

Techno-Economic Challenges and Opportunities

Behind the Perovskite-Silicon Alliance

Table.1 Consumptions and prices of perovskite component materials in 2T tandem modules (1 m²)

Material	Consumption	Price	Utilization rate	Cost (\$/m ²)
ITO (Electrode)	0.02 cm ³	3.86 \$/cm ³	0.8	0.096
NiO _x	0.03 cm ³	18.6 \$/cm ³	0.8	0.696
MeO-2PACz	0.0028 g	70.0 \$/g	0.95	0.211
ethanol	2.8 mL	0.02 \$/mL	0.95	0.051
PbI ₂	2.77 g	0.43 \$/g	0.9	1.319
CsBr	0.4 g	0.93 \$/g	0.9	0.413
FAI	0.64 g	1.29 \$/g	0.95	0.866
FABr	0.47 g	2.00 \$/g	0.95	0.989
MAcI	0.06 g	0.02 \$/g	0.95	0.001
MASCN	0.08 g	0.10 \$/g	0.95	0.008
IPA	17 mL	0.02 \$/mL	0.95	0.358
LiF	0.005 g	0.21 \$/g	0.5	0.002
C ₆₀	0.034 g	21.4 \$/g	0.5	1.457
SnO _x (TDMASn)	0.2 g	5.71 \$/g	0.5	2.286
ITO (tunnel layer)	0.1 cm ³	3.86 \$/cm ³	0.8	0.482
Total				9.236

The prices are derived from the market prices of perovskite materials in China PV market.

Table.2 Costs of equipment used for perovskite component in 2T tandem module manufacturing line (1GW/year).

Equipment	Throughput (m ² /h)	Investment (\$)	Power Usage (kW)	Operation time (h/year)
Sputter Chamber (ITO/NiO _x)	200	3000000	500	7140
Slot-die Coater (SAMs)	100	1800000	150	7140
Thermal Evaporator (perovskite)	60	2000000	450	7933
Slot-die Coater (perovskite)	100	1800000	150	7140

Thermal Evaporator (LiF/C ₆₀)	60	2000000	450	7933
Atomic Layer Deposition (SnO _x)	100	4500000	450	7140
Sputter Chamber (ITO)	200	3000000	500	7140

When the module efficiency is 35%, achieving an annual production capacity of 1 GW requires a manufacturing line throughput of 326 m²/h. The prices and power usage of the equipment are provided by the manufacturers and references. ¹

Table.3 Consumptions and prices of perovskite component materials in 4T tandem modules (1 m²)

Material	Consumption	Price	Utilization rate	Cost (\$/m ²)
FTO Glass	1 m ²	7.14 \$/m ²	0.98	7.286
NiO _x	0.03 cm ³	18.6 \$/cm ³	0.8	0.696
MeO-2PACz	0.0028 g	70.0 \$/g	0.95	0.211
ethanol	2.8 mL	0.02 \$/mL	0.95	0.051
FAI	0.62 g	1.29 \$/g	0.95	0.839
CsI	0.058 g	1 \$/g	0.95	0.061
MABr	0.075 g	2 \$/g	0.95	0.158
PbI ₂	1.48 g	0.43 \$/g	0.95	0.668
PbBr ₂	0.47 g	1 \$/g	0.95	0.495
DMF	4.2 mL	17.1 \$/L	0.95	0.076
DMSO	1.05 mL	35.7 \$/L	0.95	0.039
LiF	0.005 g	0.21 \$/g	0.5	0.002
C ₆₀	0.034 g	21.4 \$/g	0.5	1.457
SnO _x (TDMASn)	0.2 g	5.71 \$/g	0.5	2.286
ITO (tunnel layer)	0.1 cm ³	3.86 \$/cm ³	0.8	0.482
junction box	1	2.86 \$	0.98	2.915
Total				17.724

Table.4 Costs of equipment used for perovskite component in 4T tandem module manufacturing line (1GW/year).

