Direct Observation of Cation-Exchange in Liquid-to-Solid Phase Transformation in FA$_{1-x}$MA$_x$PbI$_3$ Based Perovskite Solar Cells

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Figure S1. Detailed view of main XRD peak of MOCPs prepared with NSPS FA$_{0.85}$MA$_{0.3}$PbI$_3$ without thermal annealing (stand still for 5 min after spin-coating) and annealed at 130 °C for 2 or 10 min respectively.
Figure S2. Steady state photoluminescence spectrum of pure \( \text{FA}_{0.85}\text{MA}_{0.15}\text{PbI}_3 \).
Figure S3. a) XRD patterns of perovskite films prepared with precursor solution FAPbI$_3$ and FAPbI$_3$·0.3MAI annealed at 130 °C for 10 min, b) UV-Vis results of films corresponding to Figure S3a.
Table S1  Device performance of PVSCs fabricated with NSPS FA_{0.85}MA_{0.3}PbI\textsubscript{3} adopting different annealing time.

<table>
<thead>
<tr>
<th>Annealing time (min)</th>
<th>$V_{oc}$ [V]</th>
<th>$J_{sc}$ [mA/cm$^2$]</th>
<th>$FF$ [%]</th>
<th>$PCE$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.95</td>
<td>12.9</td>
<td>55</td>
<td>6.7</td>
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<tr>
<td>5</td>
<td>0.96</td>
<td>16.4</td>
<td>65</td>
<td>10.2</td>
</tr>
<tr>
<td>8</td>
<td>0.96</td>
<td>21.6</td>
<td>72</td>
<td>14.9</td>
</tr>
<tr>
<td>10</td>
<td>0.96</td>
<td>21.1</td>
<td>73</td>
<td>14.8</td>
</tr>
</tbody>
</table>
Figure S4. a) XRD patterns of MOCPs prepared with NSPS FA$_{0.85}$MA$_{0.3}$PbI$_3$ annealed at 130 ℃ for 3, 5, 8 and 10 min, respectively. b) SEM results of MOCPs corresponding to Figure S4a.
Figure S5. Top view SEM images of MOCPs prepared with precursor solution of $\text{FA}_{0.85}\text{MA}_{0.15}\text{PbI}_3$, $\text{FA}_{0.85}\text{MA}_{0.17}\text{PbI}_3$, $\text{FA}_{0.85}\text{MA}_{0.2}\text{PbI}_3$, $\text{FA}_{0.85}\text{MA}_{0.3}\text{PbI}_3$, respectively, the scale bar is 1 µm.
Figure S6. AFM images of MOCPs derived from FA$_{0.85}$MA$_x$PbI$_3$ precursor solutions, $x$ ranges from 0.15 to 0.3, the roughness (root mean square (RMS)) is decreased from 39.9 nm (MOCP prepared with SPS FA$_{0.85}$MA$_{0.15}$PbI$_3$) to 31.7 nm (MOCP prepared with NSPS FA$_{0.85}$MA$_{0.3}$PbI$_3$).