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IOM
Leibniz Institute of Surface Modification
Laser Processing in Photovoltaics

Investigations of laser-induced layer lift-off processes for thin-film solar cell processing

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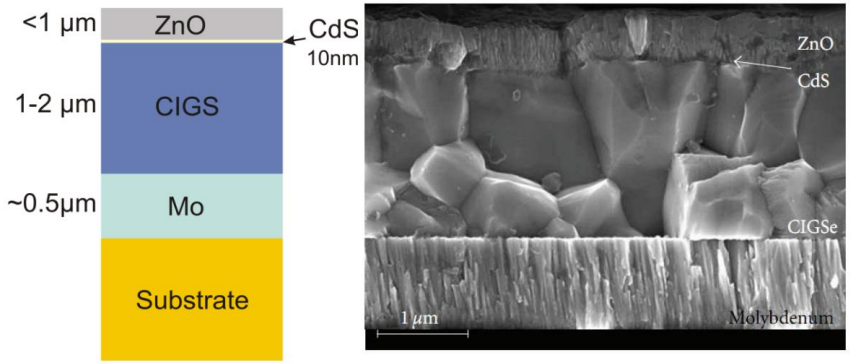
Motivation: Thin-film solar cells

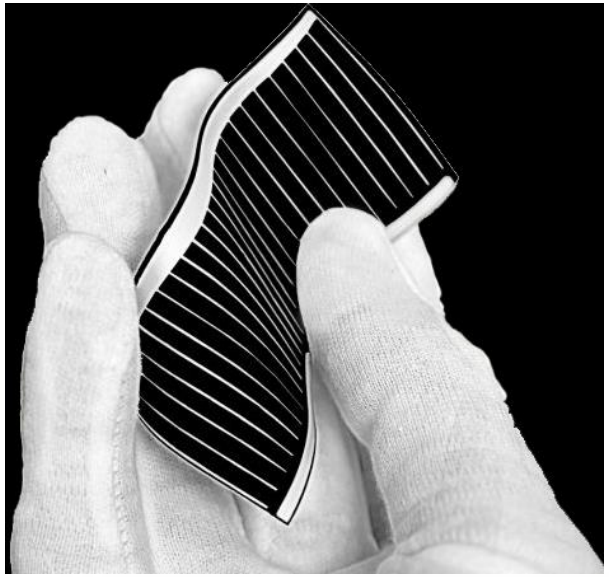
Cu-chalcopyrite based solar cells technologies:

$CuIn_xGa_{1-x}Se_2$ -(CIGS)

$Cu_2ZnSn(S,Se)_4$ – (CZTSe)

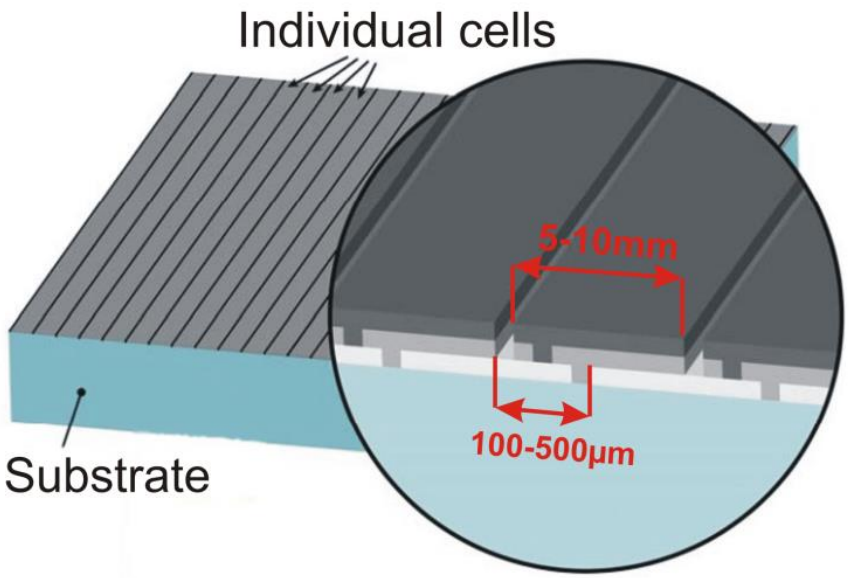


- Save resources (thin layers)
- Low manufacturing cost expected in the future (Roll-to roll process)
- Flexible substrate (easy to integrate)
- Good W_p/ weight ration (space applications)
- Performance up to 21.7% (ZSW) for CIGS and 12.6% (Solar Frontier) for CZTSe

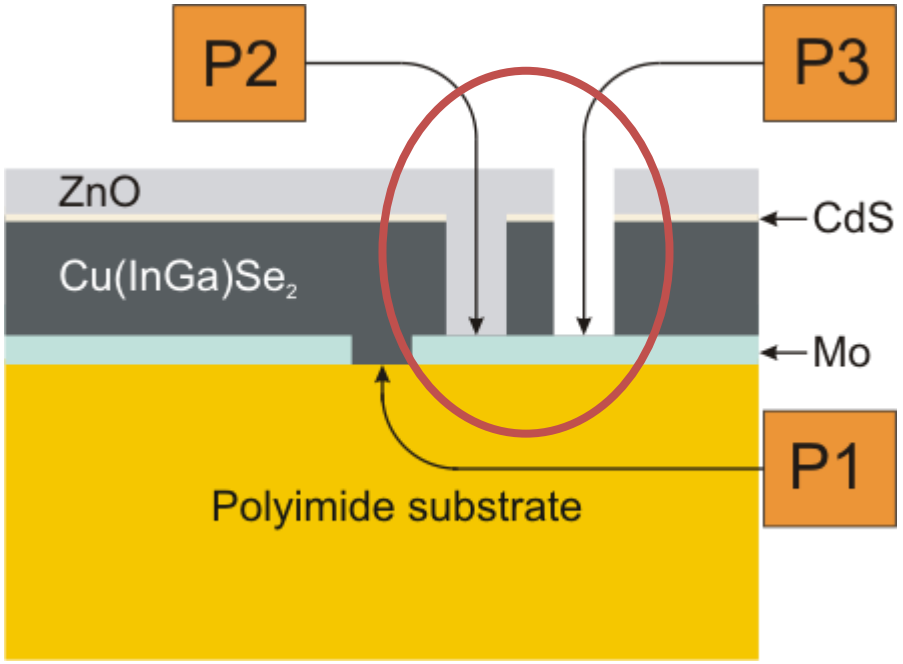


www.solarion.de

Motivation: Series interconnects



C. Dunsky and F. Colville: Solid state laser applications in photovoltaics manufacturing, Proceedings of SPIE 6871, (2008).

