Laser processing of perovskite absorber layers: Ablation, modification and degradation

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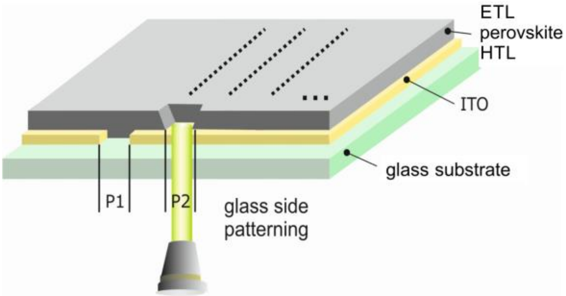
Metal halide perovskites are very promising materials for absorbers in low-cost, high-efficiency solar cells, due to its outstanding physical properties such as strong optical absorption, high charge carrier mobility and excellent transport properties. At small laboratory scale perovskite solar cells with power conversion efficiencies comparable to c-Si solar cells have been fabricated already. However, successful up-scaling to industrial relevant production sizes requires the development and implementation of – preferably - laser-based patterning processes (P1 – P3) for monolithic serial interconnection (Fig. 1a). Particular, the P2 scribe, which opens the perovskite layer to interconnect the front and back contact, is most challenging and is considered as the origin of distinct power losses when advancing from the cell to module level.

Thus, the objective of this work is to deliberately control the impact of nanosecond laser pulses for P2 preparation by optimization of the incident laser fluence and to achieve a fundamental understanding of the underlying laser–material interaction. Successful P2 patterning is assumed, when narrow trenches of nearly constant width are obtained, without modification the vicinity of the trench. Moreover, the perovskite layer has to be completely and selectively removed, that the bottom of the trench is free of debris and enables low contact resistances. Thus, particular emphasis is put on the detailed characterization of the trench and its vicinity.

(a)



(b)

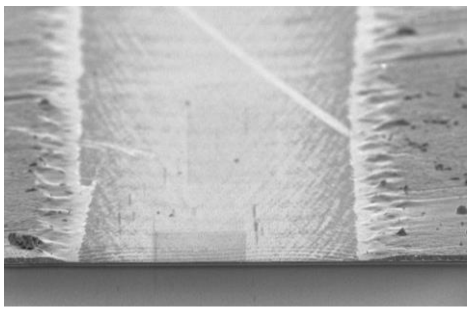


Fig. 1. (a) Illustration of the sample layout and the experimental approach. Multiple P2 lines were patterned into the perovskite layer by ns laser pulses at varied fluences. (b) SEM image of a P2 scribe line, patterned with a laser fluence of: 1.95 J/cm² (image width: 57 µm, 5 kV, tilt: 10°)

As shown in Fig. 1b, successful selective layer ablation from the glass side of a high-efficiency solar cell sample with an inverted planar architecture [1, 2] is obtained at a laser fluence of 1.95 J/cm², resulting in a homogeneous topography and a constant scribe width of about 35 µm. However, at the bottom of the trench some residuals remain, which form alternating regions with higher and lower conductivity, which are attributed to laser-induced periodic surface structures (LIPSS) [3, 4]. PL imaging reveals, that the residuals contain PbI_2 is upon laser impact and remain in the trench after P2 laser patterning. Accordingly, Fig. 2a reveals the PL distribution of a P2 scribe and its vicinity after filtering with a long-pass filter that transmits the main emission perovskite line, while Fig. 2b was acquired at the same area using a bandpass filter that transmits the PL signal of PbI_2, while blocking the perovskite PL emission [4].

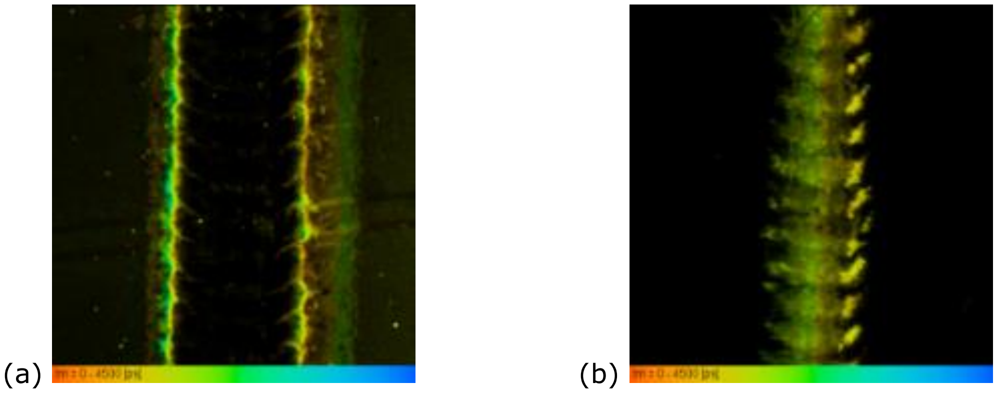


Fig. 2. PL images of a P2 trench, revealing the emission originating from (a) perovskite and (b) PbI_2. Spectral selectivity was achieved by specific filters.

PbI_2 formation in Pb-containing perovskite layers and its role for the performance is a controversial issue [5, 6]. Though some beneficial effects are ascribed to the presence of PbI_2, such as passivation of grain boundaries, increased shunt resistance and reduced ion mobility, detrimental effects on the photo-stability by excess PbI_2 might dominate the module performance and is also considered a barrier for the charge carrier transport in our interconnected perovskite solar cell samples.

Further work is required to overcome these drawbacks and to adjust the process windows for industrial manufacturing. Currently, further process optimization is in progress evaluating different laser wavelengths and pulse durations for improved P2 patterning.

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