Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Electronic Supplementary Information (ESI) for

ITO-free Carrier Selective Contact for Crystalline Silicon Solar Cell

Deokjae Choi,[a, b] *Hyun Yoon,*[c] *Ka-Hyun Kim,*[c,d,*] *Han-Don Um,*[a,*] *and Kwanyong Seo* [a,*]

[a] Department of Energy Engineering, Ulsan National Institute of Science and Technology (UNIST), Ulsan 44919, Republic of Korea

[b] Max Planck Center for Attosecond Science, Max Planck POSTECH/KOREA Research Initiative, Pohang, Gyeongbuk 37673, Republic of Korea

[c] KIER-UNIST, Advanced Center for Energy, Korea Institute for Energy Research, Ulsan 44919, Republic of Korea

[d] Division of Energy & Optical Technology Convergence, Cheongju University, Cheongju 28503, Republic of Korea

[*] Address correspondence to: kseo@unist.ac.kr, handon@unist.ac.kr, ka-hyun.kim@kier.re.kr

SUPPORTING FIGURES

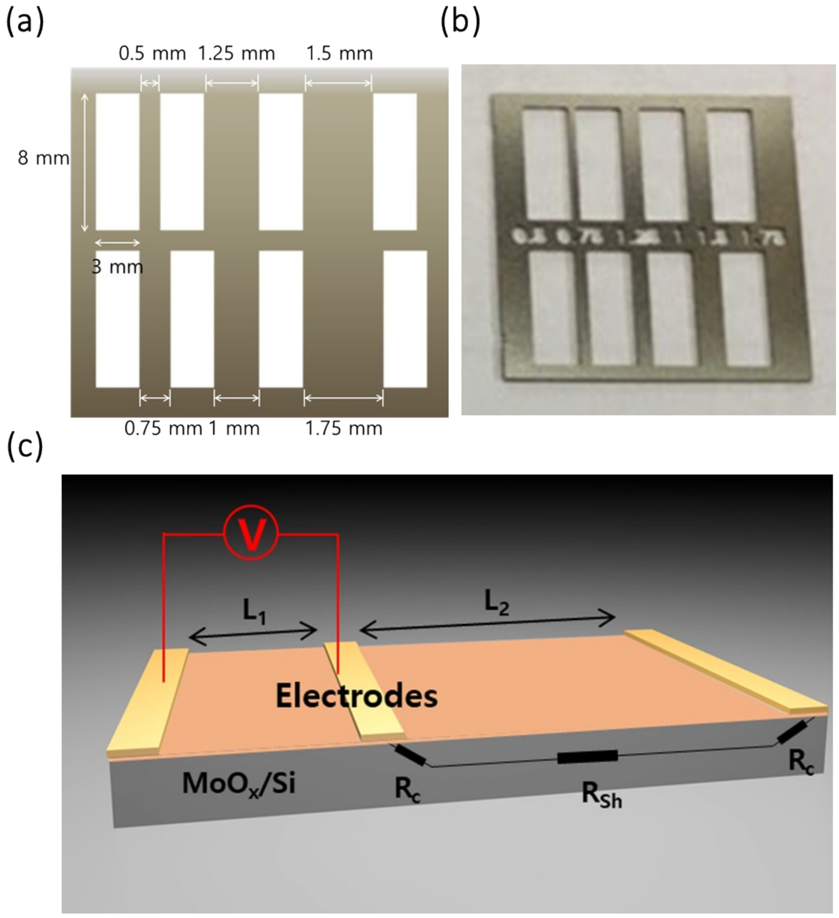


Fig. S1. (a) A design schematic and (b) an optical image of metal shadow mask used for Transfer Length Method in this work. (c) A schematic showing the measurement of Transfer Length Method where L is a distance between electrodes, R_c is contact resistance between metal and semiconductor, and R_{sh} is sheet resistance of semiconductor.