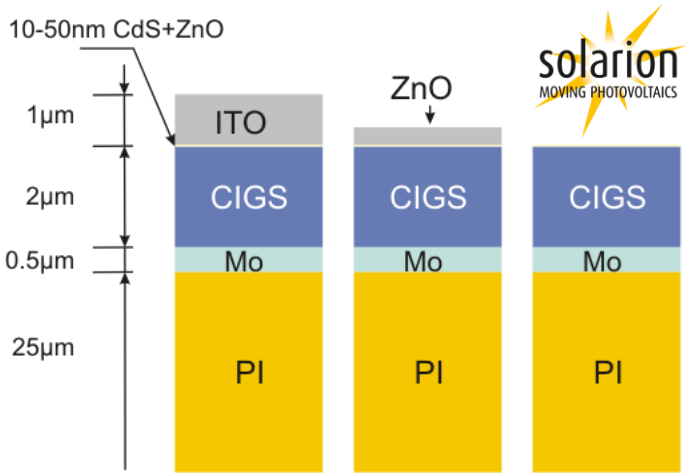


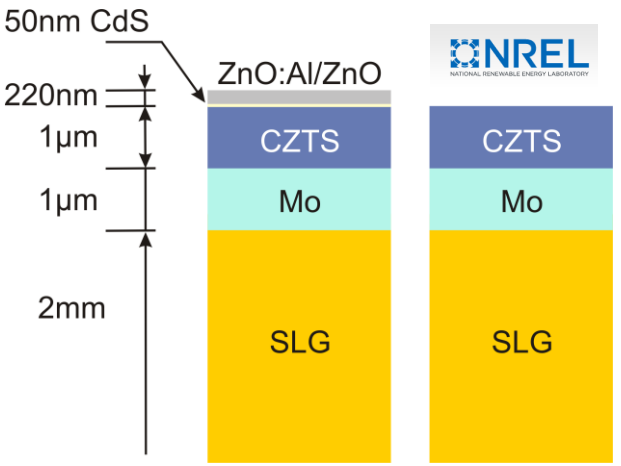
Demands on laser technology
- Layer selectivity
- Fast 1-2m/s scribing
- Reliable

P1- laser scribing
P2, P3- mechanical scribing

P3 and P2 laser scribing

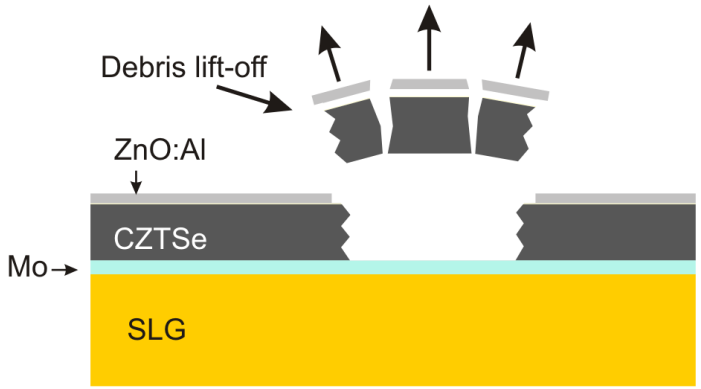
Experiment





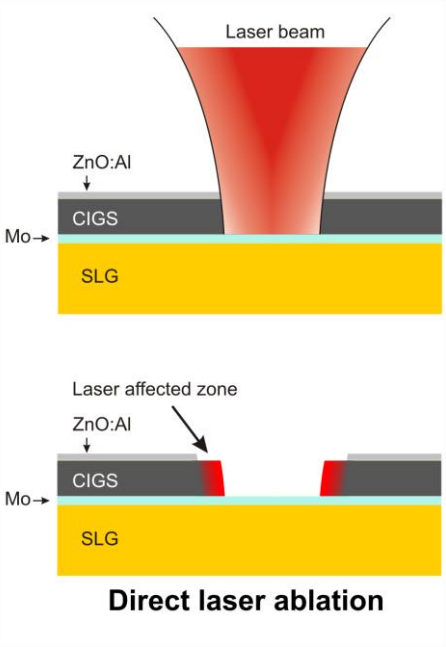
300fs-16ps,
6W@100kHz, 1030nm, PHAROS (Light Conversion)

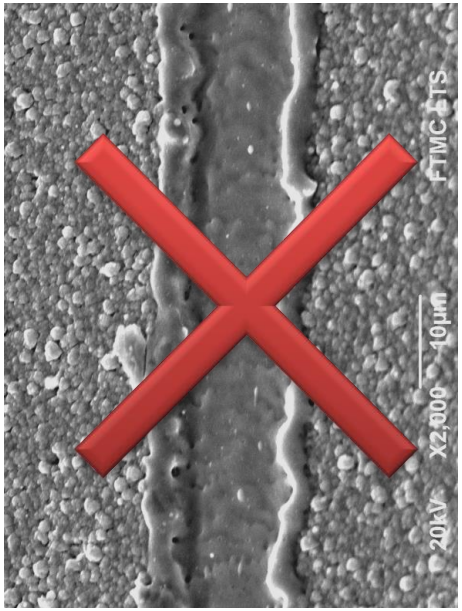
10ps,
10W@100kHz, 1064nm, Atlantic (EKSPLA)
60ps,
4W@4kHz, 1064nm, Atlantic HE (EKSPLA)



