On the Role of Interfaces in Planar-Structured HC(NH$_2$)$_2$PbI$_3$ Perovskite Solar Cells

Dong-Jin Seol, Jin-Wook Lee, and Nam-Gyu Park$	extsuperscript{[a]}$

Planar-structured HC(NH$_2$)$_2$PbI$_3$ (FAPbI$_3$) perovskite solar cells were prepared via a two-step deposition process. To investigate the role of interface, the perovskite morphology was intentionally modified by varying HC(NH$_2$)$_2$I concentration. Surface and grain sizes of the deposited FAPbI$_3$ became rougher and larger as the HC(NH$_2$)$_2$I concentration decreased from 58.2 to 40.7 mM. Average photocurrent was improved but photovoltage deteriorated slightly with decreasing concentration. Consequently, the average efficiency was improved from 7.82% to 10.70% and the best efficiency of 12.17% was obtained at 40.7 mM. Photoluminescence (PL) at TiO$_2$/FAPbI$_3$ interface was reduced with decreasing concentration, which was, however, reversed at FAPbI$_3$/spiro-MeOTAD one. By correlating PL data and the photovoltaic performance, we concluded that the TiO$_2$/perovskite interface plays a crucial role in determining photocurrent while the perovskite/spiro-MeOTAD interface is important in governing photovoltage.

Introduction

Since the first report on long-term durable perovskite solar cells with a power conversion efficiency (PCE) of 9.7% in 2012$^{[1]}$ and subsequent reports on liquid-type dye-sensitized solar cells employing methylammonium (MA) lead halide perovskite as a sensitizer$^{[2,3]}$, intensive efforts have been made to improve PCE and understand the working principle of perovskite solar cells over the years. Burschka et al. achieved a PCE of 15.0% by using sequential deposition of PbI$_2$ and CH$_3$NH$_3$I with a mesoporous TiO$_2$ layer$^{[4]}$. Lee et al. demonstrated that charge could be transported within a perovskite layer without injection into nanostructured oxide by using a nanocrystalline Al$_2$O$_3$ scaffold layer, which exhibited a PCE of 10.9%.$^{[5]}$ Besides nanoparticle oxide scaffolds, oxide nanorods were also found to be good candidates, where ZnO nanorod-based perovskite solar cells showed a PCE of 11.13% and better charge collection behavior than TiO$_2$ nanorods.$^{[6]}$ However, even without a nanostructured oxide layer, high efficiency perovskite solar cells could be fabricated, and these have a planar-heterojunction structure. By applying a vapor deposition method to obtain this structure, a 15.4% PCE perovskite solar cell was reported.$^{[7]}$ By far the highest PCE of 20.1% was recently certified using organo metal halide perovskite.$^{[8]}$

These outstanding photovoltaic performances of MA halide perovskite solar cells are attributed to excellent light absorption, nearly ideal band gap, and long range charge transporting characteristics.$^{[9,10]}$ Nevertheless, some issues should be addressed for these materials, particularly with respect to CH$_3$NH$_3$PbI$_3$ and CH$_3$NH$_3$PbI$_3$.Cl. Specifically, reversible phase transition between tetragonal and cubic phases was reported for CH$_3$NH$_3$PbI$_3$,$^{[11]}$ which may affect photovoltaic performance due to probable changes in electronic structure. Moreover, this structural phase transition may cause concern about photo- and/or thermal-stability. Thus, an alternative to MA lead iodide (MAPbI$_3$) that has no phase transition at a solar cell operation temperature ranging from ambient temperature up to 120°C is required.