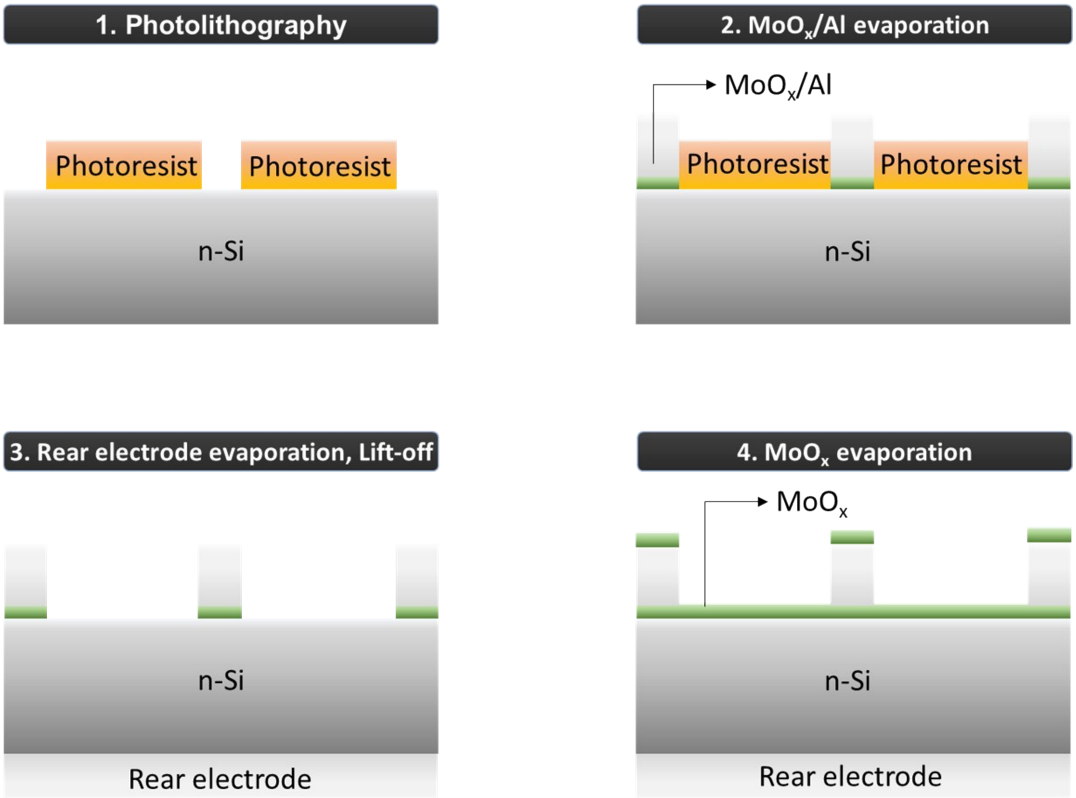
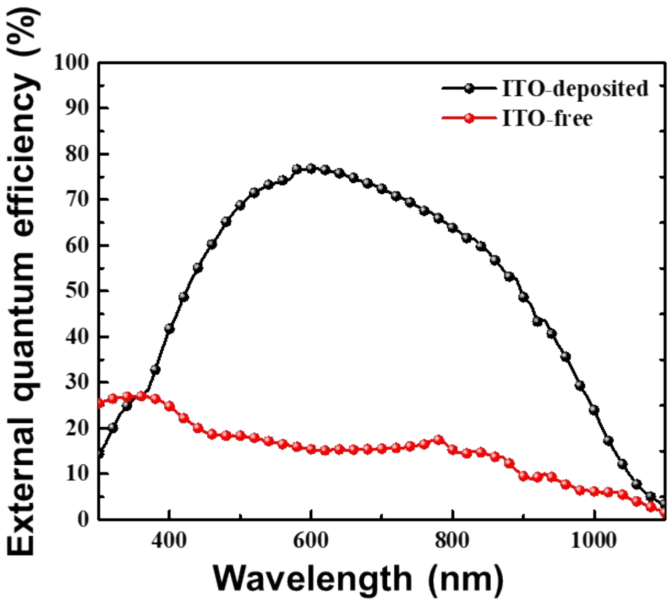


Fig. S2. (a) Schematics of the fabrication processes for ITO-free MoO_x/n-Si solar cells.