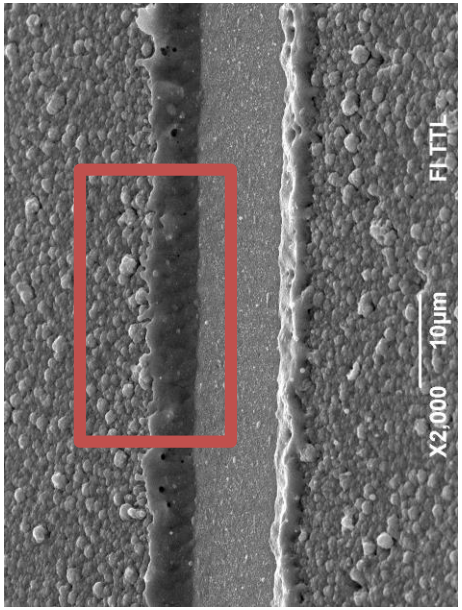
Laser induced ablation

Motivation: Direct laser ablation

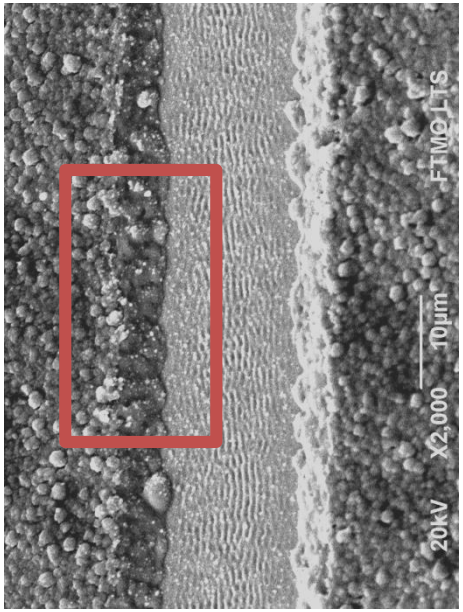




1064nm, 200 mW, 100 kHz, 2 uJ, 150 mm/s



1064nm, 600 mW, 100 kHz, 6 µJ, 200 mm/s



1030nm, 200 mW, 100 kHz, 2.0 uJ, 70 mm/s

30ns

10ps

300fs

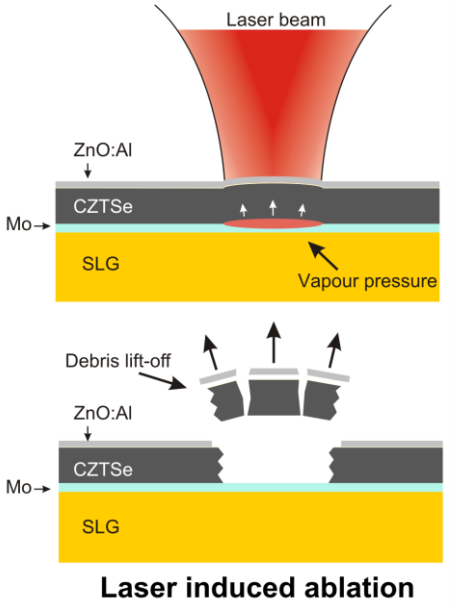
ns- not favorable

A.D. Compaan; I. Matulionis; S. Nakade: Laser scribing of polycrystalline thin films. In: Opt. Laser Eng., 34 (2000) 15

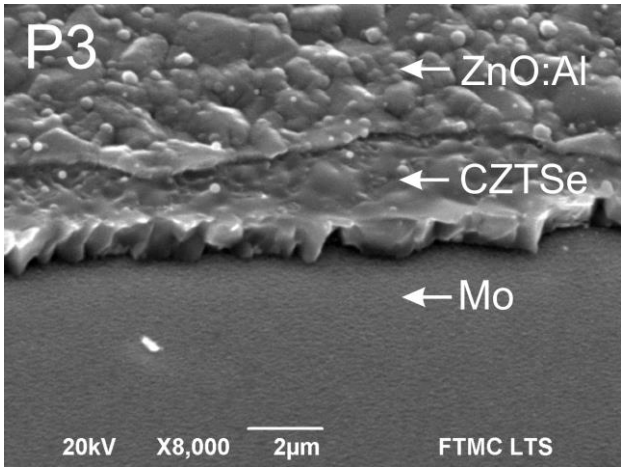
ps, fs – marginal degradation

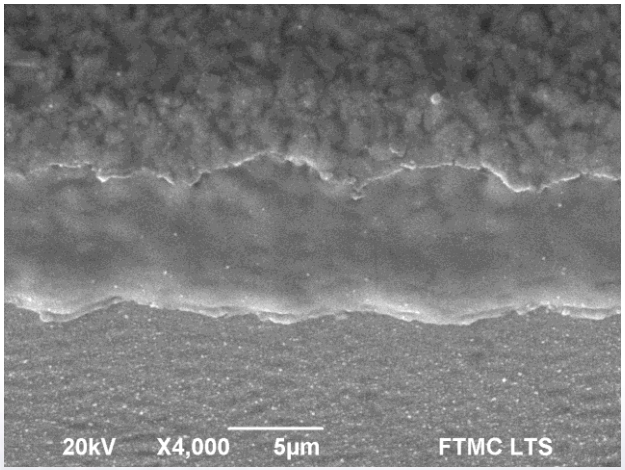
P. Gecys, G. Raciukaitis, A. Wehrmann, et al., J. Laser Micro/Nanoeng., 7 (2012) 33-37.

