NEW PROTOTYPE IPL DEVICE WITH FULL AREA ILLUMINATION OF SHJ SOLAR CELLS FOR DRYING AND CURING

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ABSTRACT: In this work, a new prototype of an intense pulsed light (IPL) device by the company *Botest Systems* is presented. This device is used for drying and curing silicon heterojunction (SHJ) solar cells in the range of milliseconds, while conventional oven drying and curing (in furnaces) is in the range of seconds to minutes. Therefore, this IPL-based alternative can significantly increase the solar cell throughput. The IPL drying and curing process achieves power conversion efficiencies similar to those of the conventional method. Prior to this work, Schube et al. [1] have already demonstrated similar results using a different IPL device. Compared to that device, the one used in the present work is capable of illuminating larger areas, allowing M2 size solar cells to be processed at once. In the future, the illumination area can be upgraded to current standard wafer formats such as G12. This device has the potential to be integrated into an industrial SHJ production line.
Keywords: intense pulsed light, flash light anneal, silicon heterojunction solar cells, drying, curing

1 INTRODUCTION

The recent ITRPV report predicts a significant increase in PV market share for silicon heterojunction (SHJ) solar cells [2]. The drying and curing of the paste is part of the SHJ manufacturing process route. In 2020, Schube et al. [1] successfully demonstrated that industrial SHJ solar cells dried and curing using a so-called “intense pulsed light” (IPL) process [3] had similar power conversion efficiencies (η) to conventionally dried and cured samples (i.e., in a furnace). An IPL device contains flash lamps that illuminate a sample with a high power density flash whose spectrum is mainly in the visible range. Hence, this spectrum can be absorbed by a silicon solar cells, which heats the sample for the duration of the flash, typically in the range of milliseconds. Thus, the IPL method allows for very short drying and curing processes, compared to conventional drying and curing times, which are typically in the range of a seconds to minutes [3]. Thus, the IPL process has the potential to increase the throughput of solar cells and reduce the cycle time for manufacturing a solar cell. However, in Ref. [1], an IPL device is used that only allows illumination of an area of 5x7 cm^2. In contrast, the present work presents a novel prototype IPL device by the company *Botest Systems* [4] that can illuminate an area of 16x16 cm^2, allowing a solar cell of M2 size to be fully illuminated at once. Upgrading to fully illuminate larger solar cells (up to G12 size) is estimated to be relatively straightforward. Thus, such a device has the potential to be integrated into an industrial SHJ production line. The aim of the present work is to demonstrate at least similar η for industrial SHJ solar cells dried and cured with the novel IPL device as for conventionally dried and cured samples.

2 METHODOLOGY

Figure 1 shows images of the *Botest* IPL device. The centerpiece of this device are two xenon flash lamps that illuminate the sample. The lamps are powered by two driver racks and are located in a mirror-coated chamber to ensure a uniform illumination of the sample. To remove volatile organics during paste drying, compressed dry air is introduced into the sample chamber and exhausted at the opposite side of the chamber. The sample is placed on a height-adjustable chuck. The following parameters can be set via a software: lamp current (I_{LAMP}), pulse duration (t_P), pulse number (n_P), and pulse frequency (f_P). The power density of the lamp is controlled via I_{LAMP}. The power density on the sample is regulated by I_{LAMP} and the distance (d) between the lamps and the sample.

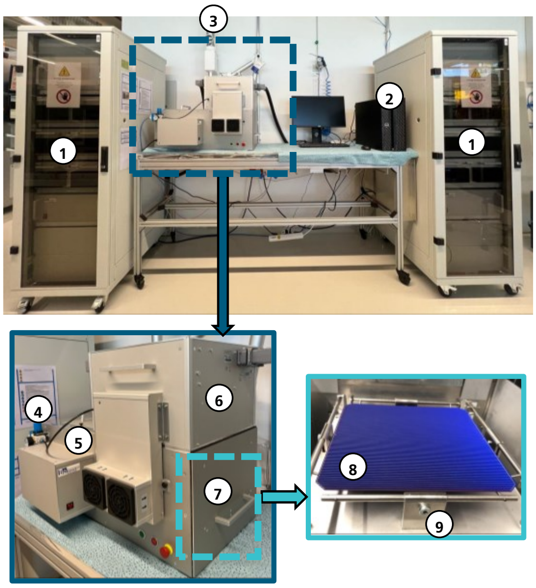

Figure 1: Images of the IPL device by *Botest Systems*. 1) Two lamp driver racks. 2) PC with software to set I_{LAMP}, t_P, n_P, f_P. 3) Exhaust. 4) Compressed dry air. 5) Chamber with photodiode for power density measurement. 6) Mirror-coated chamber with two xenon flash lamps. 7) Process chamber. 8) Sample. 9) Height-adjustable chuck.

In this work, only the drying and curing process is varied. The rest of the SHJ process steps are kept similar and conventional. Industrial M2 size SHJ precursors are metallized on the rear and front side by conventional silver pastes.

