Electronic Supplementary Material (ESI) for Nanoscale.


Supplementary Information

# Photon Upconversion-assisted Dual-band Luminescence Solar Concentrators Coupled with Perovskite Solar Cells for Highly Efficient Semi-transparent Photovoltaic Systems

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**Table S1.** Summary of previous LSC-PV studies.

| No. | LSC materials<br>Dimension [$cm^3$] | Abs. of LSC | Cell type | PCE of LSC-PV | Ref. |
|---|---|---|---|---|---|
| **1** | **Perylene/PdTPBP**<br>**5.0 x 1.0 x 0.1**<br>**/ 10 x 5 x 0.1** | **350 - 450,**<br>**600 - 650** | **Perovskite solar cells** | **7.84% / 9.631%** | **Our results** |
| 2 | CuInSeS/ZnS<br>12 x 12 x 0.3 | 350 - 680 | c-Si | 3.27% | [1] |
| 3 | CdSe/CdS<br>21.5 x 1.3 x 0.5 | 350 - 500 | c-Si | 1% | [2] |
| 4 | PbS/CdS<br>10.2 x 10.2 x 0.16 | 300 - 400 | c-Si | 1% | [3] |
| 5 | Red 305/Perylene-perinone<br>5 x 5 x 0.5 | 400 - 700 | c-Si | 4.2% | [4] |
| 6 | Red 305/CRS040<br>5.0 x 5.0 x 0.5 | 350 - 450 | GaAs | 7.1% | [5] |
| 7 | CdSe/CdS/CdZnS/ZnS<br>4.95 x 3.1 x 0.4 | 350 - 550 | c-Si | 2.8% | [6] |
| 8 | Commercial LSC(Japan)<br>10.3 x 10.3 x 0.3 | 500 - 600 | Dye solar cells | 0.14% | [7] |
| 9 | $CuInS_2$/ZnS<br>2.2 x 2.2 x 0.3 | < 350 | c-Si | 8.71% | [8] |
| 10 | Si<br>12 x 12 x 0.26 | 350 - 600 | c-Si | 2.85% | [9] |

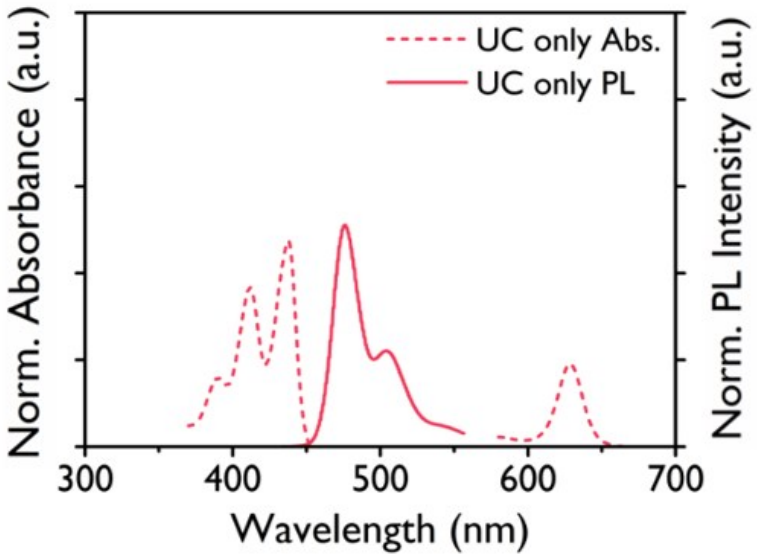



**Figure S1.** The absorbance and PL emission spectra of the UC panels.

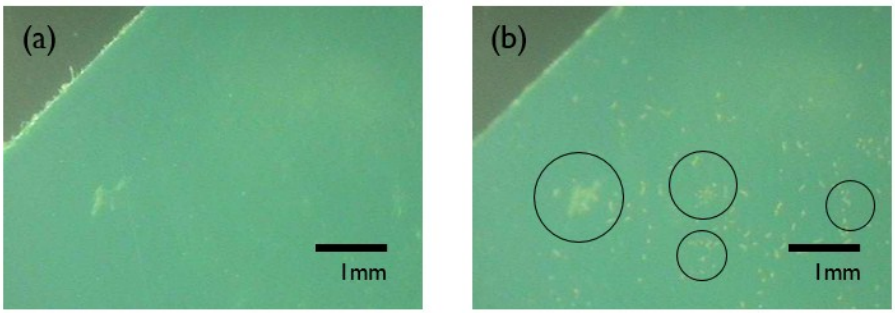



**Figure S2.** Microscopic image for the DS panel containing (a) 2.0 mM perylene and (b) 2.25 mM perylene. The needle-like aggregation of perylene crystalline was observed with higher perylene concentration.

