Perovskite Solar Cells:

From Lab-scale to Solar Module

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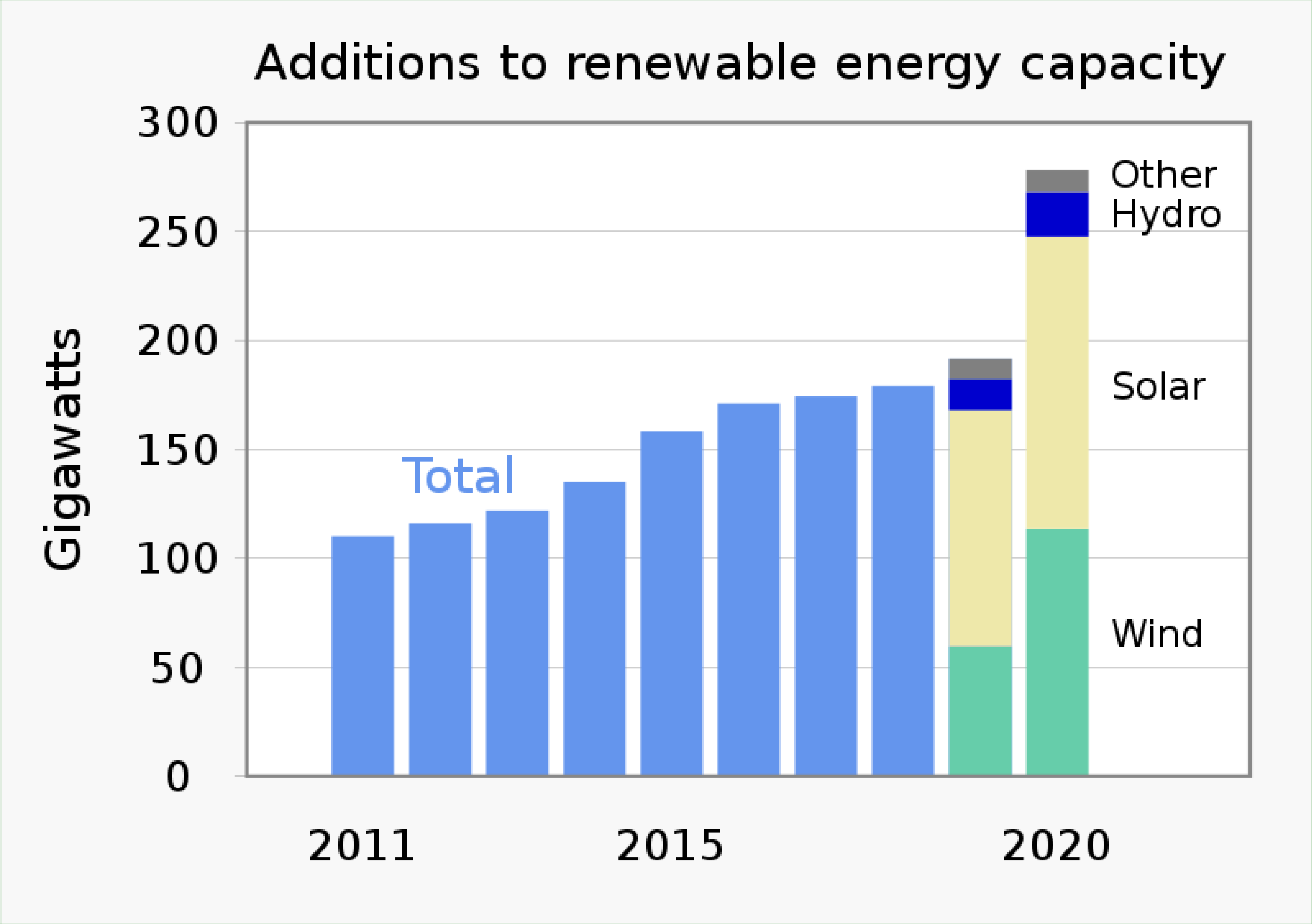
Sharif University of Technology

Renewable Energy Conference, November 2021, Tehran

Renewable Energy Growth



Wikipedia

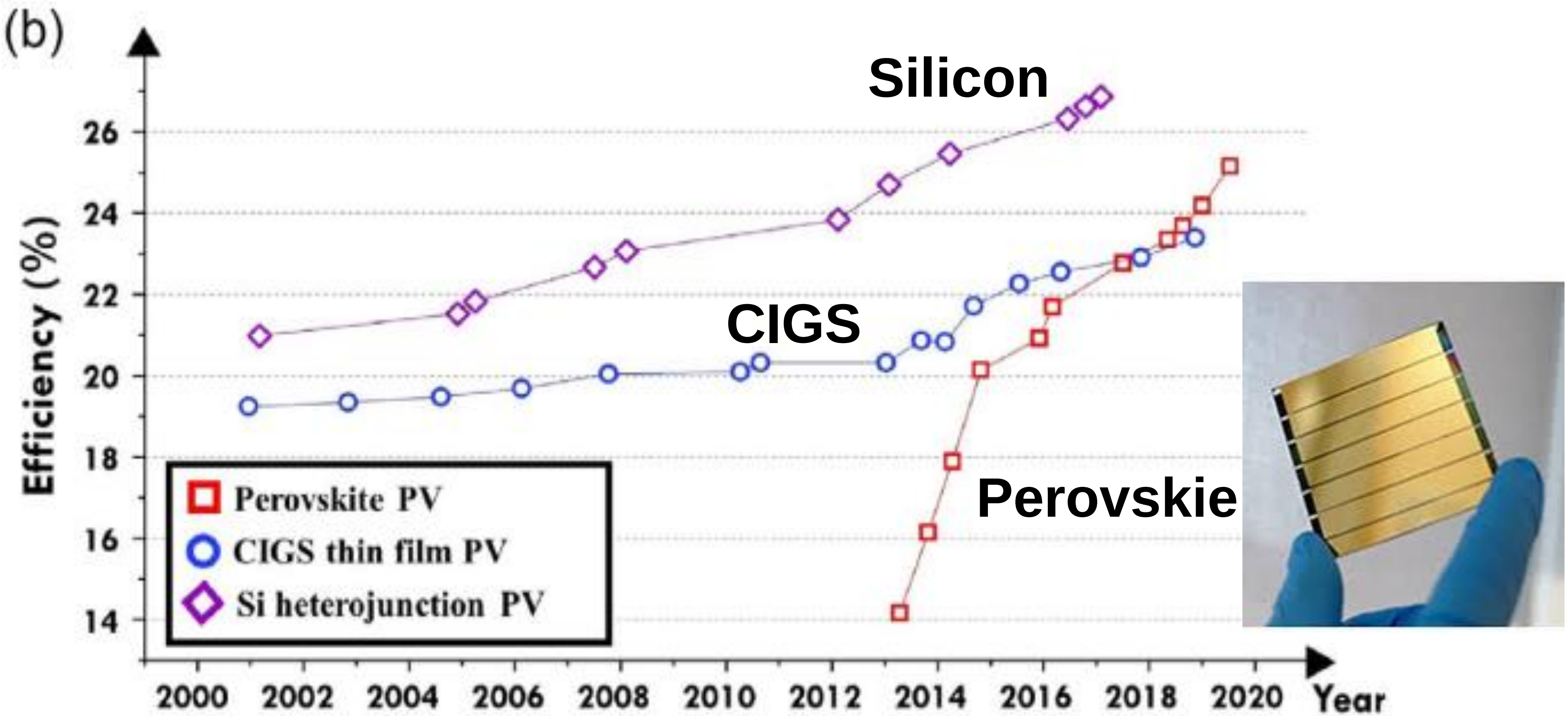
Silicon Solar Cells: Dominant Technology

Silicon Cell

Silicon modules

Silicon has been the dominant PV technology in the last decade

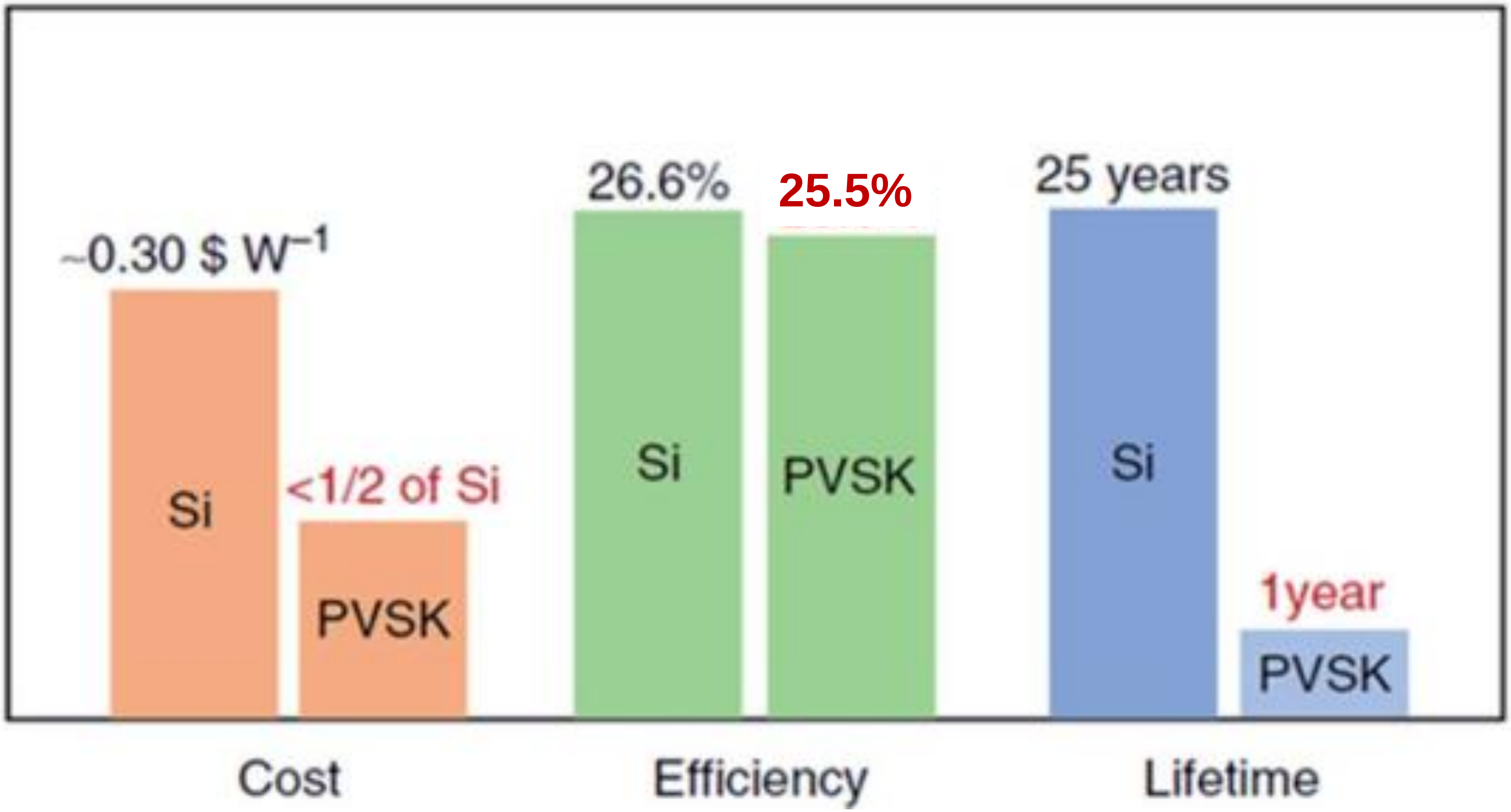
Perovskite Solar Cells: The New Technology



Sol. RRL 2021, 2100401

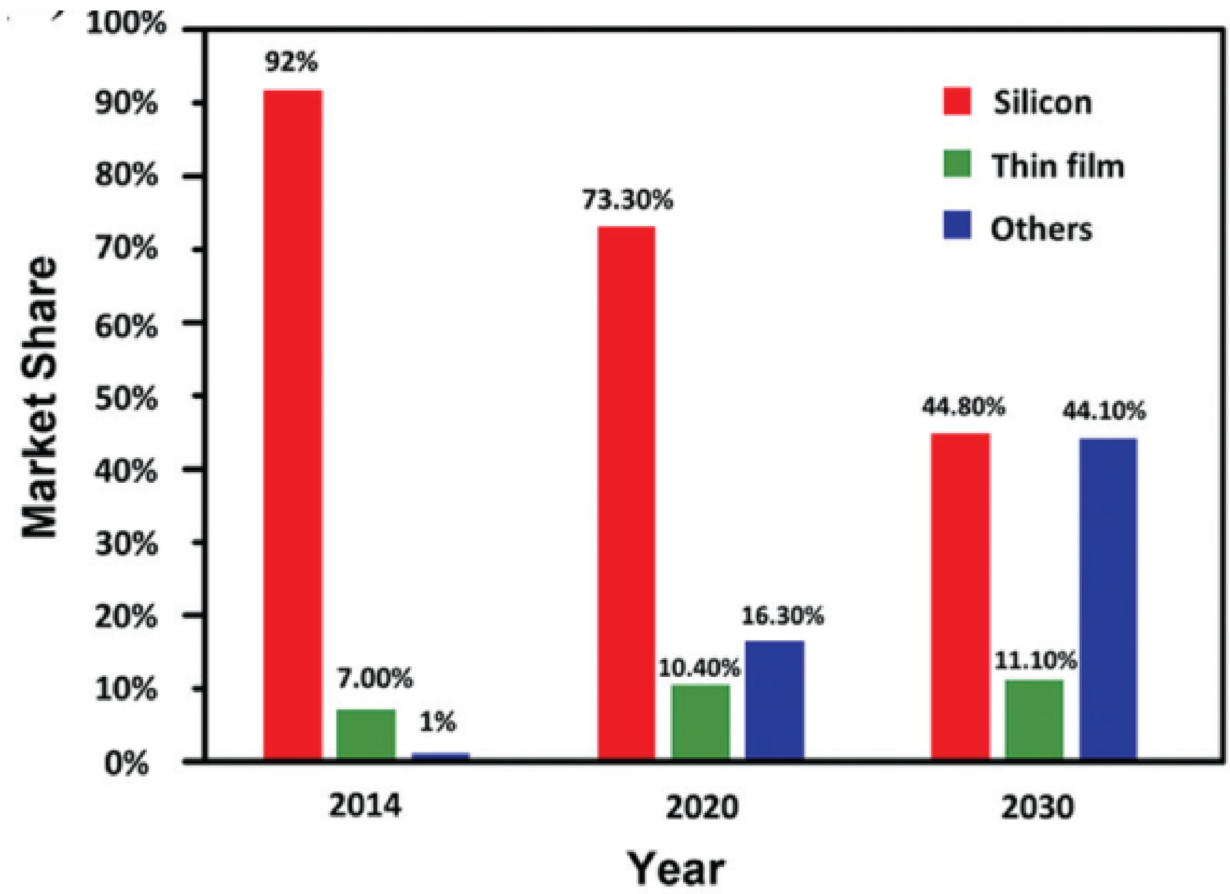
Perovskite solar cells are thin film devices, with comparable efficiency as silicon cells

Silicon vs. Perovskite



Wang, Chem. Sci., 2021, 12, 11936–11954, PSC efficiency updated.

