Physics of PV

Schottky-barrier and MIS solar cells

(Metal-Insulator-Semiconductor)

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NSE 290 Final Presentation

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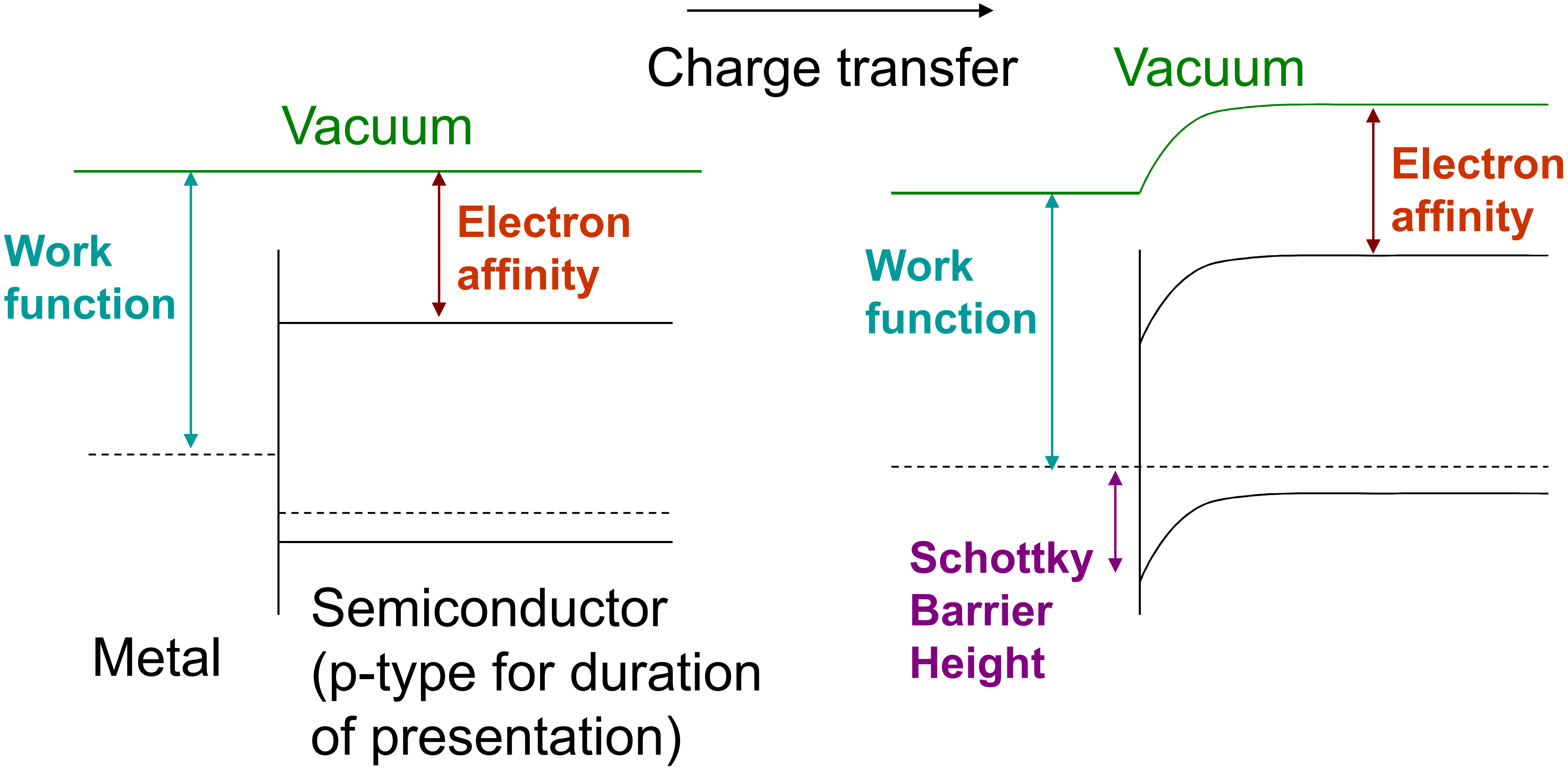
Outline

- Background on Schottky barriers
- Dark and light I-V curves, and effect on photovoltaic efficiency
- Cell manufacturing process: Advantages and disadvantages relative to p-n junctions
- Current status, pilot-plant production, future potential

Background on Schottky barriers



Charge transfer

Vacuum

Work function

Electron affinity

Metal

Semiconductor
(p-type for duration
of presentation)