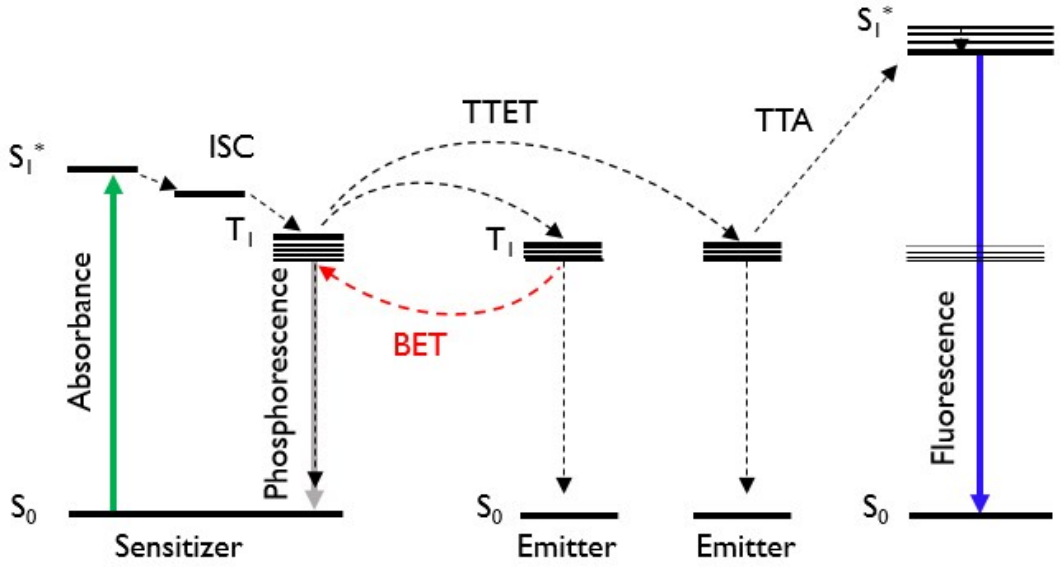



**Figure S3.** The energy diagram shows the backward energy transfer (BET) from emitter to sensitizer triplets which may occur when the involved levels are fully resonant. Efficiency of TTET may be deteriorated by the activation of back energy electron transfer.

