1. Introduction

The most appealing features of perovskite solar cells (PSCs), such as high light absorption, excellent ambipolar charge mobility, small binding energy, high efficiency and low fabrication cost, have drawn attention of scientific community achieving remarkable power conversion efficiency (PCE) improvements in few years, from 3.9 to 25.5%. Despite the strong advances in technology, there is still a number of relevant effects that are subject to ongoing investigations. These effects could include, for example, less stability against light exposure, temperature and moisture and the hysteresis.

Moreover, in the wide variety of perovskite chemical compositions, multi cation perovskites are increasing the attention for different photovoltaic (PV) applications such as transparent windows, photodetectors, flexible and tandem devices.

In an ideal cell the only recombination channel is the radiative recombination of free electrons and holes in the same layer where they are generated, on the contrary the real presence of defects, in the perovskite absorber material, inserts energy transition levels (trap states) trapping the free charges and affecting the charge transport. The most efficient strategies to compensate these disadvantages are surface and interface passivation. A wide variety of materials, ranging from inorganic to organic molecules or even polymers, has been used as passivating layers, such as self-assembled monolayer deposition and self-passivation due to excess or deficiency of PbI$_2$. Recently the air was studied as the means of passivation. According to many authors low level of humidity and oxygen could actually improve the crystallinity of perovskite layer while taking care to keep high performances. More efforts are also pointed on ETM layer properties, fundamental together the HTM, for effective carrier separation at perovskite interface resulting in lower charge recombination at the interface contacts. One of commonly employed ETM is TiO$_2$, which, together with a transparent conductive oxide (TCO) such as indium tin oxide (ITO) or fluorine-doped tin oxide (FTO), forms the photoanode in both planar and mesoscopic perovskite high efficiency solar cells.

However, whatever ETM or HTM were chosen, it should be thereby important decreasing of defects, which are spontaneously and inevitably formed during the conventional device manufacturing process, both at the surface of perovskite film and interfaces of ETM and HTM. Lowering defects implies a reduction of recombination mechanisms obtaining high quality PSCs. In an ideal cell the only recombination channel is the radiative recombination of free electrons and holes in the same layer where they are generated, on the contrary the real presence of defects, in the perovskite absorber material, inserts energy transition levels (trap states) trapping the free charges and affecting the charge transport. The most efficient strategies to compensate these disadvantages are surface and interface passivation. A wide variety of materials, ranging from inorganic to organic molecules or even polymers, has been used as passivating layers, such as self-assembled monolayer deposition and self-passivation due to excess or deficiency of PbI$_2$. More recently the air was studied as the means of passivation. According to many authors low level of humidity and oxygen could actually improve the crystallinity of perovskite layer.
enhancing the photovoltaic (PV) performance. Oxygen in air could act as reactant to passivate the traps, not only under illumination but also by thermal treatment in air and it could also act as a p-type dopant. Further it was suggested that the water molecules could be also a strong n-type dopant and interact filling deep charge carrier traps. Therefore, it becomes crucial to understand the effects of humid air during fabrication and probable storage. Whilst moderate levels of humidity would positively affect to have high efficiency, at high levels of moisture or prolonged time exposure at low humidity, the PCE would decrease because of formation of hydrate phase perovskite. About that, just recently, Cho et al. clarified the mechanism that induces PCE increasing after ambient and moderate humidity storage in n-i-p architecture based on mesoporous perovskite solar cells, with 200 nm mesoporous TiO₂ as ETM and 400 nm capping perovskite layer. They found a PCE increasing in double cation perovskite, in the first 48 h of storage, from 17.1 % to 20.4 %, at room temperature and moderate humidity, finding that the effect of moisture on initial cell performance improvement was a combined result of temporal changes in both perovskite and HTM, showing a surface passivation and changes in conductivity. The insight of the competitive mechanisms of humidity and oxygen is fundamental to improve perovskite solar cells performance, helping the future development of the PSCs technology.

