Efficient 1 cm² mesoscopic perovskite solar cell on ITO substrate

Meng Zhang, Benjamin Wilkinson, Yuanxun Liao, Jianghui Zheng, Cho Fai Jonathan Lau, Jincheol Kim, Jueming Bing, Martin A. Green, Shujuan Huang, Anita Wing-Yi Ho-Baillie

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Australian Centre for Advanced Photovoltaics
School of Photovoltaic and Renewable Energy Engineering
University of New South Wales
Perovskite solar cells (PSCs)
Perovskite

Hybrid metal halide perovskite $\text{ABX}_3$

- Large absorption coefficient
- Low exciton binding energy
- High charge mobility
- Tolerance to defects
- Low-cost fabrication

Challenges:

Long-term stability

Large area device
First 1 cm\(^2\) PSC with certified efficiency

Certified PV parameters
Area: 1.017 cm\(^2\)
\(J_{SC}=20.61\) mA/cm\(^2\)
\(V_{OC}=1090\) mV
FF=66.8%
Efficiency=15.0%

Certified 1 cm² PSC

Certified PV parameters
Area: 1.022 cm²
$J_{SC}=21.48$ mA/cm²
$V_{OC}=1081$ mV
FF=78.4%
Efficiency=18.2%

Certified 1 cm$^2$ PSC

Certified PV parameters
Area: 1.025 cm$^2$
$J_{SC}$=22.60 mA/cm$^2$
$V_{OC}$=1122 mV
FF=75.7%
Efficiency=19.2%

Certified 1 cm$^2$ PSC

n-i-p structure (meso)

Certified PV parameters
Area: 1.000 cm$^2$
$J_{SC}=22.59$ mA/cm$^2$
$V_{OC}=1143$ mV
FF=75.7%
Efficiency=19.6%

Certified 1 cm² PSC

Certified PV parameters
Area: 0.992 cm²
$J_{sc} = 24.67$ mA/cm²
$V_{oc} = 1104$ mV
FF = 72.3%
Efficiency = 19.7%

Certified 1 cm$^2$ PSC

n-i-p structure (meso)

Certified PV parameters
Area: 0.991 cm$^2$
$J_{SC}$=24.92 mA/cm$^2$
$V_{OC}$=1125 mV
FF=74.5%
Efficiency=20.9%

Summary of literatures

Efficient device structure for 1 cm$^2$ PSC:
- n-i-p meso > p-i-n planar

Strategies to get high efficiency 1 cm$^2$ PSC:
- Charge extraction layer
- Interfacial engineering
- Film deposition method
Spray anti-solvent

Spray anti-solvent

Gas-quenching

Compressed gas

Gas-quenching (Gas-assisted spin-coating)

In-house measured
PCE=19.4% FAMA-Cs
PCE=19.6% FAMA-Rb
PCE=20.0% FAMA-Rb (w/ AR layer)


Advantage:
Reduce toxic chemical usage
Fresh atmosphere for fabrication
Good reproducibility

0.65 cm² device
## New strategy to improve large area device

### Charge extraction layer
- Interfacial engineering
- Film deposition method

### Substrate optimization

<table>
<thead>
<tr>
<th>Substrate &amp; structure</th>
<th>Certification Time</th>
<th>Publication Time</th>
<th>$J_{sc}$ [mA/cm$^2$]</th>
<th>$V_{oc}$ [V]</th>
<th>FF</th>
<th>PCE [%]</th>
<th>Area (cm$^2$)</th>
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<td>0.75</td>
<td>20.9</td>
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</table>
FTO vs ITO

Transparency

Stability upon heat treatment

Meso-TiO$_2$ layer requires high temperatures annealing

ITO-based mesoscopic device suffered from high series resistance ($R_s$) and low FF
New electrode for 1 cm$^2$ device
ITO-based meso-PSC