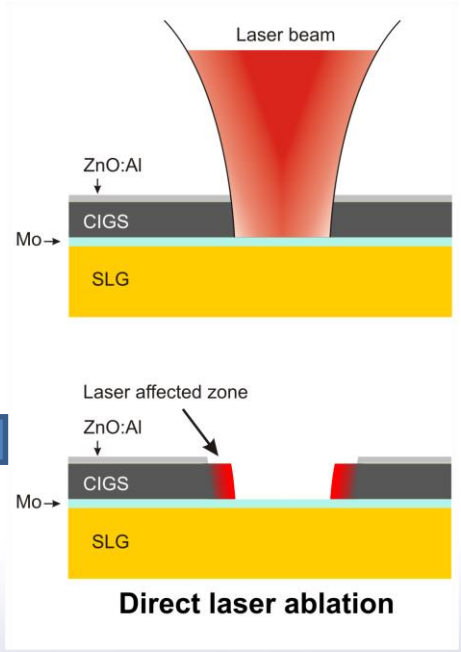
Motivation: Laser induced ablation



Laser induced ablation

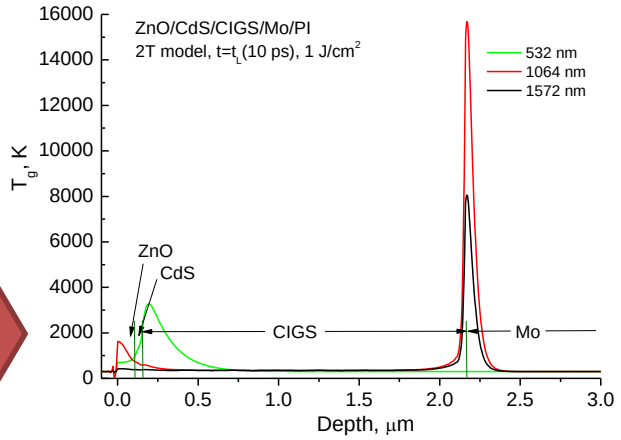


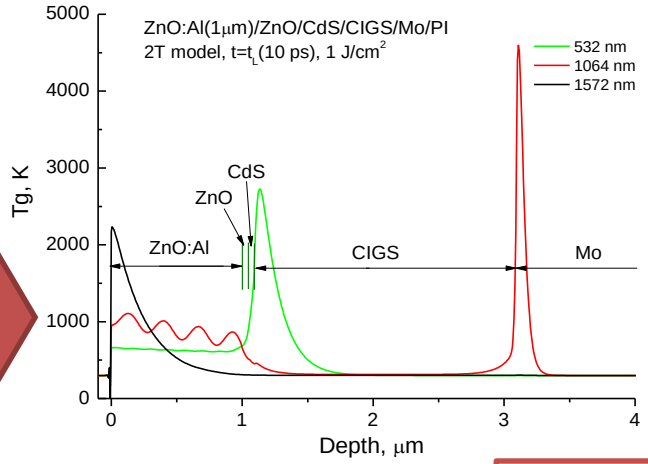




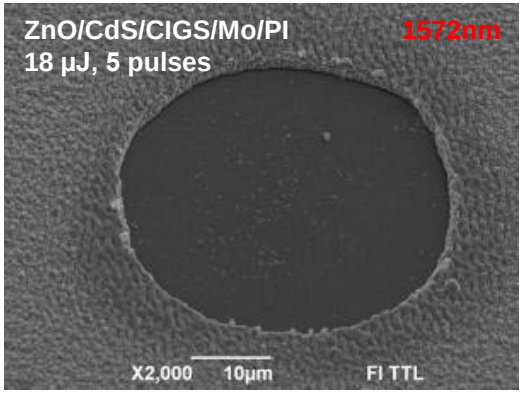
Direct laser ablation

Laser induced ablation in CIGS structures

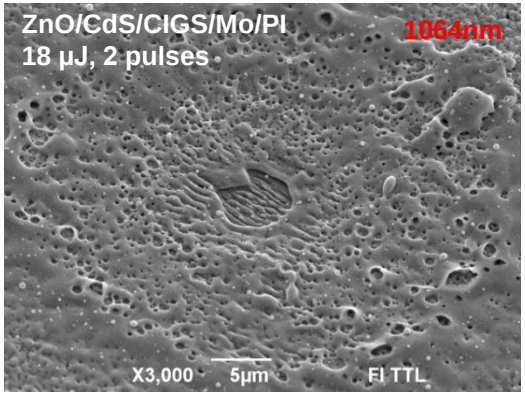




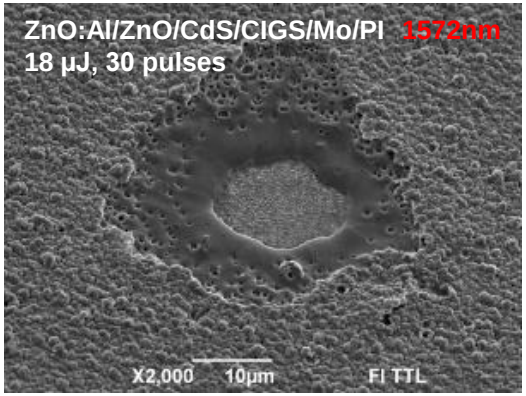
Linear model



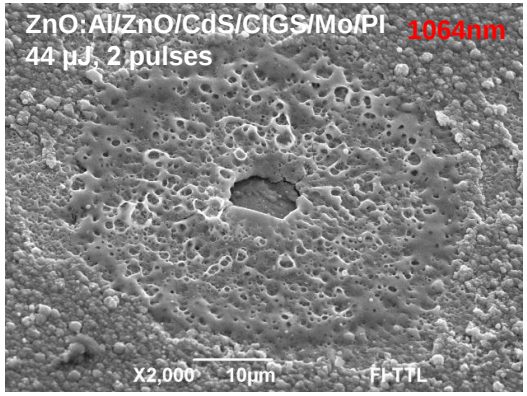
Lift-off



Nonlinear effects



Absorption in top-contact



Absorption in top-contact
Nonlinear effects

1340nm wavelength:

