Silicon Photovoltaics

David L. Young

Senior Scientist, Group Research Manager

High Efficiency Crystalline Photovoltaics

Photo by Josh Bauer / Bryan Bechtold, NREL 82067

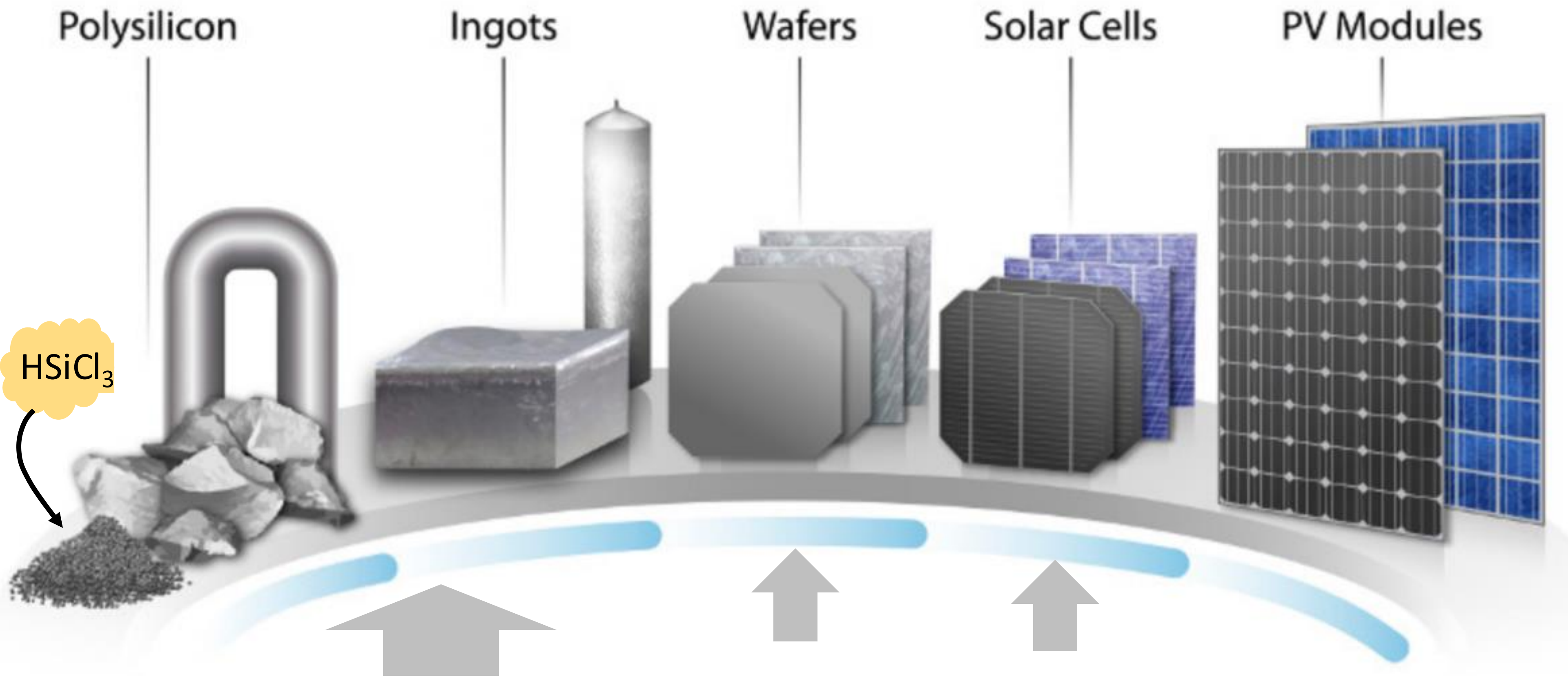
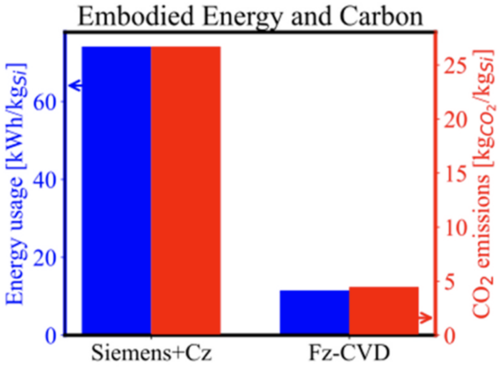


