Studies on perovskite film ablation and scribing with ns, ps and fs laser pulses

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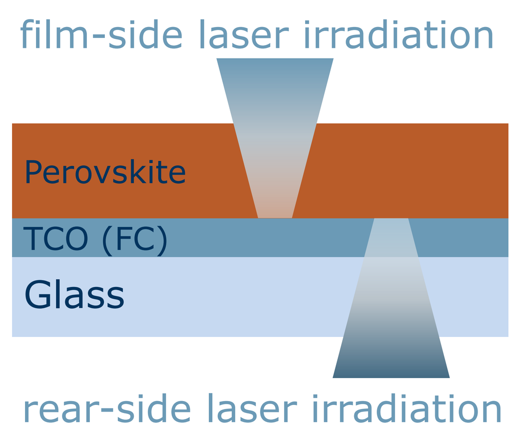
Introduction

Hybrid organic-inorganic perovskites have attracted a lot of attention from the scientific community thanks to their outstanding optoelectronic properties. In order to upscale perovskite solar cells to solar modules, a precise and reliable patterning of the material layers is mandatory. Currently still lithography, shadow mask and mechanical scribing are applied for the patterning process. However, for industrial fabrication processes laser scribing results to be an ideal technique for precise, fast and reliable selective removal of the different layers.
In this work the structuring of perovskite layers with a large range of different laser sources (ns, ps, fs long laser pulses with wavelengths of 248 nm – 2.5 µm) was investigated. Using optical and scanning electron microscopy (SEM) the morphology and topography of laser scribes as well as single laser pulse ablations were studied and compared. Here the structuring of the perovskite material was not only performed from the film-side but also through the substrate (rear-side ablation).

Irradiation directions



Materials

Solar cell scribe (P2):
$CH_3NH_3PbI_3$/TCO/glass
single pulse:
$CH_3NH_3PbI_3$/glass

Laser

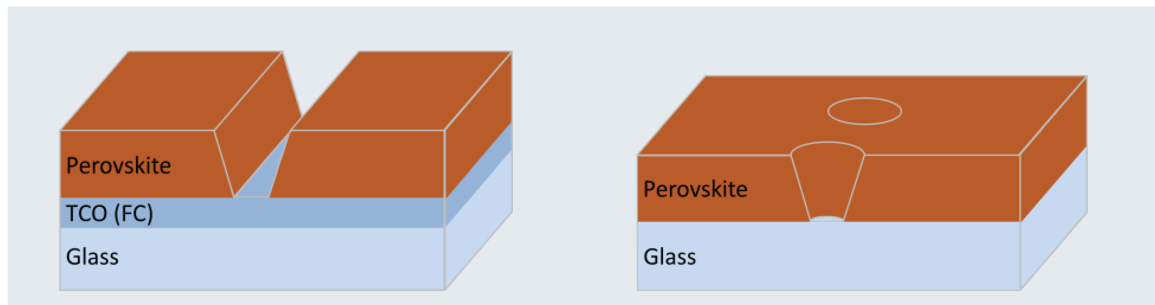
Pulse-length	Wavelength
7 ns	2500 nm
300 ns	1064 nm
25 ns	248 nm
10 ps	355 nm (3rd)
10 ps	532 nm (2nd)
10 ps	1064 nm
150 fs	780 nm