- Lower nonlinear effects
- Insignificant top-contact absorption

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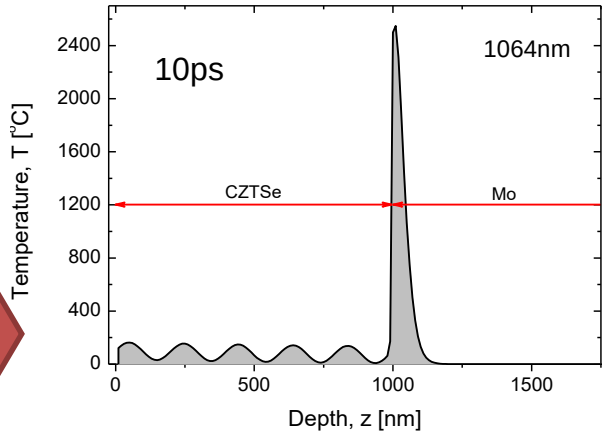
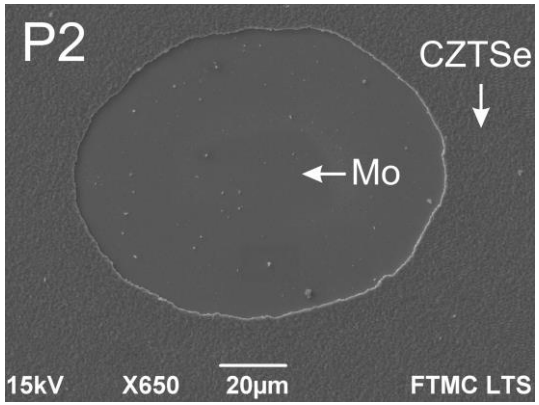
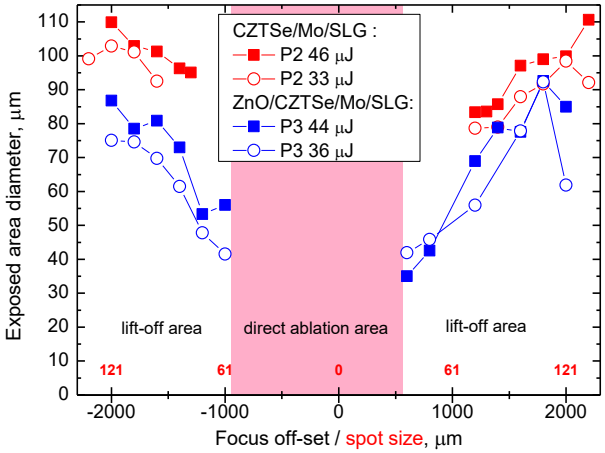
Laser induced ablation in CZTSe

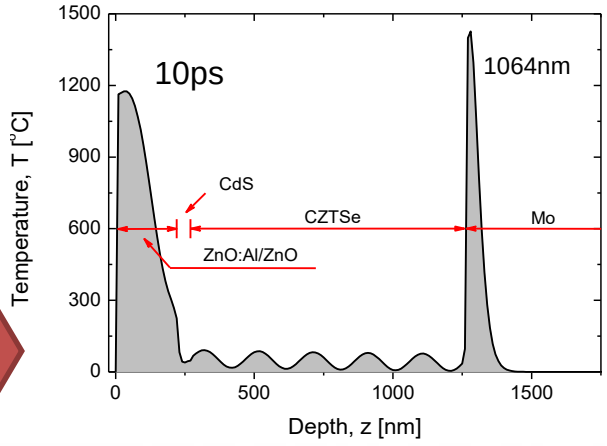




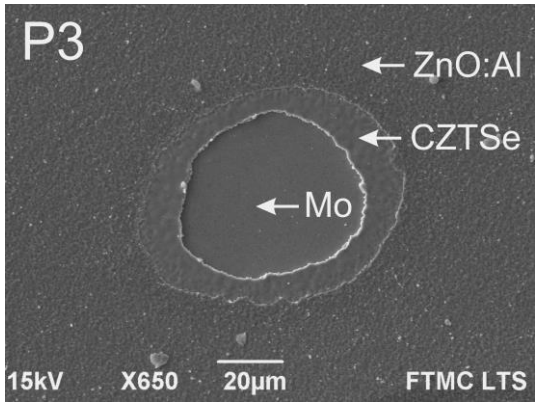
10ps, 46 µJ laser pulse energy, 73 µm laser spot size, single shot