Market Share of Perovskite Solar Cells

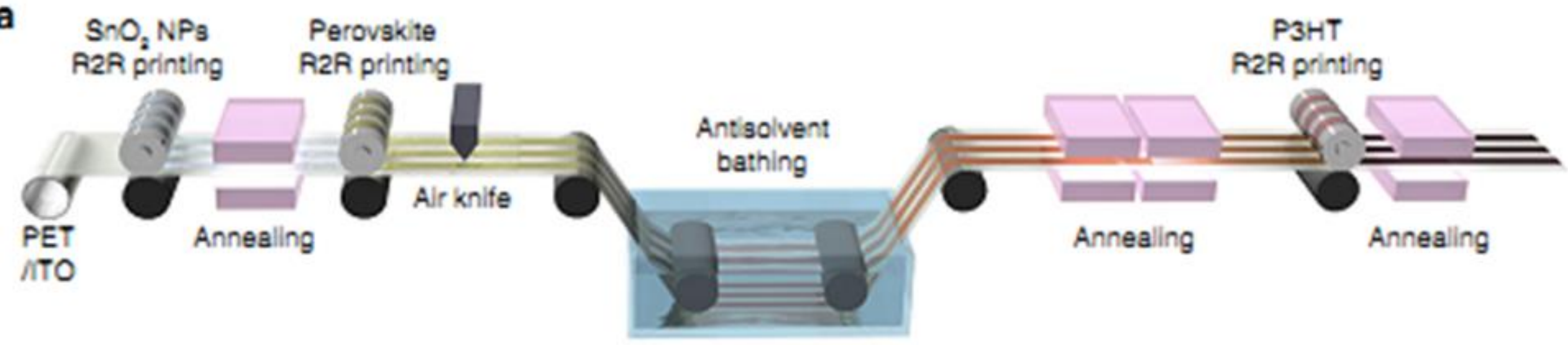


Md. ShahariarChowdhury, Energy Strategy Reviews, 2020, 100431

Perovskites are expected to gain equal market share with silicon, in a decade

Competitive Advantage of Perovskite over Silicon

Roll to roll processing: Flexible and fast

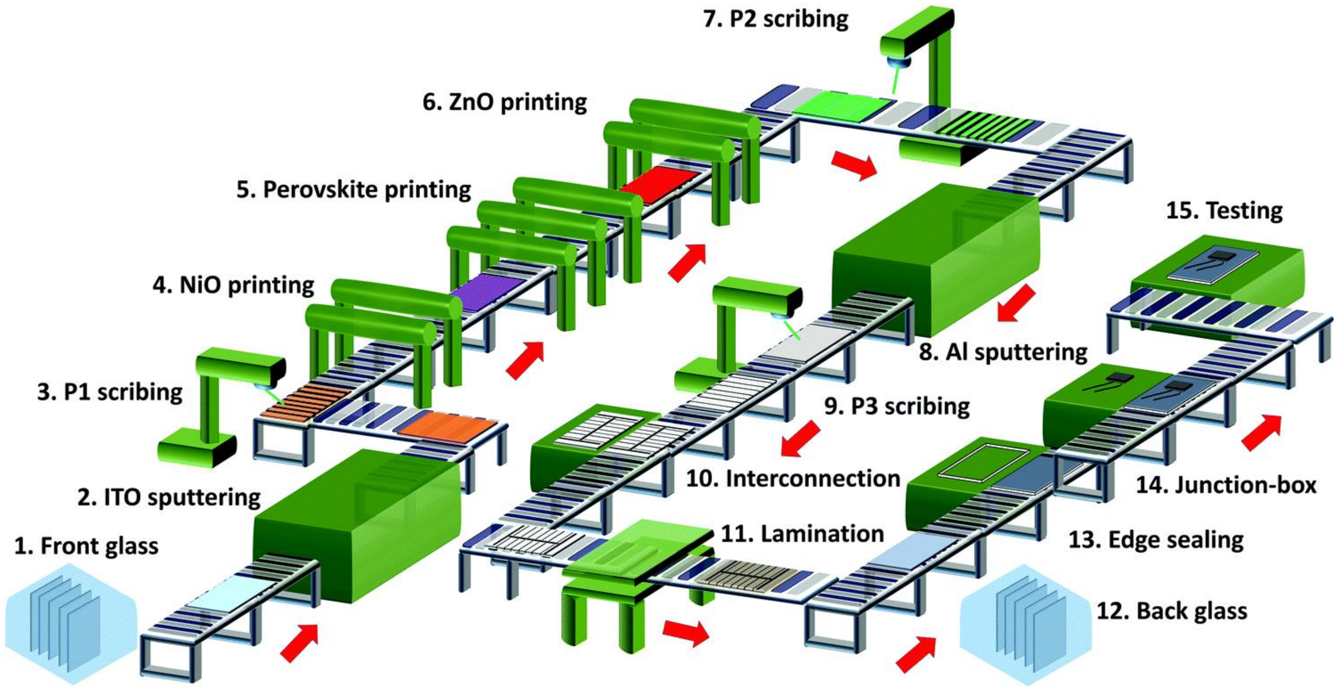


Y. Kim, et al., Nature communications, 2020,11: 5146

Fast and low-cost production, low weight cells, ideal for BIPV

Competitive Advantage of Perovskite over Silicon

From materials to module under the same roof



Energy Environ. Sci., 2017,10, 1297-1305

Competitive Advantage of Perovskite over Silicon

Required investment: low

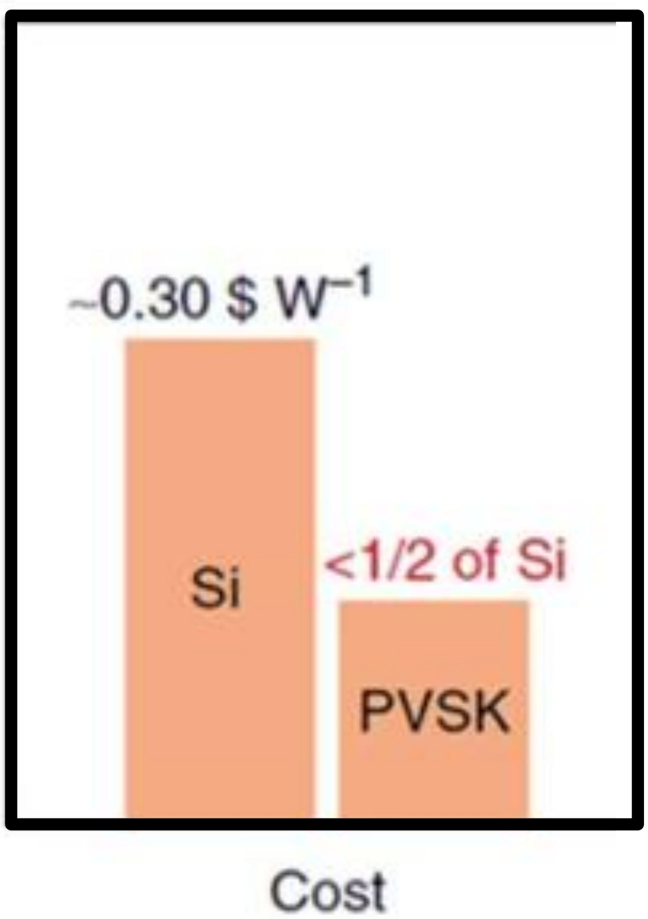
Assumptions	A	B
Plant capacity (MW)	100	100
Total land area (acre)	3	3
Equipment cost (US$ million)	7.51	7.51
Human resources	150	100
Debt: Equity	70:30	70:30
Life of the plant (years)	10	10
Construction period (months)	12	12

Global Challenges **2021**, 2100070

Module production near solar farm is possible:
Lower shipping and logestic costs

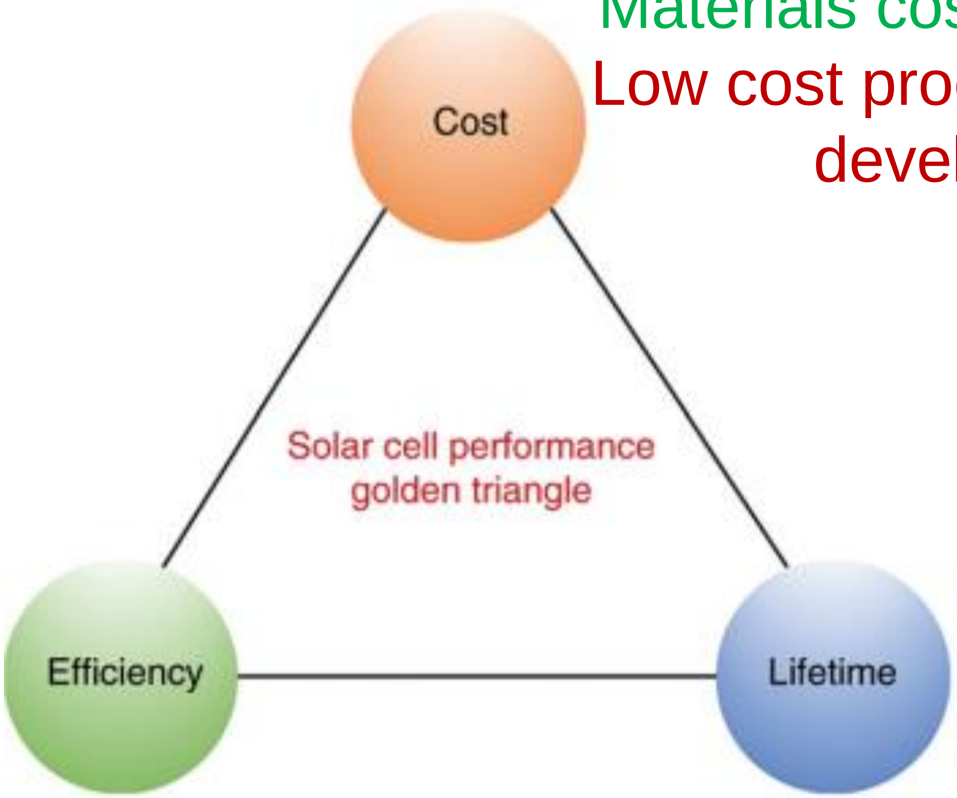
Competitive Advantage of Perovskite over Silicon

Lower cost



Wang, Chem. Sci., 2021, 12, 11936–11954, PSC efficiency updated.

Perovskite Success and Challenge

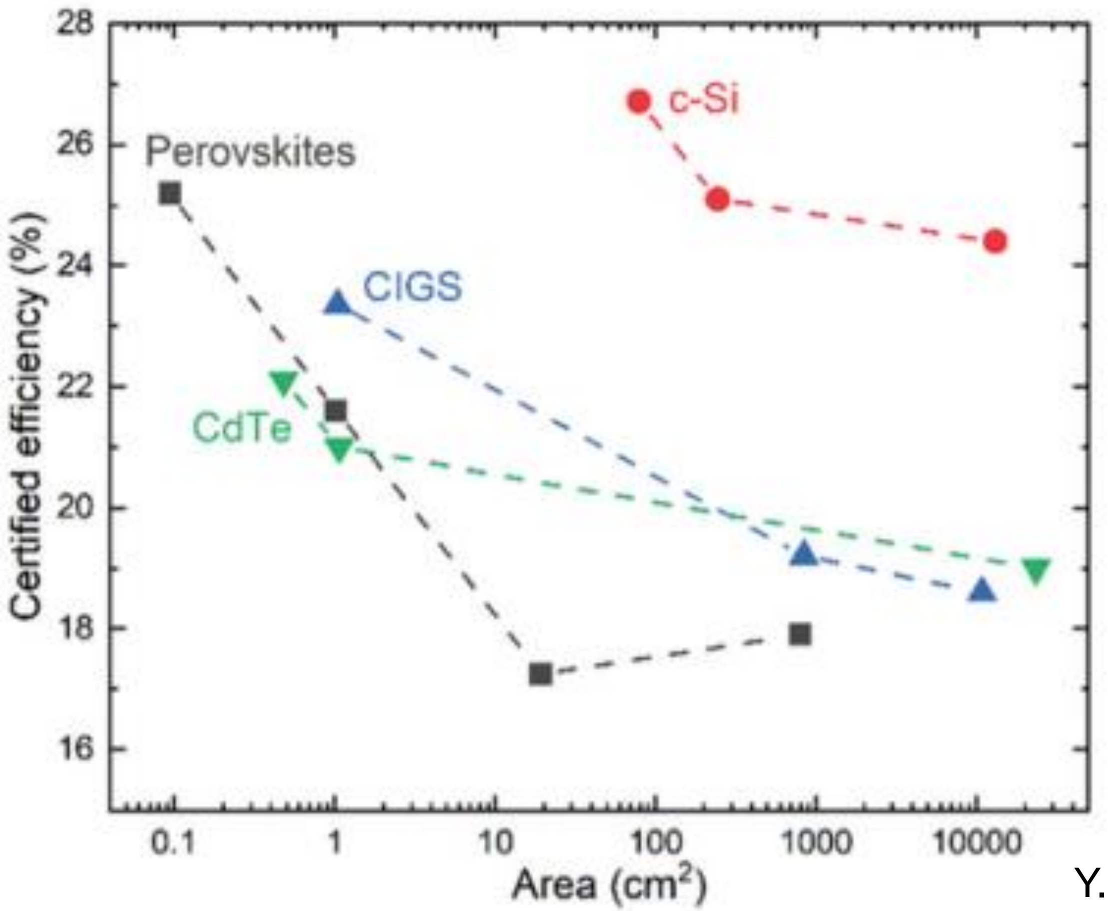


Materials cost is very low.
Low cost processing to be developed

Good for small cell,
Challenge for large cell
(Manufacturing challenge)

Stability has dramatically improved, but still needs improvement

Challenge of Scale-up



Y. Cheng, et al, EES 2021

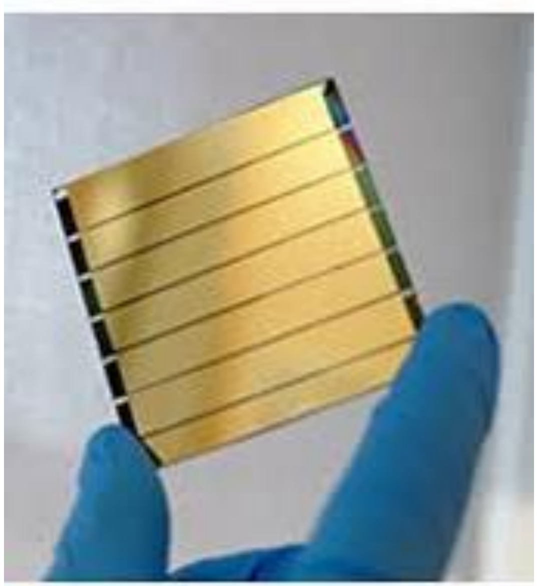
Technologoes should be developed for efficienct manufacturing of perovskite solar cells

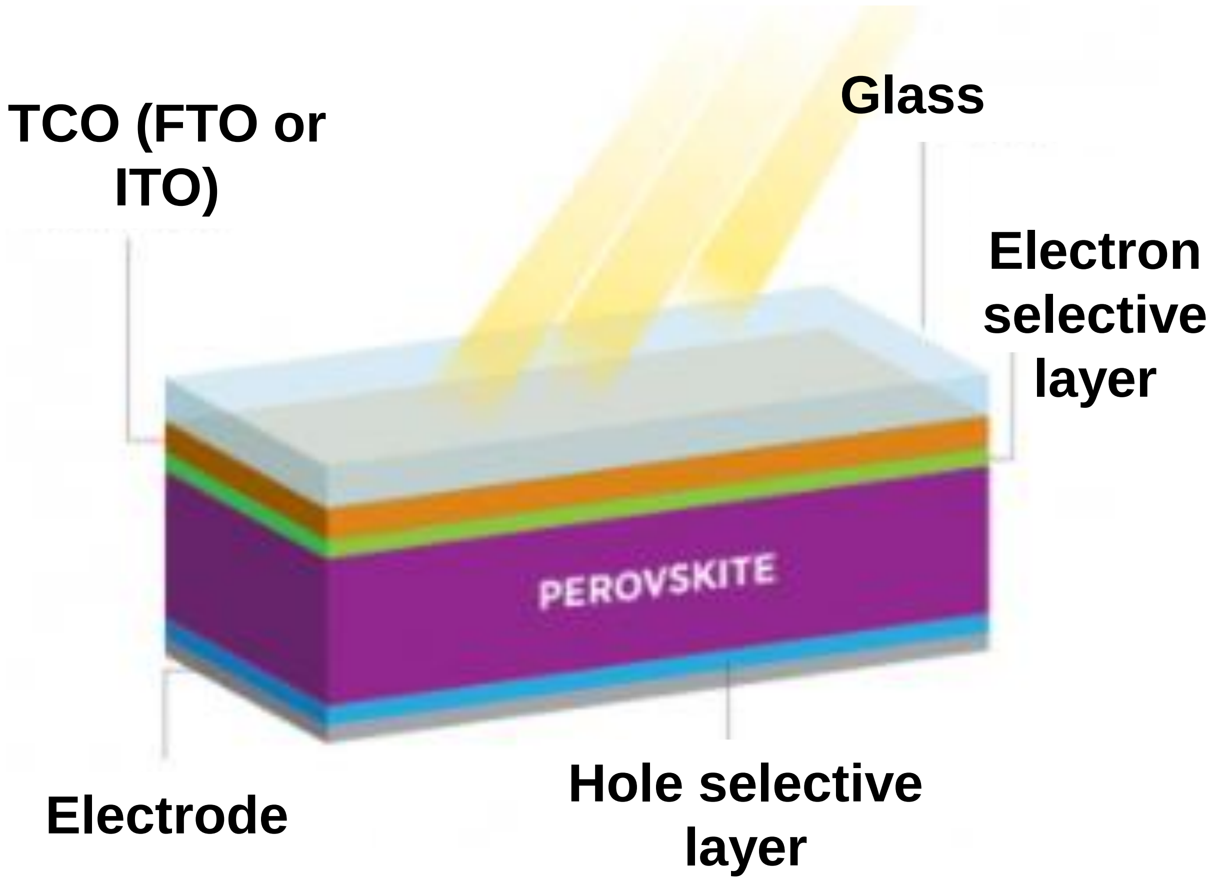
What Physics Makes Perovskite so Special?