(a)



(b)

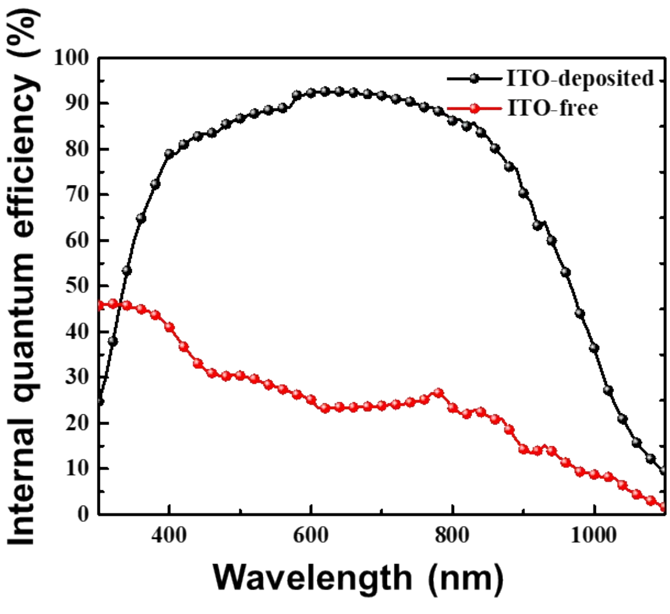


Fig. S3. (a) External and (b) Internal quantum efficiency of MoO_x/n-Si solar cells with (black solid lines) and without ITO (red solid lines) layer using busbar and finger electrode.

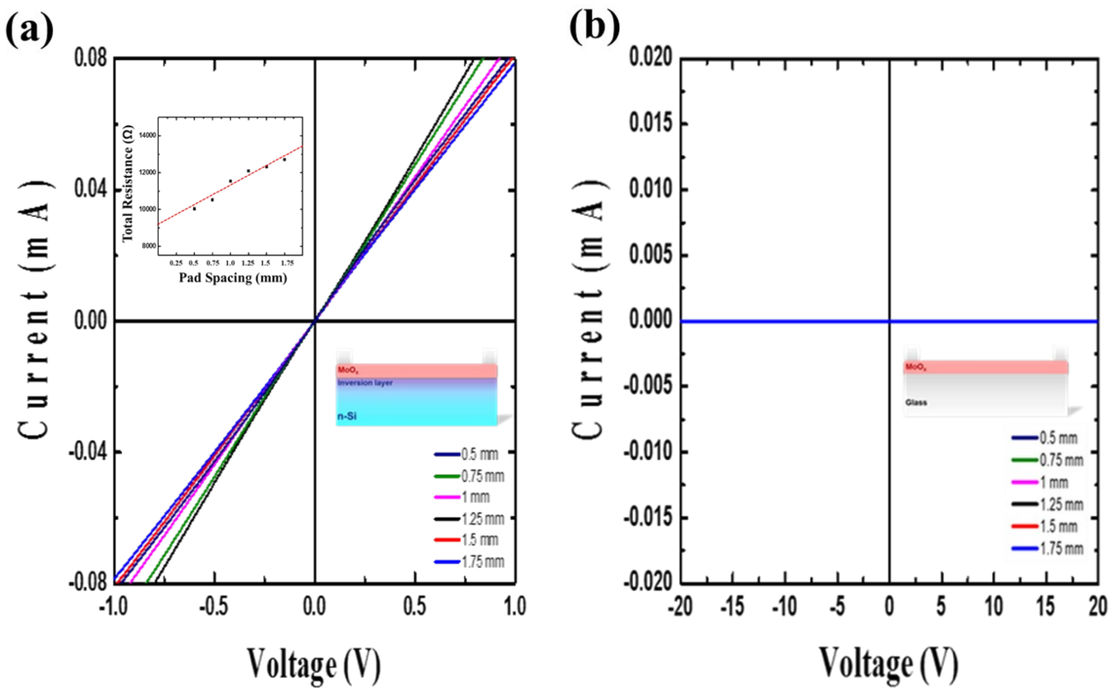


Fig. S4. Current-voltage measurements of 20-nm-thick MoO_x/Al contacts on (a) n-Si and (d) glass substrates. Inset of panel (a) shows resistance depending on the pad spacing.