In this work we focus on fabrication and storage procedure of thin (~320 nm) un-encapsulated triple cation perovskite solar cells in planar architecture and consequently on influence of related PV parameters. We show, for the first time, to the best of our knowledge, a remarkable increase to 20.9 % after subsequent low vacuum storage and further storage procedure of thin (~320 nm) un-encapsulated triple cation perovskite solar cells in planar architecture and consequently on influence of related PV parameters. We show, for the first time, to the best of our knowledge, a remarkable increase to 20.9 % after subsequent low vacuum storage and further humid air/vacuum storage cycles. Oxygen in air could act as reactant to passivate the traps, not only under illumination but also by thermal treatment in air and it could also act as a p-type dopant. Further it was suggested that the water molecules could be also a strong n-type dopant and interact filling deep charge carrier traps. Therefore, it becomes crucial to understand the effects of humid air during fabrication and probable storage. Whilst moderate levels of humidity would positively affect to have high efficiency, at high levels of moisture or prolonged time exposure at low humidity, the PCE would decrease because of formation of hydrate phase perovskite. About that, just recently, Cho et al. clarified the mechanism that induces PCE increasing after ambient and moderate humidity storage in n-i-p architecture based on mesoporous perovskite solar cells, with 200 nm mesoporous TiO₂ as ETM and 400 nm capping perovskite layer. They found a PCE increasing in double cation perovskite, in the first 48 h of storage, from 17.1 % to 20.4 %, at room temperature and moderate humidity, finding that the effect of moisture on initial cell performance improvement was a combined result of temporal changes in both perovskite and HTM, showing a surface passivation and changes in conductivity. The insight of the competitive mechanisms of humidity and oxygen is fundamental to improve perovskite solar cells performance, helping the future development of the PSCs technology.

2. Experimental

Materials and device characterization

SnO₂ colloid precursor (tin(IV) oxide 15% H₂O colloidal dispersion), PbI₂ (≥99.999, ultradry) and PbBr₂ (Puratronic, ≥99.998) were obtained from Alfa Aesar; CsI (≥99.999, anhydrous) and acetonitrile (ACN) from Acros Organics; N,N-dimethylformamide (DMF), dimethylylsulfoxide (DMSO), formamidium iodide (FAI), methylammonium bromide (MABr, ≥99%, anhydrous), Spiro-OMeTAD, Chlorobenzene (CB), 4-tert-butylypyridine (TBPY), Bis(trifluoromethan)e sulfonimide lithium salt (Li-TFSI), FK 209 Co(III) TFSI salt were purchased from Sigma Aldrich/Merck. All chemicals were used without further purification. We have used 2 x 2 cm² glass/ITO substrates received from Kintec (10 Ω/sq). The scanning electron microscopy (SEM) and energy-dispense X-ray (EDX) were performed with Thermo Fisher Scientific Phenom pro X SEM, which uses and electron beam accelerated at 15 kV and it is equipped with long life time thermoionic source cerium hexaboride. The cross section to evaluate the different layers in PSCs was made by a FEI Dual Beam Quantar 200 3D apparatur, which integrates a finely focused gallium ion beam (FIB). Thickness of different layers was also measured by KLA Tencor profilometer. Solar cells performances were characterized under solar simulator (Wacom Electric Co. LTD, WXS 155S, L2.AM 1.5 G) generated by two AAA class lamps (Ha and Xe) located in a not air-conditioned laboratory. The current–voltage characteristics of the devices were obtained by applying external potential bias to the cell while recording the generated photo-current using a Keithley (Model 2651A) high power system source meter. J-V data acquisition is performed with rate of 2 V/s for all the electrical measurement, both forward and reverse scans and both pristine and stored devices. All the samples are not polarized, scan range is from reverse scan, from 1.2 V to -0.1V.

Device fabrication

The fabrication process of PSCs for triple cation perovskite was developed by different authors50,51 but the final process was often modified according to requirements. To prepare the perovskite solar cell, ITO glass substrate was cleaned by sonication with acetone and ethanol for 15 minutes each in order. Then, two thin layers of tin oxide layer, as electron transport material were deposited, under a fume extractor system at temperature of 90°C and the relative humidity. Depending on outdoor atmospheric conditions, by spinning, at 6000 rpm 30sec, onto ITO substrates previously treated with UV-ozone. The SnO₂ solution was prepared diluting a commercial SnO₂ colloidal dispersion with deionized water (1:5). Annealing temperature was 130°C for 1 h on hotplate, controlled with a thermocouple, in humid air. Substrates were again treated with UV-ozone before perovskite layer deposition. Perovskite and Spiro-OMeTAD were deposited by spinning approach under glove box (Jacomex) in N₂ carrier and RH less than 1 ppm. A schematic diagram for device fabrication procedures is shown in Fig. S1 of the supplementary information.
Two batches of PSCs were fabricated in the same day (T = 20°C and RH = (30 ± 10) %): the former batch, after SnO₂ spinning process in humid air, was inserted in nitrogen-filled glove box for perovskite and HTM spinning depositions and subsequent thermal evaporation of gold electrical contacts (hereafter named as devices completed inside the GB) (Fig. S1a†); the latter, after perovskite and HTM spinning depositions, was put outside the glove box, left in humid air for 1 h, time needed from transferring and loading in an external evaporator, for subsequent gold evaporation (hereafter named as devices completed outside the GB) (Fig. S1b†).