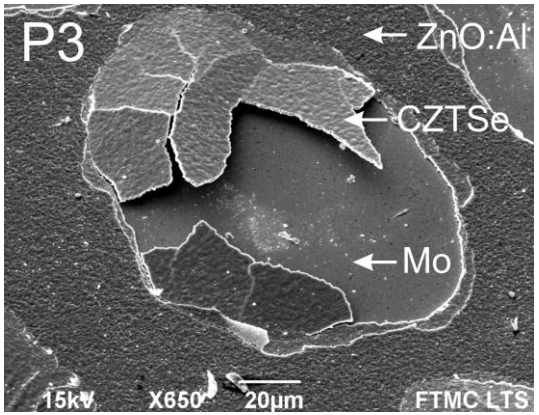
Spot size dependant lift-off behavior



Linear model

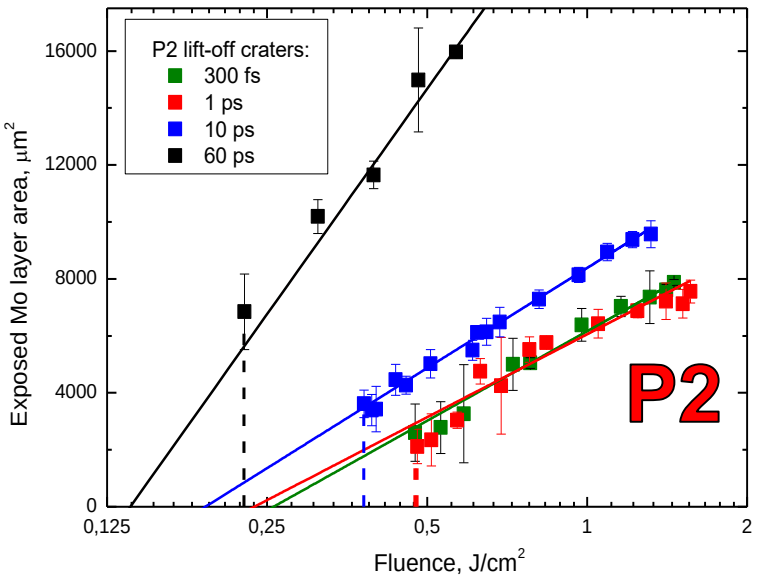


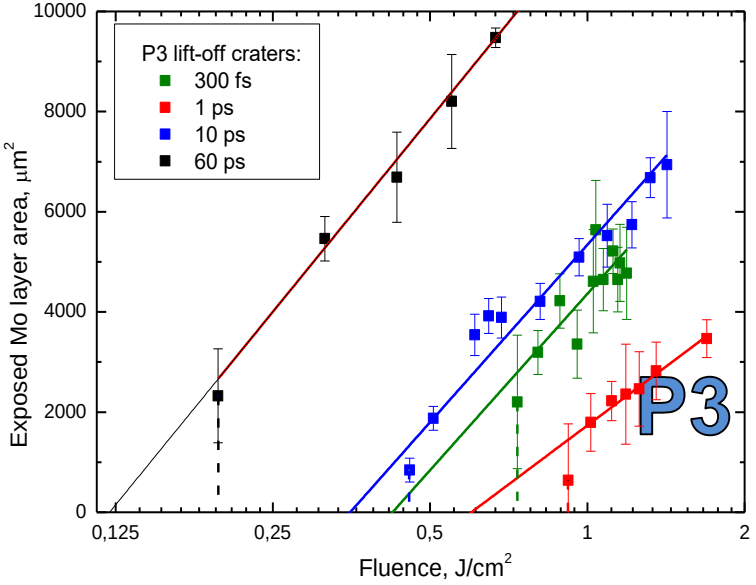
10ps, 32 µJ laser pulse energy, 36 µm laser spot size, single shot



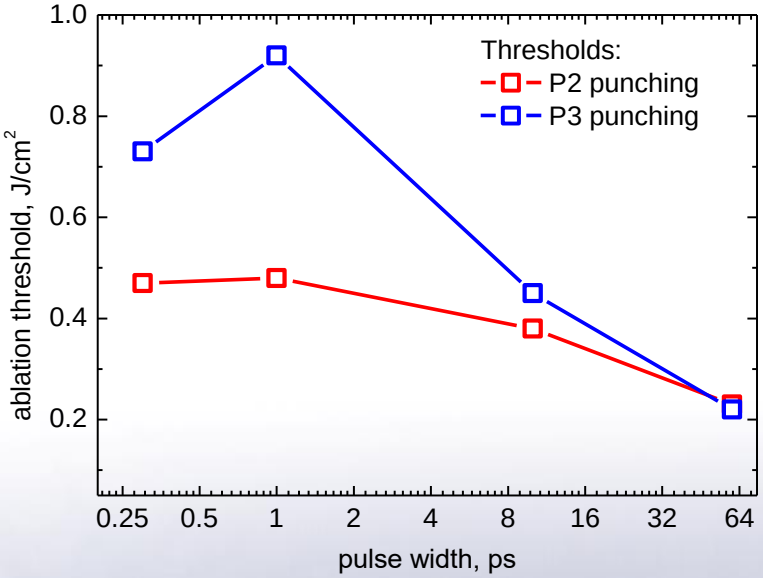
36 µJ laser pulse energy, 120 µm laser spot size, single shot.