Image credit: NREL

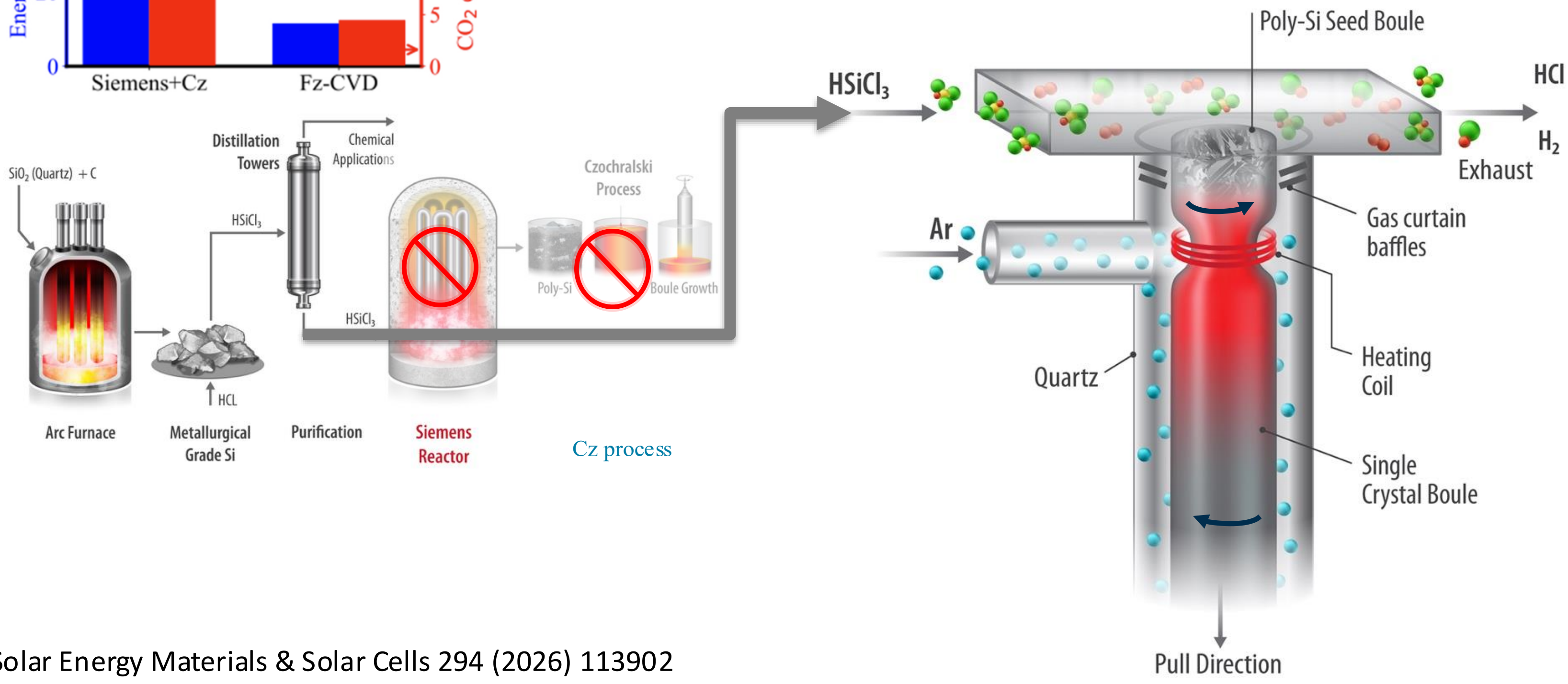


Low embodied energy and carbon, high lifetime silicon boules via a combined chemical vapor deposition/float zone process

David L. Young [a,*], Ethan Young [a], Xin He [a], Aubry Kleinsorge [a,b], Malik Hassanaly [a], Mark Loboda [c], Kevin L. Schulte [a,**]

[a] National Renewable Energy Laboratory, Golden, CO, USA
[b] University of Missouri-Kansas City, Kansas City, MO, USA
[c] Hemlock Semiconductor Corp., H

FZ-CVD Reactor



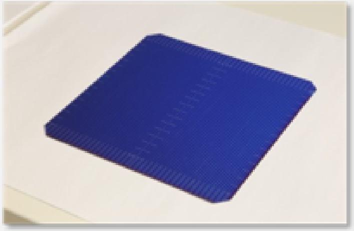
Solar Energy Materials & Solar Cells 294 (2026) 113902