The formation of a perovskite ABX$_3$ structure can be predicted by employing a tolerance factor ($t$) using effective ionic radii.$^{[12]}$ Effective ionic radii of A-site cations ranging between about 160 pm and about 240 pm are estimated to be available from lead- or tin-based halide perovskite. The MA ion is suitable for this criterion because of its ionic radius being 188 pm.$^{[13,14]}$ Formamidinium cation HC(NH$_2$)$_2$C$^+$ (FA) can be also stabilized in A site because of similar ionic radius. In contrast to the cubic-tetragonal phase transition from MAPbI$_3$, no phase transition was observed in FA lead iodide HC(NH$_2$)$_2$PbI$_3$ (FAPbI$_3$), which also provided a smaller band gap compared to MAPbI$_3$.$^{[15]}$ Hence, a higher photocurrent can be expected using FAPbI$_3$ because of its broader absorption. Due to these advantages, a PCE as high as 16% was demonstrated from FAPbI$_3$ coupled with a mesoporous TiO$_2$ layer via a two-step deposition procedure.$^{[16]}$ Photostability was measured to be better for FAPbI$_3$ than for MAPbI$_3$.$^{[15]}$ Furthermore, a PCE of 14.2% was achieved using FAPbI$_3$ in a planar heterojunction structure without a mesoporous TiO$_2$ layer.$^{[17]}$ Since morphology and crystal size of MAPbI$_3$ were reported to be significantly influenced by MA iodide concentration in two-step solution-processed perovskite deposition,$^{[18]}$ we utilized this method to...
alter the interfacial morphology of FAPbI$_3$ in a planar-junction structure without a mesoporous TiO$_2$ layer.

Here, we report on the role of interfaces in FAPbI$_3$ perovskite solar cell based on a planar junction structure with a FTO/bl-TiO$_2$/FAPbI$_3$/spiro-MeOTAD/Au configuration, where FTO and bl-TiO$_2$ stand for fluorine-doped tin oxide and blocking layer TiO$_2$, respectively. Interfacial morphology was altered by changing the formamidinium iodide (FAI) concentration in a two-step deposition procedure. Photocurrent-voltage, scanning electron microscopy (SEM), X-ray diffraction (XRD), UV/Vis spectroscopy and photoluminescence (PL) measurements were performed to study interface–property relationships.

**Results and Discussion**

FAPbI$_3$ was formed by a two-step method, in which PbI$_2$ was deposited on a bl-TiO$_2$-coated FTO glass substrate and then the PbI$_2$-coated film was immersed in the FAI solution according to the method described elsewhere.$^{[16]}$ To make a planar junction structure, we did not use a mesoporous TiO$_2$ layer in this study. During the second step deposition of FAI, the concentration of FAI is varied from 40.7 to 58.2 mM. Figure 1 compares SEM images of FAPbI$_3$ as a function of the FAI concentration. Chrysanthemum-like morphology is created by the two-step method, and this morphology becomes clearer with decreasing the FAI concentration, as can be seen in the plane-view SEM images. Moreover, the size of flower-like FAPbI$_3$ increases with decreasing FAI concentration, as determined by an increase in the petal size, which is further confirmed from the tilted side-view SEM images. When FAPbI$_3$ is formed from a 40.7 mM FAI solution, fluctuation of FAPbI$_3$ height is evident, whereas the 58.2 mM FAI solution generates a relatively even surface of FAPbI$_3$, indicating that surface roughness of the FAPbI$_3$ film increases as the FAI concentration decreases due to enlarged grain size. Surface roughness was further confirmed using a surface contact profilometer (Figure S1 in the Supporting Information). We have also investigated the FAPbI$_3$ morphology for the lower concentration of 34.9 mM (Figure S2 in the Supporting Information), where the flower-like FAPbI$_3$ becomes larger, with petals being about 2 μm long and 1 μm wide; the surfaces not covered with the flower-like FAPbI$_3$ are still composed of FAPbI$_3$ perovskite. Grain size and surface roughness are consequently found to simultaneously increase as the FAI concentration decreases.

XRD patterns confirm the formation of FAPbI$_3$ regardless of the FAI concentration (Figure 2a). All the peaks are indexed to a black polymorph of FAPbI$_3$ and no yellow phase (non-perovskite phase) is detected.$^{[16]}$ However, a peak at around 12.6° corresponding to PbI$_2$ is observed for all samples, which indicates that unreacted PbI$_2$ exists. It is probably difficult for the densely deposited PbI$_2$ film to completely react with FAI in 60 s. We have tried to fully convert PbI$_2$ into FAPbI$_3$ by increasing dipping time. However, no significant difference in XRD pattern and peak intensity was observed for the longer dipping times of 90 s and 120 s (Figure S3 in the Supporting Information). Prolonged exposure to FAI solution was found to damage the PbI$_2$ layer as confirmed by SEM images (Figure S4).