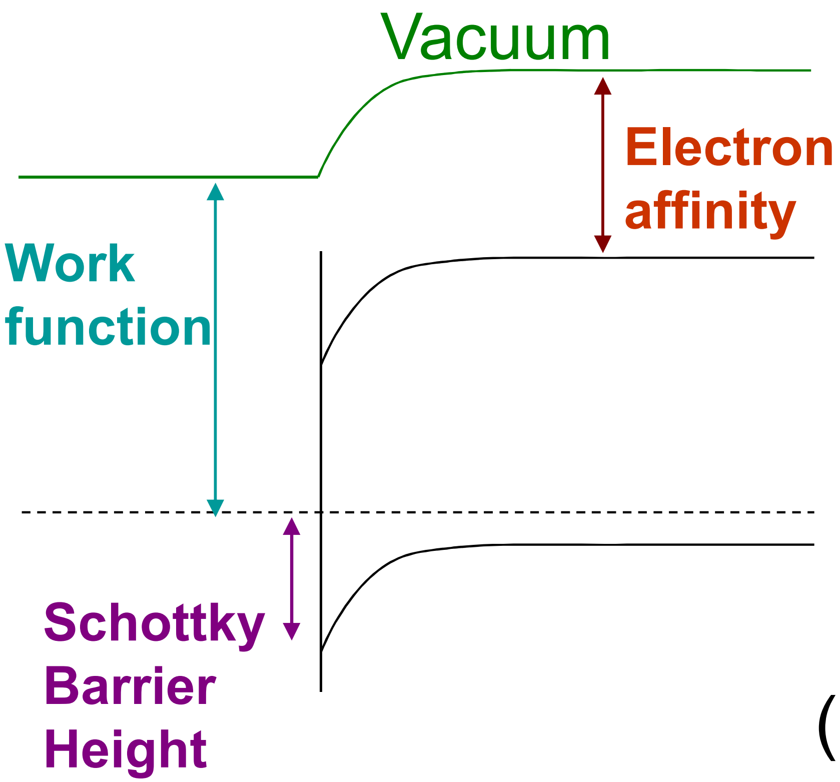
Vacuum

Electron affinity

Work function

Schottky Barrier Height

Background on Schottky barriers



Vacuum

Electron affinity

Work function

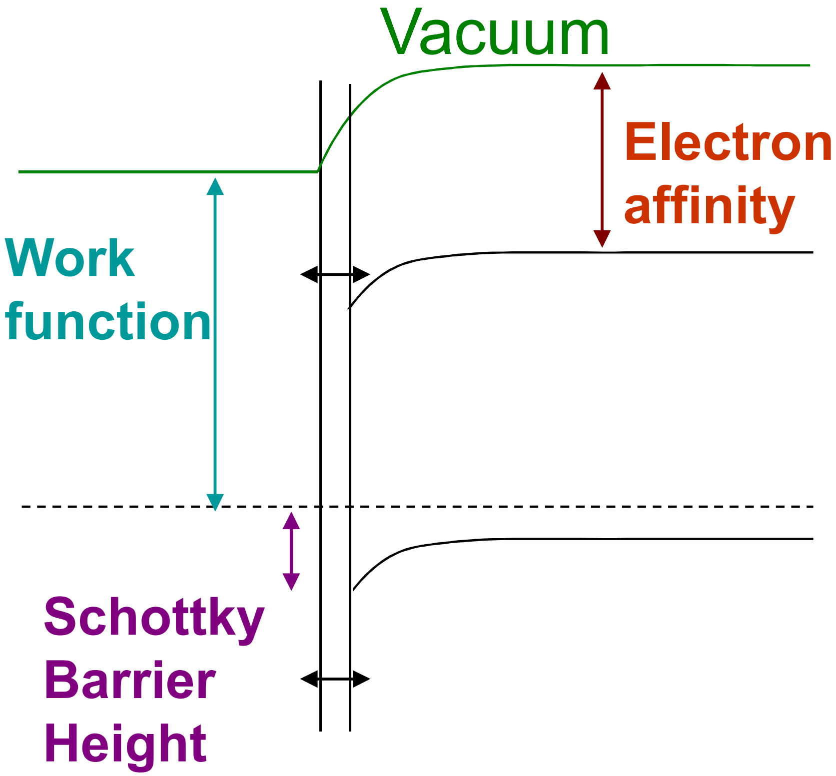
Schottky Barrier Height

This is Schottky-Mott model:

(Barrier height) = (Band gap)
+ (Electron affinity) – (Work f’n)

(In reality, this model is not terribly accurate, because there isn’t an abrupt perfect interface.)