Equipment	Throughput (m ² /h)	Investment (\$)	Power Usage (kW)	Operation time (h/year)
Substrate Cleaner	200	700000	50	7578
P1 Laser	50	300000	15	8660
Sputter Chamber (NiO _x)	200	3000000	500	7578
Slot Die Coater	100	1800000	150	7578

(SAMs)				
Thermal Evaporator (LiF/C ₆₀)	60	2000000	450	8420
Atomic Layer Deposition (SnO _x)	100	4500000	450	7578
P2 Laser	50	600000	17	8660
Sputter Chamber (ITO)	200	3000000	500	7578
P3 Laser	50	300000	17	8660
P4 Laser	40	450000	17	8660

When the module efficiency is 33%, achieving an annual production capacity of 1 GW requires a manufacturing line throughput of 357 m²/h. The prices and power usage of the equipment are provided by the manufacturers and references. ¹

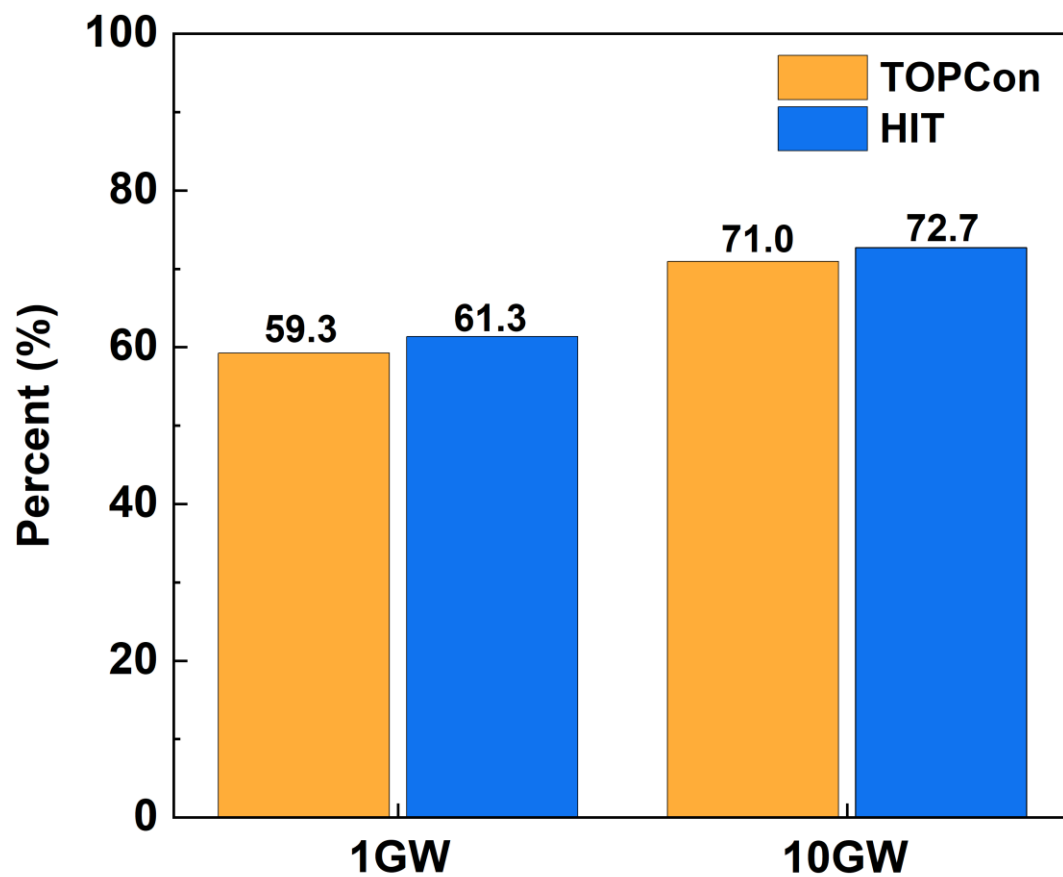


Fig.1 Cost share of the silicon bottom cell in the total perovskite/silicon tandem module cost at different production scales.