![Figure 1. Plane-view and tilted side-view of SEM images for FAPbI$_3$ formed from (a) and (b) 40.7 mM, (c, d) 46.5 mM, (e, f) 52.4 mM, and (g, h) 58.2 mM of FAI solution, respectively. FAPbI$_3$ was formed by dipping the PbI$_2$ film in FAI solution. Scale bars represent 1 μm.](image)

![Figure 2. (a) XRD patterns depend on the FAI concentration. Unreacted PbI$_2$ was detected for all samples at 12.6°, but was not detected in the presence of a mesoporous (mp) TiO$_2$ layer. (b) (220) peaks showing a decrease in FWHM with lowered FAI concentration. Open circles and solid lines represent measured data and fit results, respectively.](image)
in the Supporting Information), which might be ascribed to dissolution of PbI$_2$. We therefore determined 60 s as an optimal dipping time. Contrary to the planar structure, in the presence of a mesoporous TiO$_2$ film, a PbI$_2$ peak is not detected, as can be seen in Figure 2a, which is indicative of complete conversion of PbI$_2$ to FAPbI$_3$. These results are correlated to the previous report for the case of MA cation lead iodide perovskite,\cite{20} which manifests that complete conversion of PbI$_2$ into FAPbI$_3$ is difficult in the planar structure while PbI$_2$ can be completely converted to FAPbI$_3$ by using porous TiO$_2$. This also underscores that a porous PbI$_2$ structure with the aid of a mesoporous TiO$_2$ layer is better for complete conversion of PbI$_2$ in such a short period in the two-step process.

In Figure 2b, the full width at half maximum (FWHM) at (220) reflection decreases with decreasing FAI concentration, which is an indicative of an increase in the X-ray crystallite size. X-ray crystallite sizes were estimated to be 34.0, 31.7, 30.7, and 27.7 nm for 40.7, 46.5, 52.4, and 58.2 mm, respectively, by using the well-known Scherrer equation,\cite{19} which is much smaller than the size observed from SEM. This indicates that the petal-like FAPbI$_3$ crystal in the SEM image in Figure 1 is composed of small grains.

Average photovoltaic parameters with standard deviation are listed in Table 1 and the dependence of the photovoltaic parameters on FAI concentration is plotted in Figure 3. Since the data do not seem to be significantly changed, one may argue whether or not the photovoltaic parameters of the solar cells are statistically different. Student t-test was carried out to verify the difference and consequently the observed data passed t-test, which indicates that there is obviously a significant difference between the solar cells. As can be seen in Figure 3, except for the 34.9 mm FAI, no significant change in open-circuit voltage ($V_{oc}$) was observed, but it is obvious that the short-circuit current density ($J_{sc}$) increases gradually as the FAI concentration decreases. The average $J_{sc}$ and fill factor (FF) increase from 17.73 to 18.90 mA cm$^{-2}$ and from 0.444 to 0.582, respectively, but average $V_{oc}$ decreases slightly by 2.2% from 0.993 to 0.972 V as the FAI concentration fell from 58.2 to 40.7 mm. Consequently, PCE is enhanced from 7.82% at 58.2 mm FAI to 10.70% at 40.7 mm. The highest PCE of 12.17% was attained using the 40.7 mm FAI solution. These results indicate that large FAPbI$_3$ formed by low FAI concentration leads to higher photovoltaic performance. However, the 34.9 mm FAI solution cannot further improve the photovoltaic performance in spite of its larger size, probably due to the fact that the compact TiO$_2$ layer is not fully covered by the large-sized FAPbI$_3$ (Figure S2 in the Supporting Information). Moreover, many cracks are unavoidable when using the lowest concentration, which might provide sites for shunting and recombination by directly connecting the hole transporting material (HTM) to the compact blocking layer.\cite{26} This leads to low FF and $V_{oc}$ values. For the FAPbI$_3$ films prepared from FAI concentrations ranging from 40.7 to 58.2 mm, UV/Vis and PL studies were performed to clarify the basis for $J_{sc}$ and $V_{oc}$ changes with FAI concentration.