Geometry optimization

Mask area: 0.159 cm²
Jsc = 22.7 mA/cm²
Voc = 1088 mV
FF = 81.5%
PCE = 20.1%

Mask area: 0.159 cm²
Jsc = 22.7 mA/cm²
Voc = 1090 mV
FF = 80.4%
PCE = 19.9%

Negative contact

$R_s$ (Ωcm²)

Square

Rectangular

Strip

FF = 72%

J-V simulation

FF = 77%
Geometry optimization

![Image of solar cells with different geometries](image)

<table>
<thead>
<tr>
<th></th>
<th>$J_{SC}$ (mA/cm$^2$)</th>
<th>$V_{OC}$ (mV)</th>
<th>FF (%)</th>
<th>Sim. FF (%)</th>
<th>$R_s$ (Ωcm$^2$)</th>
<th>PCE (%)</th>
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Devices using strip design on FTO and ITO

Improving $J_{sc}$ without compromising FF

Substrate limitation for mesoscopic PSCs can be overcame by proper design of electrode
Effectiveness of the electrode design

Skinnier electrode design is more effective on less-conductive substrates.
ITO thickness optimization on strip device

**Graphs:**

- **Energy loss** (%), \( R_{\text{Sheet}} \) (\( \Omega /\text{sq} \)) vs. ITO thickness (nm)
- **Efficiency** (%) vs. ITO thickness (nm)

**Table:**

<table>
<thead>
<tr>
<th>Thickness of ITO [nm]</th>
<th>( J_{sc} ) [mA/cm²]</th>
<th>( V_{oc} ) [mV]</th>
<th>( FF ) [%]</th>
<th>PCE [%]</th>
<th>( R_s ) [( \Omega ) cm²]</th>
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<td>22.4</td>
<td>1150</td>
<td>1150</td>
<td>77.5</td>
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Optimized devices

Device sent for certification:
In-house measured PCE = 20.0%

<table>
<thead>
<tr>
<th>Scan direction</th>
<th>$J_{SC}$ (mA/cm$^2$)</th>
<th>$V_{OC}$ (mV)</th>
<th>FF (%)</th>
<th>PCE (%)</th>
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<td>74.2</td>
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</table>

PCE = 19.63%
$J_{SC} = 23.2$ mA/cm$^2$
$V_{OC} = 1142$ mV
FF = 75.8%

strip device
250 nm ITO
w/ AR layer
Conclusions

- Proper electrode design overcomes the substrate limitation of mesoscopic PSCs.
- ITO-based mesoscopic PSCs are more efficient than FTO due to improved photocurrent without compromising FF.
- When ITO thickness is at 250 nm, the conductivity of the substrate is adequate (20 Ω/sq) and optical loss is sufficiently low (20%) for decent FF and $J_{SC}$ to be achieved.
- Certified efficiency of 19.63% on 1.02 cm$^2$ is the highest for ITO-based mesoscopic PSCs. And also the highest for PSCs fabricated by gas-quenching.
Acknowledgement

Thanks for your attention!
Other perovskite composition

Default perovskite composition:

\[
\text{FA}_{0.75}\text{MA}_{0.15}\text{Cs}_{0.05}\text{PbI}_{2.55}\text{Br}_{0.45}
\]

5% Cs 15% Br

5% Cs 5% Br

5% Rb 15% Br

Strip device

<table>
<thead>
<tr>
<th>J\text{sc} (mA/cm^2)</th>
<th>V\text{oc} (mV)</th>
<th>FF</th>
<th>R_S (\Omega cm^2)</th>
<th>PCE (%)</th>
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<table>
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<th>J\text{sc} (mA/cm^2)</th>
<th>V\text{oc} (mV)</th>
<th>FF</th>
<th>R_S (\Omega cm^2)</th>
<th>PCE (%)</th>
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<tbody>
<tr>
<td>22.5</td>
<td>1155</td>
<td>76.4</td>
<td>5.0</td>
<td>19.9</td>
</tr>
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Large area PSCs

Record efficiency of small/large area devices

PSCs need to provide competitive performance on large scale devices