In the first step, the implied open circuit voltage (iV_{OC}) is measured for all samples before metallization via modulated photoluminescence [5]. Only the samples with similar iV_{OC} before metallization and curing are selected for further processing, since different initial lifetime levels may affect the lifetime gain due to curing. In this context, it is ensured that the lifetime of the solar cell batch used is improved by the curing process. Here, the conventional drying and curing are conducted in a conveyor belt furnace at a temperature of T = 200 °C and a process time of t = 1 min, respectively, t = 10 min. In a second step, the goal is to find the best IPL parameter set for the curing process by sweeping I_{LAMP}, t_P and d, and comparing the resulting current-voltage (*I-V*) parameters with conventionally cured solar cells, while keeping the drying step conventional for both groups. In a third step, the solar cells are completely dried and cured using the IPL method and compared with the conventionally processed samples in terms of the *I-V* results. To find the best parameter set for the IPL drying process, a parameter sweep is conducted again, taking the best parameter set for the IPL curing process as the initial condition. Tape tests are performed to ensure proper drying conditions.

Table 1: Different drying and curing conditions used in this work. "I_{LAMP} (RS 1)" contains I_{LAMP} after rear side printing. "I_{LAMP} (FS 1)" contains I_{LAMP} of the first flash after front side printing. "I_{LAMP} (FS 2)" contains I_{LAMP} of the second flash after front side printing. "Conv" stands for the conventional method.

Name	**Definition**	**I_{LAMP} (RS 1)**	**I_{LAMP} (FS 1)**	**I_{LAMP} (FS 2)**
Conv	Conventional drying and curing	-	-	-
Conv/ IPL$_1$	Conventional drying, IPL curing	-	I_{OPT}	-
IPL$_2$	IPL drying and curing	I_{OPT}	I_{OPT}	I_{OPT}
IPL$_3$		I_{OPT}	I_{OPT} - 5 A	I_{OPT}
IPL$_4$		I_{OPT}	I_{OPT}	I_{OPT} + 5 A
IPL$_5$		I_{OPT}	I_{OPT} + 4 A	-

3 RESULTS AND DISCUSSION

It is positive to note that no technical problems, such as deflagration of the solvent, have occurred during processing. The best parameters for the IPL curing process that give the highest η are: $I_{LAMP} = I_{OPT}$, t_P = 200 ms and d = 1 cm. This parameter set results in a similar η to conventionally cured samples (see Figure 2). Conveniently, the best parameter set for the IPL drying process is found to be the same as for the IPL curing process. Regarding the best sequence for the IPL route, the first IPL flash is conducted on the sample with its rear side facing the lamps after printing the rear side grid, followed by a second and a third IPL flash conducted on the sample with its front side facing the lamps after printing the front side grid (corresponding to "IPL3" in Table 1 and Figure 2). The first IPL flash acts primarily as the rear side drying step, the second flash as the front side drying and the third flash as the curing step, although both drying and curing can and probably do occur during the same flash. Tape tests indicate proper drying conditions for the chosen IPL parameter set.

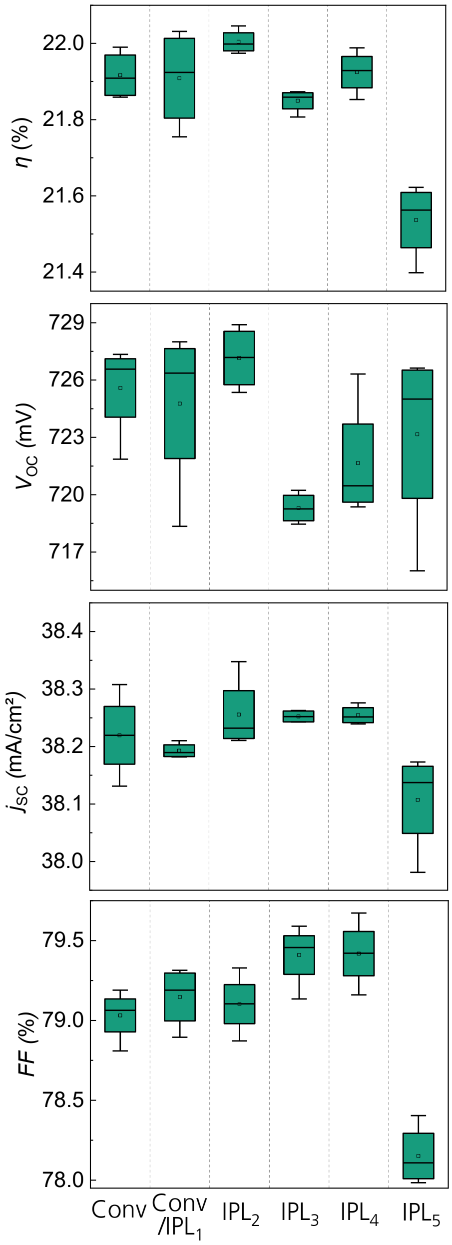

Figure 2: *I-V* results of the IPL-dried and -cured SHJ solar cells (boxplots 3-6) compared to conventionally dried and IPL-cured (boxplot 2) as well as conventionally dried and cured samples (boxplot 1). Here, η, the open circuit voltage (V_{OC}), the short circuit current density (j_{SC}) and the fill factor (FF) are displayed. The different methods of drying and curing shown in the x-axis are described in Table 1.

As a next step, the solar cell interconnection and module integration should be investigated for IPL-processed SHJ solar cells. Further, Cu pastes should be investigated by IPL-drying and curing, as well. Finally, further technologies like perovskite-tandem devices should be investigated.

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