Laser induced ablation of CZTSe

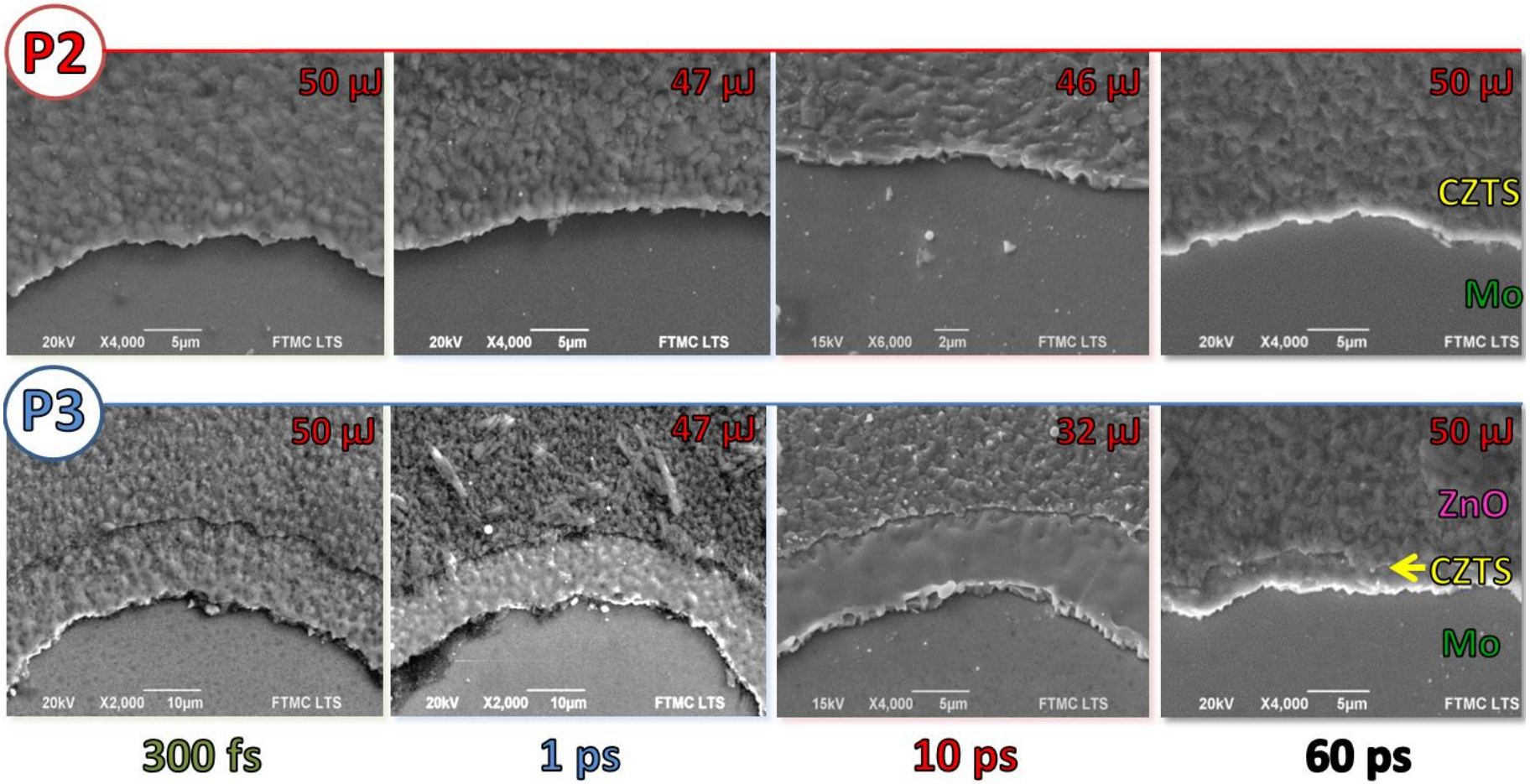




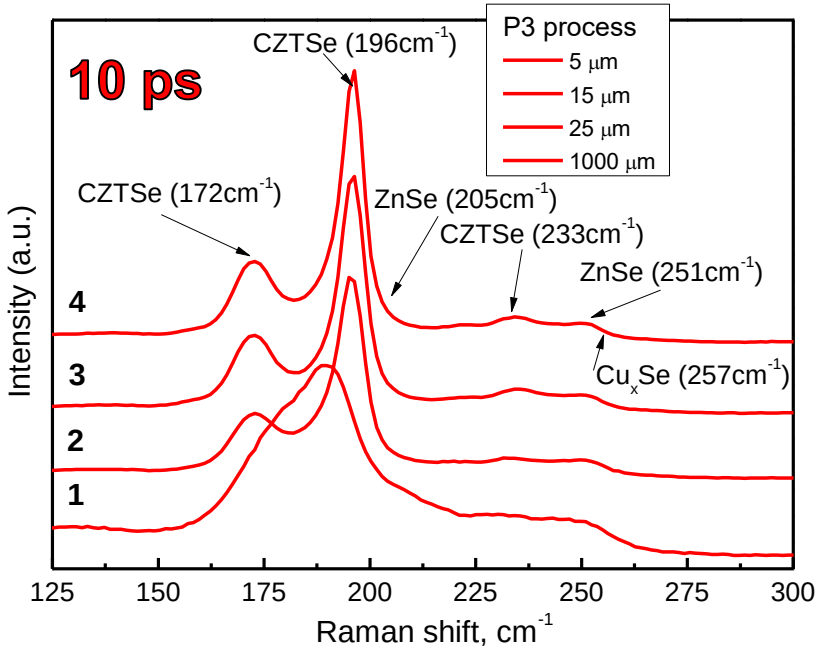
	P2		P3	
Pulse duration	Punching threshold, J/cm²	Direct ablation (5pulses)	Punching threshold, J/cm²	Direct ablation (5pulses)
300 fs	0,76	1,9	-	1,34 (10 pulses)
1 ps	0,57	2	0,98	5,18
10 ps	0,38	4,19	0,45	4,9
60 ps	0,2	-	0,2	-