Figure 4a shows UV/Vis absorption spectra for the FTO/bl-TiO$_2$/FAPbI$_3$ configuration (without HTM layer), where absorbance numbers in parentheses represent the best-performing devices. The device active area was 0.123 cm$^2$, obtained from eight cells for 34.9 and 40.7 mm, seven cells for 46.5 and 52.4 mm, and 11 cells for 58.2 mm. The fill factor, FF, and power conversion efficiency, PCE, of the FAPbI$_3$ films prepared from FAI concentrations ranging from 0.28 (19.33) to 1.01 (10.11)

<table>
<thead>
<tr>
<th>FAI concentration [mmol L$^{-1}$]</th>
<th>$J_{sc}$ [mA cm$^{-2}$]</th>
<th>$V_{oc}$ [V]</th>
<th>FF</th>
<th>PCE [%]</th>
</tr>
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<tbody>
<tr>
<td>34.9</td>
<td>17.70 ± 0.43 (18.14)</td>
<td>0.875 ± 0.023 (0.852)</td>
<td>0.516 ± 0.046 (0.581)</td>
<td>8.00 ± 0.81 (8.98)</td>
</tr>
<tr>
<td>40.7</td>
<td>18.90 ± 0.28 (19.33)</td>
<td>0.972 ± 0.014 (0.980)</td>
<td>0.582 ± 0.045 (0.642)</td>
<td>10.70 ± 0.99 (12.17)</td>
</tr>
<tr>
<td>46.5</td>
<td>18.70 ± 0.22 (18.97)</td>
<td>0.988 ± 0.021 (1.001)</td>
<td>0.562 ± 0.039 (0.604)</td>
<td>10.38 ± 0.80 (11.47)</td>
</tr>
<tr>
<td>52.4</td>
<td>18.28 ± 0.37 (18.61)</td>
<td>0.995 ± 0.019 (1.012)</td>
<td>0.534 ± 0.046 (0.604)</td>
<td>9.73 ± 1.08 (11.37)</td>
</tr>
<tr>
<td>58.2</td>
<td>17.73 ± 0.49 (17.93)</td>
<td>0.993 ± 0.016 (1.000)</td>
<td>0.444 ± 0.052 (0.564)</td>
<td>7.82 ± 1.01 (10.11)</td>
</tr>
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Figure 3. Plot of (a) $J_{sc}$, (b) $V_{oc}$, (c) FF, and (d) PCE as a function of FAI concentration.
low concentrations consisted of more crystalline perovskite with fewer defects, which provides a more efficient band-to-band transition resulting in higher \( J_{sc} \) values.

PL intensity substantially decreases with decreasing the FAI concentration (Figure 4c); PL intensity is measured in the FTO/bl-TiO\(_3\)/FAPbI\(_3\) configuration. The PL is maximized at around 815 nm, which is consistent with previous observations.\(^{16, 25}\) PL intensity decreases significantly as the FAI concentration decreases. The decreased PL intensity may be related to density of traps because an increased trap density is expected to decrease the PL yield. Large grain with high crystallinity is likely to have low trap density as mentioned before, which can lead to high PL yield. However, the PL yield is lowered as the size increases. This indicates that the reduction in the PL intensity in Figure 4c is not attributed to the trap density but likely to result from injection of electrons from the perovskite to the compact bl-TiO\(_3\). Therefore, strong reduction in PL at low concentration suggests effective electron separation. Such effectiveness in electron injection could lead to better charge collection, consequently resulting in high \( J_{sc} \). Relative PL reduction is calculated with respect to the PL data for the 58.2 mm FAI and is plotted against FAI concentration together with \( J_{sc} \) (Figure 4d). There is a strong correlation between PL reduction and \( J_{sc} \) in which the dependence of \( J_{sc} \) on concentration is similar to that of PL reduction. This indicates that the increased \( J_{sc} \) is attributed to better electron injection and also implies that the bl-TiO\(_3\)/FAPbI\(_3\) interface is influenced by the preparation conditions. Moreover, this interface is one of the major determinants of \( J_{sc} \).

PL measurements for the glass/FAPbI\(_3\)/spiro-MeOTAD configuration are performed to study hole-injection behavior. Figure 5 shows PL intensity for the FAI concentrations of 34.9, 40.7, and 58.2 mm. Contrary to the PL results for the FTO/bl-TiO\(_3\)/FAPbI\(_3\) case without spiro-MeOTAD HTM, PL is reduced as the FAI concentration increases. Compared to the PL intensity at 34.9 mm, those for 40.7 and 58.2 mm are significantly reduced, but a small difference in PL is observed between 40.7 and 58.2 mm. Reduction in PL intensity is a consequence of injection of holes from perovskite to spiro-MeOTAD. Thus, the observation in Figure 5a indicates that holes are effectively injected into HTM for the FAPbI\(_3\) perovskite prepared at relatively
layers, it is noted that the extent of PL reduction was calculated with respect to the 34.9 mM sample. High concentration, which is probably due to the rather smoother surface compared to the rougher surfaces formed at lower concentrations. It is noted that the extent of PL reduction is closely related to change in Voc (Figure 5b), which implies that the FAPbI3/spiro-MeOTAD interface plays an important role in controlling Voc.