The perovskite Cs₀.⁰⁵FA₀.⁸MA₀.¹⁵PbI₂.⁵Br₀.⁵ (mixed cation Cs, FA = formamidinium; MA = methylammonium, and mixed halide (I, Br)) solution was prepared by mixing PbI₂ (1.10 M), PbBr₂ (0.22 M), FAI (1.05 M), MABr (0.20 M) in DMF/DMSO (4 : 1 v/v%), and CsI iodide solution (1.50 M) in DMSO was added to obtain molar ratio of 5%. The perovskite spin-coating process was set as a two-step program with 1000 and 6000 rpm for 10 and 20 seconds, respectively. 150 μl CB was dropped on the substrate few seconds before spin-coating was complete. After that, the perovskite layer was crystalized by annealing at 100 °C for 1 hour. To deposit Spiro-OMeTAD, as HTM, solution was spun on the perovskite layer at 4000 rpm for 30 seconds. The HTM solution consists of 73 mg of Spiro-OMeTAD diluted in 1 mL of CB, 27 μL of TBPy, 17 μL of a Li-TFSI solution (520 mg of Li-TFSI in 1 mL of ACN), and 7 μL of a FK 209 Co(III) TFSI (375 mg of Co-complex in 1 mL of ACN). Finally, devices were completed in a thermal evaporator inside or outside the glove box and 80 nm Au back-contact layer was evaporated on the Spiro-OMeTAD layer for all the devices, using a mask to define the positive electrode. The architecture of PSCs and photo of typical device are reported in literature, respect to air ambient storage conditions, chemical composition, thickness of perovskite and architecture.

3. Results and Discussion

J-V characteristics and PV parameters for pristine and stored PSCs

Two batches of devices, completed inside the GB and outside the GB, were fabricated in the same day with RH = (30 ± 10) % and 20°C. Solar cells, after the first electrical measurement, were initially stored for 312 h in dark and in a box with (30 ± 10) % of relative humidity and monitored over the time. When a decrease in the cell efficiency was recorded, devices were placed in a low vacuum chamber (P ~ 100 mbar) and measured over the time again.
The short circuit current density ($J_{sc}$): $J_{sc}$ of devices completed inside the glove box (Fig. 3b), after an initial strong increase in the first 72 h in humid air, exhibited a decrease to initial value. A further increase of current density was recorded, at 720 h after fabrication day and low vacuum cycle, showing a quite reversible behaviour. Meanwhile $J_{sc}$ of batch completed outside the glove box (Fig. 2b) had the maximum value only the first day ($t=0$) then started to decrease during storage in air. After 720 h and low vacuum storage $J_{sc}$ reversibly increased again such as previous batch (Fig. 2b).

The fill factor (FF): FF increased in the first 72 h (Fig. 2c and Fig. 3c), from 64.9% to 81.6% for devices completed inside the glove box and from 56.3% to 74.8% for other ones. After vacuum storage, FF was quite stable for all the devices.

The power conversion efficiency (PCE): PCE, for the first 72 h, had a great jump (Fig. 2d and Fig. 3d). After the initial rising stage (20.8% for the champion of devices completed inside the glove box and 17.4% for one completed outside the glove box, with a percentage of increase of 50% and 40% respectively), PCE continued to increase after low vacuum storage, reaching, for the champion device of batch completed inside the GB, the efficiency of 20.9%, and 19.7% for the other batch. Champion device reached 20.9% independently from pristine efficiency which was about 12-13% for both the batches. The PCE improvement, as well as FF, $V_{oc}$ and $J_{sc}$ after 72 h of humid air storage, and the slight PCE decrease, after 312 h in moisture, suggest that competitive mechanisms are always present when moisture interacts with perovskite. Oxygen and moderate moisture have then a positive effect on the photovoltaic performances, but prolonged exposure in humid air can lead to acute degradation of PSCs.

The former mechanism leads to the formation of deep charge carrier traps.