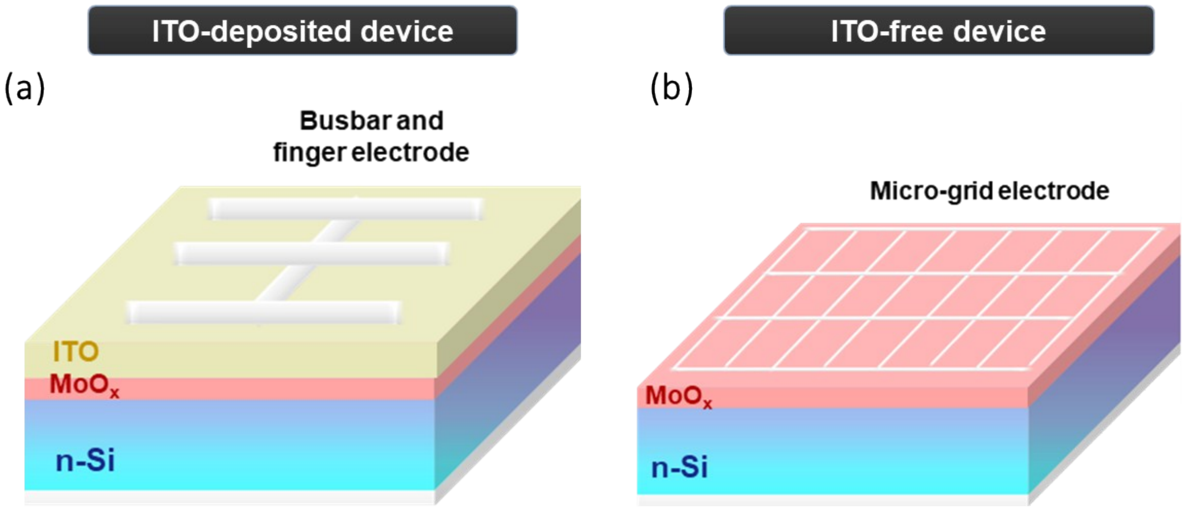


Fig. S5. Schematics of the structures of (a) ITO-deposited and (b) ITO-free MoO_x/n-Si solar cells for the analysis of current density losses.

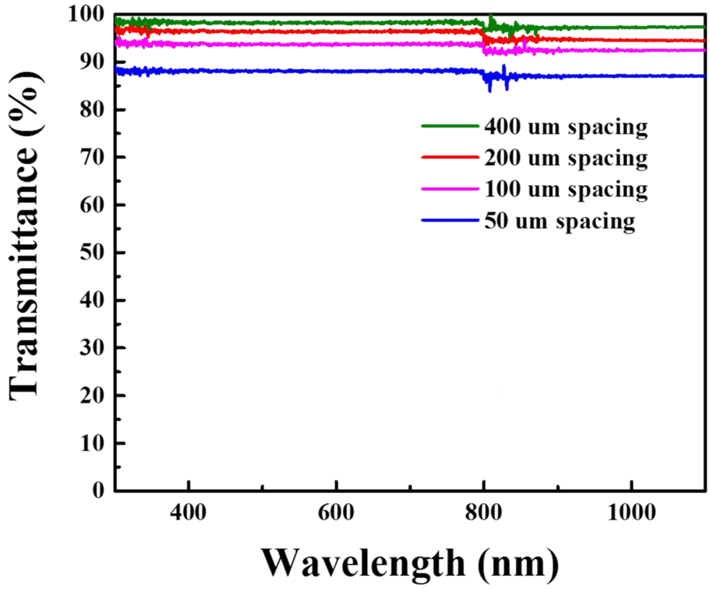
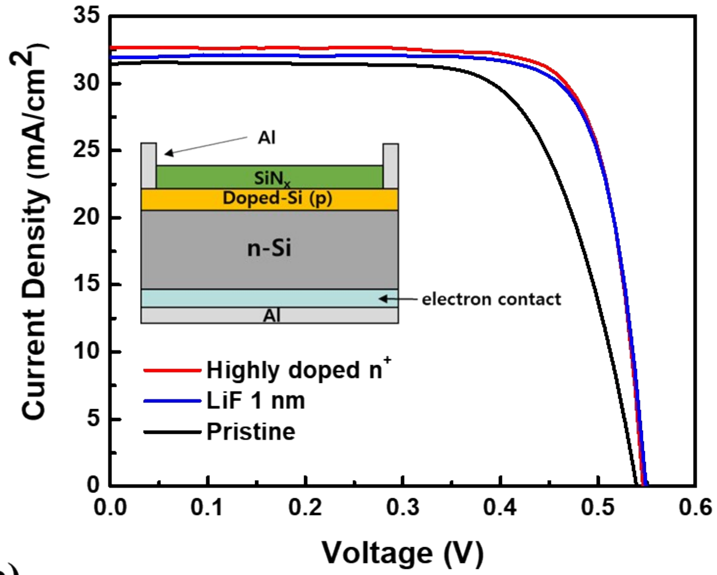