Compared to other thin film technologies, perovskites:

1. Can be deposited highly crystalline by ink printing
2. Are very defect tolerant
3. Show high mobility (> 10 $cm^2\ V^{-1}\ s^{-1}$)

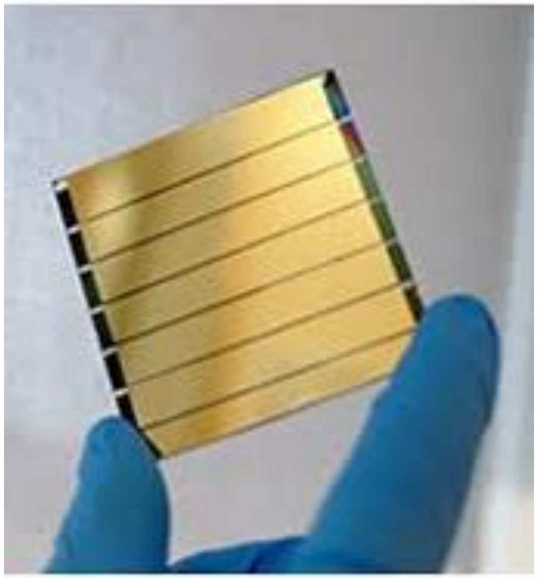
Structure of Perovskite Solar Cells

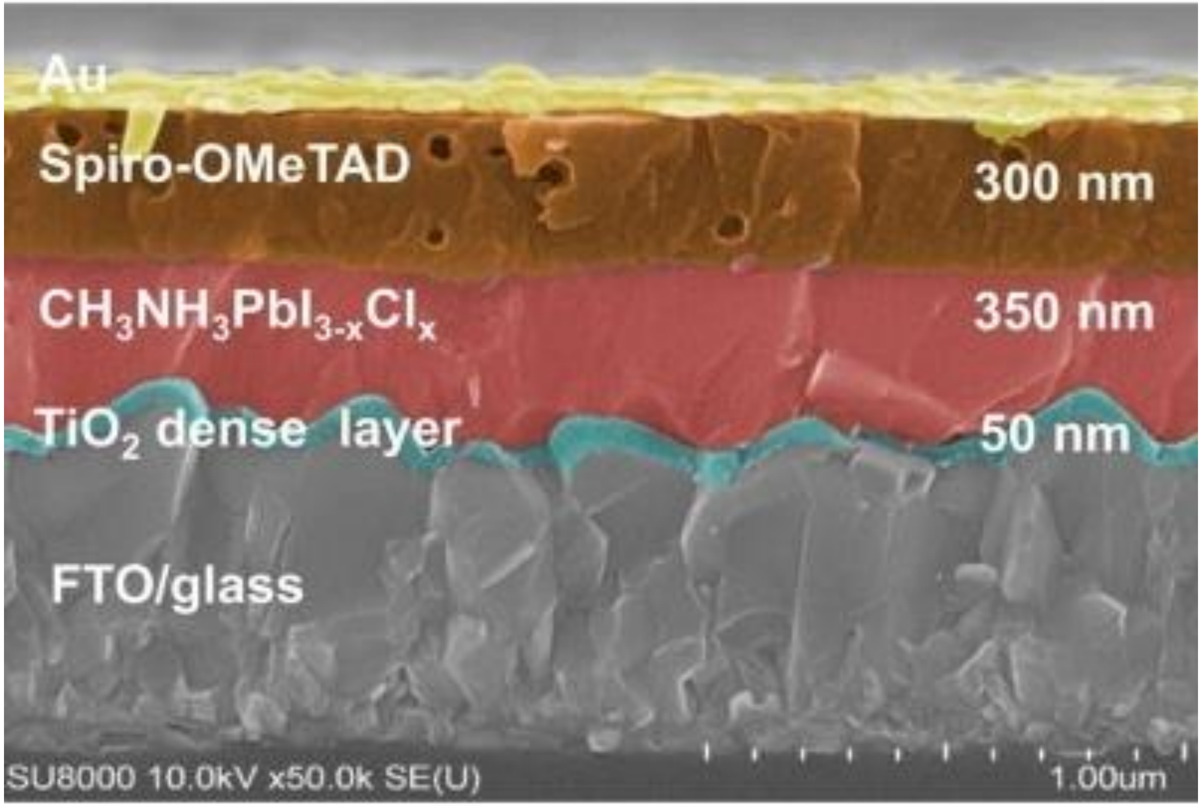




Solarviews.com

Structure of Perovskite Solar Cells





Jean, J. et al. ACS Energy Letters, 2, (11)

Device thickness is about 1 micrometer

$$\underline{CH_3NH_3}\ \underline{Pb}\ \underline{I_3}$$

$$A \quad B \quad X_3$$

Methyl Ammonium Lead Iodide

Organic-Inorganic Perovskites

$CH_3NH_3PbCl_3$

$CH_3NH_3PbBr_3$

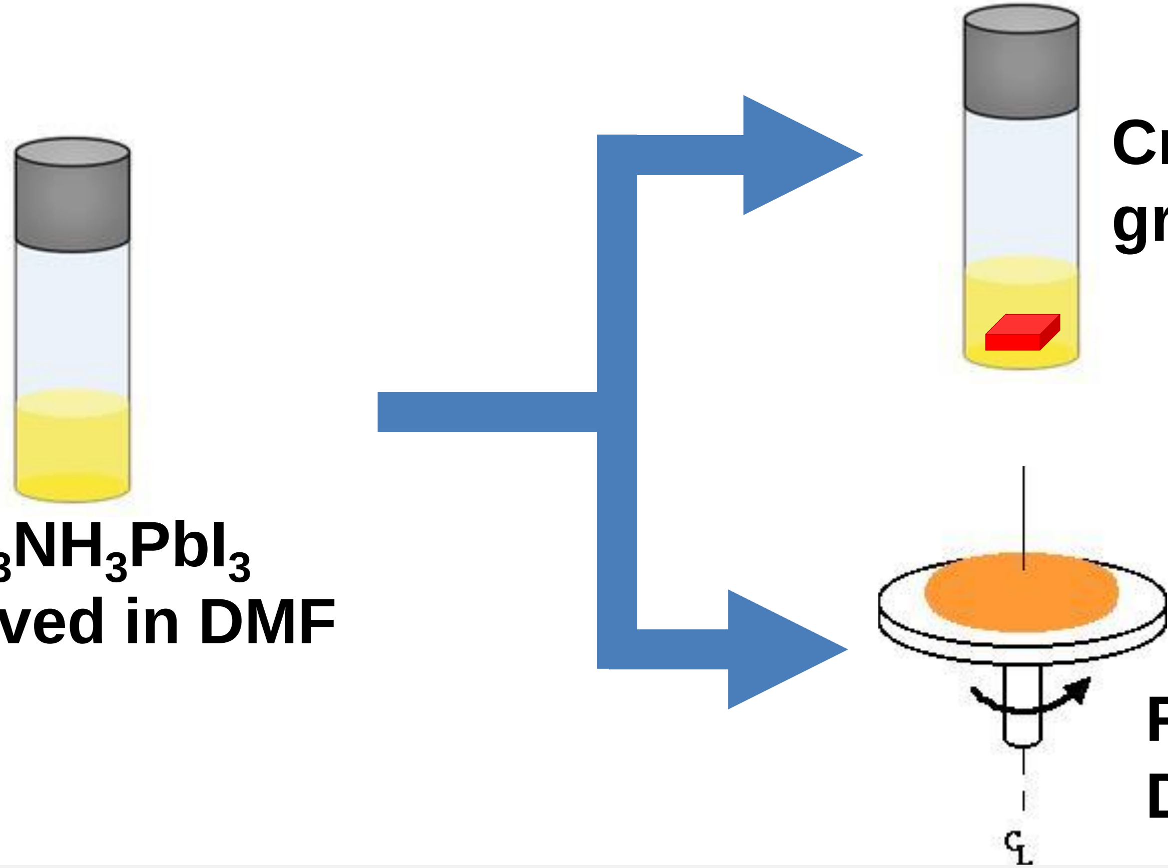
$CH_3NH_3PbI_3$

$CH_3NH_3SnI_3$

$CH(NH_2)_2PbI_3$

$CsPbI_3$

From solution to crystal



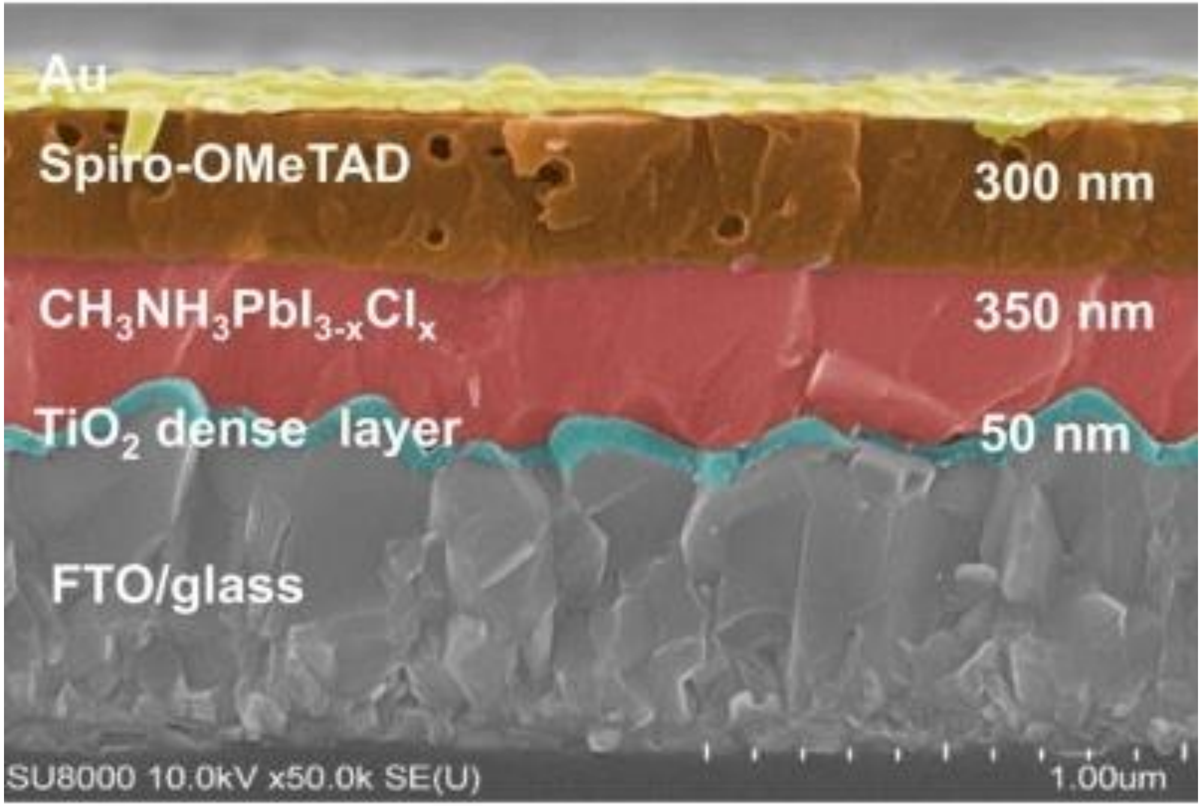
Perovskite can form high quality crystals at near room temperature by ink processing

What we do in our lab

Scale-up of Perovskite Solar Cells

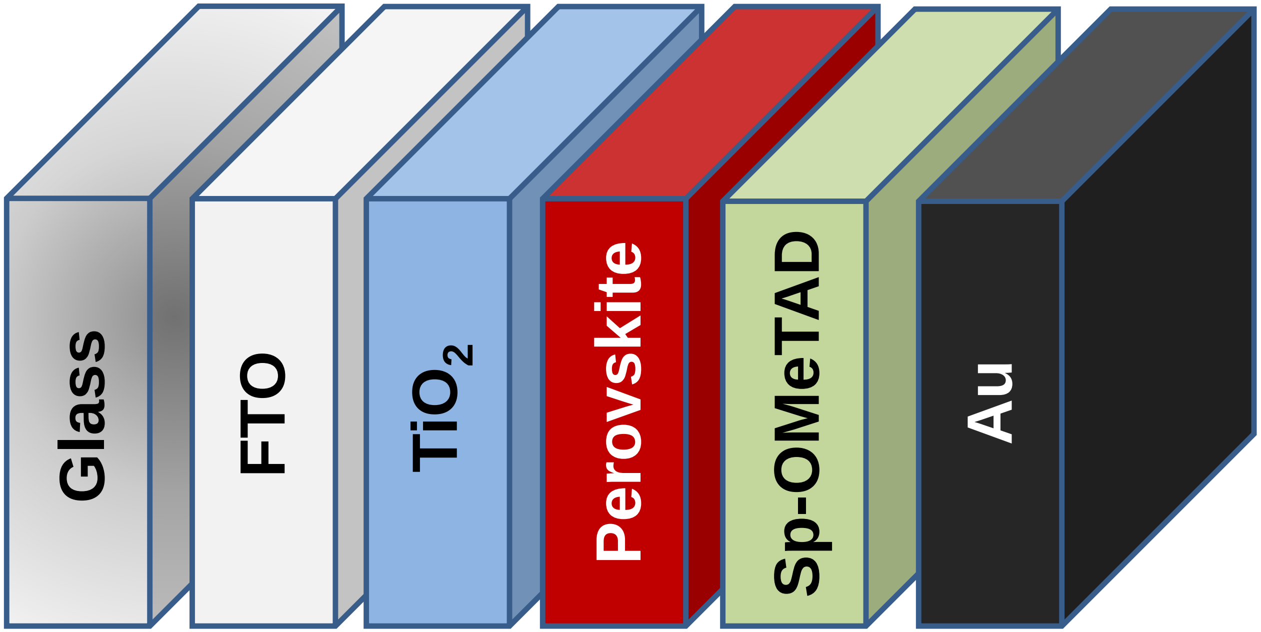
- Ink Formulations
- Deposition Methods
- Device Physics

Conventional Perovskite Solar Cells



Jean, J. et al. ACS Energy Letters, 2, (11)