Presented at SiliconPV 2025, Silicon Workshop 2025

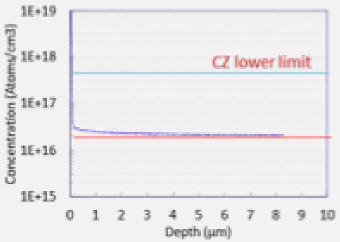
Epitaxial Wafers

Epinex® Wafers: NexWafe Key Differentiators

Efficiency

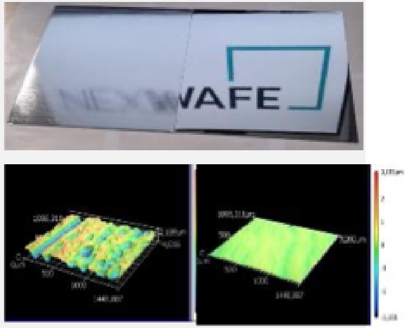


Oxygen Content



Resistivity Control

Super Flat Surfaces



24.44% efficiency reached on M6 heterojunction solar cells. Test cells also made for tandem and space applications

20-40x lower oxygen content than Cz wafers

Controllable resistance. Dialed in on the Process Recipe

Smooth surfaces: Ideal for Perovskite liquid process applications

Corning is starting up equipment & will be ramping production through year end. They are capable of n & p type wafers up to G12 size.

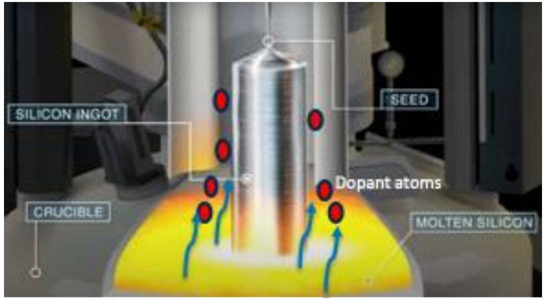
Wafer Plant update

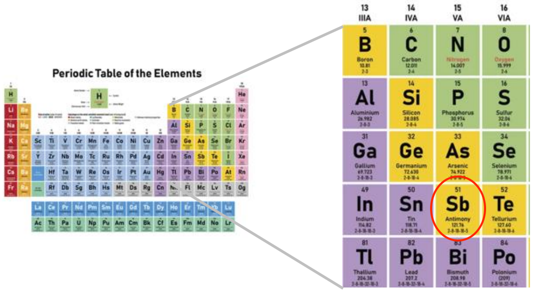
Shivani Polasani

Product Technology Manager

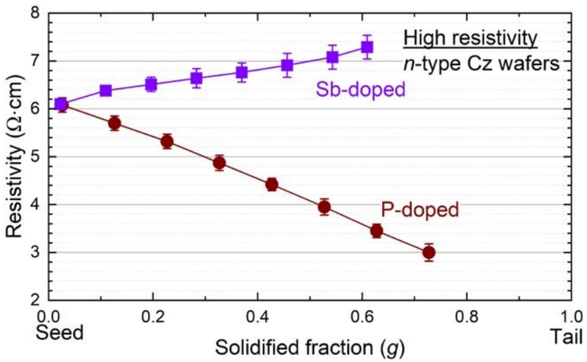
Solar Tech, LLC

Recharged-Cz, n-type Antimony-doped Si wafers



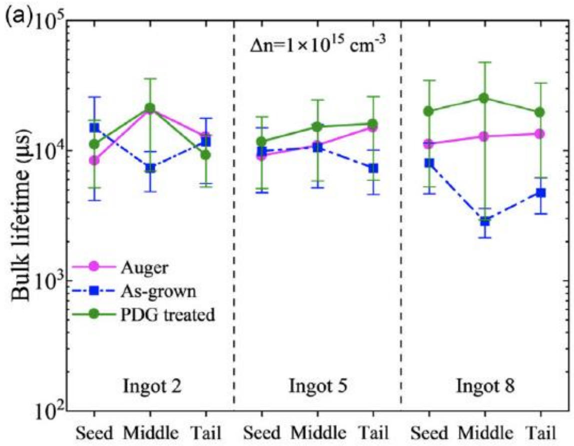


- Control of Sb evaporation from the melt controls the resistivity in the ingot



Sb-doped ingots have:

- Uniform doping
  - seed-to-tail
  - First-to-last ingots
- Low oxygen (no thermal donors activated during high-Temp processing)



- High bulk lifetimes:
  - Seed-to-tail
  - First-to-last ingots
- *Improved gettering*
- *Improved mechanical strength*

Kashizadeh et al., Solar RRL, 2025, 9:e2500335
S. Dubois et al, SiliconPV 2025 –Oxford (UK).
Basnet et al, SiliconPV 2025 –Oxford (UK).