Fig. S6. Transmittance spectra of micro-grid electrodes with spacing of 50, 100, 200 and 400 μm.

(a)



(b)

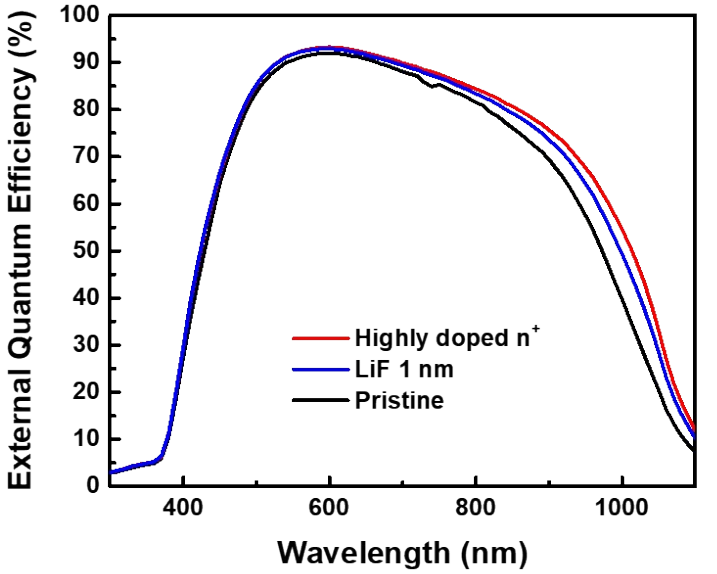


Fig. S7. (a) *J-V* curves and (b) External quantum efficiency of c-Si solar cells according to the different electron contact layer (Pristine, LiF and highly doped n^+). All of devices are fabricated with identical conditions except for rear side of device.