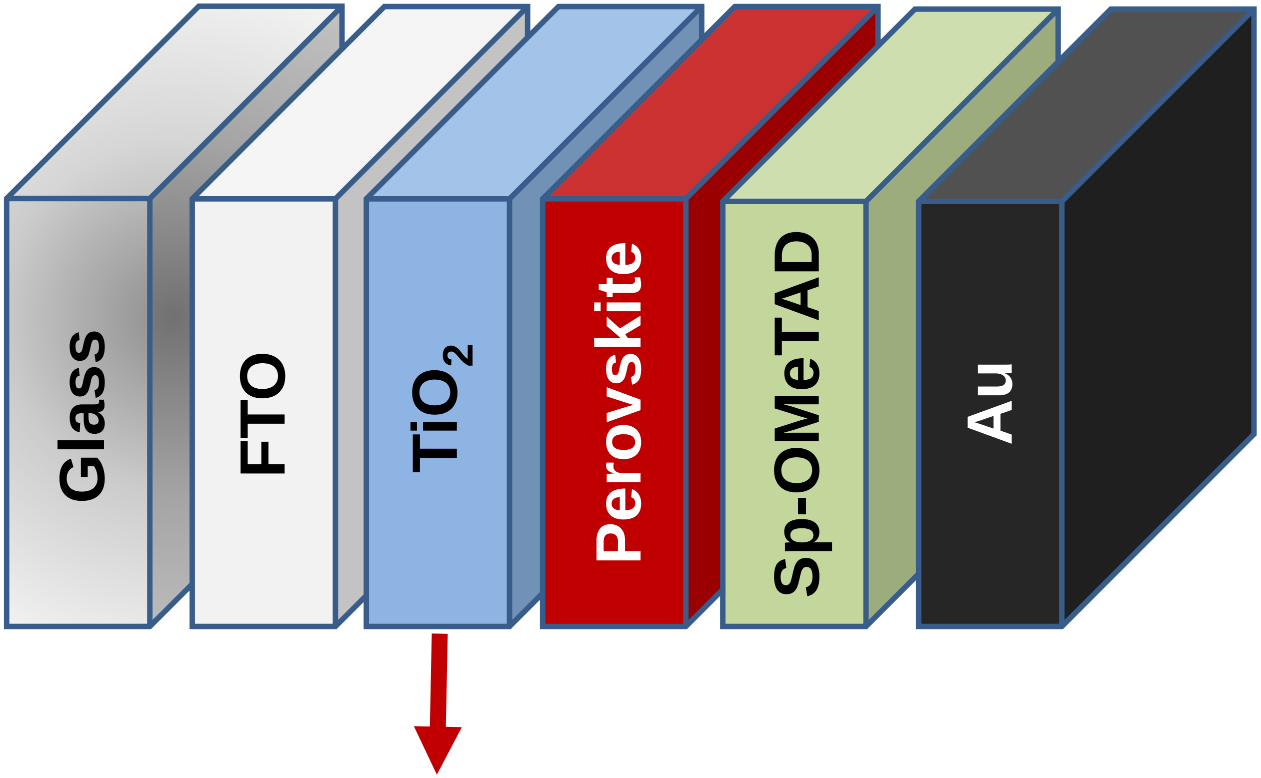
Our Approach



Our direction is making perovskite solar cells

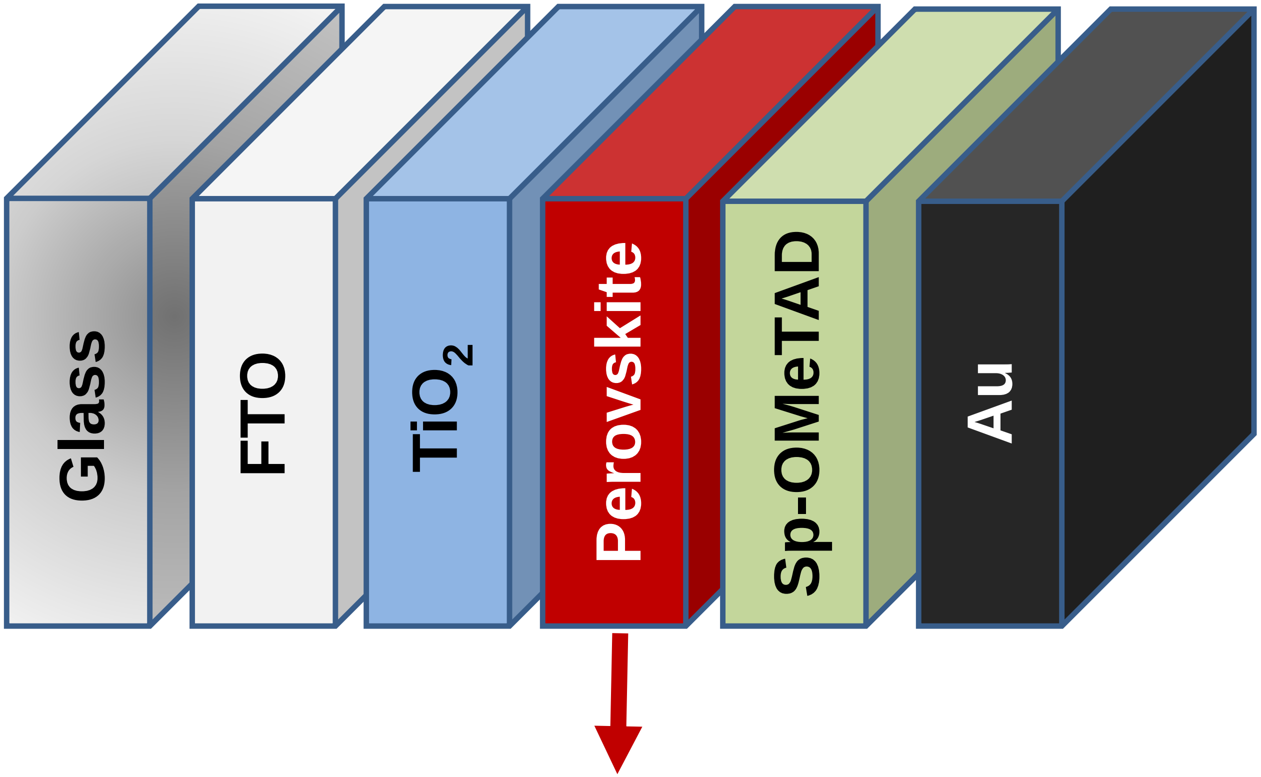
MANUFACTURABLE

Our Approach



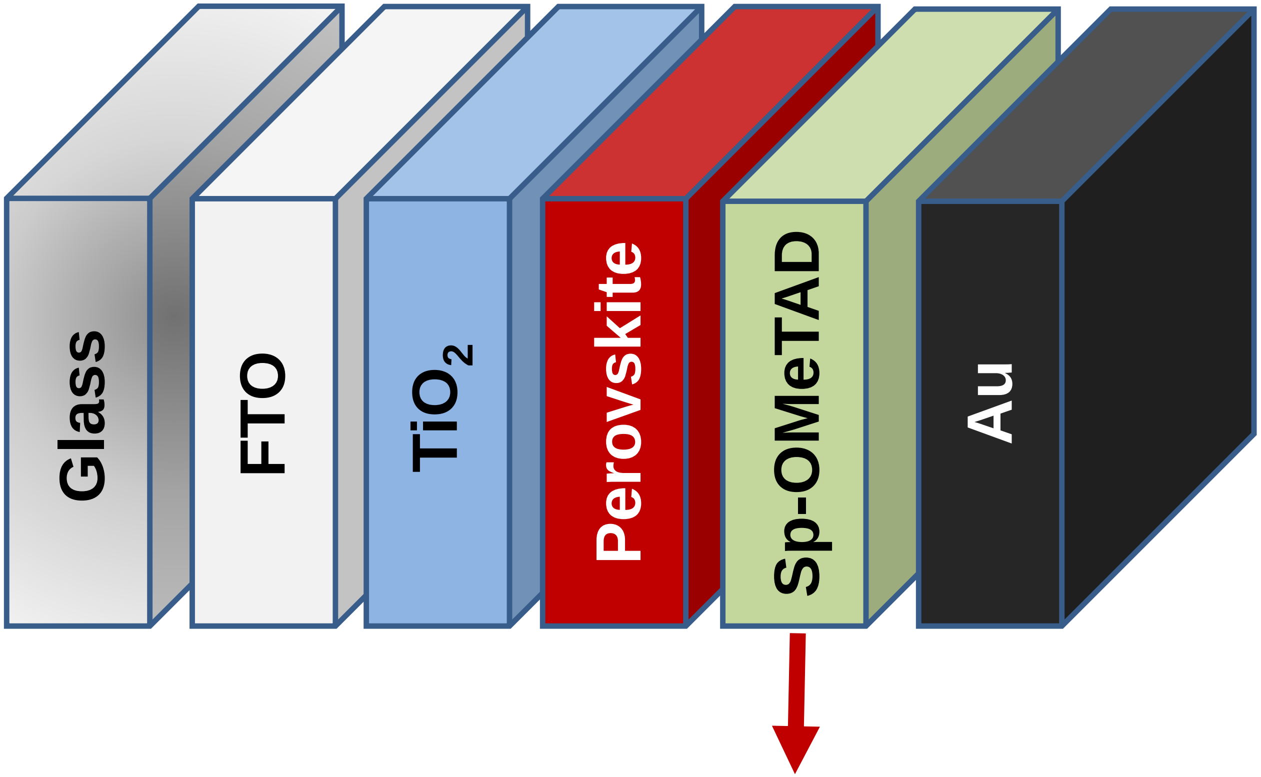
A low temperature and fast process

Our Approach



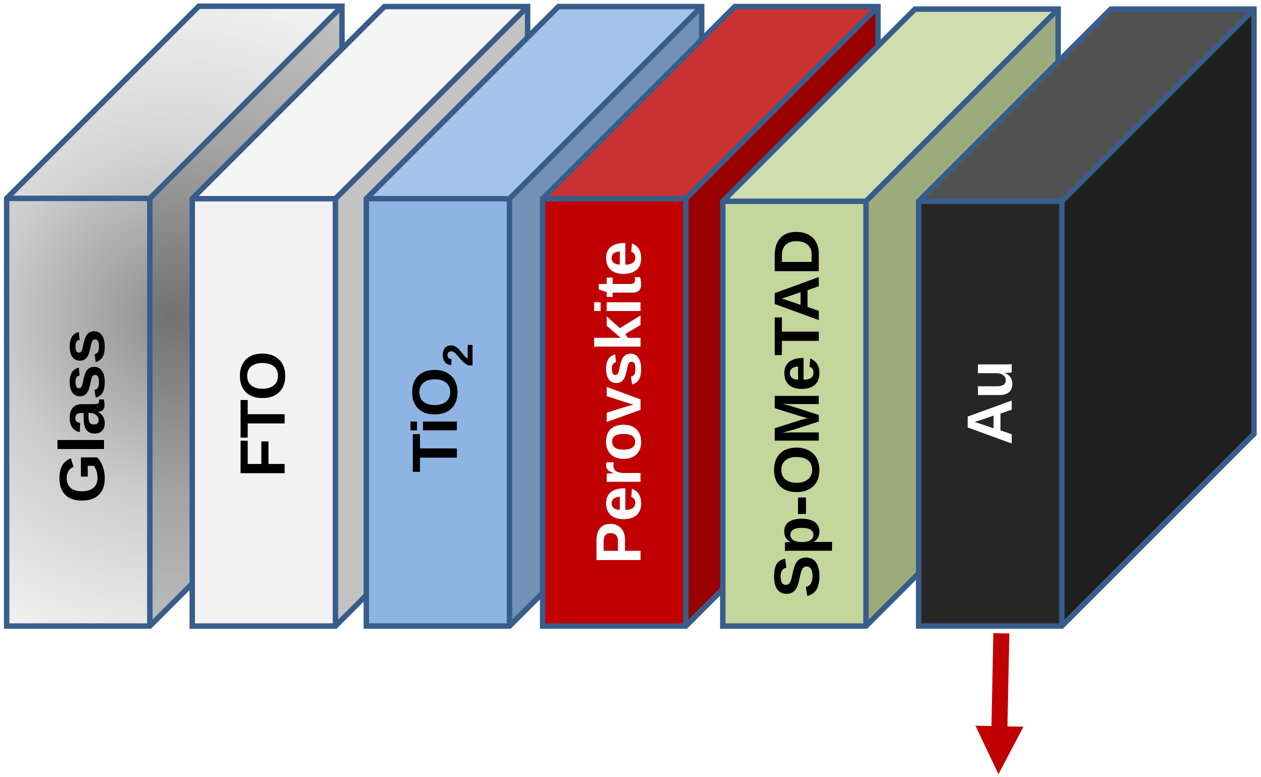
Print instead of spin coating

Our Approach



Replacing with an inorganic material

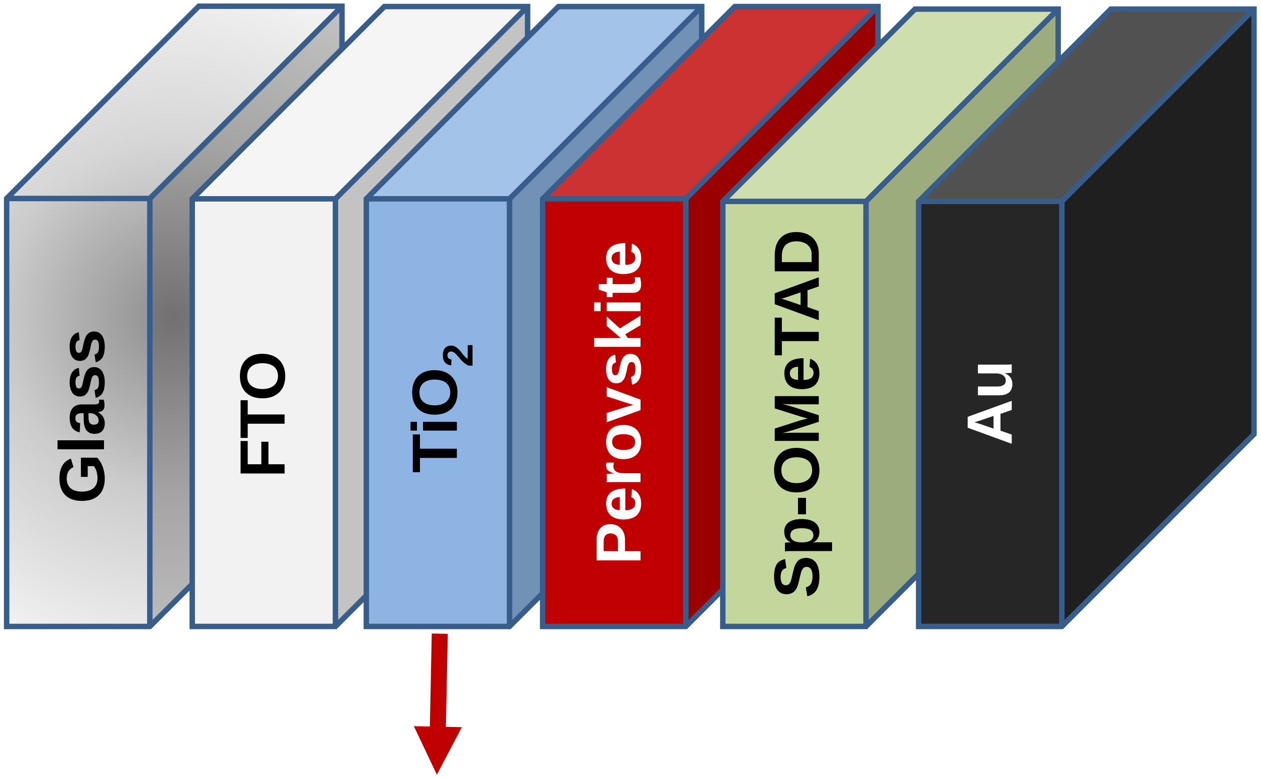
Our Approach



Printable electrode of carbon or Au

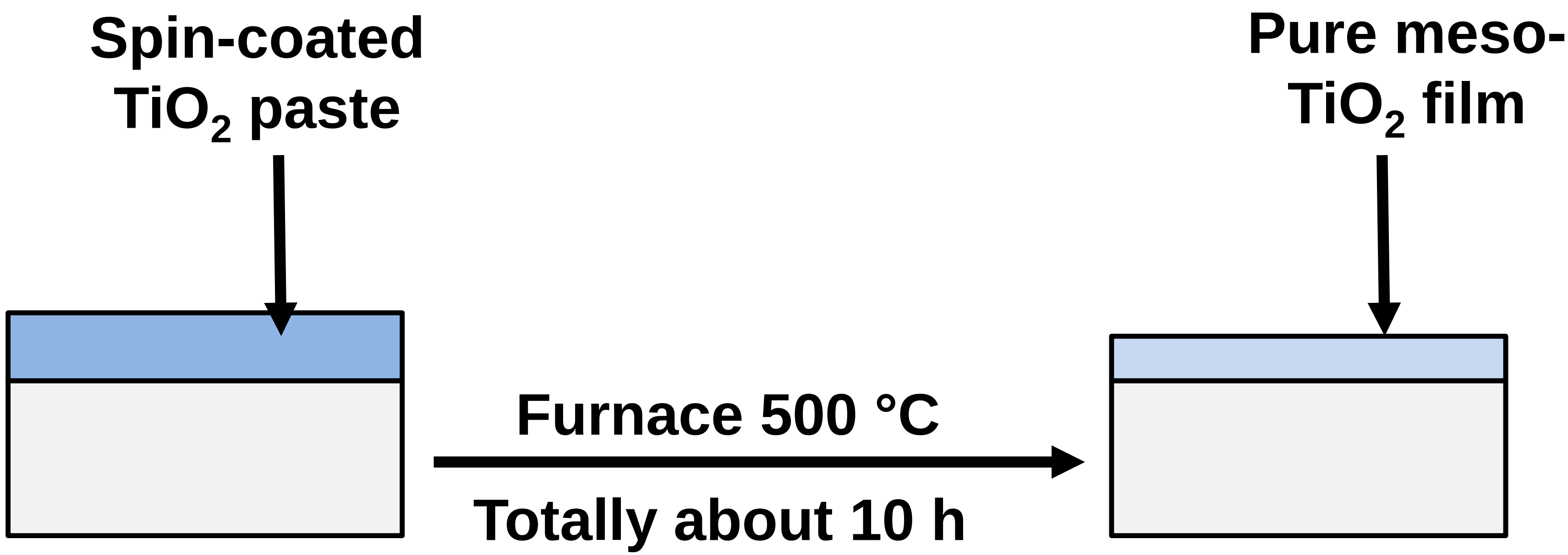
Irradiation curing of TiO_2 paste layer

Irradiation curing of TiO_2 paste layer



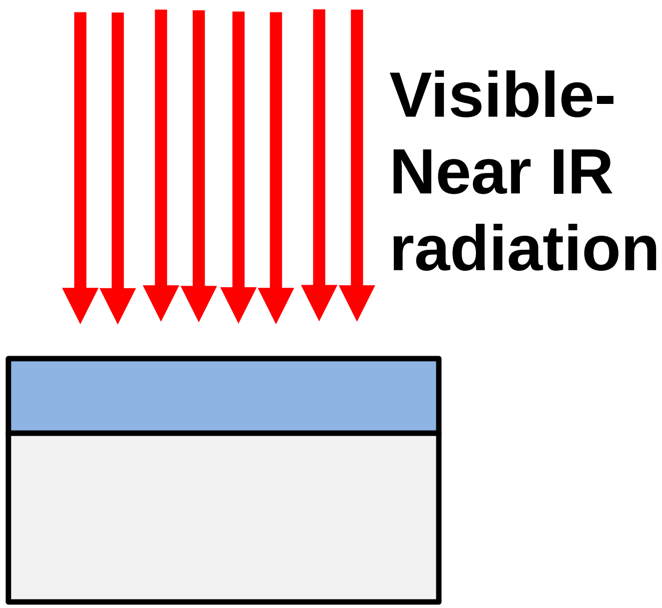
A low temperature and fast process

Conventional meso-TiO_2 deposition

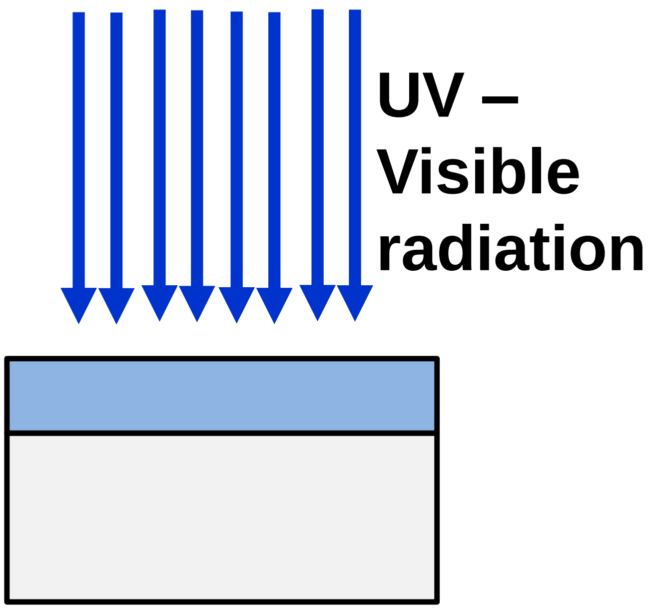


Irradiation curing of TiO_2 paste layer

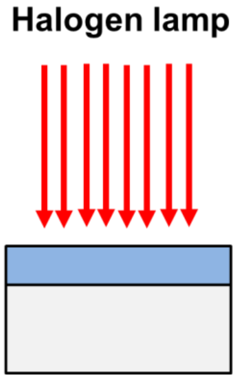
Halogen lamp

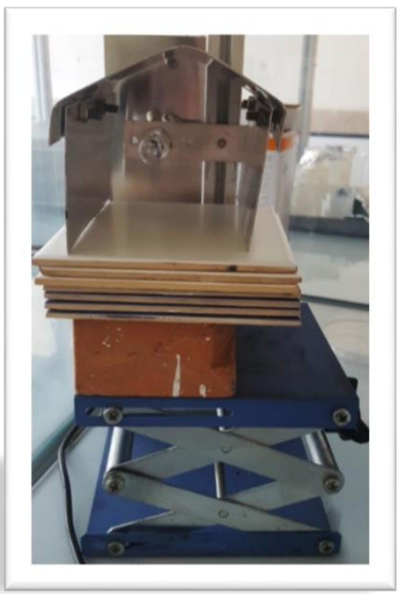


Mercury vapor lamp

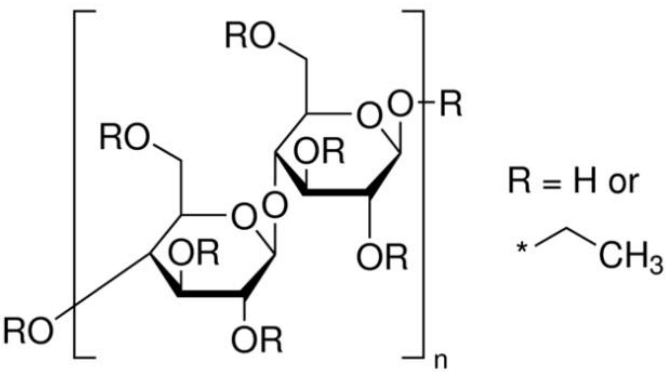


Infrared heating



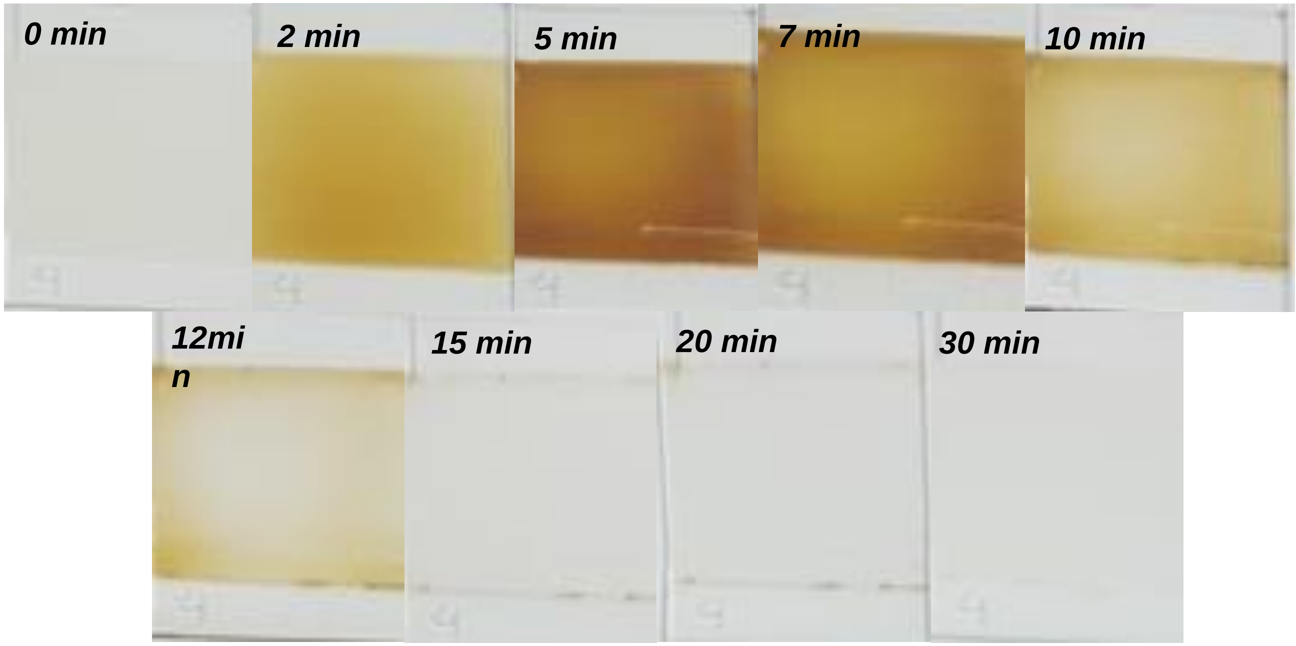


We expect to remove the binder (ethyl cellulose) and solvent by halogen lamp irradiation



