PhD thesis

# Inkjet printing of perovskite solar cells

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## Abstract

The work documented in this thesis concerns the development of perovskite solar cells fabrication by inkjet printing technique. Recently, solar cells based on hybrid perovskite absorbers have emerged as one of the most promising photovoltaic technologies. After a decade of intensive scientific research, perovskite solar cells are now approaching the commercialization stage. At this moment the production of large-area devices is still to be established. Inkjet printing is one of the solution-based methods which can satisfy the requirements for fast and cheap thin film deposition. Herein, the boundaries of perovskite research are pushed towards industrial prospects by tackling the challenge of scalable film formation in air conditions. In this work, the development of inkjet printing was carried out for a few different perovskite formulations and one electron transport layer.

The first chapter of this thesis provides the basic principles of solar cell operation. Then, in the second chapter the thesis gives an overview of the most important properties of perovskite materials pointing out the bright sides as well as the challenges of perovskite solar cells technology.

The third chapter provides the guide through the inkjet printing technique necessary to understand the correlations between the ink properties, deposition parameters and substrate surface energy. This section explains the complexity of inkjet printing and addresses the challenges of printing process development.

The experimental part consists of three publications and one patent application submitted during this PhD track.

The first publication reports the design of mixed cation perovskite ink and its stability (https://pubs.acs.org/doi/10.1021/acssuschemeng.0c09208). The work focuses on finding green solvent composition and adjustment of coordination chemistry in the perovskite precursor solution. The study points out the importance of careful evaluation of ink stability, especially for perovskite ink formulation where chemical interactions can strongly affect the ink properties. By understanding the coordination mechanisms occurring in the precursor solution, the sufficient reliability of the ink is obtained leading to printable devices of 11.4% power conversion efficiency (PCE) on a flexible substrate.

The second study is concerning the printing and post-processing of quasi-2D perovskite (https://doi/abs/10.1002/admt.202200606). In this work, the correlation between crystallization conditions and specific phases distribution is being analysed. Adjustment of the ink composition and optimization of the drying method allowed to achieve good morphology

and crystallinity of the film. Inkjet-printed devices surpassed 14% PCE on glass and 10% on flexible substrates, being one of the highest results for flexible quasi-2D perovskite solar cells up to date.

In the next publication, inkjet printing is evaluated for electron transport layer deposition (https://doi.org/10.1002/adfm.202004357). The ink based on a new fullerene material ([6,6]-phenyl-C61 butyric acid n-hexyl ester; $PCBC_6$) is composed to meet inkjet criteria and printing parameters are optimized to obtain uniform coverage. Perovskite solar cells with printed $PCBC_6$ reached efficiency similar to fully spin-coated devices showing high applicability of inkjet printing for the fabrication of multiple layers stack of perovskite solar cells.

The last part of the experimental section attached as a description of the patent application addresses the challenge of inorganic perovskite processing (Application number:EP22461539.3, Title: A PEROVSKITE STRUCTURE, A PHOTOVOLTAIC CELL AND A METHOD FOR PREPARATION THEREOF). The innovative method of introducing an additional seeding layer to the solar cell device stack allows to drastically decrease the temperature of $CsPbI_3$ perovskite phase crystallization allowing the use of polymeric substrates and making the process more industrially viable. The procedure developed during this study has a high implementation potential for inorganic perovskite printing as well as for other solution-based coating processes.