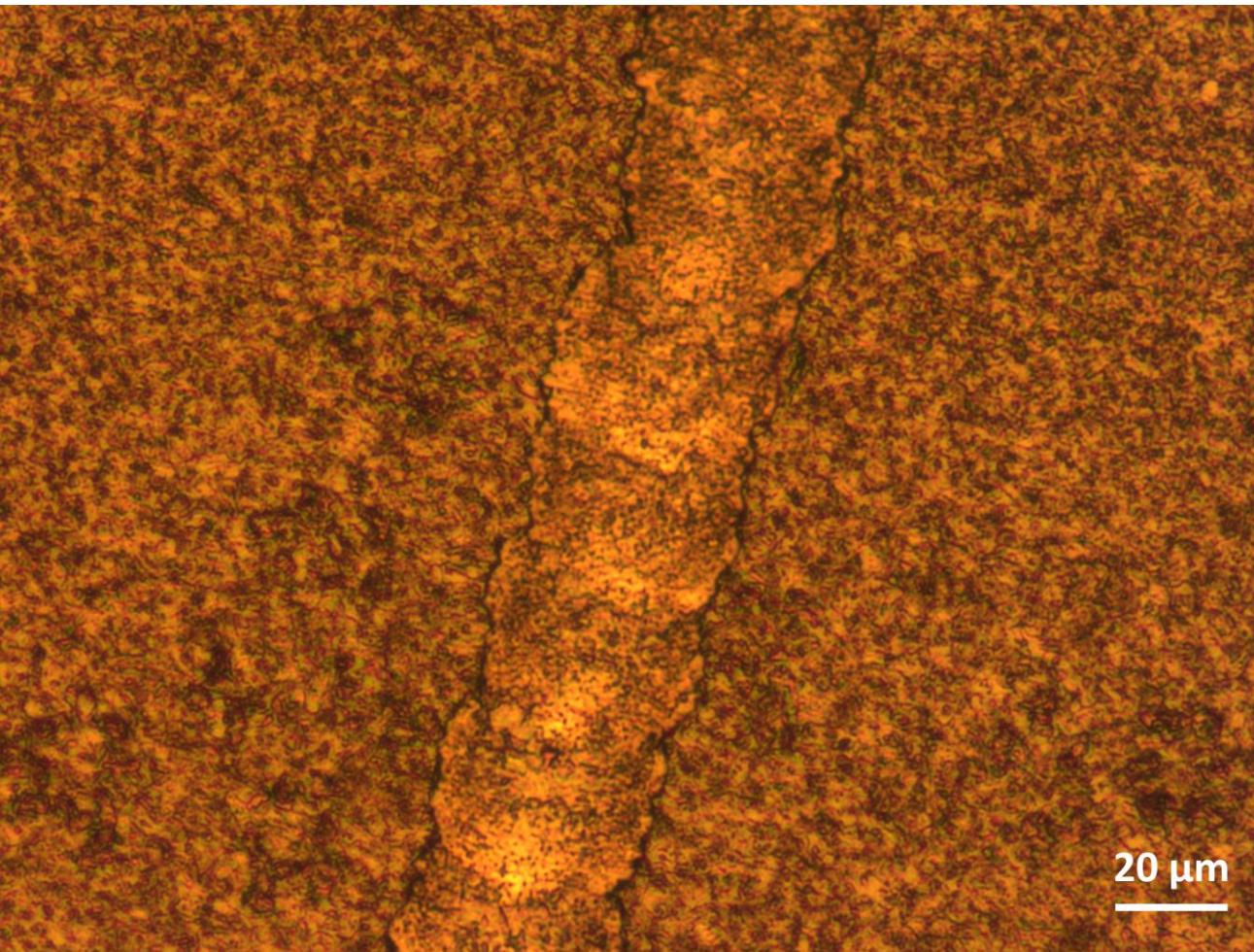
confined ablation
induced thin film
delamination