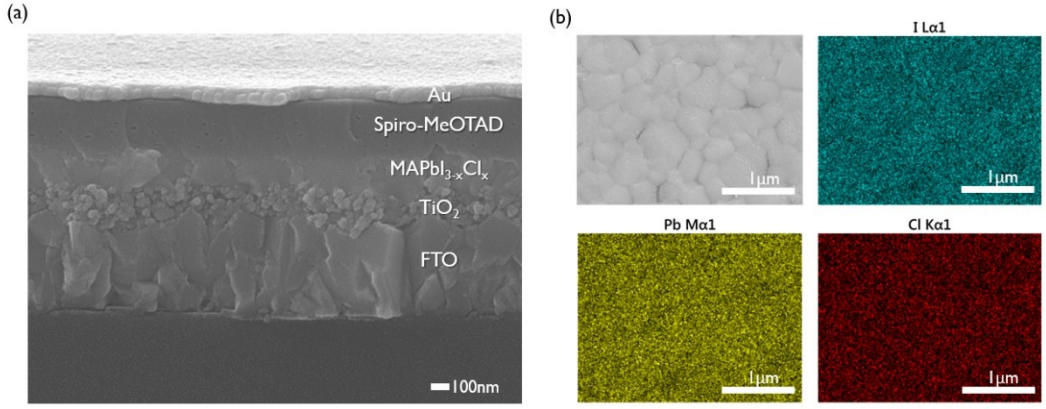



**Figure S4.** (a) Cross-sectional SEM image of $MAPbI_{3-x}Cl_x$ PSC. (b) Elemental analysis of $MAPbI_{3-x}Cl_x$ film.

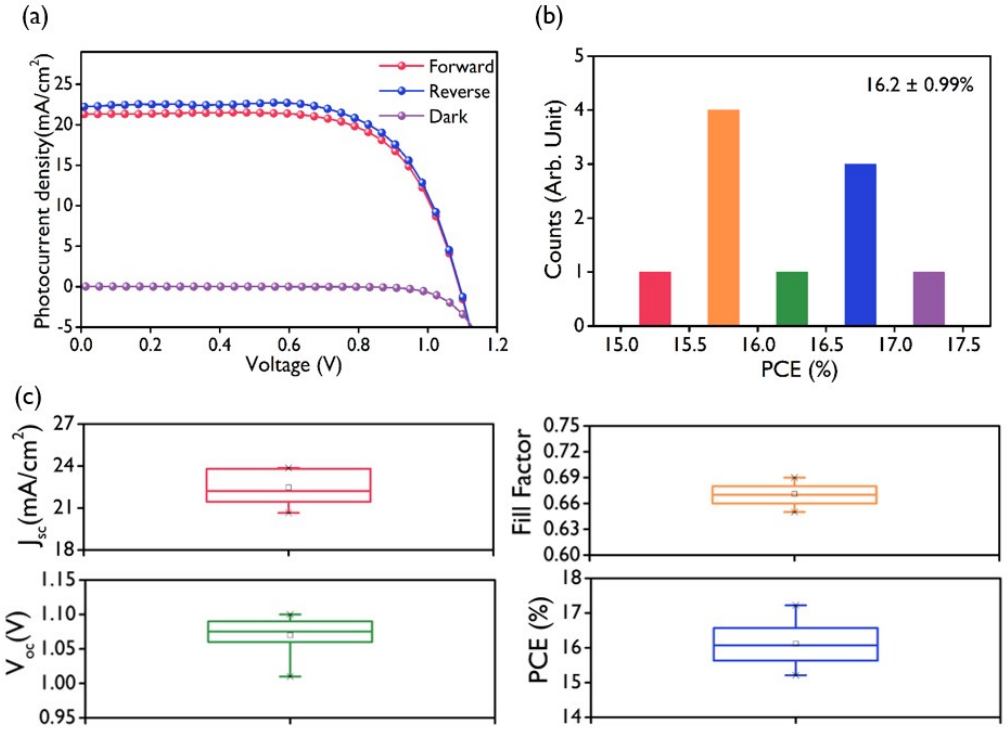



**Figure S5.** The average efficiency (a) *J-V* curves and distribution of (b) PCE (c) Detailed photovoltaic performances of 10 cells.

