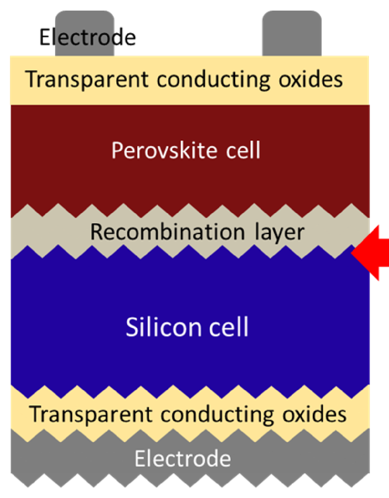
Si nanopyramid textures enabling solution-processed perovskite for tandem solar cell application

Motivation

Double-sided textured tandem solar cells

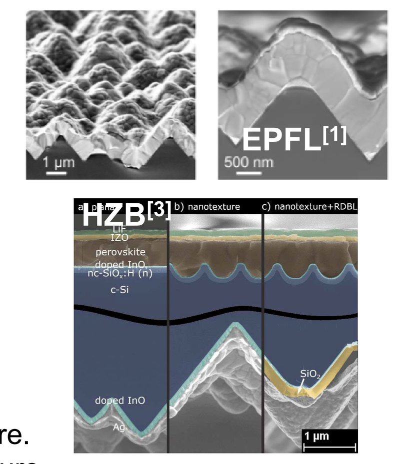


- ✓ EPFL: 31.25%[1]
- ✓ Longi: 33.9%[2]

Micron-sized Si pyramids + evaporated perovskite

- ✓ HZB: 29.8%[3]

Si nanopyramids by nanoimprint lithography + spin-coated perovskite



Merits

- Reduced light reflection at the perovskite/Si interface.

Problems

- Technically complex/expensive methods for the conformal growth of perovskite on micrometer-sized Si pyramid texture.
- Complex fabrication process of nano-sized Si pyramid texture by lithography.

Aim of this work

Development of Si nanopyramids compatible with solution processed perovskite

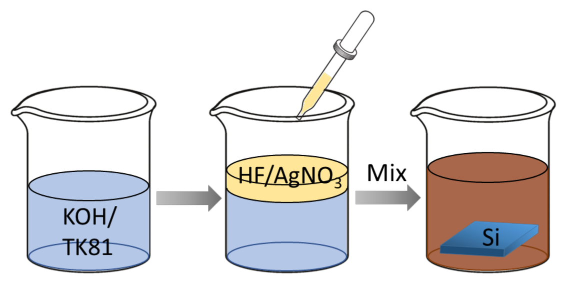
Our technology

One step wet etching process to fabricate Si nanopyramids

We investigated the effect of varying Si texture size in nanoscale on the performance of perovskite/Si tandem cells.