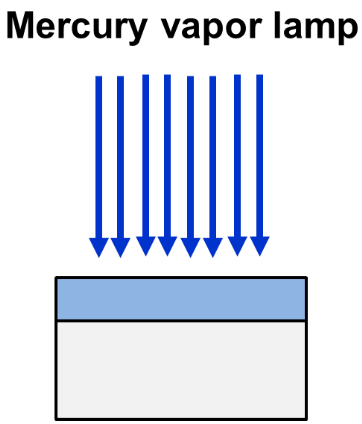
Ethyl cellulose

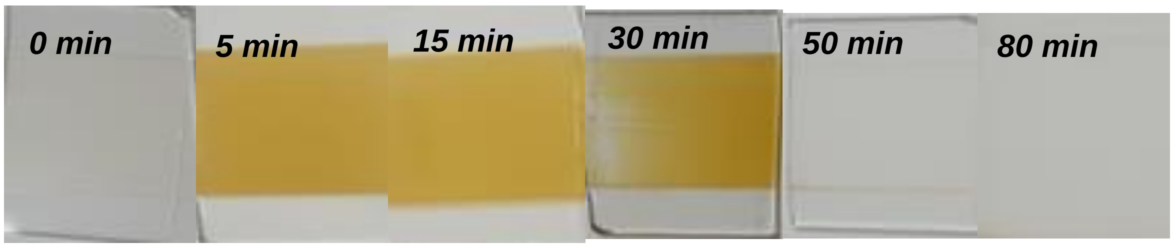
Infrared heating



Paste is first colored due to carbonization

UV Curing

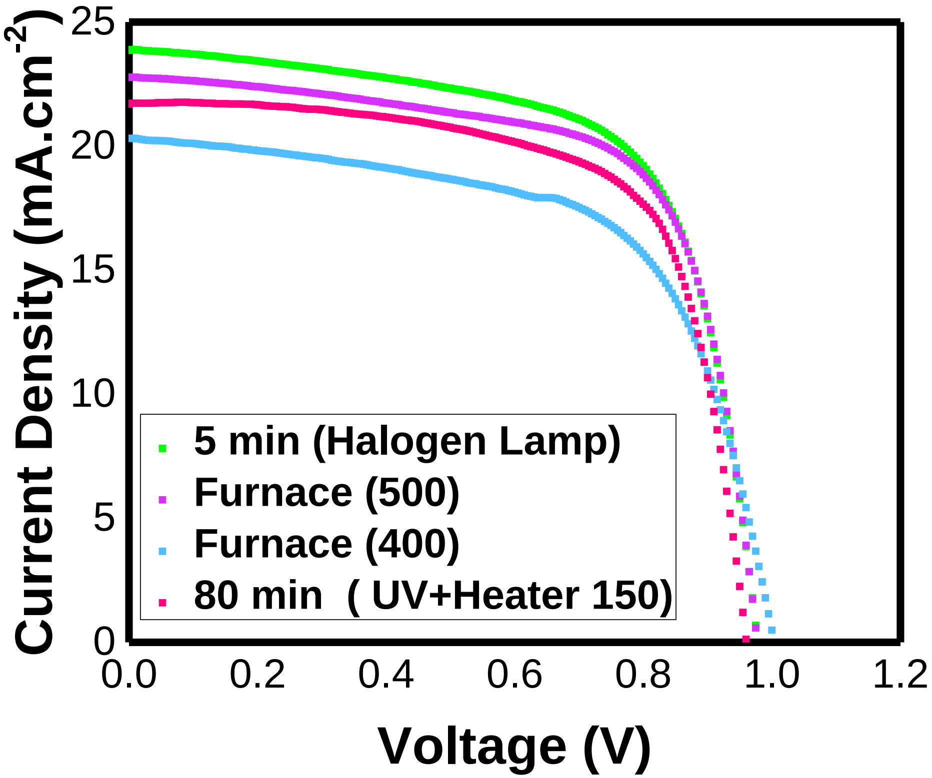


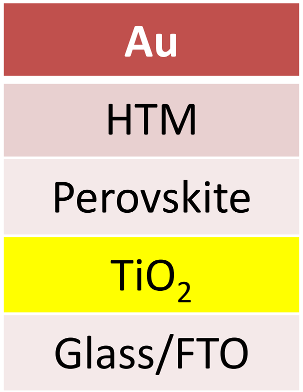


UV irradiation is expected to act photocatalytically

First carbonization and then removal of binder

Infrared and UV Curing versus annealing

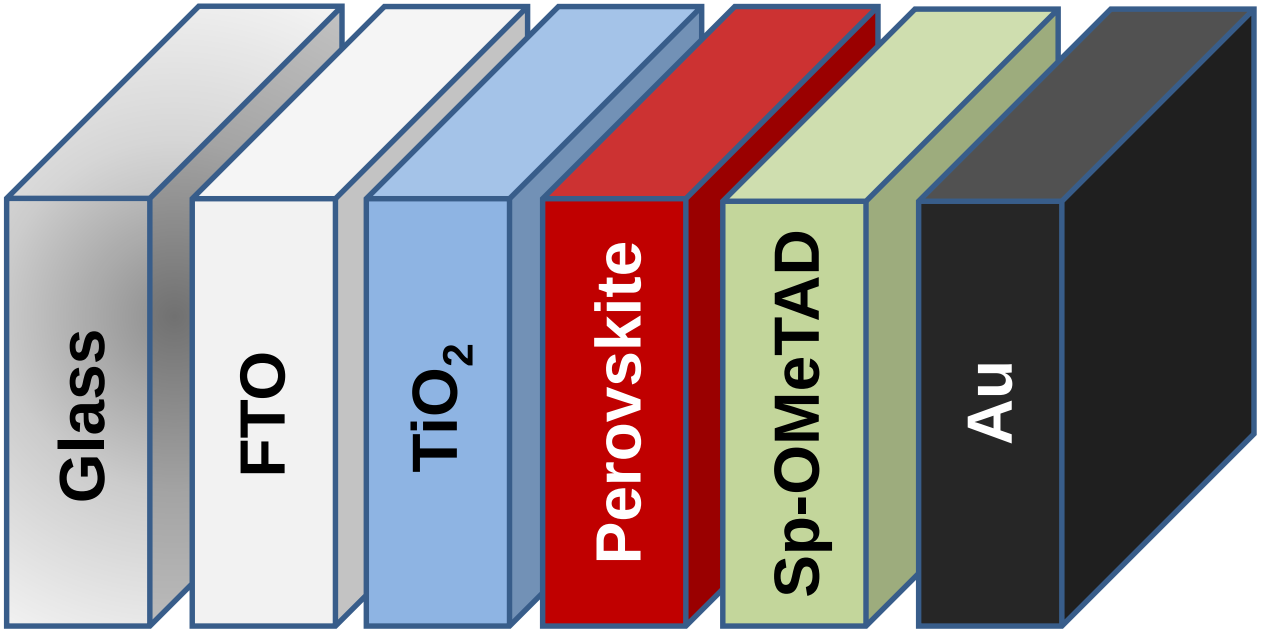




Infrared or UV results are similar to 500 °C furnace heating

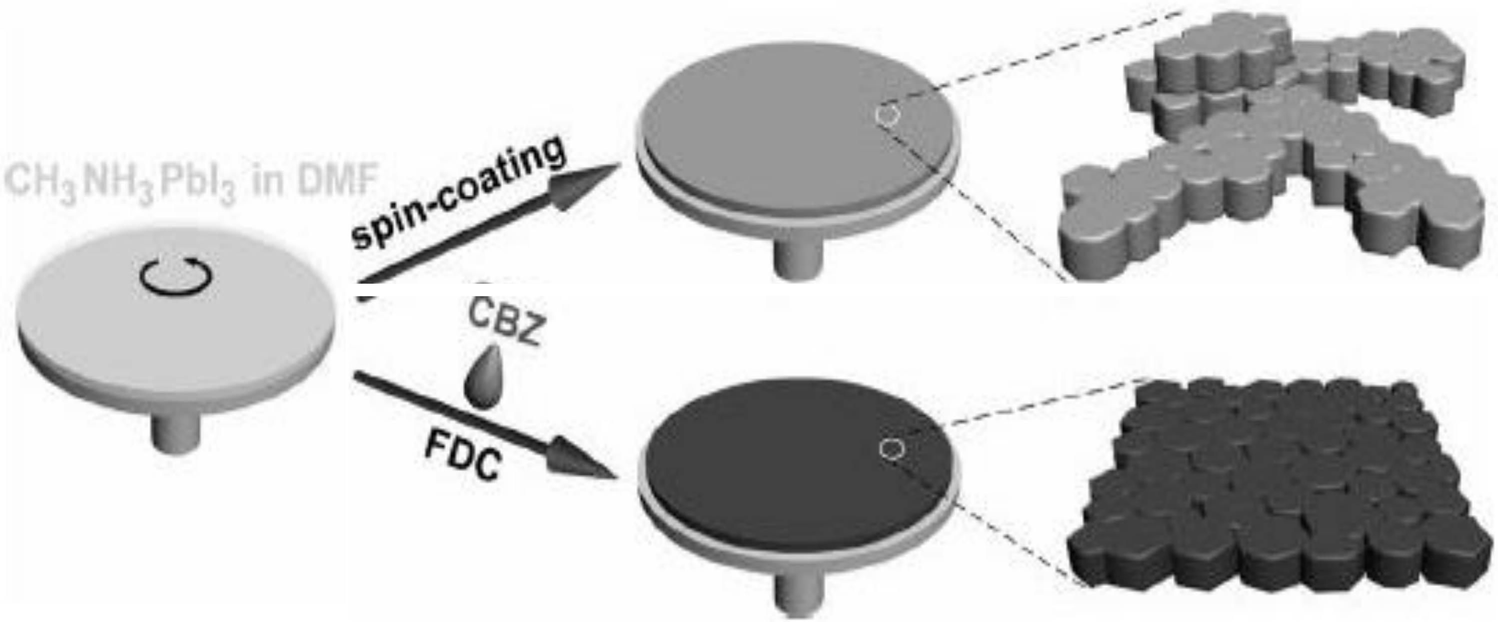
Printing of Perovskite Layers

Printing of perovskite layer



Print instead of spin coating

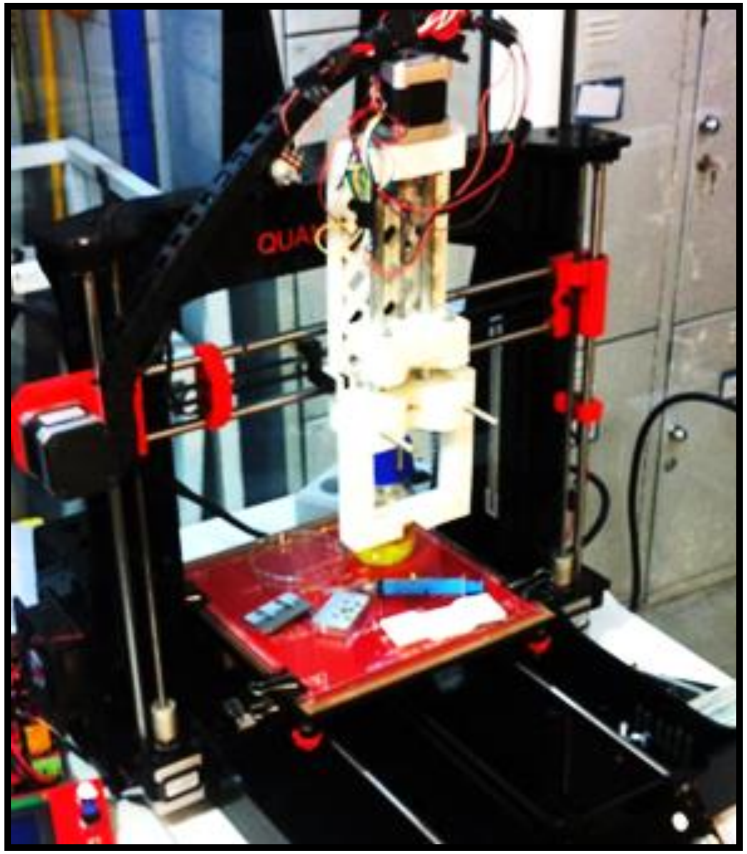
Conventional perovskite film deposition



Conventional method: Spin coating + anti-solvent

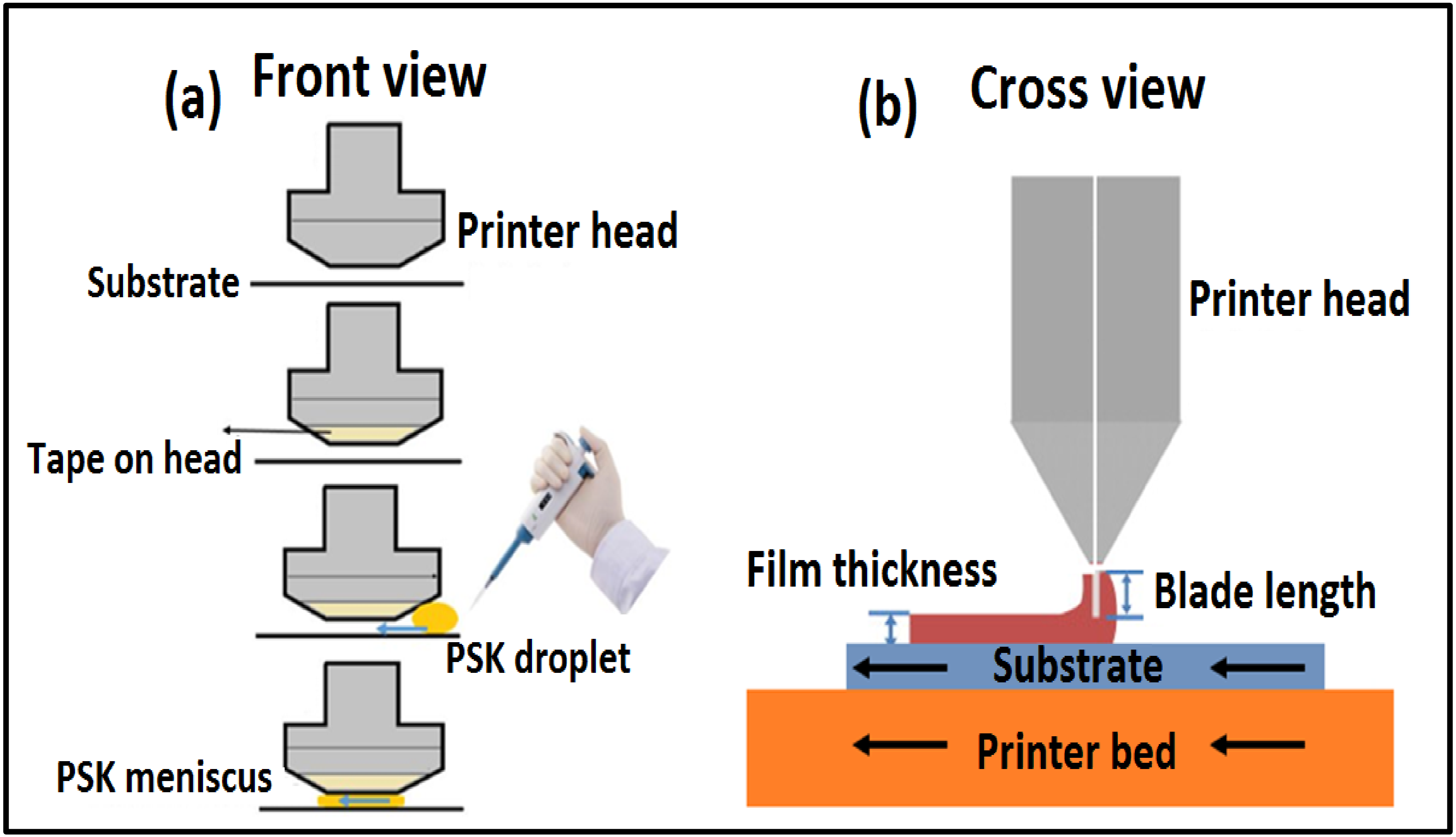
Spin coating and anti-solvent *Not scale-up friendly*