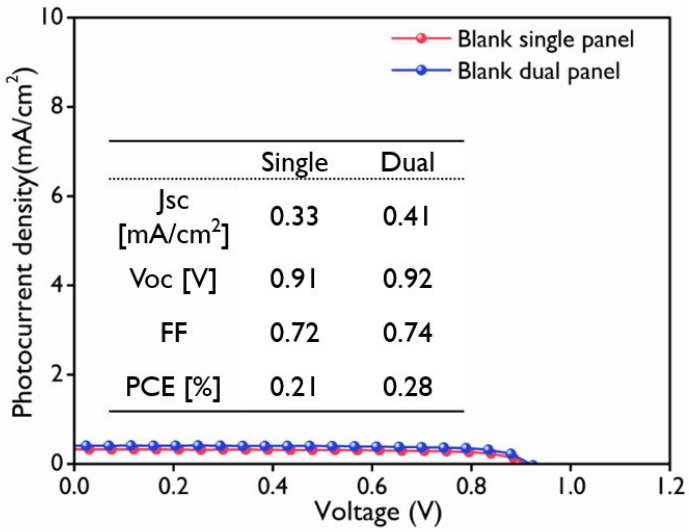
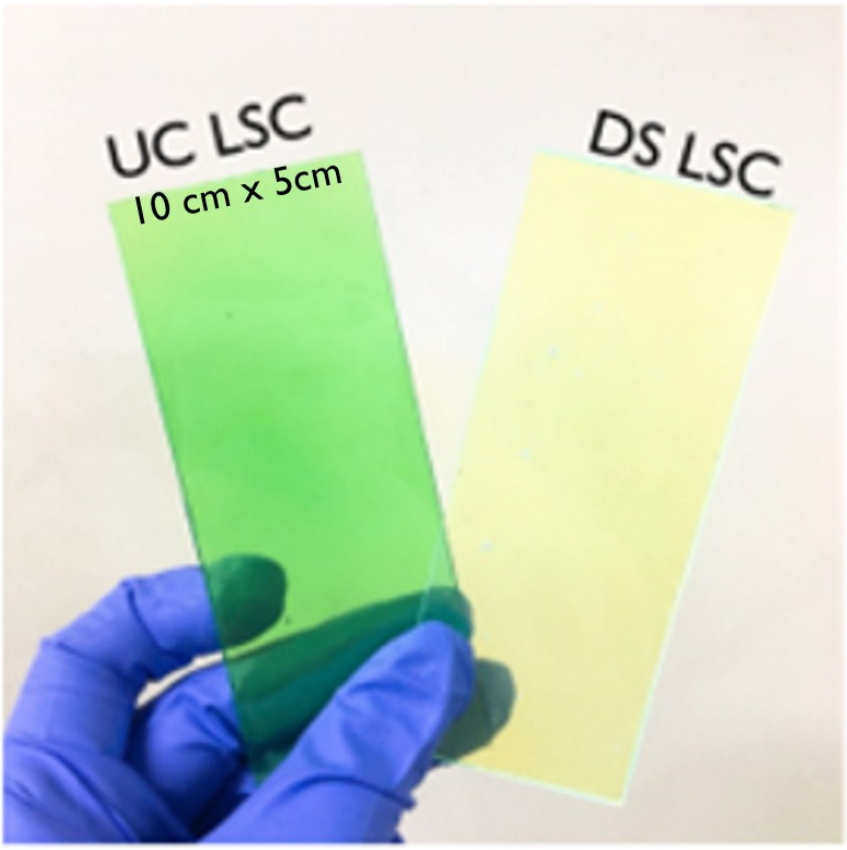



**Figure S6.** *J-V* curves of the PSC attached to the LSCs for Blank single panel and Blank dual panel.



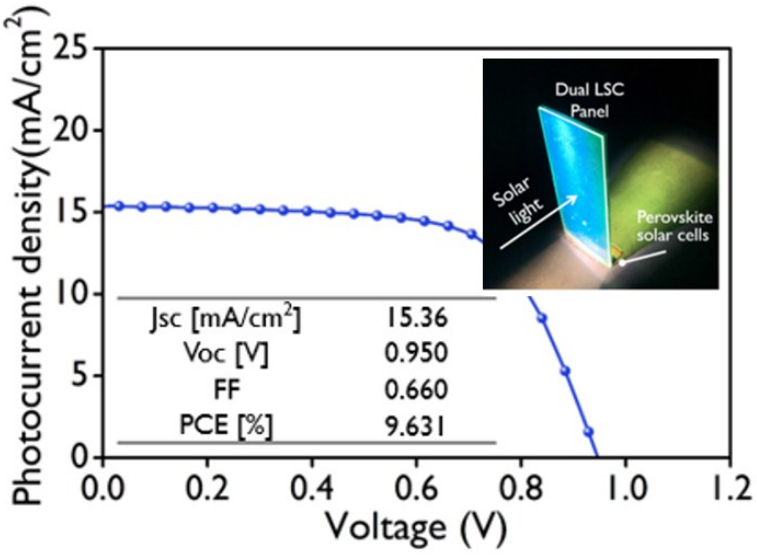




**Figure S7.** (top, left) a digital camera photograph of a large-area (10 cm x 5cm) dual LSC panel, (top, right) a photograph of a large area LSC-PSC, and (bottom) a *J-V* curve of this LSC-PSC.