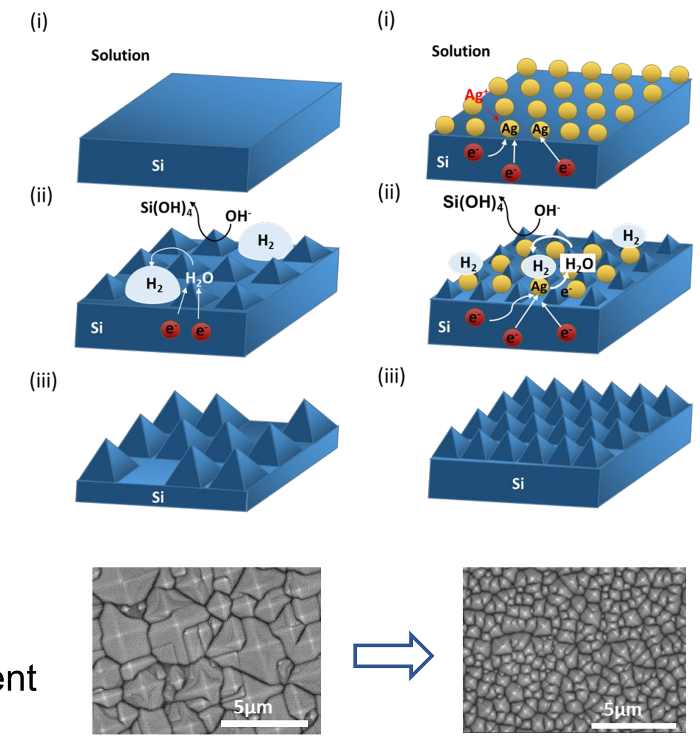
Experiments

Ag-assisted one-step alkaline etching [4]



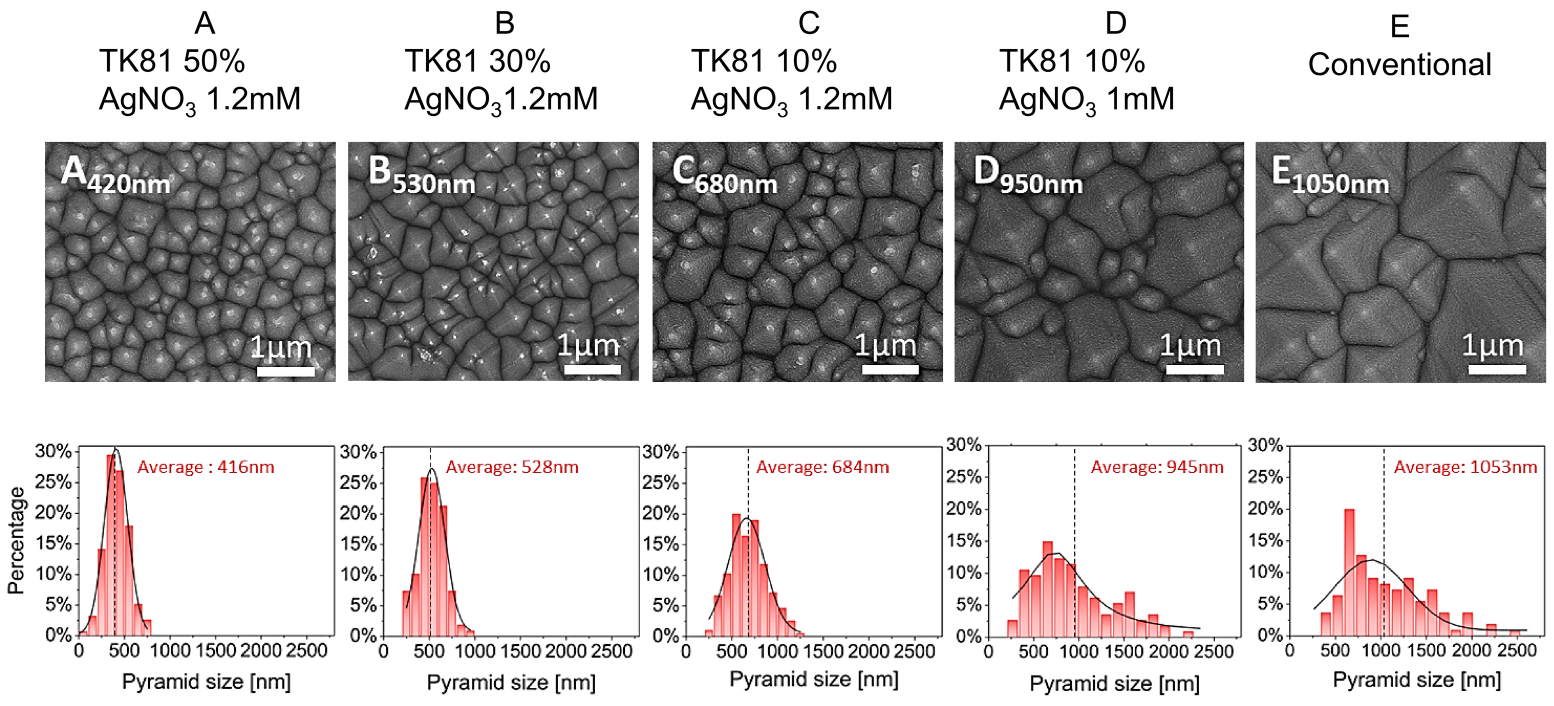
	A	B	C	D	E(Conventional)
TK81 concentration	TK81 50%	TK81 30%	TK81 10%	TK81 10%	TK81 10%
$AgNO_3$ concentration	1.2mM	1.2mM	1.2mM	1.0mM	0mM
Temperature	70℃	70℃	70℃	70℃	80℃
Time	15min	5min	15min	15min	15min