Our print setup

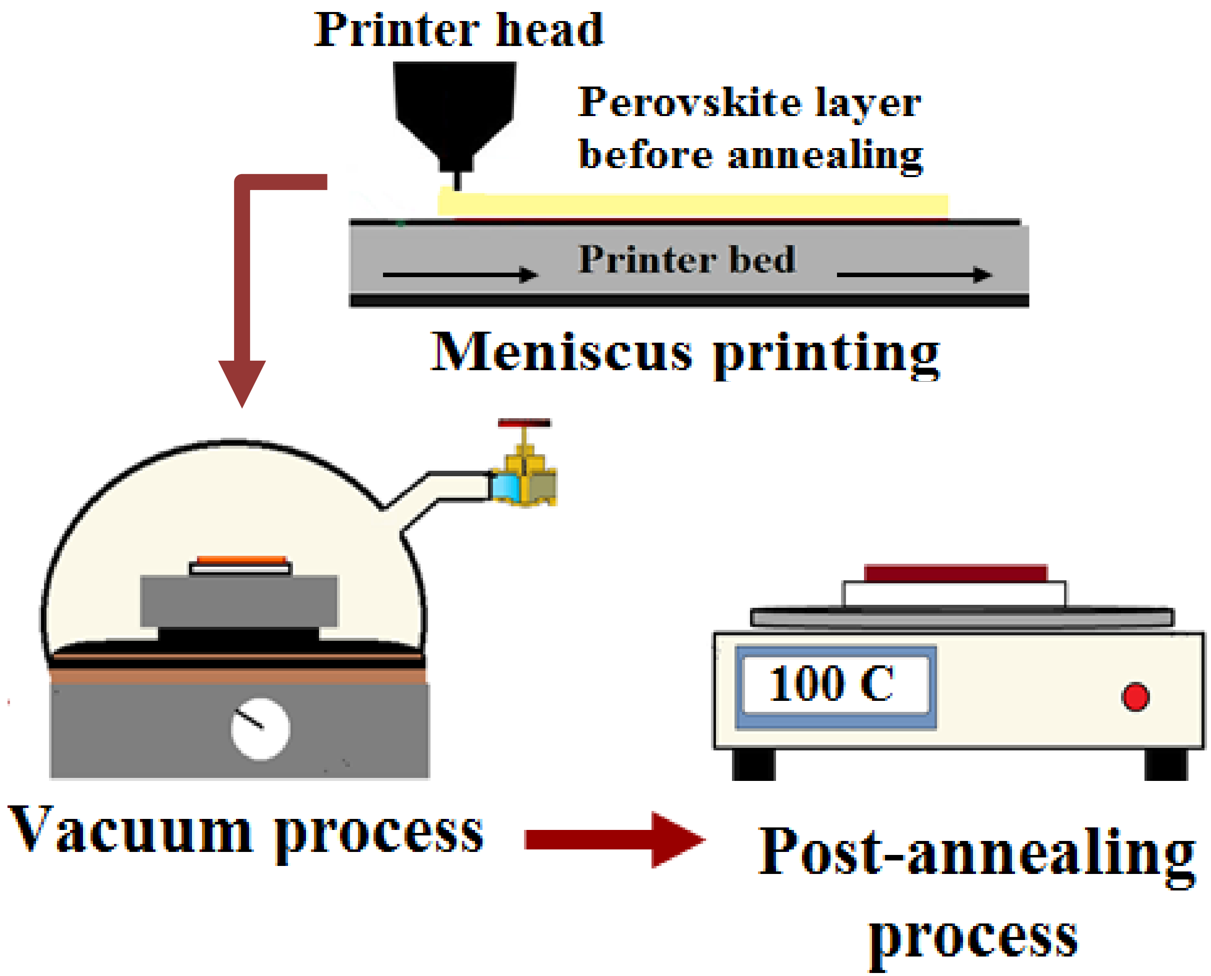


A 3D printer modified setup for blade coating

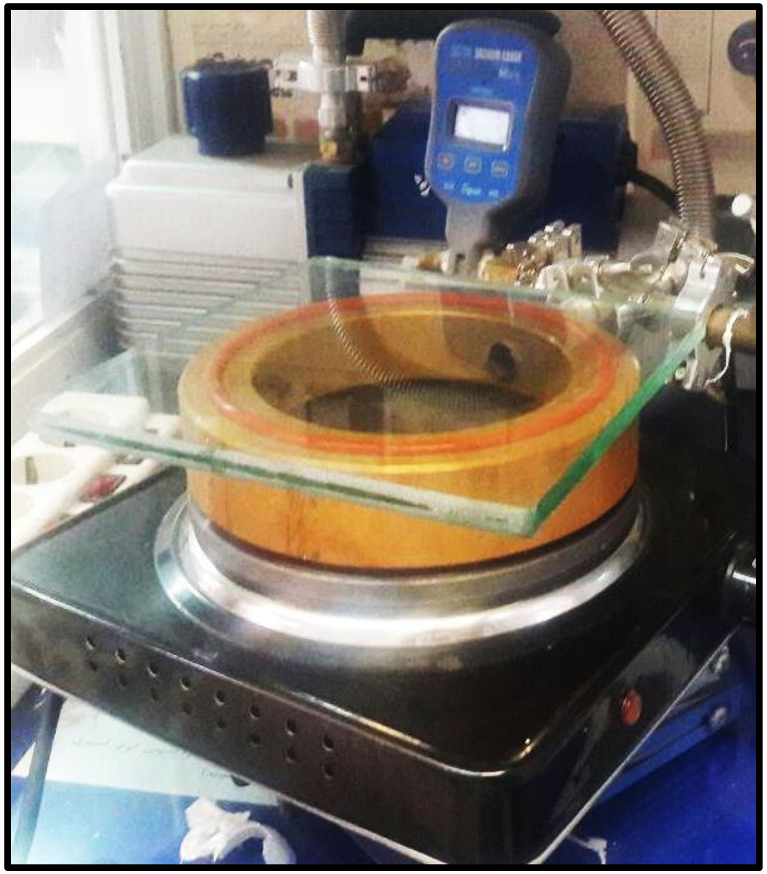
Meniscus Printing



Vacuum Curing



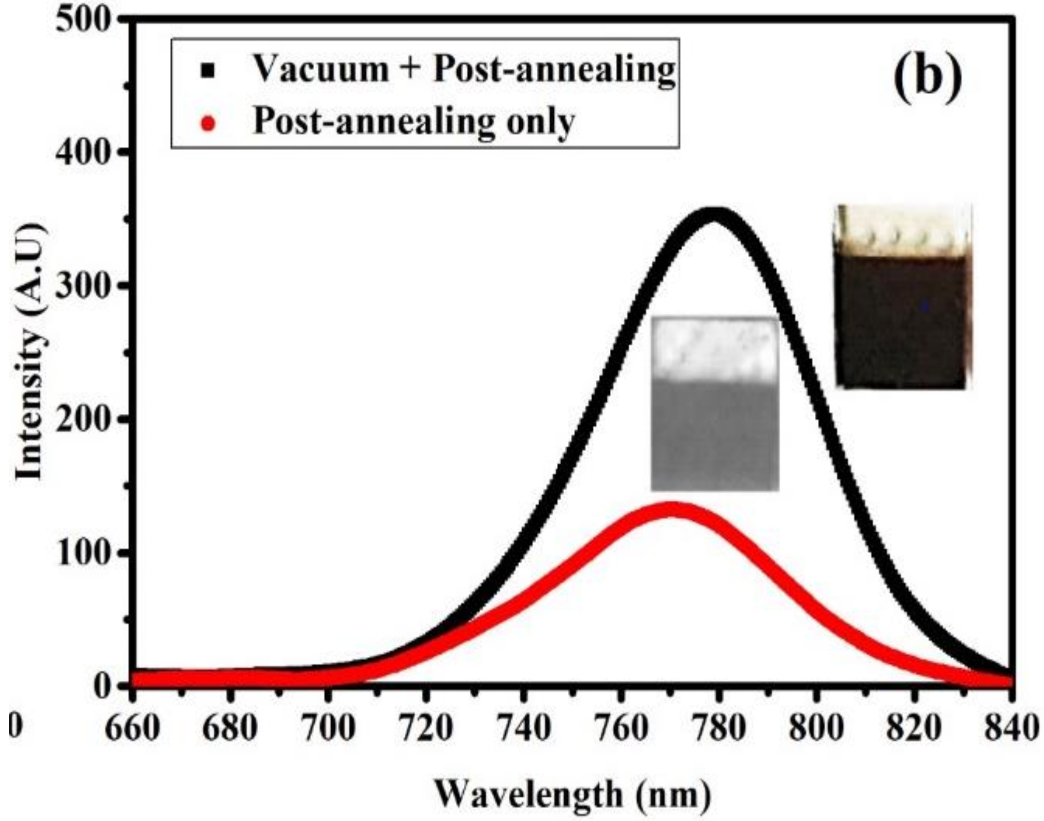
Vacuum Curing Setup



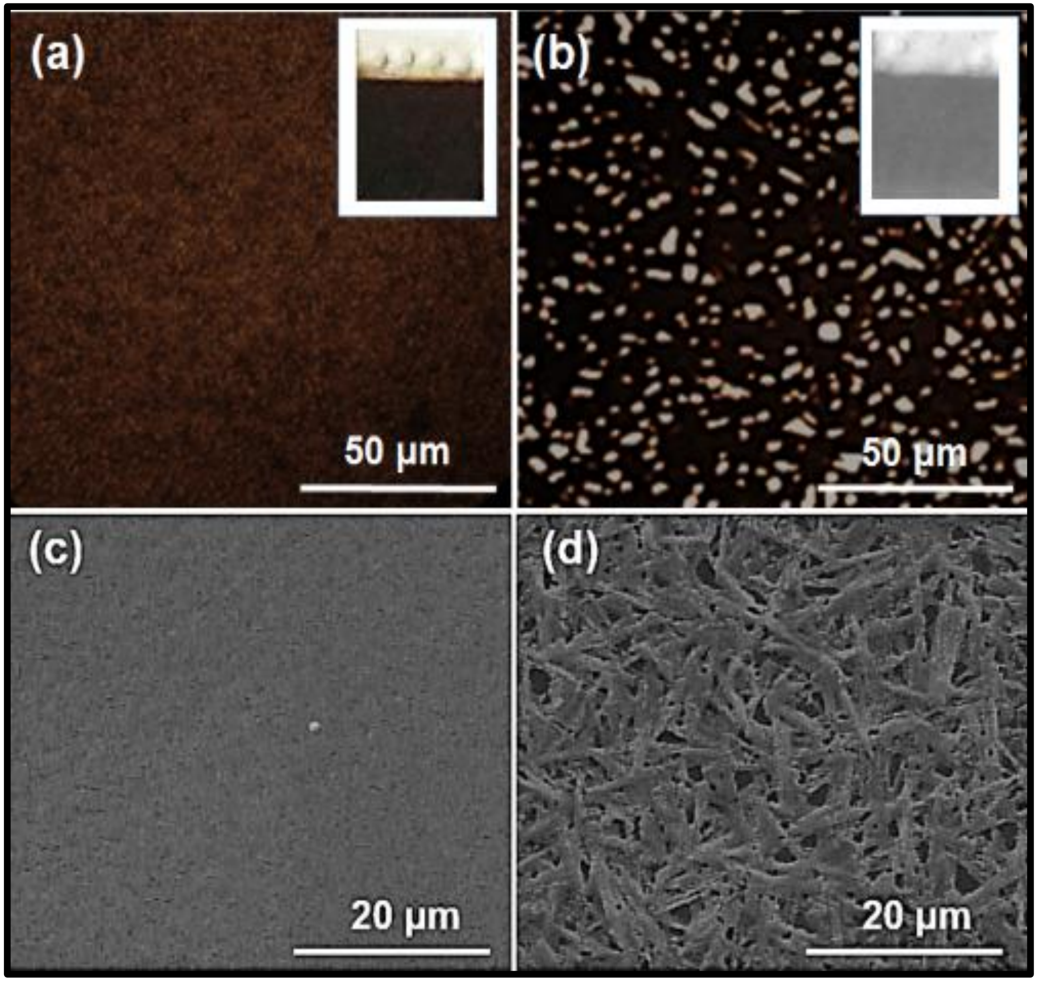
Our Vacuum Chamber

Effect of vacuum curing

Photoluminescence (PL)