If thereby the exposure of devices to oxygen and moisture produced a remarkable PCE enhancement of 50% respect to pristine value, a prolonged exposure to humid air, could instead be caused by formation of more perovskite hydrate species.31

Consequently, the fill factor, dependent on $R_{s}$ enhances, as well as the $V_{oc}$55,56 A subsequent decrease of conductivity, recorded after 312 h, observed after prolonged exposure to humid air, could instead be caused by formation of more perovskite hydrate species.5 If whereby the exposure of devices to oxygen and moisture produced a remarkable PCE enhancement of 50% respect to pristine value, a prolonged exposure to humid air to led to a degradation of devices. We show that this degradation could be removed when moistened devices were transferred into low vacuum chamber, also getting a further improvement of all PV parameters.
Low vacuum storage in fact should erase the effect of hydrates species formed during the first exposure to humid air storage. Furthermore, oxygen, present in the low vacuum chamber, should continue to improve the interface recombination between perovskite/HTM and HTM/gold, increasing $V_{oc}$. Finally, best efficiency was obtained for devices fabricated completely in nitrogen filled glove box and after storage in humid air/low vacuum, for a total period of 720 h from fabrication day. Batch of PSCs completed outside the GB confirmed the results previously discussed. This set of devices, having been exposed to humid air before gold evaporation, showed a high value of pristine $J_{sc}$, probably caused by the doping of water molecules incorporated into perovskite bulk. As we formerly expected, after 72 h in humid air, also this batch of devices completed outside the GB, exhibited a higher $V_{oc}$, taking place the oxidation of HTM, and consequently a higher PCE. An interesting stability of performance, were recorded after 312 h in humid air and it was not observed a decrease in PCE. However also for these devices, after storage into low vacuum chamber, PCE improvement was observed, confirming that reversible hydration was also present. In Fig. 4 J-V curves over storage time of champion perovskite devices of two different batches, completed inside (Fig. 4a) and outside the GB (Fig. 4b) monitored over time are shown. SEM and EDX elemental mapping of perovskite film confirmed that moisture changed both morphology and bulk composition of perovskite layer after exposure to humid air before gold evaporation (Figs. 5a, 5a1 and 5a2). More grains with smaller area was observed when the perovskite absorber was exposed to humid air before gold evaporation (Fig. 5a and Fig. S4), while larger grain area were observed (Fig. 5b) when the cells were completed inside the GB. This feature could explain at least partially the better performance measured on these PSCs.

A proof that oxygen was deeply incorporated into devices completed outside the GB, and then stored in humid air before gold evaporation, was given by EDX mapping. The presence of oxygen, among atoms, into devices exposed to air, before gold evaporation, evidenced the presence of probable hydrate compounds (Fig. 5a1). Moreover, after one storage cycle in low vacuum only a small reduction of oxygen occurred (Fig. 5a2). Meanwhile devices completed inside the glove box, after storage in humid air and low vacuum, did not show oxygen into the structure, demonstrating a non-significant absorption (Fig. 5b1 and Fig. 5b2).

**Hysteresis-free for aged PSCs after storage**

Typical hysteresis graphs were shown for pristine devices and stored ones, e.g. after humid air and low vacuum storage (Fig. 6). The J-V data of pristine device exhibited a large discrepancy (Fig. 6a) between the reverse and forward scan directions, which decreases after 72 h in humid air (Fig. 6b). A hysteresis-free behaviour was instead observed for all the devices after 720 h, then after a cycle of humid air and low vacuum exposure (Fig. 6c and Fig. 6d). The J-V hysteresis is a
dynamic process, which can be influenced both from pre-conditioning and measurement conditions, and from material properties such as the crystallite size in the perovskite layer and interfaces between absorber and electron/hole transport materials.\(^\text{59}\)

In our case the reduction of hysteresis depends on storage conditions and not from measurement procedure because scan rate was always the same and applied pre-bias was settled to 1.2V close to \(V_{\text{oc}}\). Humid air, then, improving also the HTM conductivity, balance the charge transport between the electrons and holes in ETM and HTM, reducing then the number of surface traps and consequently reducing hysteresis.

### Dark J-V and ideality factor

The absence of hysteresis over time allowed to evaluate more in depth the diode characteristics with and without illumination. Dark-current–voltage curves for four different devices, both completed inside and outside the GB, recorded after 720 h from fabrication day are reported in Fig. S5\(^\text{†}\).