Irradiation

Environment: air
Temperature: 20.5°C

Results

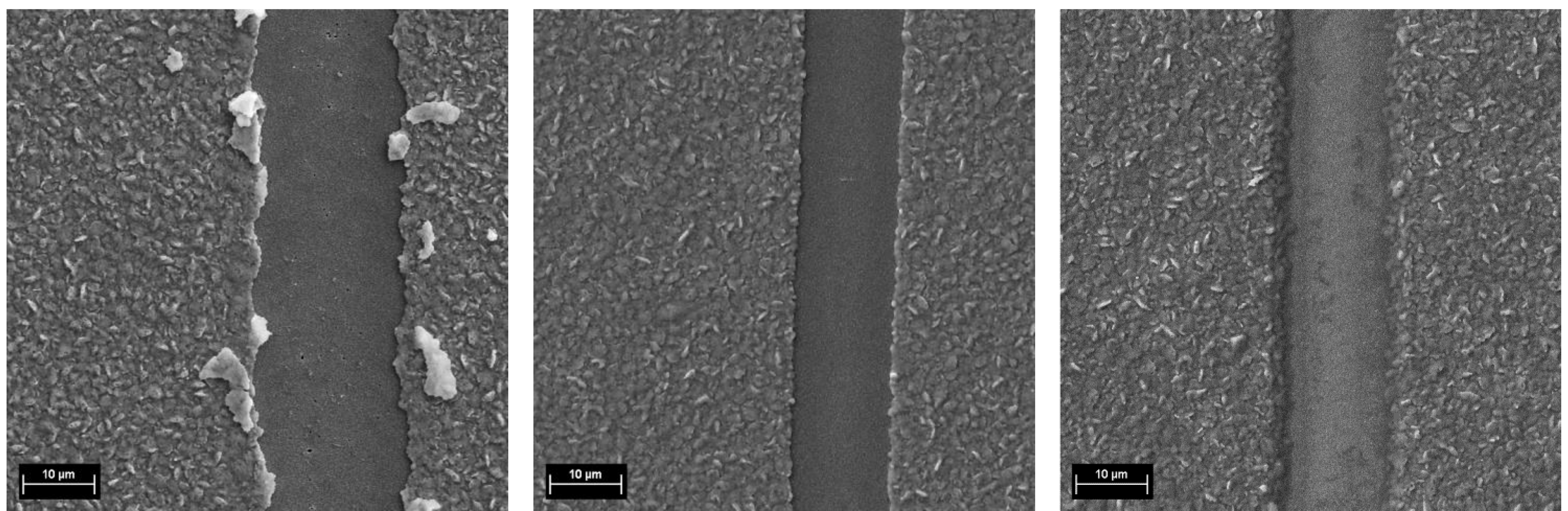
Ablation mechanisms



Pulse-/wavelength	P2 Solar cell scribe: Front side	P2 Solar cell scribe: Rear side	Single pulse on perovskite layer: Front side	Single pulse on perovskite layer: Rear side
7 ns 2500 nm	lift-off (with flakes)	-	-	-
20 / 300 ns 1064 nm	lift-off (with flakes)	lift-off (with flakes)	ablation, grain lift-off	ablation, grain lift- off
25 ns 248 nm	ablation	-	ablation	-
10 ps 355 nm	ablation	lift-off (with flakes)	ablation	ablation lift-off
10 ps 532 nm	ablation lift-off	ablation lift-off	ablation	ablation lift-off
10 ps 1064 nm	ablation	ablation	ablation, grain lift-off	ablation, grain lift-off
150 fs 775 nm	ablation	ablation lift-off	ablation	ablation lift-off