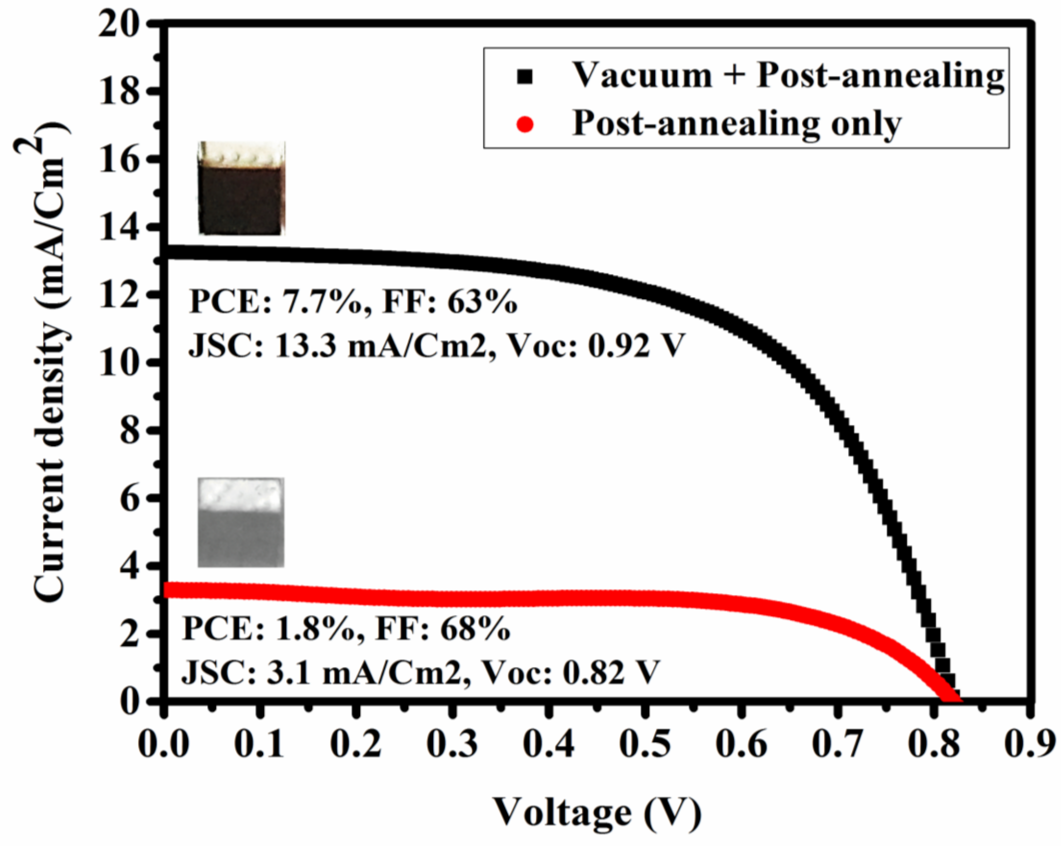


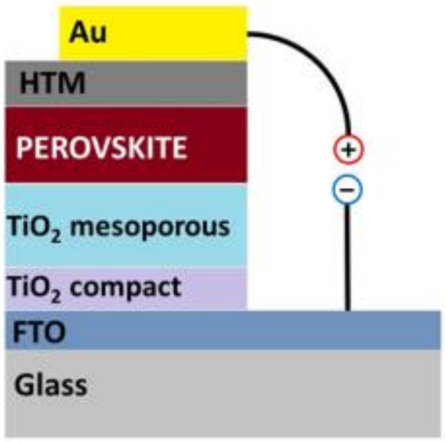
Effect of vacuum curing



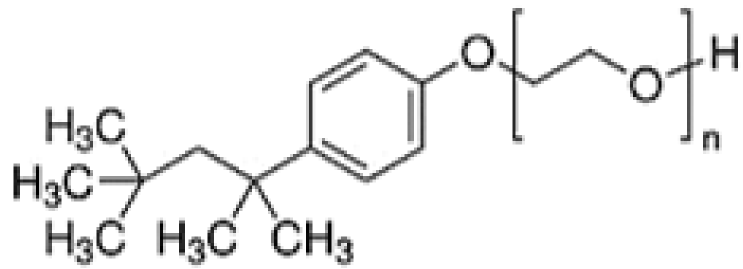
Effect of vacuum curing

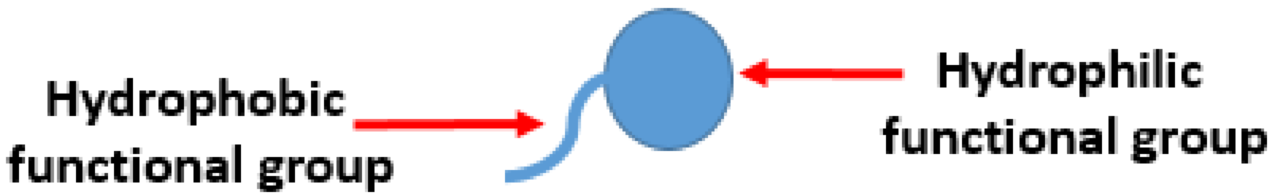
Solar cell performance



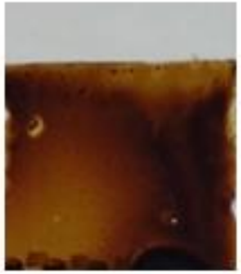


Improved layers by surfactants

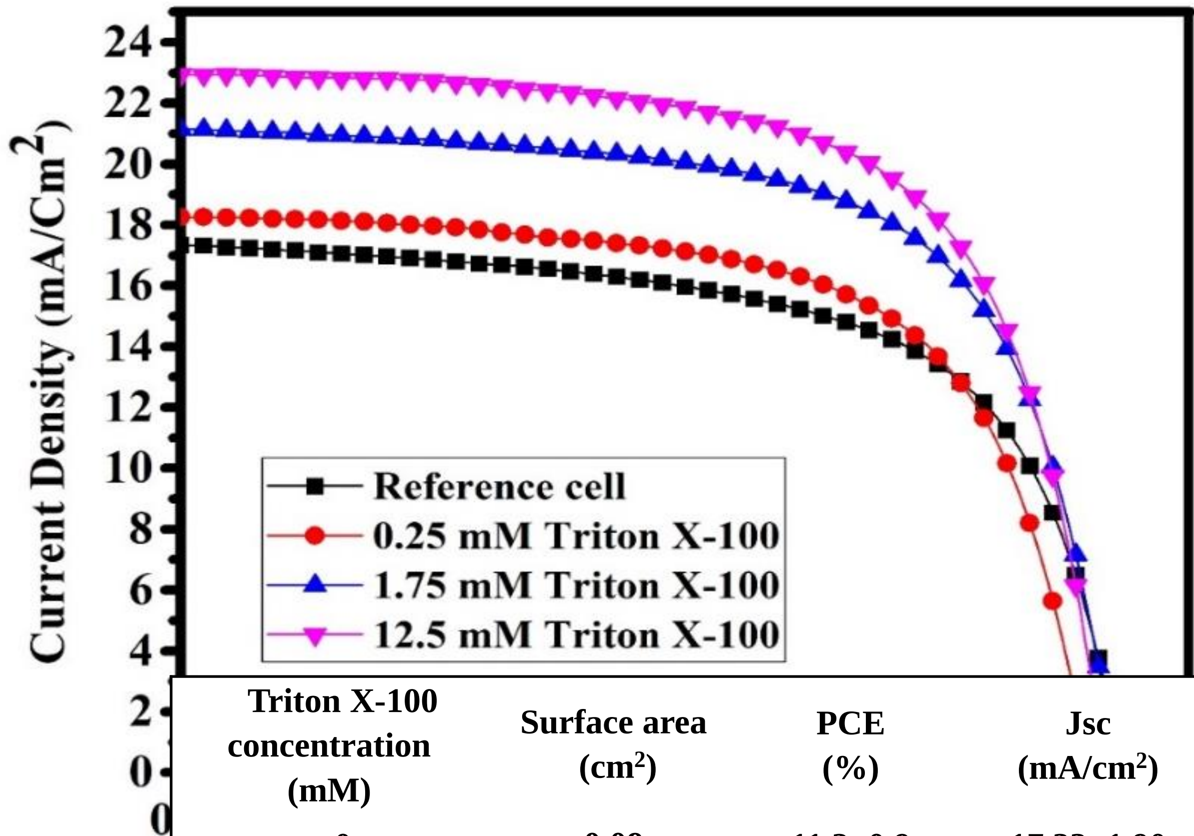


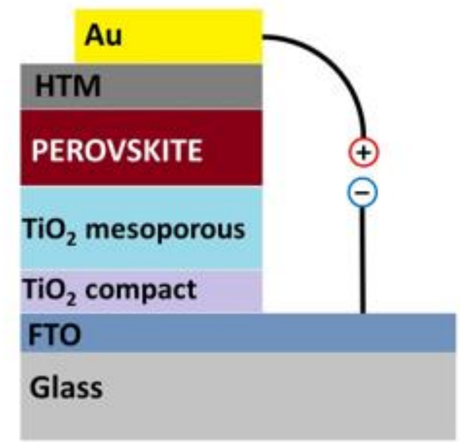


Improved layers by surfactants

	Glass substrate without heat-treatment	Glass substrate with 500 °C heat-treatment
Perovskite precursor with no surfactant		
Perovskite Precursor with 12.5 mM X-100		

Improved layers by surfactants

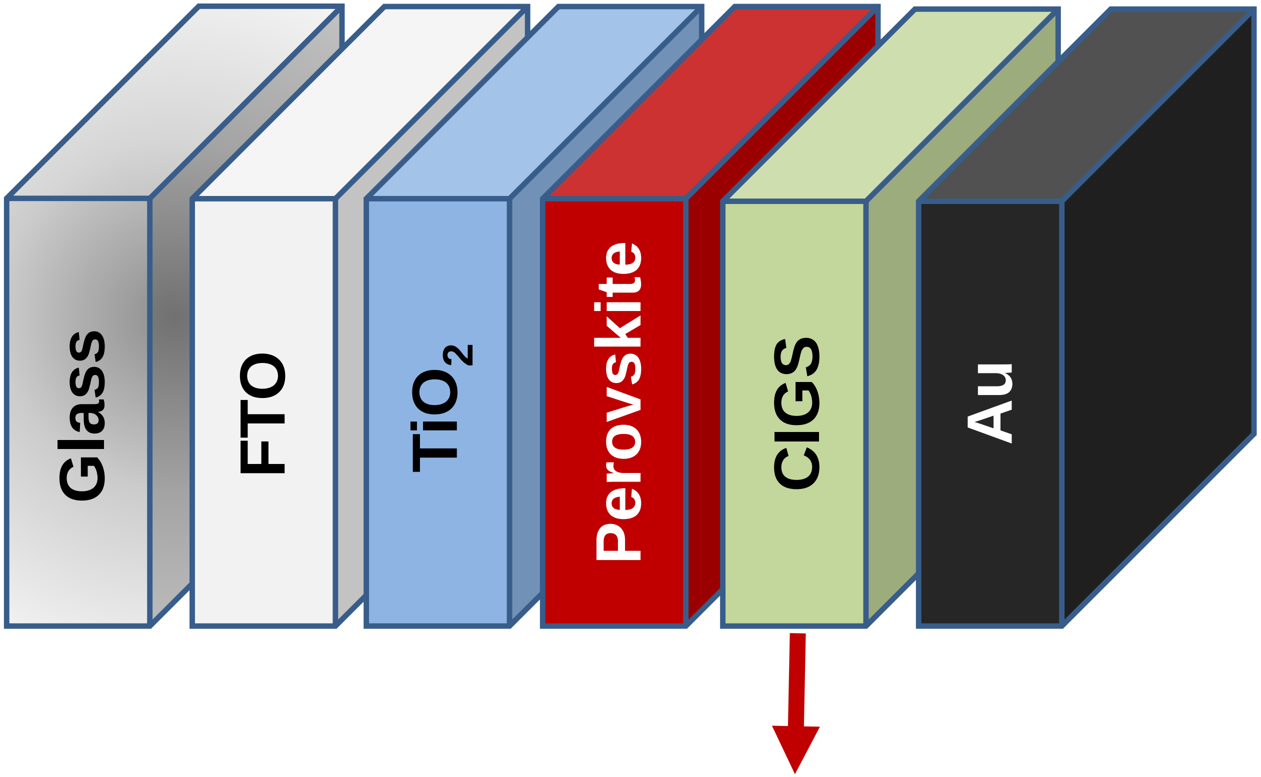




Triton X-100 concentration (mM)	Surface area (cm^2)	PCE (%)	Jsc (mA/cm^2)	Voc (V)	FF (%)
0	0.09	11.2±0.9	17.33±1.90	1.01±0.04	0.62±0.06
0.25	0.09	11.5±0.4	18.25±0.90	0.99±0.06	0.64±0.03
1.75	0.09	14.0±0.3	17.82±1.30	1.02±0.02	0.65±0.04
12.5	0.09	15.1±0.3	22.90±1.08	1.02±0.02	0.65±0.02
12.5	1.0	12.3±0.4	20.01±1.05	0.98±0.06	0.63±0.03

Application of $CuInGaS_2$ as HTM

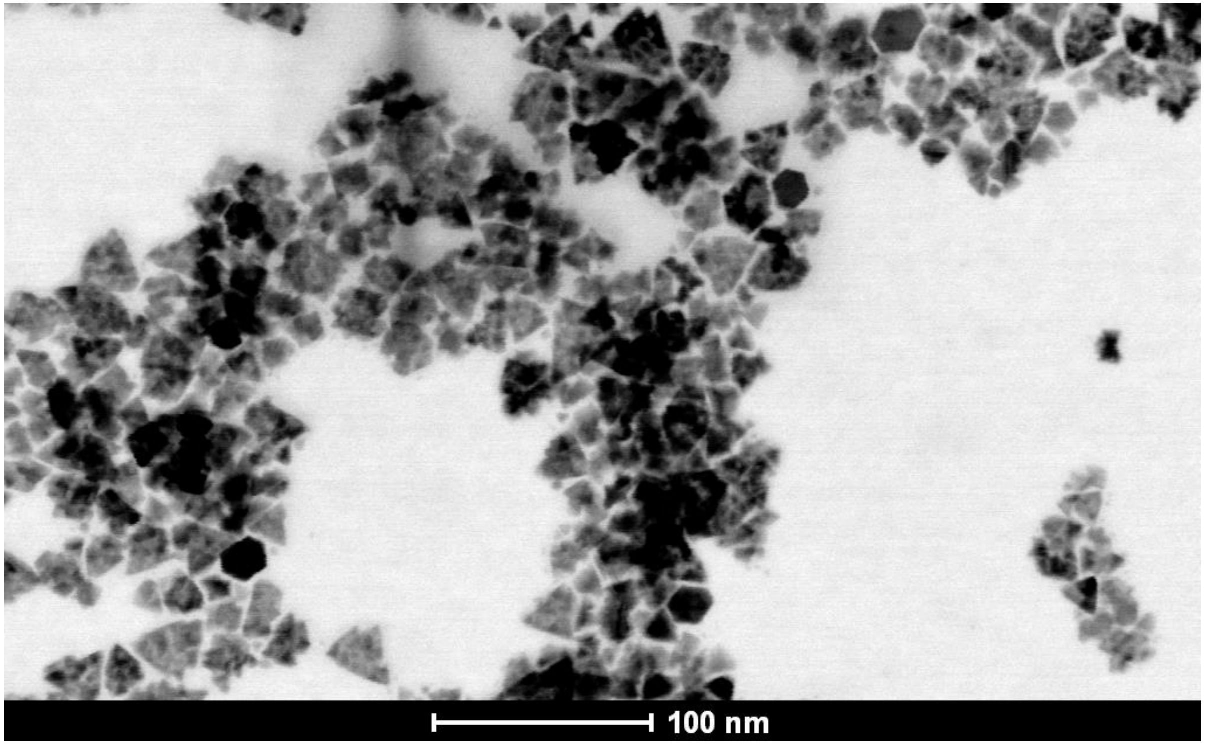
Use of $Cu(In,Ga)S_2$ Nanoparticle HTM



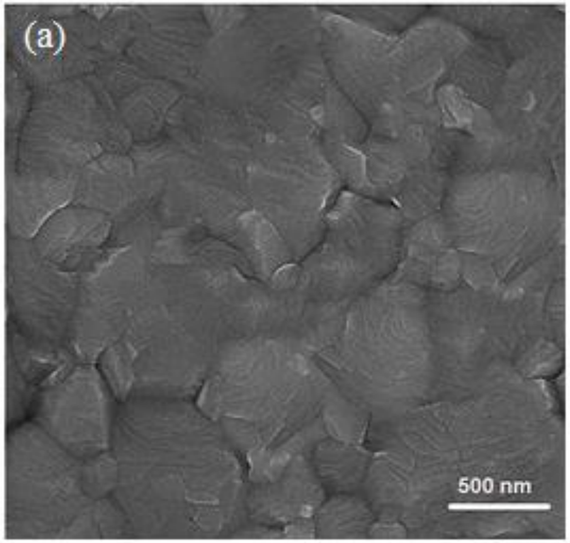
Replacing with an CIGS as an inorganic film

CIGS Nanopartciles

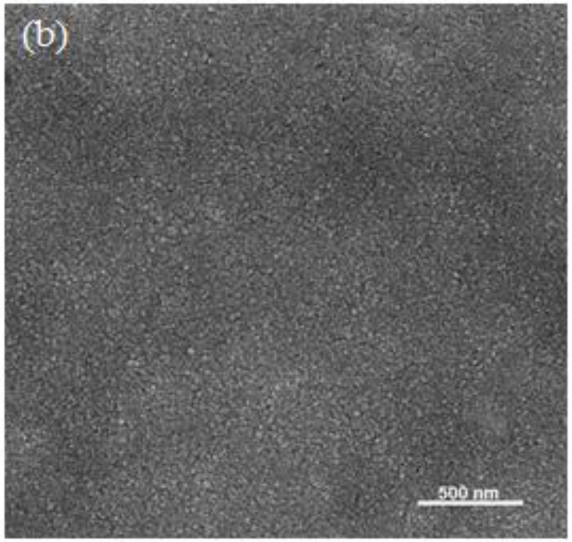
CIGS nanoparticles were synthesized in olleylamine at high temperature and dispersed in chloroform



