Two-page summary for QUANTSOL 2019 Winter Workshop

Monolithic interconnection of perovskite solar cells: Approaches for low contact resistances

Bert Stegemann[1], Christof Schultz[1], Markus Fenske[1], Andreas Bartelt[1], Antje Neubauer[2], Rutger Schlatmann[1,3], Lukas Kegelmann[4], Marko Jošt[4], Steve Albrecht[4]

[1]HTW Berlin - University of Applied Sciences, D-12459 Berlin, Germany
[2]Becker & Hickl GmbH; Berlin D-12277, Germany
[3]PVcomB / Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, D-12489 Berlin, Germany
[4]Helmholtz-Zentrum Berlin für Materialien und Energie, Young Investigator Group for Perovskite Tandem Solar Cells, D-12489 Berlin, Germany

Metal halide perovskites (MHP) are very promising materials for absorbers in low-cost, high-efficiency solar cells, due to its outstanding optoelectronic properties. At small, laboratory scale perovskite solar cells exceed power conversion efficiencies of 23%. However, successful up-scaling to module sizes relevant for industrial fabrication requires monolithic series interconnection, which is achieved by P1 – P3 patterning of the individual solar cell layers. Laser patterning is preferred over conventional mechanical patterning due to its non-contact processing, high reproducibility and selectivity.

Though successful laser-based series interconnection of perovskite solar cells and mini-module fabrication has been reported, the P2 scribe which opens the perovskite layer remains most challenging and is considered as the origin of distinct power losses when advancing from the cell to module level [1].

During the P2 laser patterning step MHP material is removed and thin narrow grooves (width <100 µm) are formed within the absorber layer, enabling an electrical interconnection of the front and the back contact layers. Complete MHP removal normally facilitates low contact resistance and, thus, improved solar cell performance. However, undesired laser-induced material modifications may increase the series resistance. MHP debris can easily be formed within the trenches mainly due to the thermal sensitivity of the MHP layer, reducing the conductivity between front and back electrodes [2]. Also, laser-induced modifications of the underlying front contact and the surrounding absorber material might occur during the laser ablation processes. This may induce recombination centers which reduce the charge carrier lifetimes. Therefore, high quality laser patterning of MHP solar cells with little remaining residuals on top of an intact front contact is challenging [1].

In this study, scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDX) on laser-scribed spin-coated perovskite solar cell samples consisting of the layer sequence ITO/PTAA/MHP/PCBM+C_{60}/BCP [3,4] are combined with time-resolved photoluminescence (TRPL) imaging. TRPL images of spectral regions corresponding to the emissions of MHP and PbI_2 were acquired for different scribing laser fluences, pulse durations and wavelengths. EDX was used to determine the elemental composition within the corresponding scribed lines and their vicinities.

It is found that laser-induced debris formation and modifications of the material in the vicinity of the scribed lines depend on laser pulse lengths and wavelengths. Though, with nanosecond laser pulses, trenches can be scribed with nearly complete removal of the perovskite layers, residuals consisting of PbI_2 still remain in the trench. By using shorter laser pulses, the amount of PbI_2 at the bottom and the edges of the scribed lines is clearly reduced, allowing for nearly PbI_2-free P2 laser patterning. This is consistent with our EDX results which show the successful elimination of Pb-containing materials.

Moreover, laser-induced MHP modifications at the scribe edges were found to affect the radiative charge carrier lifetimes. Nanosecond laser ablation shortened the lifetimes in the scribe edges, indicating enhanced charge carrier recombination, while ultrashort laser patterning on the other hand produced longer lifetimes and enhanced PL yields at the scribe edges. The higher yield and longer lifetime are a result of the selectively removed electron transport (ETL) layer indicating a reducing the laser-induced degradation of the underlying MHP layer.

Based on the optimized patterning parameters, mini-modules are being prepared and investigated. Preliminary results show that the ohmic losses related to the series interconnection can be reduced to a minimum, resulting in improved mini-modules with up to 16% efficiency and aperture ratios of about 87%.

References

[1] C. Schultz, F. Schneider, A. Neubauer, A. Bartelt, M. Jost, B. Rech, R. Schlatmann, S. Albrecht, B. Stegemann, IEEE Journal of Photovoltaics 8, 1244 – 1251 (2018).

[2] J. Barbé, M. Newman, S. Lilliu, V. Kumar, H.K.H. Lee, C. Charbonneau, C. Rodenburg, D. Lidzey, W.C. Tsoi, Journal Mat. Chem. A 6, 23010-23018 (2018).

[3] M. Jošt, S. Albrecht, L. Kegelmann, C.M. Wolff, F. Lang, B. Lipovšek, J. Krč, L. Korte, D. Neher, B. Rech, M. Topič, ACS Photonics 4 (5), 1232-1239 (2017).

[4] L. Kegelmann, C.M. Wolff, C.A. Omondi, F. Lang, E.L. Unger, L. Korte, T. Dittrich, D. Neher, B. Rech, S. Albrecht, ACS Applied Materials & Interfaces 9(20), 17245-17255 (2017).