FIRA: Rapid Manufacture of High-efficiency Perovskite Solar Cells

Sandy Sanchez[a1]

[1]Adolphe Merkle Institute, University of Fribourg, Chemin des Verdiers 4, 1700 Fribourg, Switzerland

We describe FIRA, a new method to manufacture solar cells. Its main advantages are its quick implementation and the high-efficiency of the resulting devices.

Several antisolvent-free methods have been proposed to control perovskite film crystallization, resulting in perovskite solar cells (PSCs) with relatively high PCEs [1]. For example, Nie et al. demonstrated a hot-casting technique to grow continuous, pinhole-free perovskite films with millimeter-scale crystalline grains [2]. This method uses a hot (∼70 °C) solution of lead iodide and methylamine hydrochloride spin-coated onto a hot (180 °C) substrate. This technique allowed the fabrication of planar solar cells with average (not stabilized) efficiencies approaching 16%. Li et al. proposed a vacuum-assisted method for one-square-centimeter PSCs with a stabilized PCE of around 20% [3]. Nevertheless, the extension of PSCs towards a technology remains challenging because of the lack of a method allowing to produce large-area devices (100 square-centimeters or larger) with PCEs comparable to lab-scale devices.

Rapid thermal annealing methods have been successfully used to control the crystallization of inorganic semiconductors and to prepare large-area devices made of highly crystalline phase-continuous films [4]. Similar approaches have been explored for PSCs with promising results [2]. In this direction, Troughton et al. proposed a short exposure with a highly intense near-infrared radiation to crystallize perovskite films, potentially enabling the preparation of large-area PSCs with high efficiencies.

In 2018, flash infrared annealing (FIRA), an antisolvent-free method that can be used to prepare methylammonium lead iodide (MAPbI3) PSCs with stabilized power conversion efficiencies up to 18.3%, has been introduced for the first time [5]. Using this method, perovskite film crystallization is completed within 2 seconds plus 8 seconds remaining in the dark at low temperature on the FIRA camera to completely remove the solvent. Such a rapid crystallization results in micrometer-size crystal grains arranged in a dense perovskite film. FIRA allows the manufacture of large-area (100 cm^2) perovskite films and large-area devices (1.4 cm^2 of active area). Note that FIRA does not warm the substrate and is thus compatible with low-temperature processing on plastic substrates, enabling in particular roll-to-roll printing.

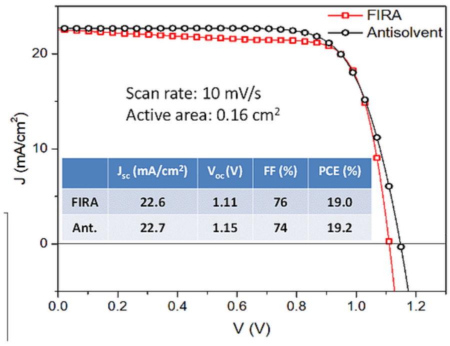

Figure 1: Current density-voltage (J-V) scans collected at 10 mV/s of two champion devices under 1.5 AM irradiation and the corresponding photovoltaic performance parameters.

Photovoltaic performance of a PSC

The current density-voltage (J-V) curves and the corresponding device performance parameters for the two champion cells are shown in Figure 1. The FIRA-annealed PSCs exhibit a slightly higher fill factor (FF) and lower open circuit voltage (Voc) than the champion device made using the antisolvent method, while the short circuit currents (Jsc) are similar. Note that the current density of the FIRA-device decreases between short circuit condition and 0.6 V forward bias, while it stays constant in the reference champion device. This is probably due to the fact the perovskite film is slightly too thick in the FIRA-device, compared to the ideal thickness of 500 nm as optimized for the antisolvent method. This results in a slightly higher series resistance, the absence of which would enhance the fill-factor even more.

FIRA as a method to scale-up the manufacture of perovskite

Foreseeing the commercialization of PSCs, Figure 2 shows a scheme of a possible roll-to-roll production method employing FIRA to crystallize the perovskite film. The perovskite precursor solution can be deposited on the substrate using any of the roll-to-roll compatible methods available on the market [4], such as doctor-blading, slot-casting, spray-coating, screen-printing and inject-printing. The deposited film is then passed through the FIRA box which enables rapid

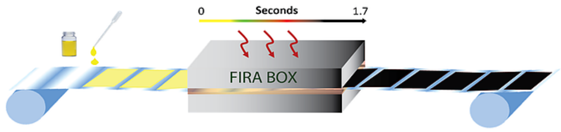

Figure 2: Scheme of a roll-to-roll production line for perovskite thin films crystallized within 2 seconds using FIRA.

(within 2 seconds) perovskite film crystallization.

Summary

We demonstrate FIRA as a new method to prepare state-of-the-art efficiency perovskite solar cells with a good reproducibility. The advantages of FIRA are: i. the elimination of the antisolvent to induce the perovskite film crystallization, which drastically reduces the use of organic solvent in the PSC manufacture, making the process environmental more friendly; ii. FIRA is compatible with large area device manufacture and flexible substrates which require low temperature processing; iii. FIRA is suitable for fast throughput production lines, such as roll-to-roll deposition methods.

Notes

a. Email: sandysanche@gmail.com

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