When current starts to increase in a non-linear way, trap filling process are activated. The kink point between the linear region and the non-linear one is defined trap filled limit voltage (\(V_{\text{id}}\)) and it is possible to calculate the trap density, according to the space-charge-limited current (SCLC) model, using the equation\(^\text{60}\):

\[
N_t = \frac{2 \varepsilon_0 \varepsilon V_{\text{id}}}{e L^2}
\]

(1)

where \(L\) is the thickness of perovskite layer (\(\approx 320\) nm), \(\varepsilon\) is the dielectric constant of perovskite film (\(\approx 33\)\(^\text{61}\)). The \(V_{\text{id}}\) is shown in Fig. 7 and used to calculate the trap density, reported in Table S4\(^\text{†}\).

Devices completed inside the GB, after 720 h, have a smaller trap density respect to devices completed outside the GB. Then the increase in \(V_{\text{oc}}\) for the first batch during the storage time is probably due to the decreasing of trap density. Probably the incorporation of water into devices completed into glove box, e.g. after gold deposition, filling deep charge carrier traps, reduces the defects and improves the conductivity of HTM. Water incorporated into devices completed outside the GB, e.g. before gold evaporation, leaves rather a larger trap density.

In order to investigate the mechanism of recombination in stored devices, illumination-dependent photovoltaic parameters were measured. To obtain light intensity dependent measurements, a set of neutral density filters was used, tuning the AM1.5 light of solar simulator. Measurements were recorded at 1 SUN (100 mW/cm\(^2\)) and at 0.4, 0.25, 0.16, 0.1 and 0.03 SUN. Recombination was then investigated by means of the so-called diode ideality factor (\(n_{\text{id}}\)) extracted from current–voltage curves measured as slope of \(V_{\text{oc}}\) as a function of illumination intensity. Identifying the ideality factor is a reliable way to indicate the dominant recombination mechanism in a solar cell which can be categorized in trap-assisted and bimolecular recombination.\(^\text{63-66}\) Tress et al.\(^\text{60}\) summarized that the ideality factor \(n_{\text{id}}\) of PSCs is reliably obtained by light-intensity-dependent \(V_{\text{oc}}\) measurements because measurements performed at open circuit are not affected by parasitic series resistance. For these measurements \(n_{\text{id}}\) can be calculated by a linear fit of the \(V_{\text{oc}}\) in function of \(\ln(I_{\text{ph}}/I)\) under relative light intensities using the equation:

\[
V_{\text{oc}} = n_{\text{id}} \frac{K_B T}{e} \ln\left(\frac{I_{\text{ph}}}{I}\right)
\]

(2)

where \(e\) is the elementary charge, \(K_B\) is the Boltzmann constant, \(T\) is the temperature and \(I_{\text{ph}}\) is the photocurrent produced by the light under illumination and \(I\) is the light intensity. Some papers reported the value of ideality factor for aged and pristine devices, suggesting that the unity value of \(n\) indicates the dominance of recombination at the surface of the perovskite film, whereas \(n_{\text{id}} < 2\) refers to trap-assisted Shockley-Read-Hall (SRH) recombination in the perovskite bulk.\(^\text{46,67}\) Authors found that for aged devices was dominant SRH recombination. For our devices the ideality factor was calculated from the slope of \(V_{\text{oc}}\) vs \(\ln(I_{\text{ph}}/I)\) reported in Fig. 8. Ideality factor values are about 1.8 for devices completed inside the GB, while about 1.3 if devices are completed outside the GB. This finding showed that the recombination mechanism changed, depending on fabrication procedure. Higher ideality factor value, for stored devices completed outside the GB, indicates the dominant existence of trap-assisted recombination, but considering the increase of \(V_{\text{oc}}\) compared to pristine devices, a reduction of traps or non-radiative recombination could be occurred.\(^\text{46}\) Conversely, smaller \(n_{\text{id}}\) calculated for stored devices completed inside the GB, is attributed to a band-to-band direct recombination also confirmed from higher values of \(V_{\text{oc}}\) respect to all the other devices. This is reliable with results.