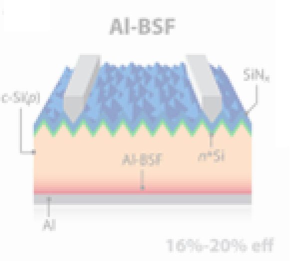
Longi https://www.youtube.com/watch?v=TV6TgHtzgCQ

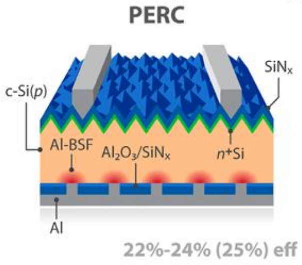
Silicon Solar Cell Road Map

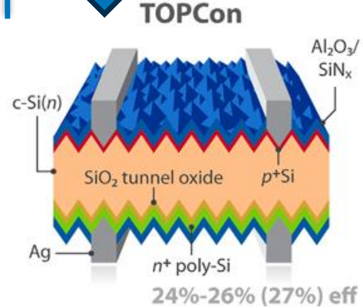
p-type wafers | n-type wafers

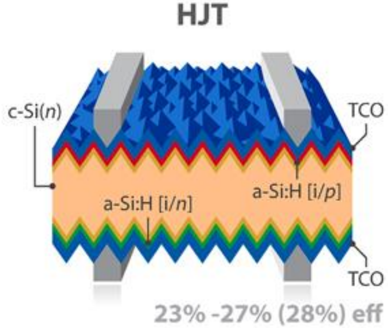
We are here

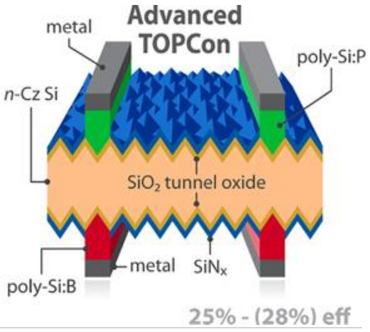
Some new US PV manufacturers have started here.

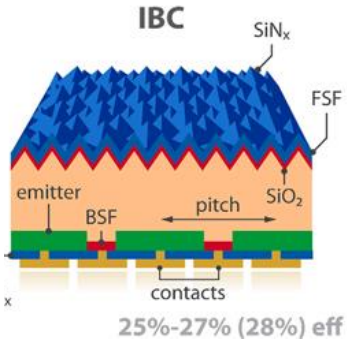


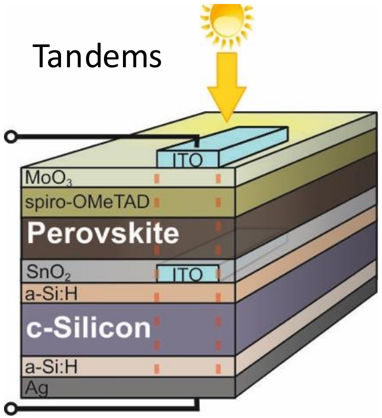












30+ % eff

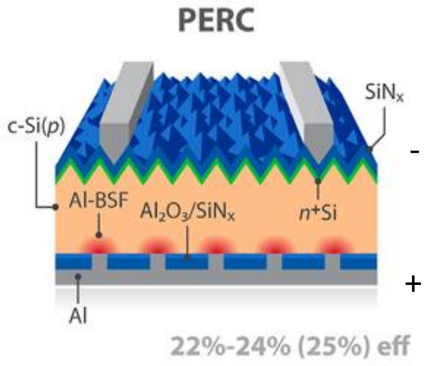
PK/Si tandems:

- "Stability is No.1 problem to solve"
- TRL 3 moving to TRL 4 (9 levels)
- 10x capex wrt TOPCon

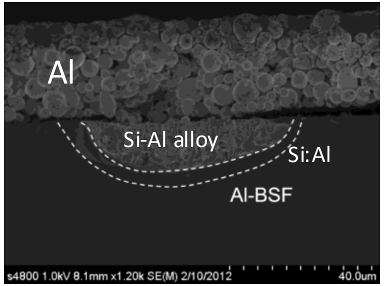
Trina Solar, SiliconPV 2025

Nature Energy **volume 10**, pages 934–940 (2025)

Passivated Emitter Rear Contact (Junction)

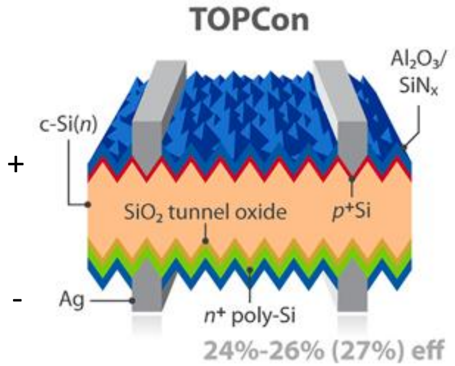


- p-type wafer (B, Ga doped)
- Phosphorus diffused emitter
- Al_2O_3/SiN_x rear passivation
- Al-Back Surface Field point contacts