LIFT-OFF | ABLATION + LIFT-OFF | ABLATION

SEM image

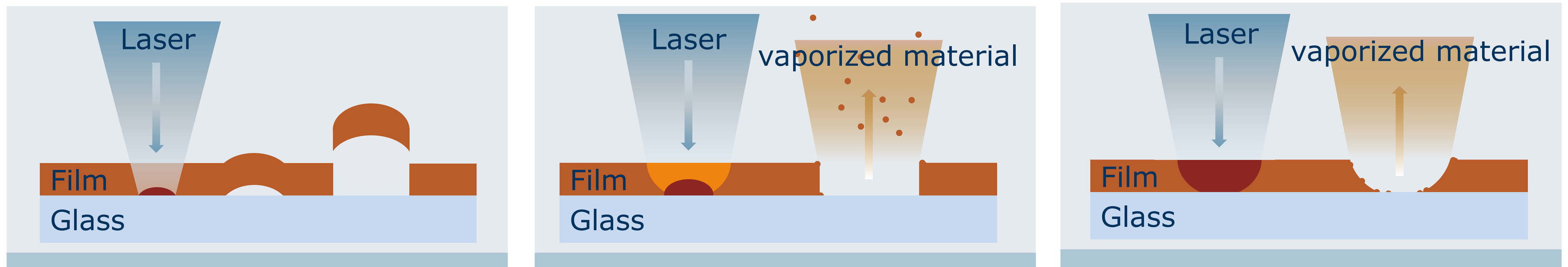


SEM image of scribe due to film-side ablation (1064 nm, 20 ns, 16 µJ, 75 % pulse overlap)

SEM image of scribe due to film-side ablation (532 nm, 10 ps, 0.2 µJ, 90 % pulse overlap)

SEM image of scribe due to film-side ablation (355 nm, 10 ps, 0.2 µJ, 90 % pulse overlap)