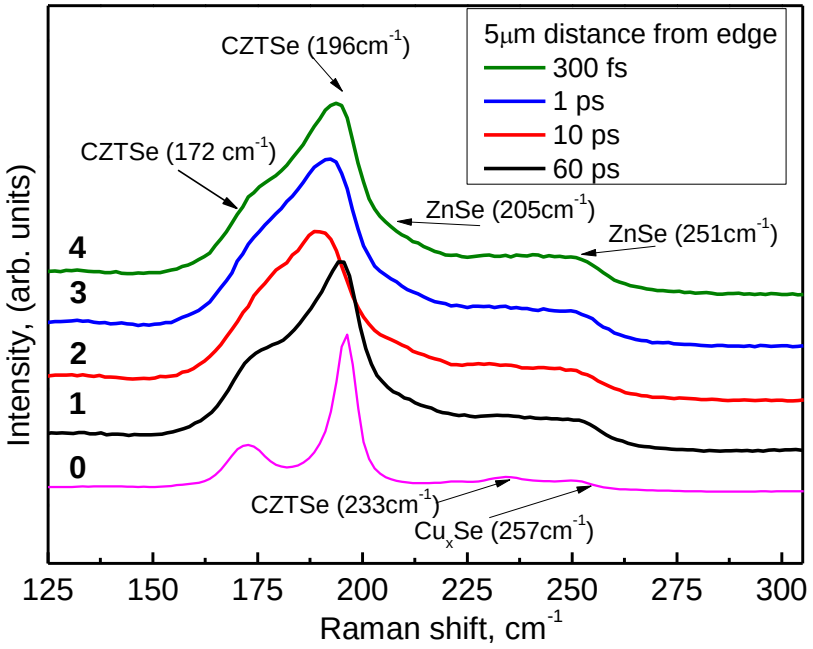


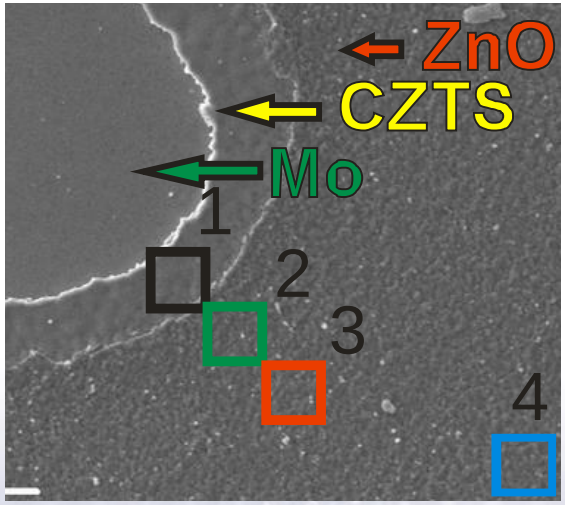
Laser induced ablation of CZTSe



Raman measurements P3

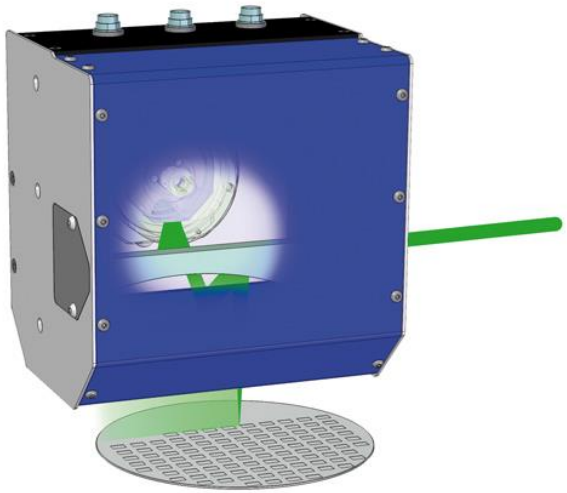






- Structural disorder was observed for all ultra-short pulses
- No secondary phase formation was observed

High speed scribing



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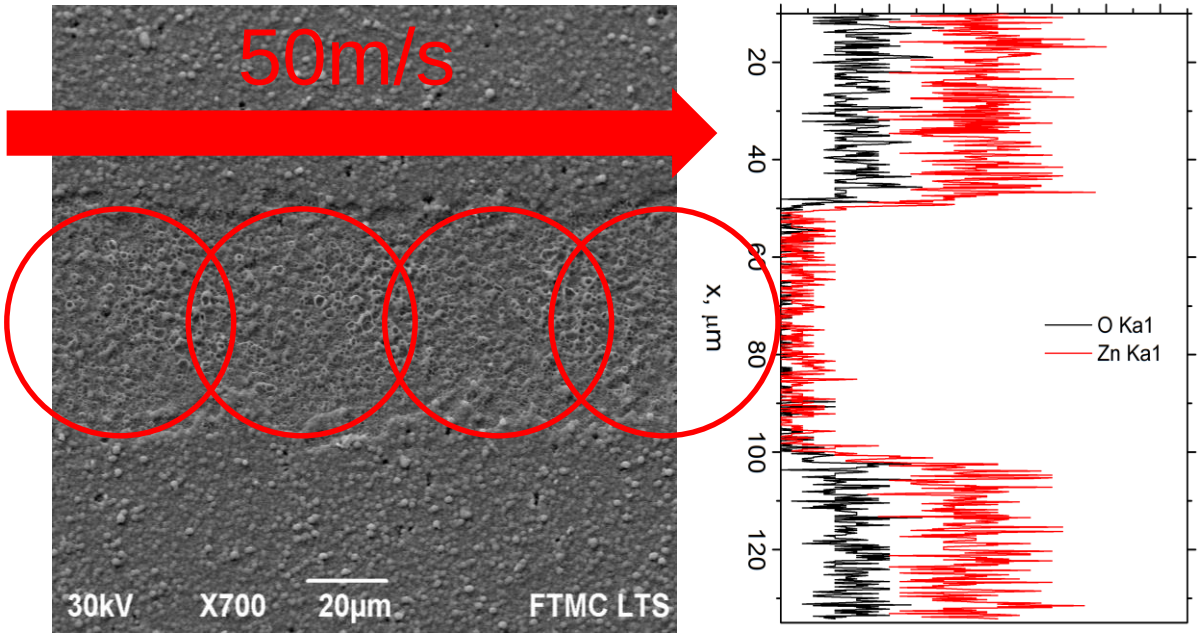
nextscantechnology.com



P3 scribe 30 W, 1000 kHz, 50 m/s, single pass, without pulse interleaving

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Conclusions

- Laser wavelength and pulse duration are critical parameters for layer lift-off process.
- The most effective laser-induced ablation was observed at 60ps laser pulses.
- The laser-induced ablation in CZTSe structure showed fine quality with absence of melt area and was up to 10 times effective then direct ablation.
- Raman spectroscopy did not detect any secondary phase formation near the laser ablation zone. Structural changes in P3 process should not notably affect electrical properties of CZTS compound.
- Extremely fast scribing process is possible by applying laser induced ablation.

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Thank you!

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