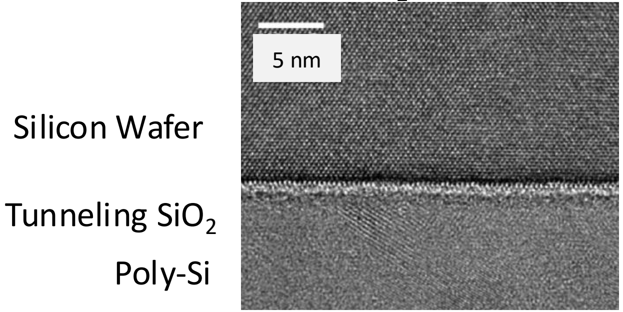


DOI: 10.1109/JPHOTOV.2013.2282893

Tunneling Oxide Passivated Contact

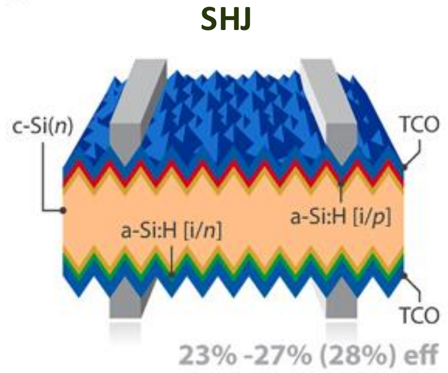


- n-type wafer (P, Sb doped)
- Boron diffused emitter
- Al_2O_3/SiN_x front passivation
- Poly-Si/SiO_2 back contact

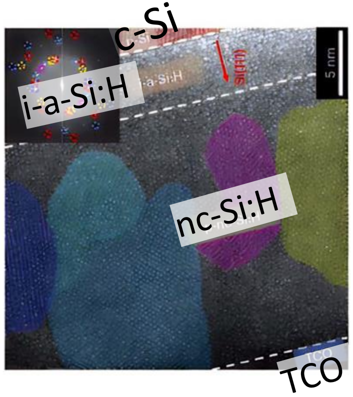


Scientific Reports **volume 14**, Article number: 17307 (2024)

Silicon Heterojunction



- n-type wafer (+ high T gettering)
- a-Si/µc-Si layers (front/back) (Low T)
- TCO (front/back)



Nature Energy **volume 8**, pages 789–799 (2023)