TK81: moderate etching speed / H_2 bubbles detachment
$AgNO_3$: etching mask / H_2 bubbles detachment



Results (I)

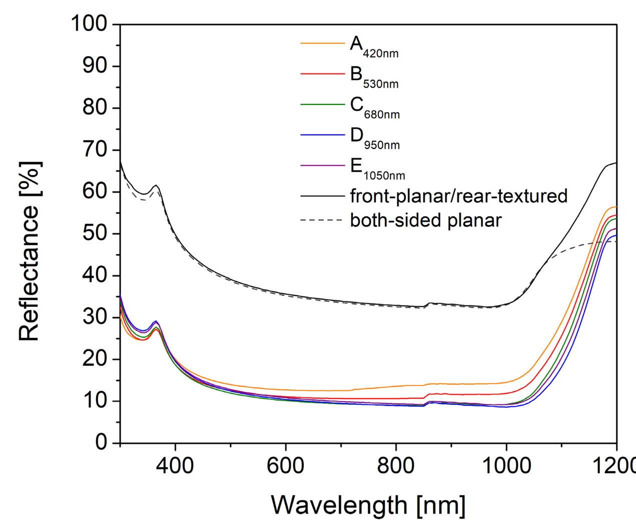
Fabrication of Si nanopyramid texture [5]



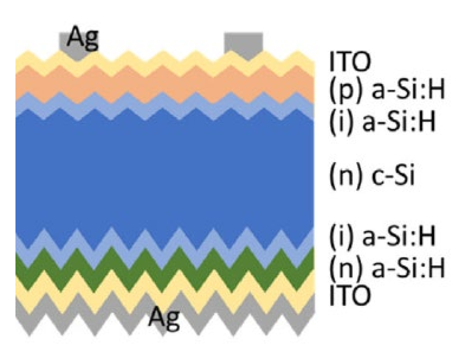
- The size of the Si pyramid texture gradually decreases as the concentration of surfactant TK81 and $AgNO_3$ increases.
- The size distribution also narrows with the reduction of texture size.

Performance of silicon heterojunction (SHJ) single-junction solar cells [5]