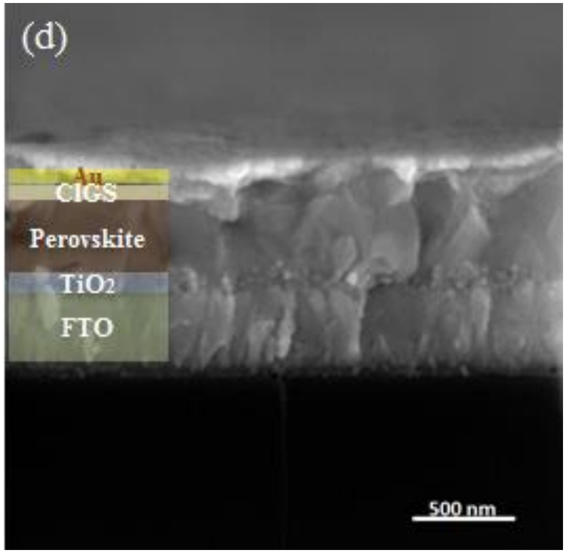
SEM images of CIGS films



Perovskite film top view

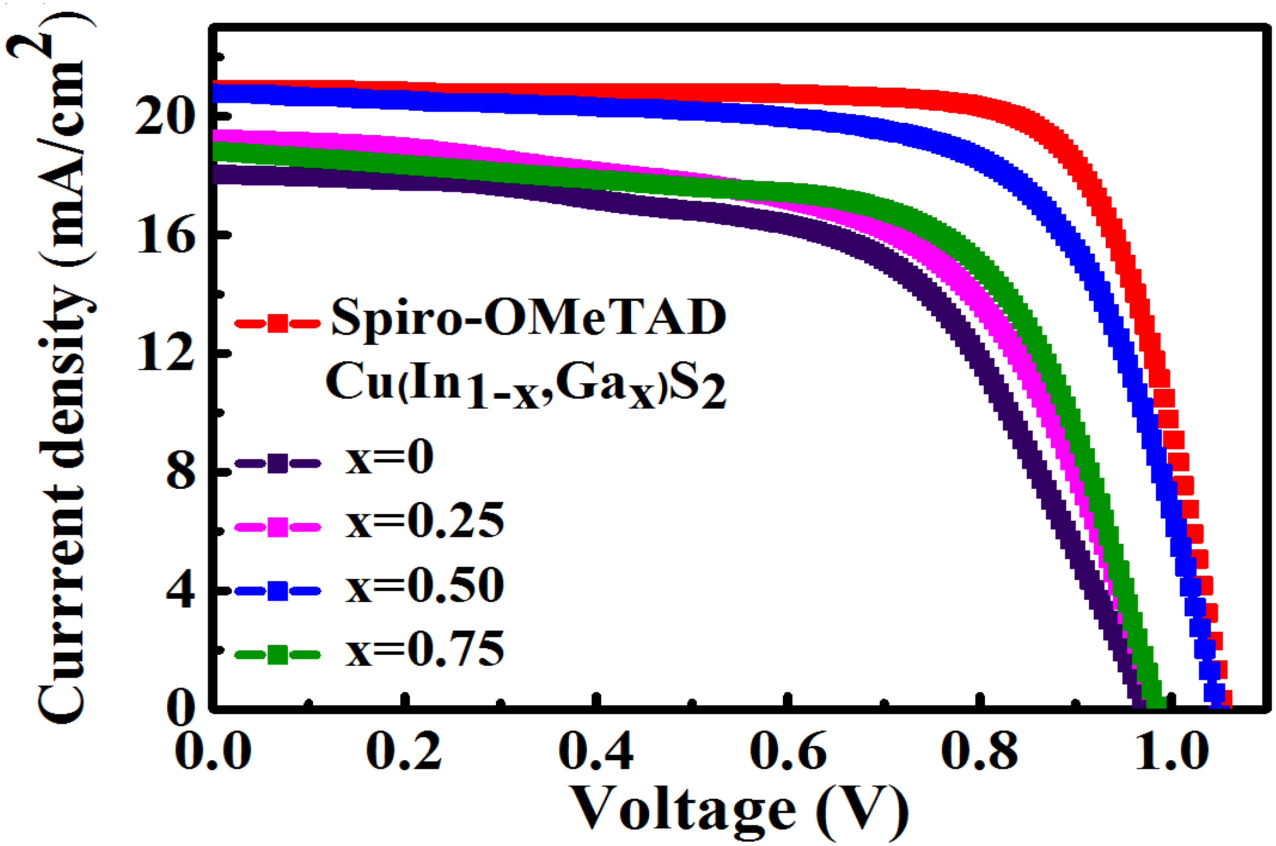


CIGS/Perovskite top view



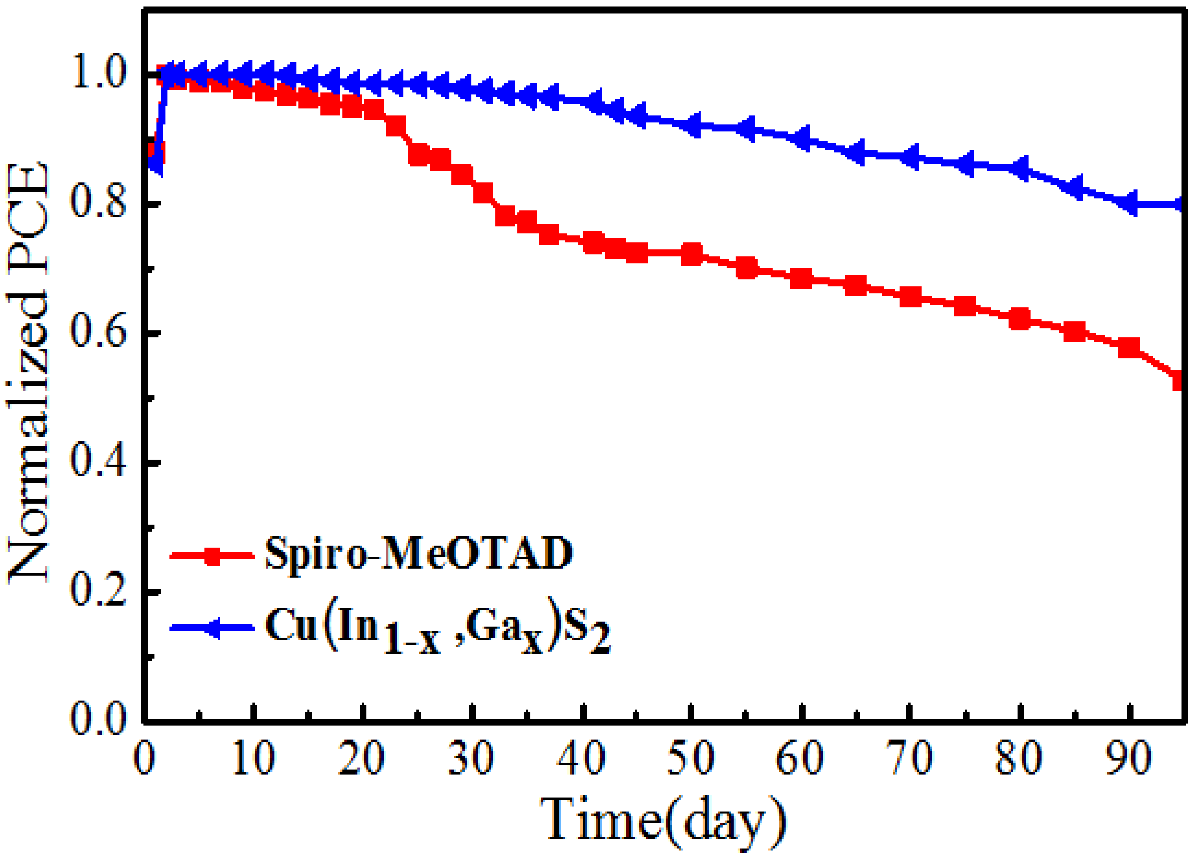
Device cross section

Device performance using CIGS HTM



Efficiency for CIGS HTM is almost equal to reference cell

Device stability test

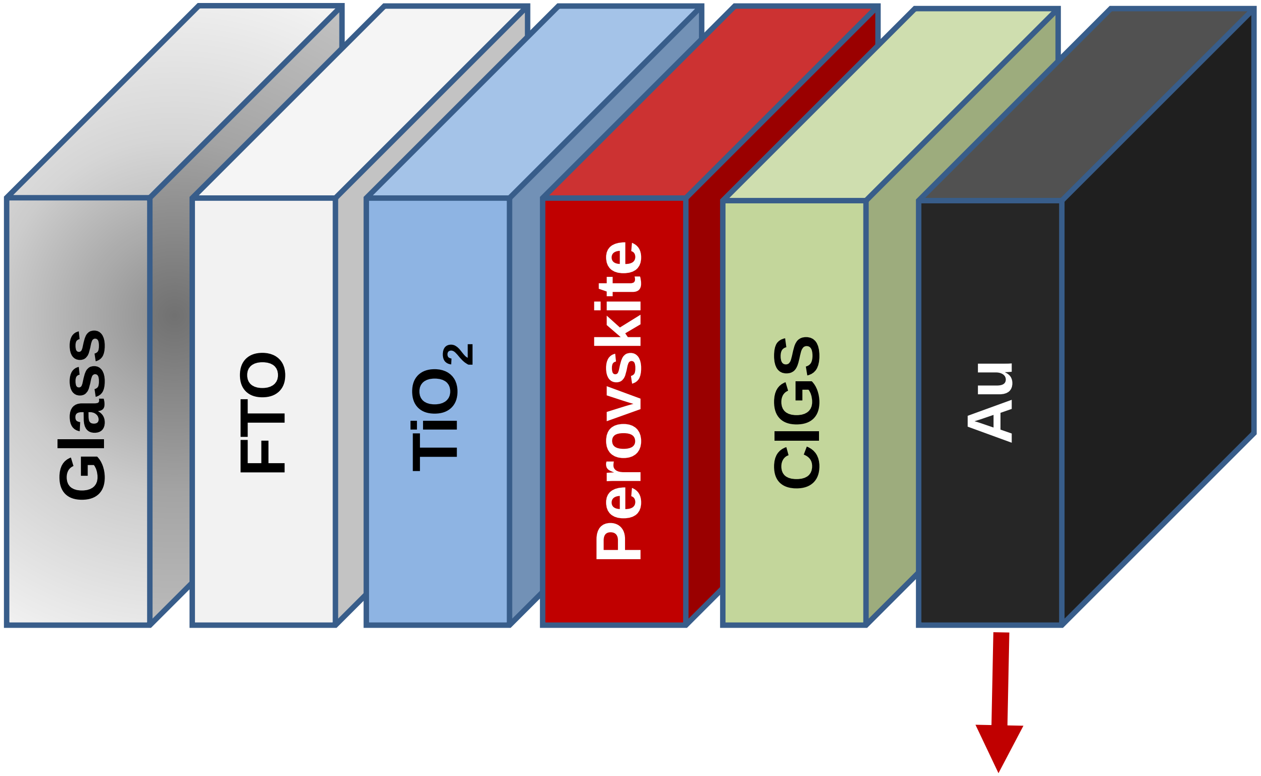


Au
CIGS
Perovskite
TiO_2
Glass/FTO

Solar cell devices with CIGS show better stability

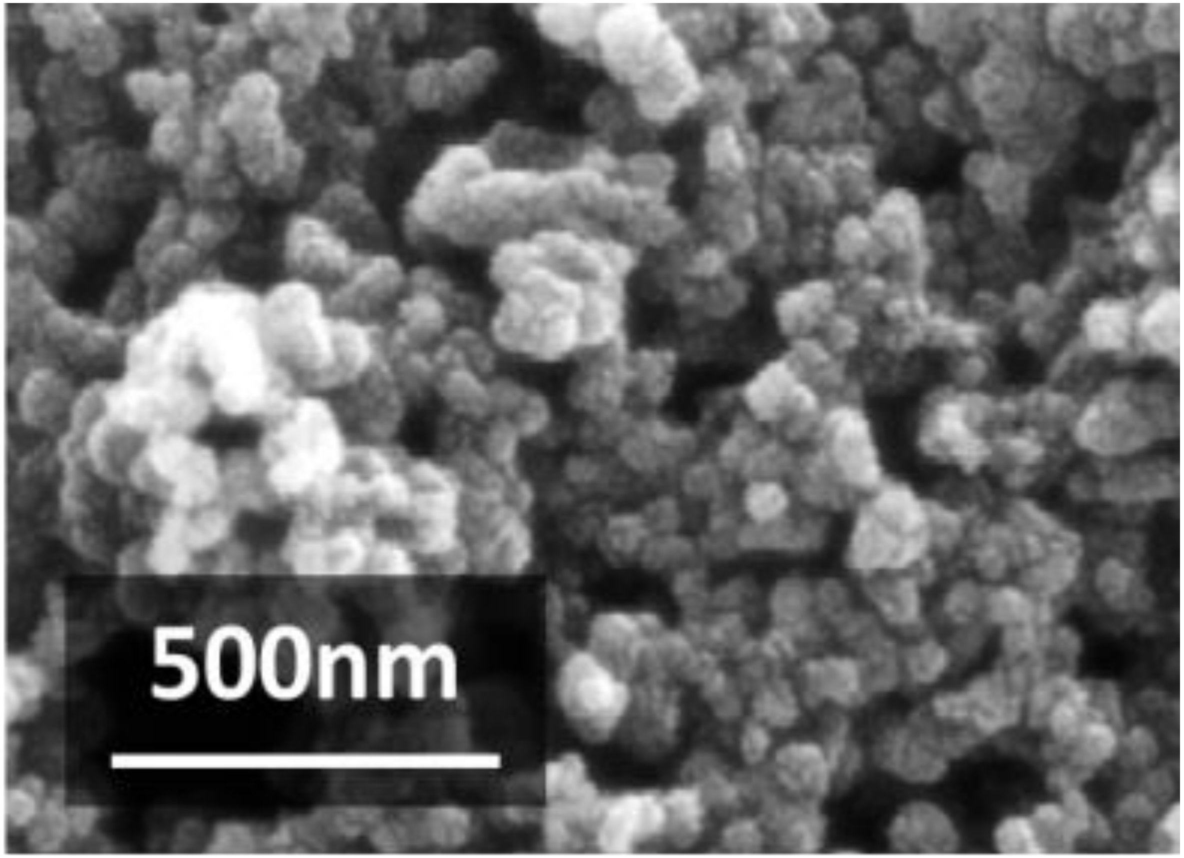
Carbon top electrode

Carbon top electrode

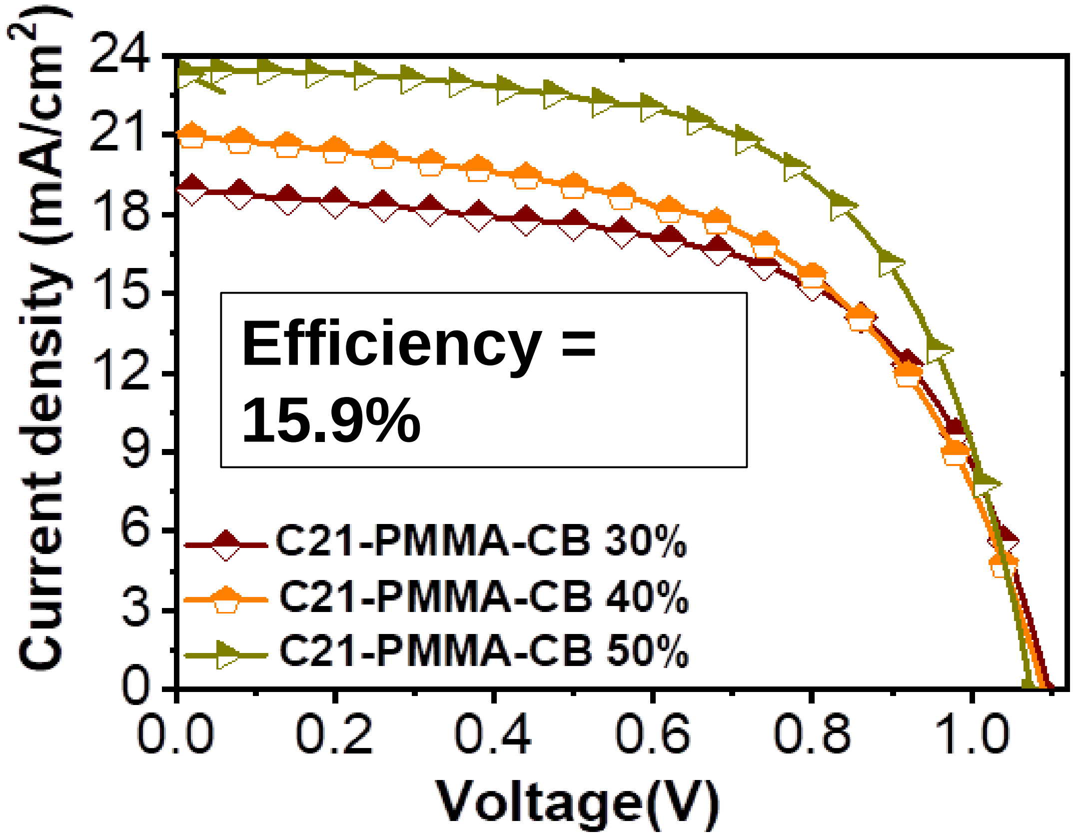


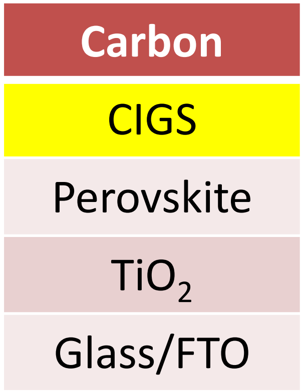
Printable electrode of carbon

Typical morphology of carbon layer

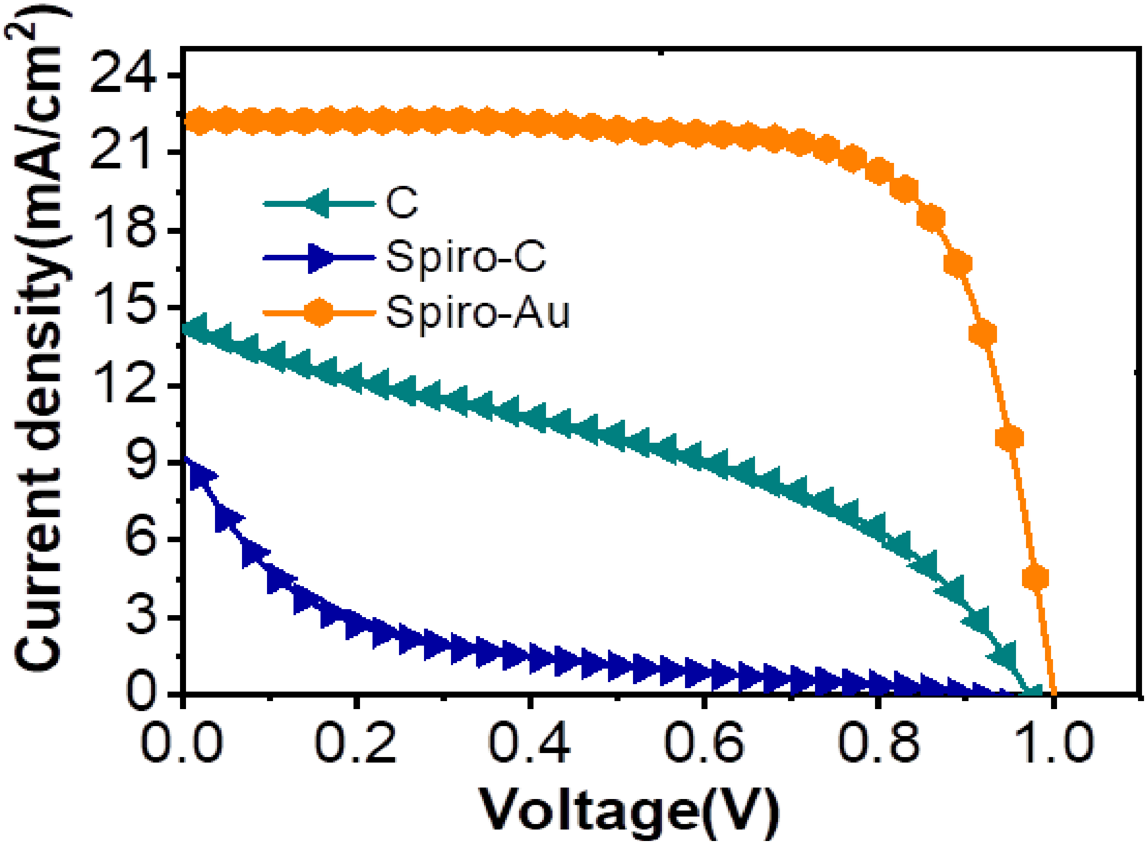


Device performance for CIS/C electrode





Carbon electrode on CIGS (HTM) shows a very good performance

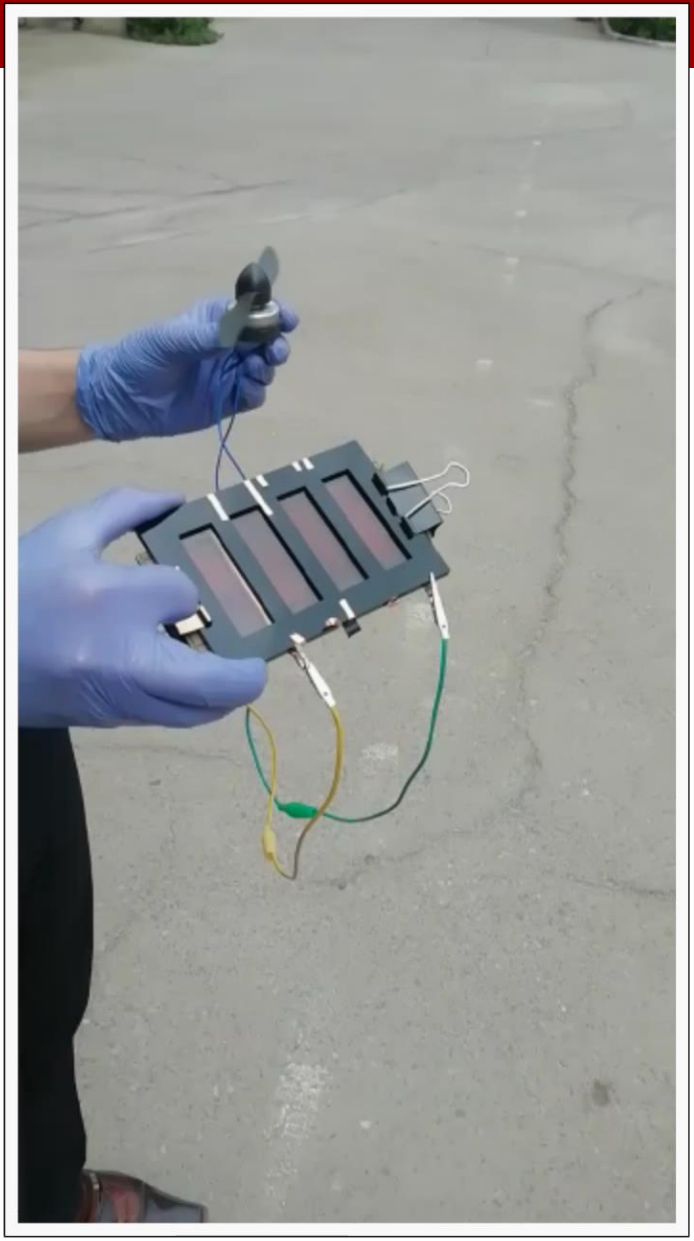


Carbon
Sp-OMeTAD
Perovskite
TiO_2
Glass/FTO

Carbon electrode works poorly with spiro-OMeTAD

Perovskite module fabrication

Au
CIS
Perovskite
TiO_2
Glass/FTO



The Last Word

- Perovskite solar cells might be a window to low cost solar energy.
- New materials/ processes are still needed for more stable devices.
- From lab-scale to module, there are still many questions to answer.

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