Longi's highest efficiency silicon solar cell: 27.81%

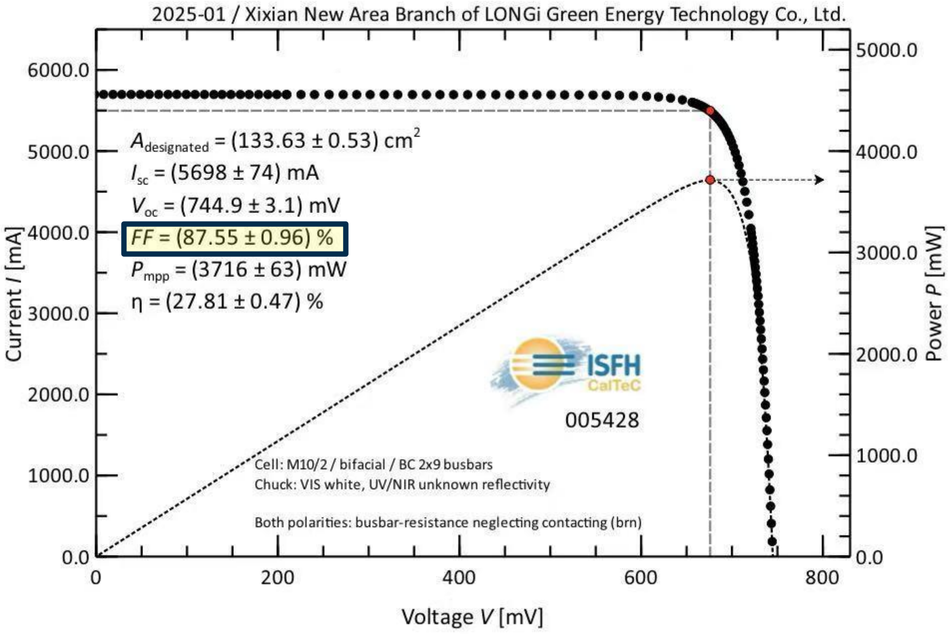


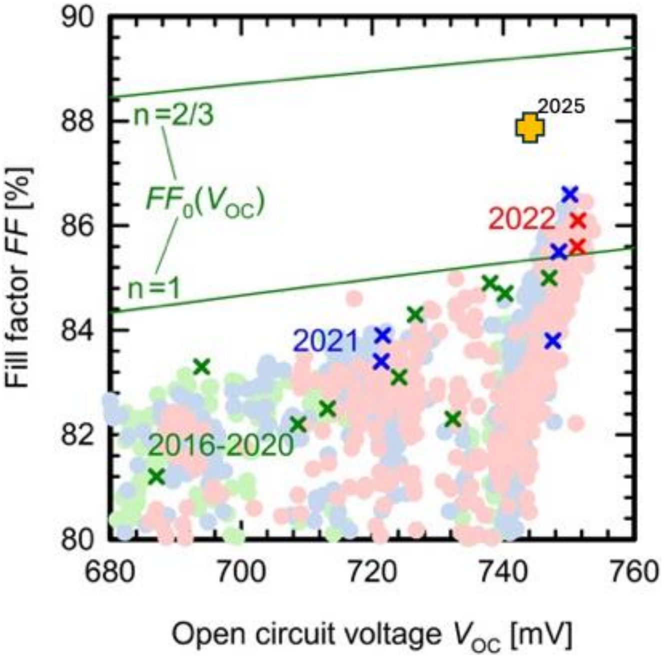
Fig. 2: Plot of the measured current-voltage characteristics under standard test conditions.

"Each one-point increase in cell efficiency translates into more than a 5% reduction in system costs." - Longi

Each 1%-point increase in efficiency = 2.8% decrease in LCOE

Each 0.1% decrease in degradation rate = 11.5% decrease in LCOE

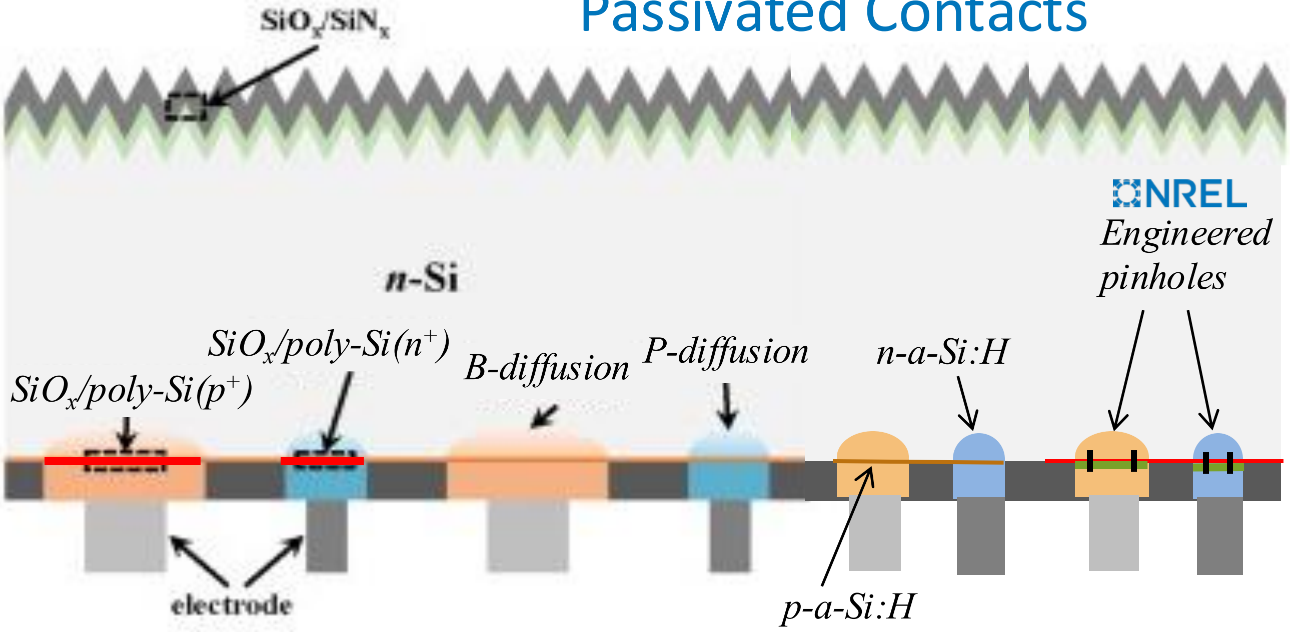
- Auger-Meitner limited bulk lifetime allows high FF
- τ_{bulk} > 15 ms