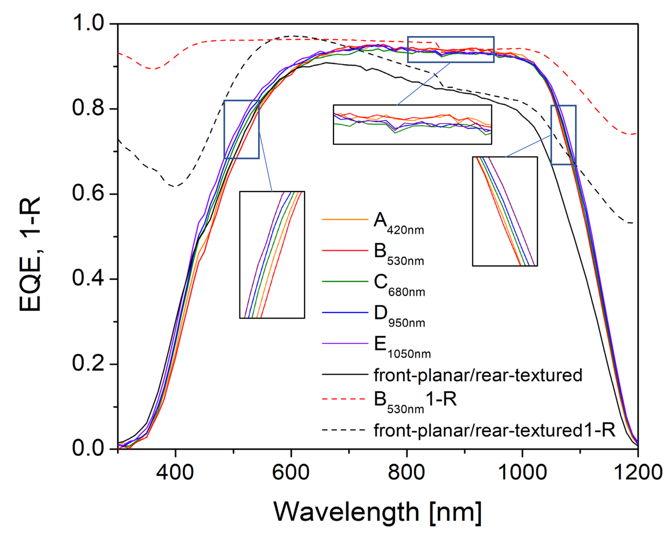
Reflectance spectra



SHJ device structure



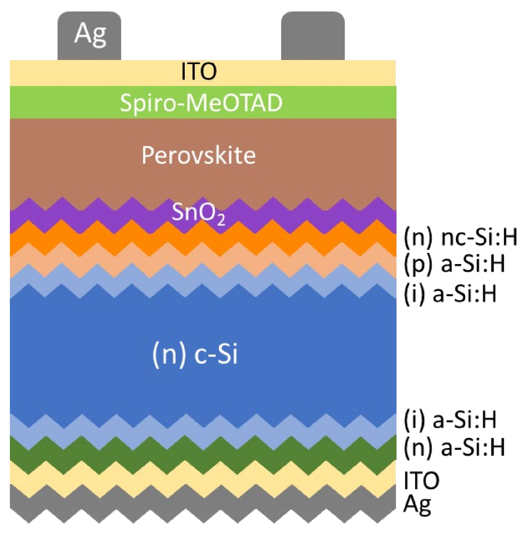
External quantum efficiency (EQE)



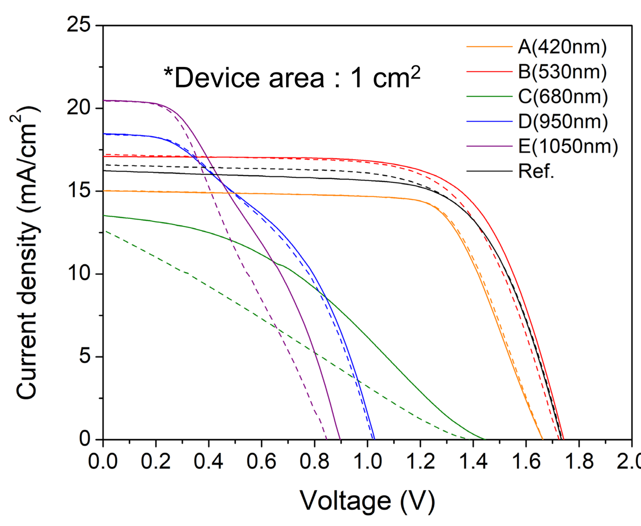
- Reflectivity increases with decreasing Si pyramid size.
- Nevertheless, nanometer-sized Si pyramids show effective anti-reflective properties in device structure (w. ITO), resulting in comparable cell performance with the reference cell.[4,5]

Results (II)

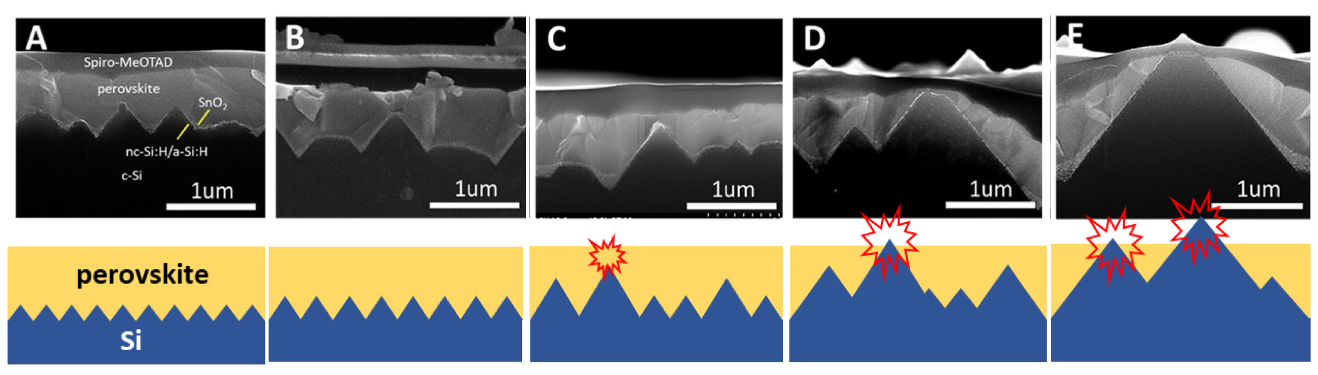
Tandem cell performance [5]