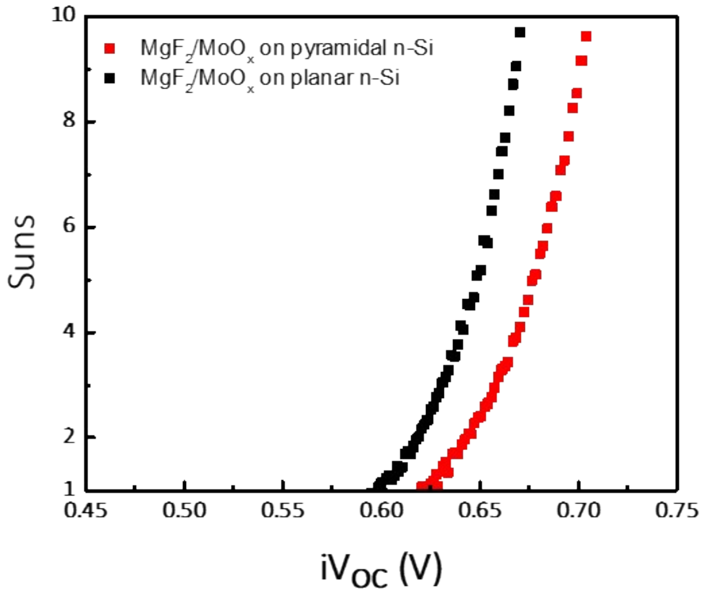


Fig. S8. Implied-open-circuit voltages (iV_{oc}) of MgF_2(100 nm)/MoO_x(20 nm)/n-Si substrates with planar (black-filled square) and pyramidal structures (red-filled square) using Quasi-Steady State photoconductance measurements.

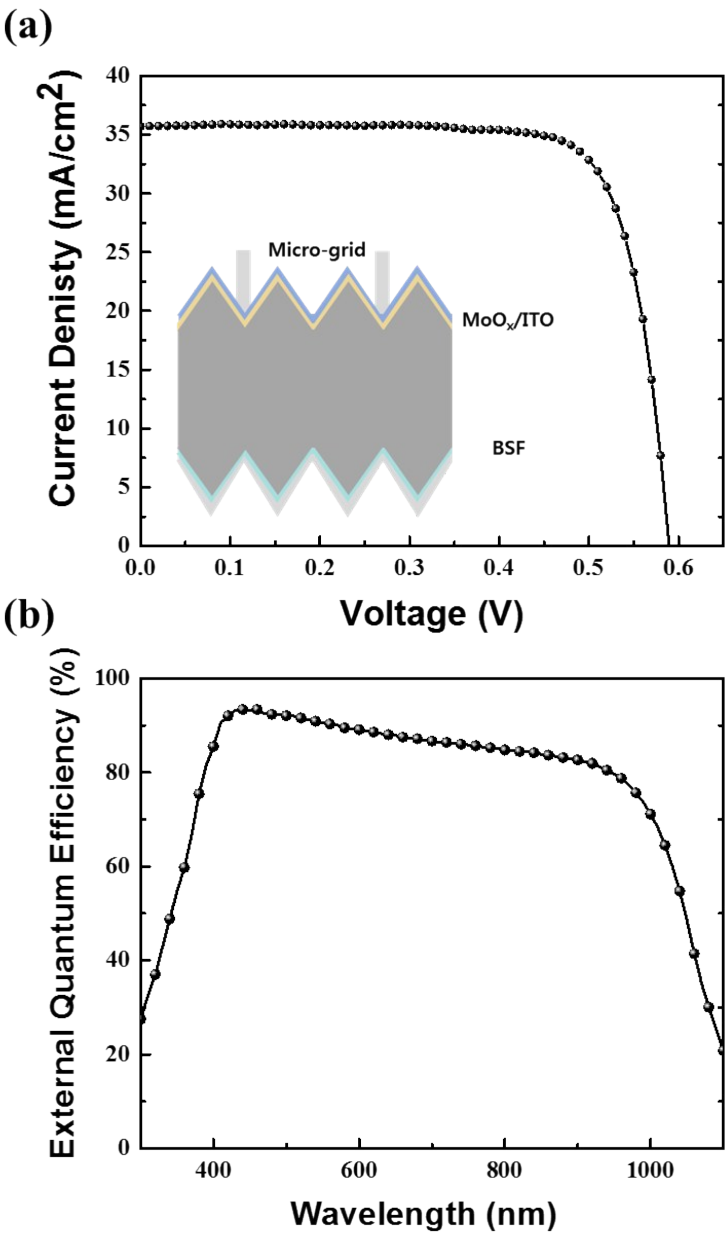
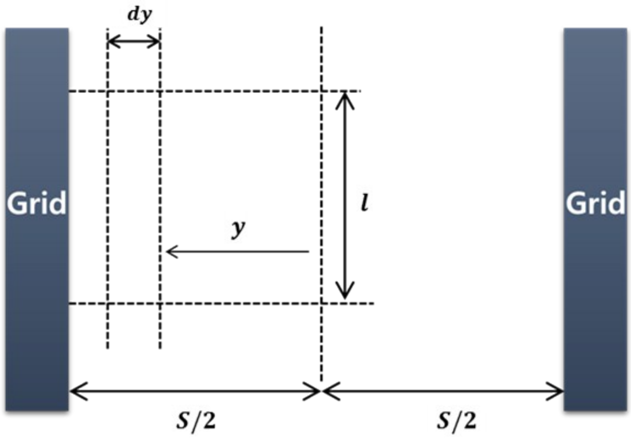