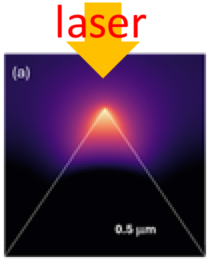
Bothe et al, IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 13, NO. 6, NOVEMBER 2023 787

https://www.nrel.gov/pv/lcoe-calculator/ PVCellTech 2025

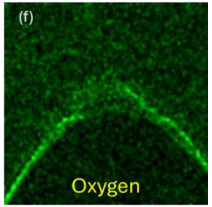
Passivated Contacts



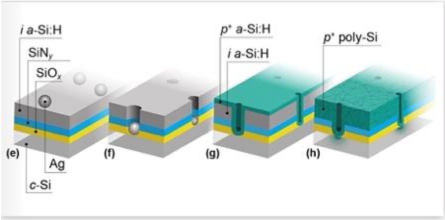
1)



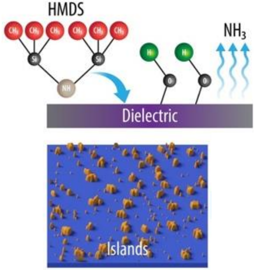
Pinhole in oxide layer



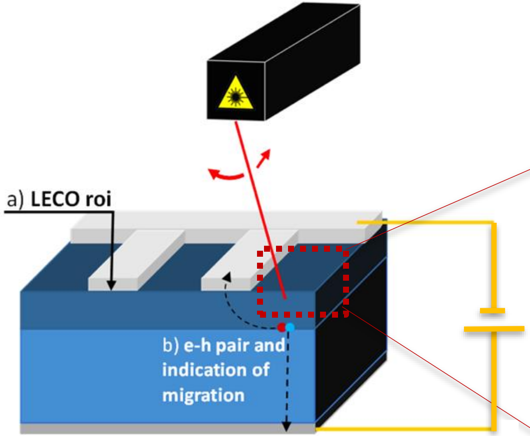
2) Metal-assisted chemical etching

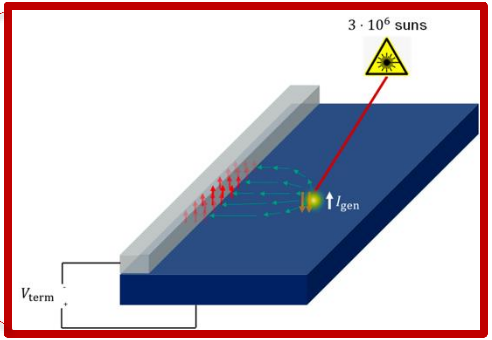


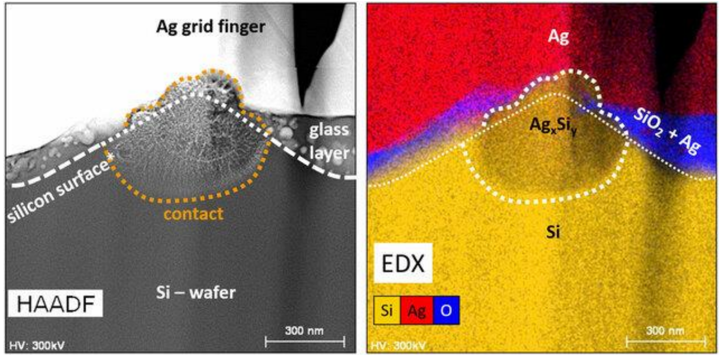
3) Self-assembled monolayer mask



Laser Enhanced Contact Optimization (LECO)







Apply reverse bias voltage to the cell.

High intensity laser is scanned across cell to generate carriers.

Local Joule heating at pyramid tip produces Ag-Si alloy.

Benefits:

- No need for selective emitter to achieve good contact resistivity. A uniform, high sheet resistance emitter is lower cost and provides better passivation (low-pressure BCl_3).
- No need for Al to contact heavy doped B emitter, no corrosion.
- Lower firing temperature, better passivation.

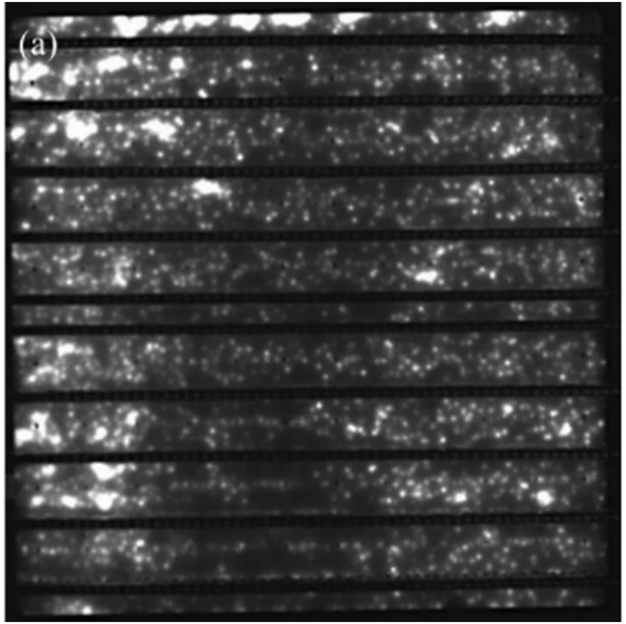
https://doi.org/10.1109/JPHOTOV.2021.3129362.