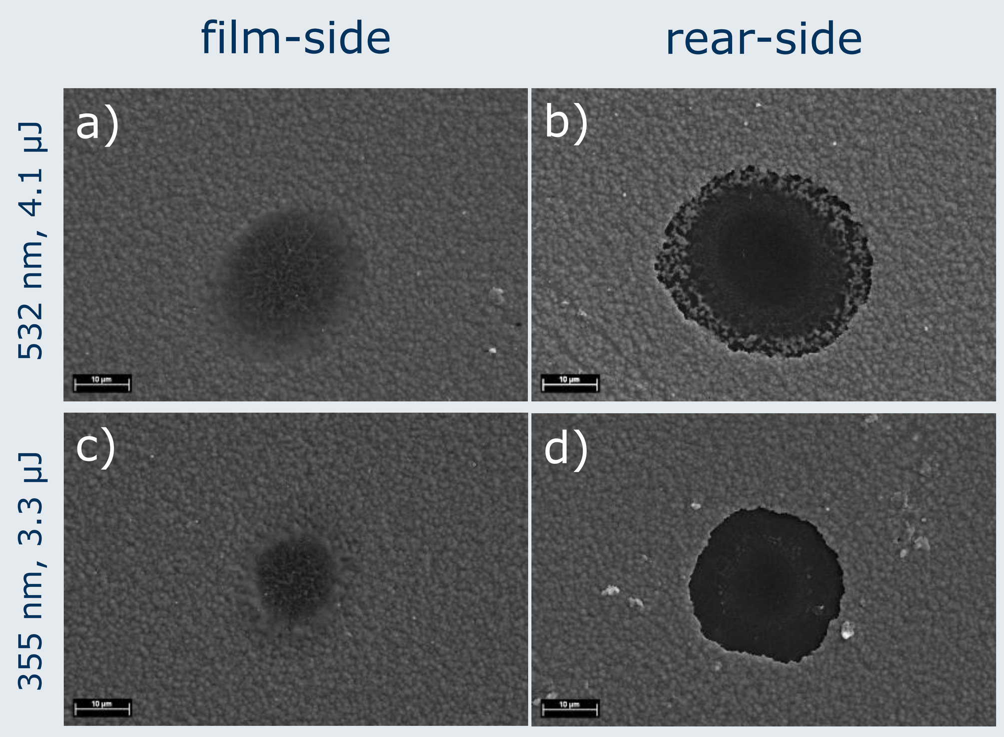
Ablation mechanism



Lift-off mechanism

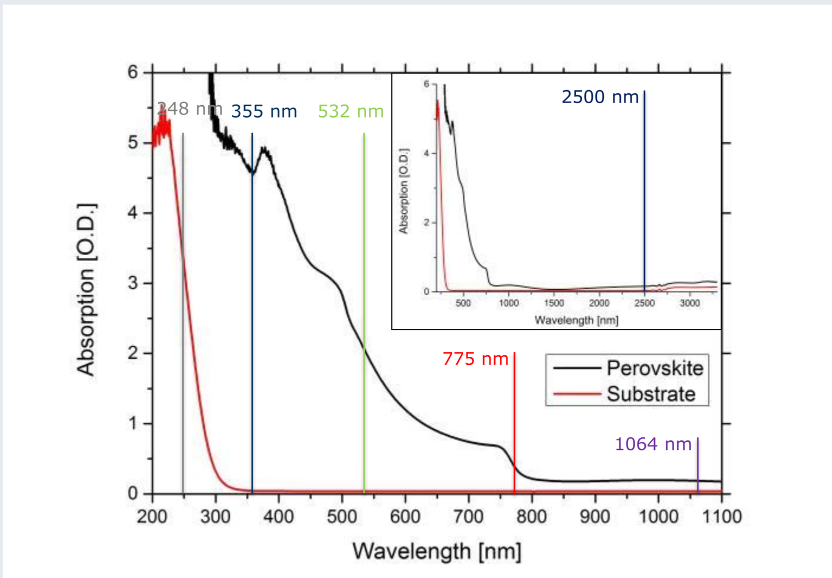
Ablation + lift-off mechanism

Ablation mechanism



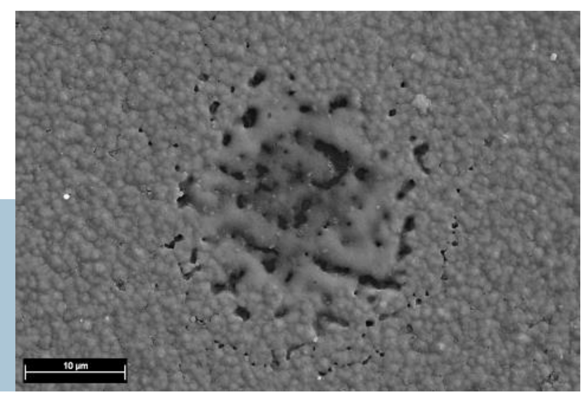
SEM images of single laser pulses (10 ps) with two different wavelengths on perovskite /glass irradiated from film-side and rear-side

a) and c) thermal film-side ablation
b) lift-off + ablation
d) lift-off effect

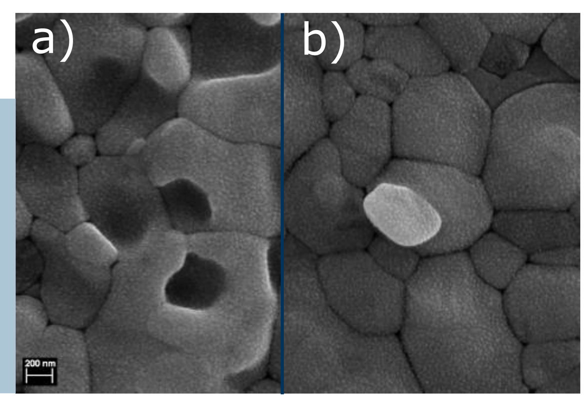


Absorption spectra of perovskite on glass substrate at room temperature

Grain lift-off



Single laser pulse (300 ns, 1064 nm, 50 µJ, rear-side) on perovskite



Single laser pulse (10 ps, 1064 nm, 0.7 µJ, film-side)
a) remaining holes after grain lift-off
b) lose grain on surface

Conclusion

- Perovskite thin films can be scribed using different ablation/delamination mechanisms depending on the laser sources and the irradiation direction used. The wavelength as well as the pulselength determine strongly the type of ablation.
- Further a grain lift-off process was observed at film- and rear-side irradiation using pulses with a length of 300 ns.
- For solar cell application the mechanism of ablation and the combination of ablation and lift-off are suitable. Due to the upstanding flakes and edges the pure lift-off process is not recommended.

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