Fig. S9. (a) *J*-*V* curves and (b) External quantum efficiency of ITO-deposited MoO_x/n-Si solar cells using micro-grid electrode with spacing of 200 μm.

Supplementary Note 1. Calculation process of resistive and optical power losses during the transport of photocarrier through inversion layer.[1]

Section 1. Resistive power loss calculation



The resistive power loss caused by the resistance of inversion layer (R_s) can be calculated as a function of electrode spacing. We setup the separated metal grid electrodes with the spacing (S) on the planar substrate with resistance (R). The incremental resistive power loss (dP_{loss}) is given by

$$dP_{loss} = I^2 dR$$

The differentiated R can be represented as

$$dR = \frac{\rho}{lt} dy = \frac{R_s}{l} dy$$

where ρ is the resistivity of inversion layer, t is the thickness of inversion layer, l is the length along the metal grid electrode, y is the distance from the metal grid electrode and R_s is sheet resistance of inversion layer. Under uniform illumination, the current (I) depends on y which is given by

$$I(y) = J\, ly$$

where J is the current density. Thus, the total power loss can be shown as

$$dP_{loss} = \int I(y)^2 dR = \int_0^{S/2} \frac{J^2 l^2 y^2 R_s\, dy}{l} = \frac{J^2 l R_s S^3}{24}$$

The maximum power photovoltaic device generates, P_{gen} is given by

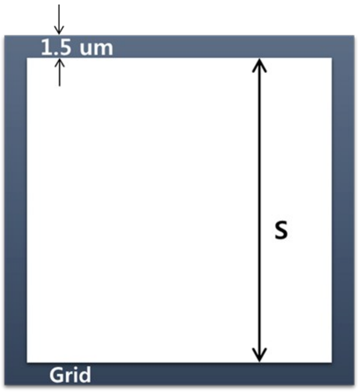
$$P_{gen} = J_{MP} l \frac{S}{2} V_{MP}$$

Thus, the fractional power loss is calculated as follow:

$$Fractional\ P_{loss} = \frac{P_{loss}}{P_{gen}} * 100 = \frac{R_s\, lS^2 J_{MP}}{12 V_{MP}} * 100$$

Here, J_{mp}, V_{mp} and R_s values of ITO-free MoO_x/n-Si solar cell are 30 mA/cm^2, 450 mV and 16,000 Ω/sq respectively.

Section 2. Optical power loss calculation



The optical power loss caused by metal electrode is calculated from its shading loss based on the following assumption; Photons are lost by only the metal reflection under uniform illumination. To calculate the shading loss of metal electrode, we considered the unit square of gird metal electrode with width of 3 μm (1.5 μm + 1.5 μm) with various spacings between two grid elecrodes. Whole area of the device is given by

$$\text{Whole area} = (S + 3)^2$$

The area of metal electrode is given by

$$\text{Metal electrode area} = 4 \times 1.5 \times (S + 1.5)$$

Thus, the total shading loss is given by

$$\text{Total shading loss} = \frac{6(S + 1.5)}{(S + 3)^2} x\ 100$$

Then, we calculated resistive and optical power losses by varying the spacing between electrodes (S) from 0 to 1,000 μm.

Supplementary References

1. Lee, H. S., *Thermal design: heat sinks, thermoelectrics, heat pipes, compact heat exchangers, and solar cells.,* John Wiley & Sons, New Jersey, 2010.