It is also noted that fill factor improves upon decreasing the FAI concentration, as presented in Table 1, except for the 34.9 mM data point. Series and shunt resistances are evaluated from I–V curves, in which series resistance decreases by about 30% and shunt resistance increases by about 4 times as the FAI concentration decreases from 58.2 to 40.7 mM (Figure 6); this is likely associated with the improvement of FF. It was reported that a decrease in series resistance and an increase in shunt resistance were observed when the pore sizes within the TiO2 film increased, which might relate to the increased grain size of FAPbI3 in the larger pores. Since the grain size of FAPbI3 is previously confirmed to increase with decreasing concentration from SEM and XRD studies, the change in the resistance components is closely related to morphological changes in FAPbI3. Large-sized FAPbI3 will reduce the number of grain boundaries, possibly leading to a decrease in series resistance. Furthermore, electron shunting at the bl-TiO2/FAPbI3 interface is perhaps involved in changes in shunt resistance. Figure S5 (Supporting Information) shows cross-sectional SEM images of complete perovskite solar cells. On closely observing the interfaces between compact bl-TiO2 and FAPbI3 layers, it is noted that perovskite with some cavities at the interface is developed at higher concentrations compared to cavity-free interfacial perovskite for lower concentrations of 40.7 mM. The imperfect connectivity of a FAPbI3 layer with a blocking layer can provide a pathway for shunting, resulting in a decrease in shunt resistance. Changes in PL intensity, as previously observed in Figure 4, are also related to such an interfacial structure. Since the compact blocking TiO2 layer is likely to affect shunt resistance, PL and inverse of shunt resistance are plotted as a function of FAI concentration because high shunt resistance correlates to low PL. As can be seen in Figure S6 (Supporting Information), there is strong correlation between PL and shunt resistance, which indicates that the bl-TiO2 with low PL contributes to high shunt resistance.

Conclusions

The role of interfaces was investigated using a planar-junction perovskite solar cell based on FAPbI3. Surface morphology of FAPbI3 could be modified by varying FAI concentration in a two-step deposition procedure. Morphology of the formed perovskite was significantly altered by the variation in concentration, which simultaneously led to changes in bl-TiO2/perovskite and perovskite/HTM interfacial morphologies. Such interfacial changes affected Jsc and Voc, in which the bl-TiO2/perovskite interface was one of the major determinants of Jsc and the perovskite/HTM plays an important role in governing Voc. This work provides important insight into the role of interfaces in FAPbI3-based perovskite solar cells.

Experimental Section

Synthesis of HC(NH3)2I

Since HC(NH3)2PbI3 is formed by reacting HC(NH3)2I with PbI2, HC(NH3)2I was synthesized by reacting HC(NH3)2I with HI (57 wt% in water, Aldrich) according to the method described elsewhere. HC(NH3)2I was prepared based on a sodium ethoxide approach. The as-synthesized HC(NH3)2I was washed with diethyl ether three times and dried in vacuum for 12 h.
Fabrication of perovskite solar cells