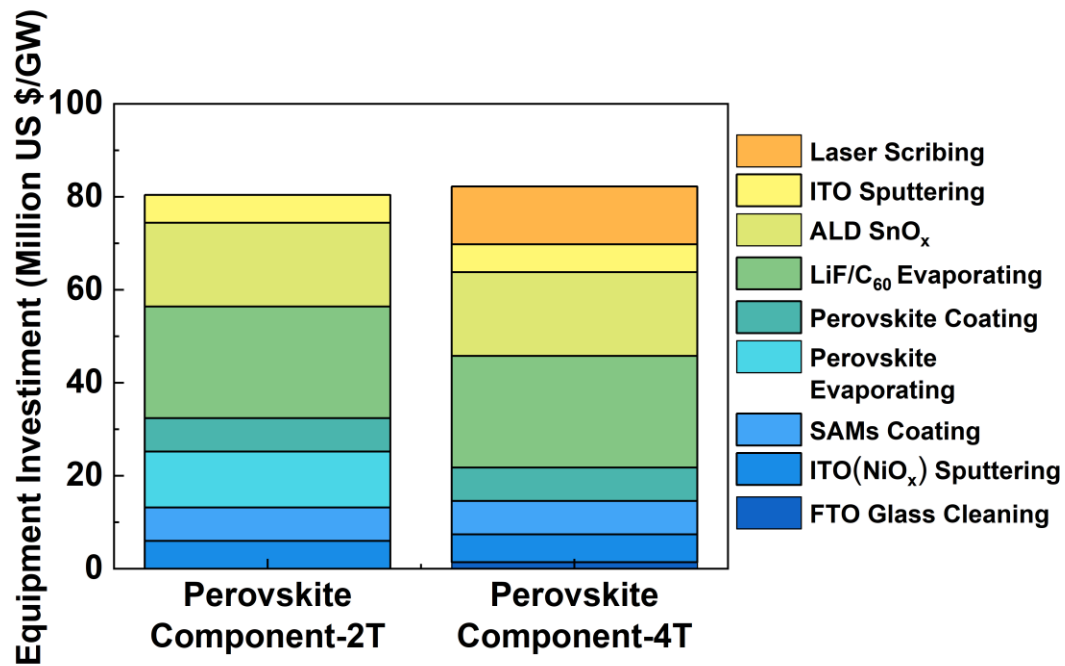


Fig.2 Comparison of equipment investment of perovskite component in 2T and 4T tandem modules.

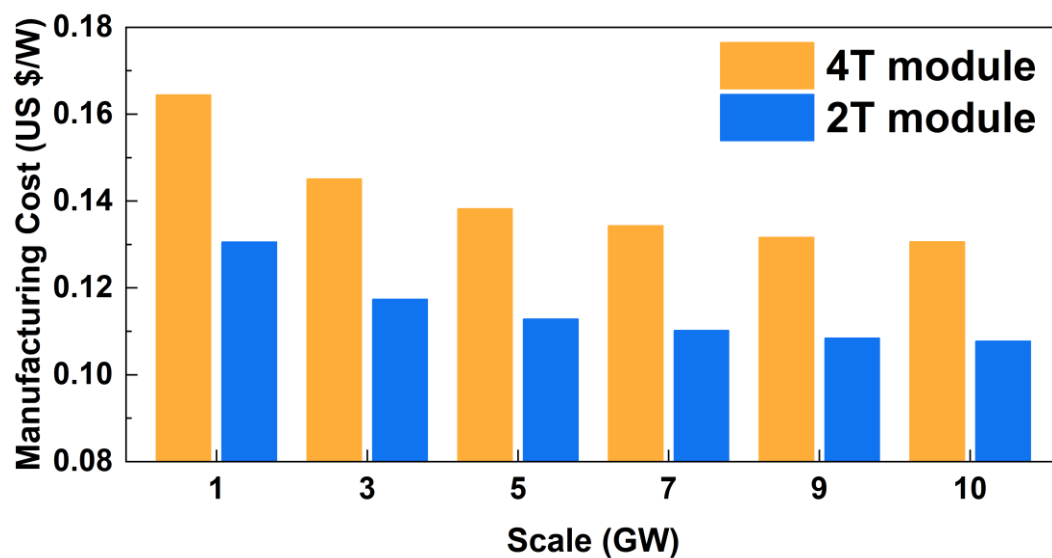


Fig.3 Dependence of tandem module manufacturing costs on manufacturing scale.

REFERENCES

- 1 Cordell, J. J., Woodhouse, M. & Warren, E. L. Technoeconomic analysis of perovskite/silicon tandem solar modules. *Joule* **9** (2025). <https://doi.org/10.1016/j.joule.2024.10.013>