Supporting information:

**H$_2$MoO$_{3-y}$ Nanobelts: An Excellent Alternative to Carbon Electrode for High Performance Mesoscopic Perovskite Solar Cells**

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Figure S1 XPS survey spectra of the $\alpha$-MoO$_3$ and H$_x$MoO$_{3-y}$ films.

Figure S2 (a) J-V curves of the $\alpha$-MoO$_3$ and H$_x$MoO$_{3-y}$ films with identical thickness. (b) Histogram of specific conductivities based on the $\alpha$-MoO$_3$ and H$_x$MoO$_{3-y}$ films, respectively.
Figure S3 (a) UPS spectra in different energy regions illustrating the derivation of the work function and the top of occupied states. Inset shows the semi-log representation of the valence band region close to the Fermi level. (b) The corresponding Tauc plot of the absorbance spectrum.

Figure S4 The steady-state PL spectra of the perovskite filled in the H$_x$MoO$_{3-y}$ and high-temperature carbon films.
Table S1. PL decay curves of the Glass/MAPbI$_3$, Glass/Carbon (MAPbI$_3$), and Glass/ H$_x$MoO$_{3-y}$ (MAPbI$_3$) samples fitted by a bi-exponential function I(t) = A$_1$exp(-t/τ$_1$) + A$_2$exp(-t/τ$_2$), and τ$_{avg}$ = (A$_1$/A$_1$ + A$_2$) + τ$_2$ × (A$_2$/A$_1$ + A$_2$).

<table>
<thead>
<tr>
<th>Substrates</th>
<th>A$_1$/A$_1$ + A$_2$</th>
<th>τ$_1$ (ns)</th>
<th>A$_2$/A$_1$ + A$_2$</th>
<th>τ$_2$ (ns)</th>
<th>τ$_{avg}$ (ns)</th>
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<tbody>
<tr>
<td>MAPbI$_3$</td>
<td>0.48</td>
<td>5.43</td>
<td>0.53</td>
<td>100.04</td>
<td>55.63</td>
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<tr>
<td>Carbon (MAPbI$_3$)</td>
<td>0.84</td>
<td>9.58</td>
<td>0.16</td>
<td>12.40</td>
<td>10.03</td>
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<tr>
<td>H$<em>x$MoO$</em>{3-y}$ (MAPbI$_3$)</td>
<td>0.71</td>
<td>4.36</td>
<td>0.29</td>
<td>5.02</td>
<td>4.55</td>
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Figure S5 (a) Top view SEM images of H$_x$MoO$_{3-y}$ film prepared by drop-casting. (b) Histogram of the width of H$_x$MoO$_{3-y}$ nanobelts. (c) Histogram of the length of H$_x$MoO$_{3-y}$ nanobelts.
**Figure S6** The optical photographs of highly dispersed H$_x$MoO$_{3-y}$ solution using deionized water (H$_2$O), ethanol (EtOH) and isopropanol (IPA) solvents, respectively.

**Figure S7** The contact angle of the H$_x$MoO$_{3-y}$ film against DMF solvent.
Figure S8 Thickness dependence of device performance based on the HₓMoO₃₋ᵧ electrode.

Table S2 Performance summary of the champion devices with different thicknesses of the HₓMoO₃₋ᵧ electrode based on the structure of FTO/c-TiO₂/m-TiO₂/MAPbI₃/m-Al₂O₃/HₓMoO₃₋ᵧ.

<table>
<thead>
<tr>
<th>Thickness (µm)</th>
<th>V_{OC} (V)</th>
<th>J_{SC} (mA/cm²)</th>
<th>FF</th>
<th>PCE (%)</th>
<th>R_{sh} (Ω/cm²)</th>
<th>R_s (Ω/cm²)</th>
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<tr>
<td>1.5</td>
<td>0.84</td>
<td>20.81</td>
<td>0.58</td>
<td>10.1</td>
<td>0.6k</td>
<td>7.5</td>
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<td>2.7</td>
<td>0.89</td>
<td>21.04</td>
<td>0.61</td>
<td>11.4</td>
<td>2.0k</td>
<td>6.1</td>
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<tr>
<td>4.0</td>
<td>0.96</td>
<td>22.54</td>
<td>0.67</td>
<td>14.5</td>
<td>3.5k</td>
<td>5.3</td>
</tr>
<tr>
<td>5.5</td>
<td>0.95</td>
<td>21.90</td>
<td>0.64</td>
<td>13.3</td>
<td>2.8k</td>
<td>5.8</td>
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</tbody>
</table>
**Figure S9** The light-intensity dependence of $J_{SC}$ for the champion devices based on the high temperature carbon and $H_xMoO_{3-y}$ electrodes, respectively.

**Figure S10** The steady-state power output at the maximum power point for both the champion devices.
Figure S11 (a)-(d) Time-dependent normalized photovoltaic parameters of unsealed devices based on the respective H$_{x}$MoO$_{3-y}$ and high temperature carbon electrodes under ambient air at 65-85% relative humidity in the dark.
Figure S12 XRD patterns of the perovskite filled in the structure of FTO/m-Al$_2$O$_3$/H$_3$MoO$_{3-y}$ before and after degradation, which were measured after continuously exposing the samples in ambient air at different relative humidity.