Fluorine-doped tin oxide-coated (FTO) glass (TEC-8, 8 Ω sq⁻¹, Pilkington) was used as a charge collector, and was cleaned by UV-ozone and ultrasonic treatments. Then, 0.15 m titanium diisopropoxide bis(acetylacetonate) (75 wt % in isopropanol, Aldrich) in 1-butanol (99.8%, Aldrich) was spin-coated onto the FTO substrate to prepare a blocking TiO₂ (bl-TiO₂) layer. Spin-coating was repeated twice to form about a 60 nm-thick bl-TiO₂ layer. The 500 °C-annealed bl-TiO₂ layer was post-treated with aqueous 20 mM TiCl₄ (>98%, Aldrich) at 70 °C for 10 min and, was washed with DI water and annealed again at 500 °C for 30 min. HC(NH₄)₂PbI₂ was formed using a two-step method. First, a 1 mM PbI₂ (Aldrich, 99%) solution in N,N-dimethylformamide (DMF) (99.8%, Sigma–Aldrich) was prepared at 70 °C. As the first step, 30 μL of the PbI₂ solution was spin-coated on the bl-TiO₂ layer at 500 rpm for 5 s and 6000 rpm for 20 s. As the second step, the PbI₂ film dried at 40 °C for 3 min and 100 °C for 10 min was immersed in a HCN(H₄)₂J solution in 2-propanol (99.5%, Sigma–Aldrich), where HC(NH₄)₂J concentration was varied from 34.9 mM to 58.2 mM. Except for 34.9 mM, dipping time was 1 min. A 2 min-immersion was carried out for the 34.9 mM solution. After dipping, the substrate was spun at 500 rpm for 5 s, 1500 rpm for 10 s, and 3000 rpm for 20 s, and was then dried at 40 °C for 3 min and 150 °C for 15 min. To remove the unreacted excess HC(NH₄)₂J, the film was washed with 2-propanol and then dried at 150 °C for 5 min. A spin-MeOTAD solution was prepared by dissolving 72.3 mg of spiro-MeOTAD in 1 mL of chlorobenzene with addition of 28.8 mM of chlorobenzene with addition of 28.8 mM of 4-(4′-tert-butyl pyridine and 17.5 mM of a lithium bis(trifluoromethanesulfonyl)imide solution ([520 mg LiTFSI in 1 mL acetonitrile (99.8%, Sigma–Aldrich)]. The solution was deposited on the HCN(H₄)₂PbI₂ layer at 4000 rpm for 20 s. Finally, an Au electrode was formed by thermal evaporation.

Characterization of materials

Surface and cross-sectional morphologies of the FAPbI₃ layer were investigated using scanning electron microscopy (SEM, JSM-7600F, JEOL). X-ray diffraction patterns were collected via a Bruker AXS (DB advance, Bruker Corporation) using CuKα radiation at scan rate of 4° min⁻¹. For transmittance and reflectance measurements, a FAPbI₃ film on a compact bl-TiO₂-coated FTO glass was used. Both transmittance and reflectance were measured by using a UV/Vis spectrometer (lamba35, PerkinElmer) with an integrating sphere, and a bl-TiO₂-coated FTO glass was used as a blank for transmittance measurements. Light was incident to the perovskite side for absorbance measurements, while light was incident to the FTO glass side for transmittance measurements. Steady-state photoluminescence (PL) spectra were collected using a Cary eclipse spectrofluorophotometer (Agilent Technologies) with a xenon flash lamp and a photomultiplier tube (PMT) detector. All samples were photoexcited at 530 nm. The thickness and surface profile of FAPbI₃ films were measured by using an alpha-step IQ surface profile (KLA Tencor).

Characterization of Photovoltaic Properties

Current-voltage was measured with a Keithley 2400 source meter under one sun illumination (AM 1.5 G, 100 mWcm⁻²) which was simulated by a solar simulator (Oriel Sol 3 A class AAA) equipped with a 450 W Xenon lamp (Newport 6279NS). Light intensity was adjusted by a NREL-calibrated Si solar cell equipped with a KG-2 filter. During measurement, the device was covered with a metal aperture mask with an area of 0.123 cm².

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Supporting Information

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Figure S1. The surface profiler of the FAPbI$_3$ films measured by alpha-step IQ surface profilometer, depending on the FAI concentration of (a) 40.7 mM, (b) 46.5 mM, (c) 52.4 mM and (d) 58.2 mM.
Figure S2. Plane-view of SEM image of FAPbI₃ formed from 34.9 mM FAI solution.

Figure S3. X-ray diffraction patterns of FAPbI₃ formed by dipping the PbI₂ film in 40.7 mM FAI solution for 60 s, 90 s and 120 s.
Figure S4. SEM images of the PbI$_2$ film dipped in 2-propanol for (a) 1 min, (b) 2 min and (c) 4 min.

Figure S5. Cross-sectional SEM images of the full cells with FAPbI$_3$ prepared from different FAI concentration of (a) 40.7 mM (b) 46.5 mM (c) 52.4 mM and (d) 58.2 mM. Scale bars indicate 100 nm.
Figure S6. Plot of the normalized PL and the inverse of shunt resistance ($1/R_{sh}$) as a function of FAI concentration.