![Fig. 7: Dark I-V measurements of the devices displaying the \(V_{\text{oc}}\) kink point](image1.png)

![Fig. 8: Intensity-dependent \(V_{\text{oc}}\) for devices completed inside and outside the GB](image2.png)
To insight into charge recombination, we also studied the variation of $J_{sc}$ as a function of illumination intensity (Fig. 54†). Several authors have observed a power law dependence of $J_{sc}$ upon light intensity $J_{sc} \sim I^{\alpha}$, where $I_0$ is the photocurrent, $I$ is the light intensity and $\alpha$ typically range $\leq 1$. When $\alpha$ is close to 1 indicates a weak bimolecular recombination and non-space-charge limited devices, whilst if $\alpha$ deviates from unity the bimolecular recombination, space-charge effects and variations in mobility between holes and electrons could be attributed.8 Preliminary results show the coefficient $\alpha$ for devices outside the GB is 0.76 (Fig. 56a†) and for devices completed inside the GB is 0.81 (Fig. 56b†) showing sublinear dependence less marked for the second one, evidencing probably a weak bimolecular recombination. These preliminary results are calculated for ambient air stored devices showing that phenomena of charge recombination depend not only on aging but also on manufacturing environment, i.e. if PSCs were exposed to air before or after gold evaporation. All the aged devices were in any case hysteresis-free and then probably the increasing of performances was due to a lower migration of ions and consequently to less charge recombination. It is not yet clear the mechanism that rules these phenomena. It could probably be the oxygen or the water present in humid air that fill deep charge carrier traps, as shown in this work, or it could be due to lithium dopant from HTM that could significantly dope the perovskite absorber layer through diffusion, as reported in a recent study where authors studied this mechanism, monitoring over three-day window, with a decrease of spontaneous non-radiative recombination from trap states, providing an increase of photovoltaic performances.70 Moreover the improvement of PV performances, comparing fresh and aged devices, was just recently studied also for all-inorganic perovskite solar cells. Authors showed that all deep defects were reduced after resting the perovskite films overnight probably due to a self-regulation mechanism, connecting with the strain released over time and giving a suppression of hysteresis too.71 Understanding these mechanisms is not immediate and a better insight could be to apply multiple dynamic processes under different operating conditions. In literature several studies have been made to measure the charge transfer, such as time-of-flight secondary-ion mass spectrometry, glow discharge optical emission spectroscopy, transient photovoltage decay measurements and electrochemical impedance spectroscopy.11,22,67-72 These analyses could give more information on charge transport in PSCs especially when hysteresis-free devices are obtained. Further investigation could be planned to study ambient air stored devices adding information on charge recombination when PV parameters increase over time, by linking results with fabrication and storage processes.

4. Conclusions

In summary, we studied the effects of humid air and low vacuum storage on un-encapsulated planar devices glass/ITO/SnO$_2$/triple cation perovskite/Spiro-OMeTAD/Au fabricated completely inside N$_2$-filled glove box or depositing gold contacts outside the glove box. When all the devices, independently from fabrication procedure, are stored in humid air for 72 h, oxygen and moisture conduct to an electrical conductivity enhancement and consequently to an improvement of interface charge transfer. Consequently, $V_{oc}$ and FF increased for the faster charge extraction. Devices showed, after 312 h in humid air, a stability (less than 5% change) for all PV parameters, except for $J_{sc}$ which decreased of about 10%. The subsequent storage in low vacuum preserved the PV performance of all the devices, removing partly water molecules inside the cell and improving additionally the PV parameters. We found, for the first time, to the best of our knowledge, an impressive rise of power conversion efficiency (PCE) from 13.2% to 20.8% after 72 h storage in humid air (RH = 30 ± 10%) and a slight increase to 20.9%, after low vacuum storage and 720 h from fabrication day, for PSCs fabricated completely in nitrogen-filled glove box. Moreover all PV parameters increase after storage: fill factor exceeding 80%, short circuit current density of about 24 mA/cm$^2$ and open circuit voltage of 1121 mV, for champion devices. The hysteresis-free behaviour was also observed for all the devices after 720 h. Preliminary study about possible charge recombination mechanisms were presented and confirmed that devices completed inside the glove box showed a weak bimolecular or band-band recombination also confirmed from higher value of $V_{oc}$. Improvement of PV parameters of un-encapsulated pristine perovskite solar cells after storage cycle in moderate humid air and low vacuum exposure opens a route for following encapsulation procedures.

Author Contributions

Vera La Ferrara: Conceptualization, Investigation, Formal analysis, Writing- Original draft, Writing- Reviewing and Editing. Antonella De Maria: Investigation, Writing- Reviewing and Editing. Gabriella Rametta: Investigation, Writing- Reviewing and Editing. Paola Delli Veneri: Project administration, Writing- Reviewing and Editing.

Conflicts of interest

There are no conflicts to declare

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