https://doi.org/10.1051/epjpv/2023004

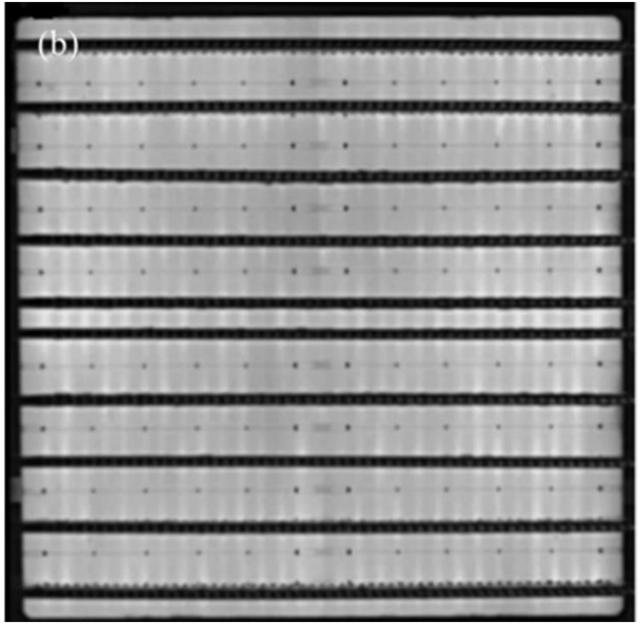
Dramatic improvement in electroluminescence after LECO treatment

- Low firing temperature
- Few contact points

- Improved contacts



LECO



Post-firing

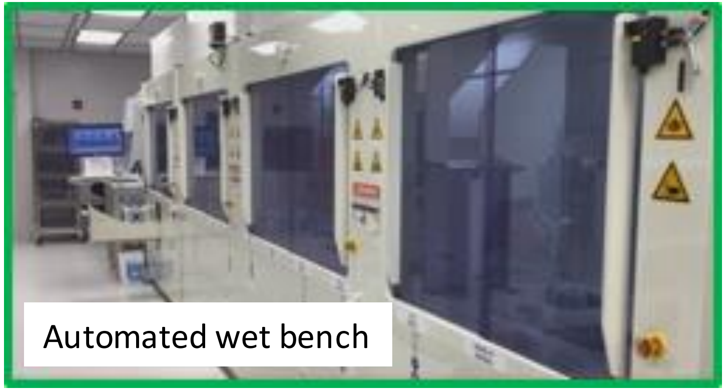
Post-LECO

Degradation studies: mixed, but on-going

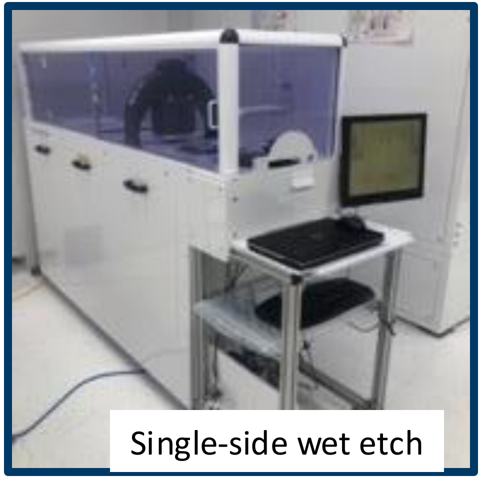
Works on PERC, TOPCon (Ag, Cu), Poly-Si

R&D facilities for silicon processing: open for collaboration

Dedicated Silicon Cleanroom – wafer level processing tools


Automated wet bench


4-tube diffusion furnace


Single-side wet etch


3-tube low-pressure CVD and PECVD furnace

10-Chamber PECVD Cluster Tool

Gases:

SiH_4
BF_3
B_2H_6
PH_3
GeH_4
NH_3
CF_4
SF_6
C_2H_6
H_2
N_2
Ar

- Atomic Layer Deposition (ALD)
- Laser processing
- Metal deposition (evap, e-beam, screen printing)