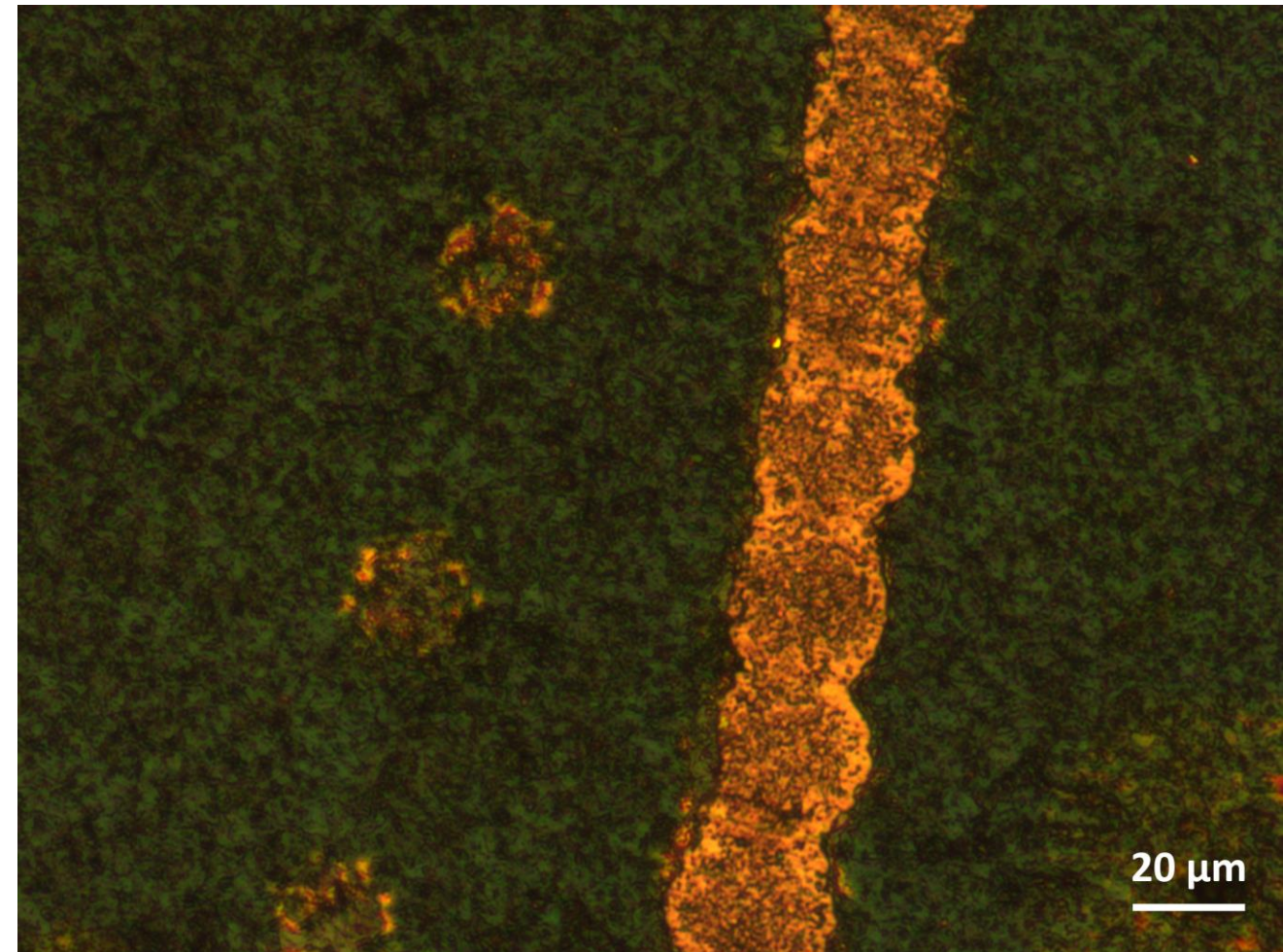
laser ablation



CIGS (P2)

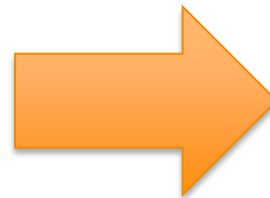


CIGS with TCO (P3)

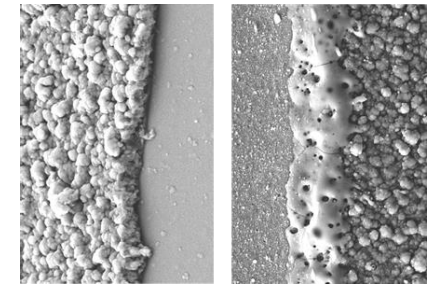
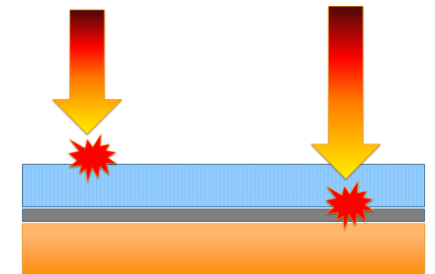
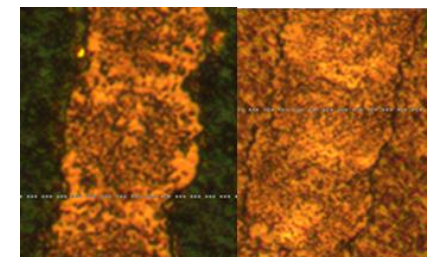


Comparison of optical micrographs of P2 and P3 scribes performed with the same parameters (18μJ , 2.5 m/s).

- Depending on the ns 1.55 μm laser irradiation parameters two different mechanism were observed: **laser ablation** and **lift-off /delamination**
- Thermal accumulation should be avoided for **lift-off /delamination**.
- **Lift-off /delamination** was found within a large parameter window → stabile laser scribing process
- The same mechanism can be utilized for P2 and P3 scribing.
- The **CIGS and CIGS/Mo interface properties** influencing
 - the mechanical properties
 - the PV efficiency
 - laser scribing mechanism



Optimization for the particular device set up!





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Thank you for your attention!