Current density-voltage (J-V) curves

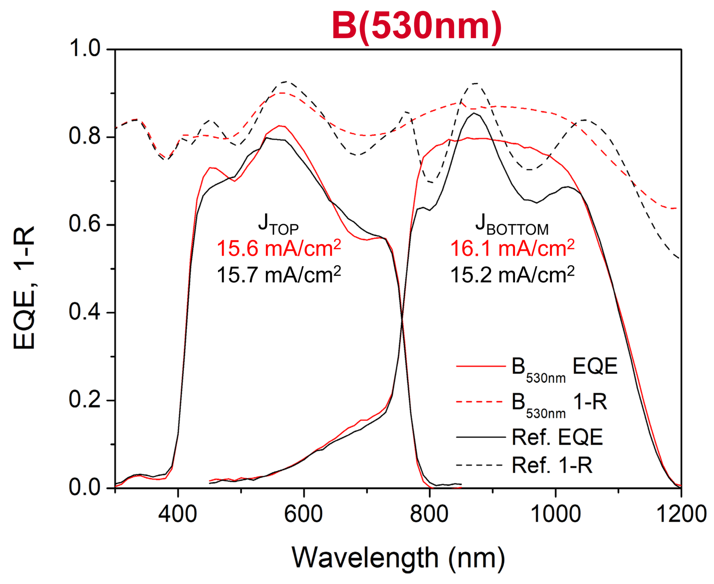


Cross-sectional SEM images



External quantum efficiency (EQE)

B(530nm)



- Low V_{OC} caused by electrical shunting due to the non-uniform perovskite layers on large Si texture.
- A substantial increase in V_{OC} from 0.89 to 1.75 V with decreasing the texture size from ~1000 to ~500 nm.
- B(530nm) shows both high V_{OC} and J_{SC} (0.8 mA cm^{-2} higher compared to the reference cells).
- Degraded passivation quality of a-Si:H layers when deposited on small-sized Si texture (A(420nm)), strongly depending on the PECVD conditioning.

- The light in-coupling effect of the Si nanopyramid texture leads to a gain in the J_{bottom} by ~1 mA cm^{-2}.
- J_{SC} is further improved after applying the AR(MgF_2) layer, leading to a 22.1% efficient tandem solar cell (J_{SC}=18.8 mA cm^{-2}, V_{OC}=1.693 V, FF=0.692, area=1.0 cm^2).
- J_{SC} is still limited by the large reflection loss caused by refractive index mismatching at the interface between the ITO (n~2.0) and the thick spiro-MeOTAD (n~1.6) layers.

Conclusions

- Double-sided Si nanopyramid textures with an average size of 400-900 nm and improved size distribution were fabricated using an original Ag-assisted alkaline etching method and applied in the bottom cell of perovskite/Si tandem cells.
- Excessive size of pyramid causes the severe shunting and thickness inhomogeneity in the perovskite absorber layer, resulting in the degradation in the performance of tandem cells.
- The optimum Si texture size is found to be 400-500 nm with perovskite layer thickness around 500 nm, by which the perovskite top cell can be processed entirely by the conventional spin-coating method.

➢ **The both-sided nanopyramid Si texture shows great potential for the cost-effective tandem cell manufacturing using the solution-based top cell process with enhanced J_{bottom} and efficiency compared with the commonly used single-sided textured Si.**

References

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Yuqing Li,[1,2] Hitoshi Sai,[1] Calum McDonald,[1] Zhihao Xu,[1] Yasuyoshi Kurokawa,[2] Noritaka Usami,[2] Takuya Matsui [1,2]
[1] Renewable Energy Research Center, AIST, Japan, [2] Nagoya University, Japan