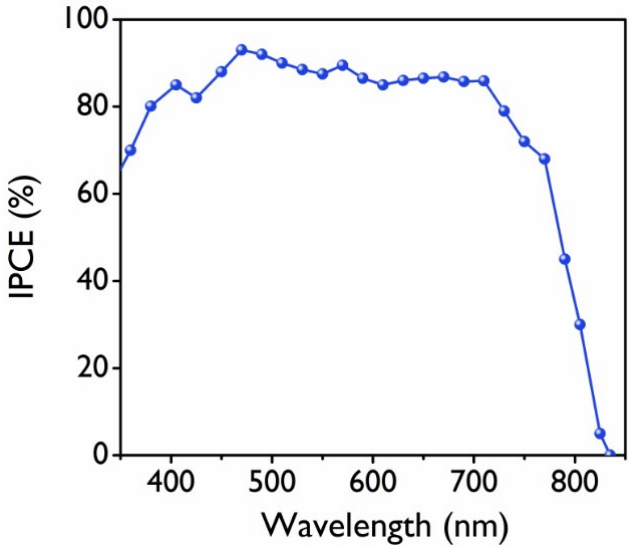



**Figure S8.** IPCE spectra of the $MAPbI_{3-x}Cl_x$ perovskite solar cells.

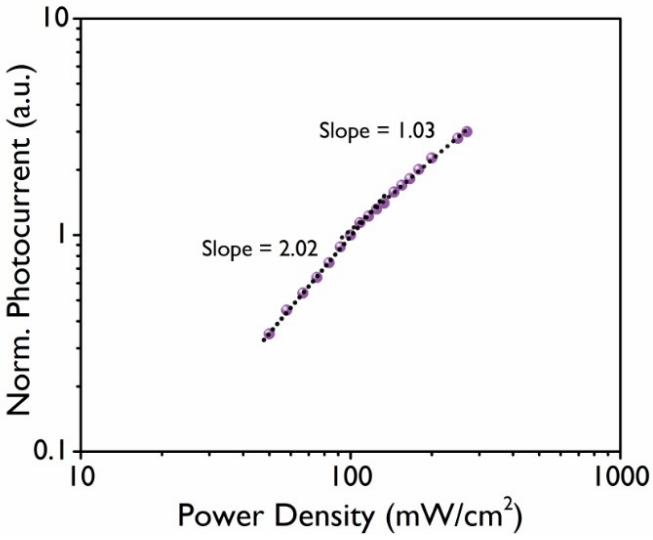



**Figure S9.** Normalized photocurrent for DS/UC LSC panel under the illumination with various power densities.

**Supplementary note #1**

The $PCE_{LSC}$ can be determined from the maximum output power value of the PSCs ($P_{max}$) when coupled with the LSC and the incident power ($P_{in}$) amplified by the factor G of the LSC.[18]

$$PCE_{LSC} = \frac{P_{max}}{P_{in} \times G}$$

| | $J_{SC}$[a] [mA/cm$^2$] | $V_{OC}$ [V] | *FF* [%] | $P_{max}$[a] [mW/cm$^2$] | $PCE_{LSC}$ [%] |
|---|---|---|---|---|---|
| **Blank** | 0.41 | 0.92 | 73.9 | 0.28 | 0.38 |
| **DS** | 10.16 | 1.03 | 64.5 | 6.74 | 1.60 |
| **DS/DS** | 10.15 | 1.04 | 64.5 | 6.71 | 1.59 |
| **DS/UC** | 11.04 | 1.04 | 65.4 | 7.53 | 1.79 |

[a] $J_{sc}$ and $P_{max}$ are determined based on the active area 0.1cm$^2$ of PSCs under 1 sun conditions.

**Supplementary note #2**

The perceived transparency, $T_v$, was calculated. $T_v$ is a standard measure of transparency, considering the transmittance of each wavelength in the incident light spectrum and the eye sensitivity factor for each wavelength. $T_v$ is calculated by the methodology prescribed in ISO 9050:2330:50

$$T_V = \frac{\sum_{380}^{780} T(\lambda) D_\lambda V(\lambda) \Delta\lambda}{\sum_{380}^{780} D_\lambda V(\lambda) \Delta\lambda} \quad (2)$$

where $V(\lambda)$ is the photonic spectral luminous efficiency function that represents the wavelength-dependent sensitivity for the observer in photometry (ISO/CIE 10527), $D_\lambda$ is the AM 1.5 G solar spectral irradiance, and $T(\lambda)$ is the spectral transmittance of the sample. The $T_v$ of the LSC is calculated to be 80.2%.

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