MIS Schottky barrier height



Electrons and holes quantum-tunnel through insulator

In the Schottky-Mott model, the interface layer slightly reduces barrier height. In reality, can get significant increase.

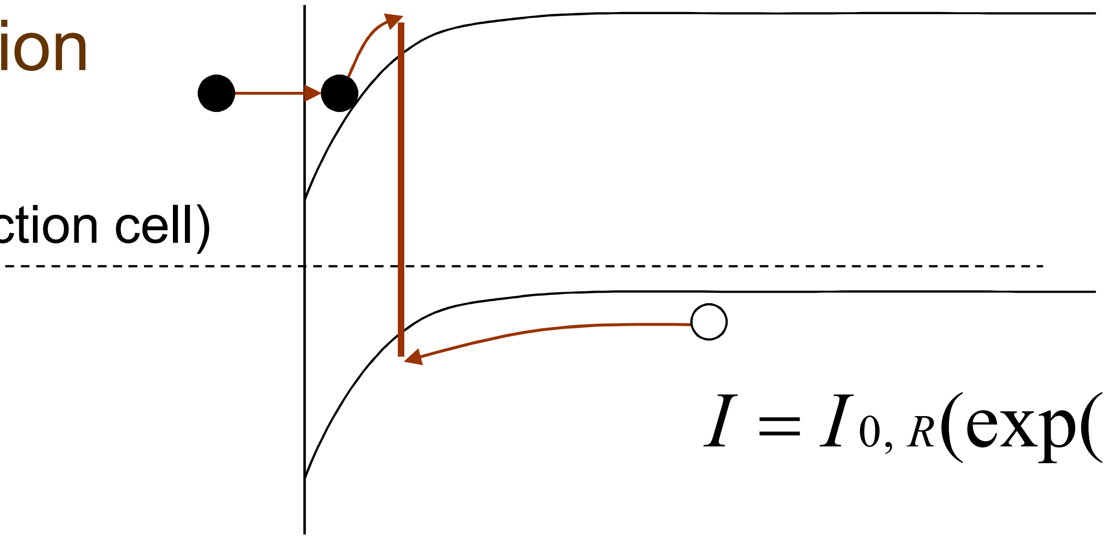
Peckerar, *1975 Int'l Electron Devices Mtg. (IEEE)*, 213 (1975)

Green, 1998

Current paths

Recombination current

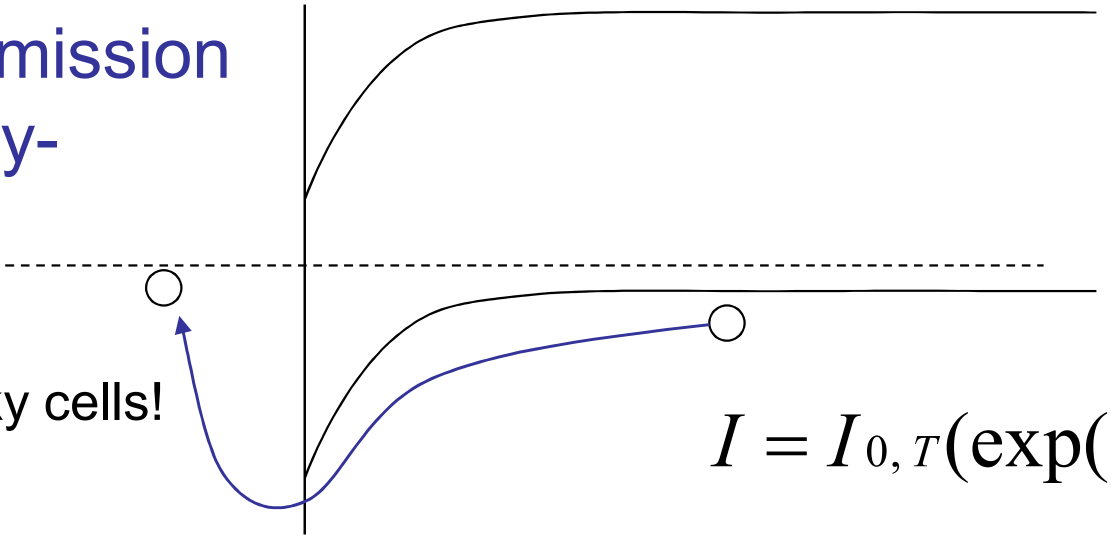
(Same as p-n junction cell)



$$I = I_{0,R}(\exp(qV/kT) - 1)$$

Thermionic emission (aka “Schottky-Richardson”)

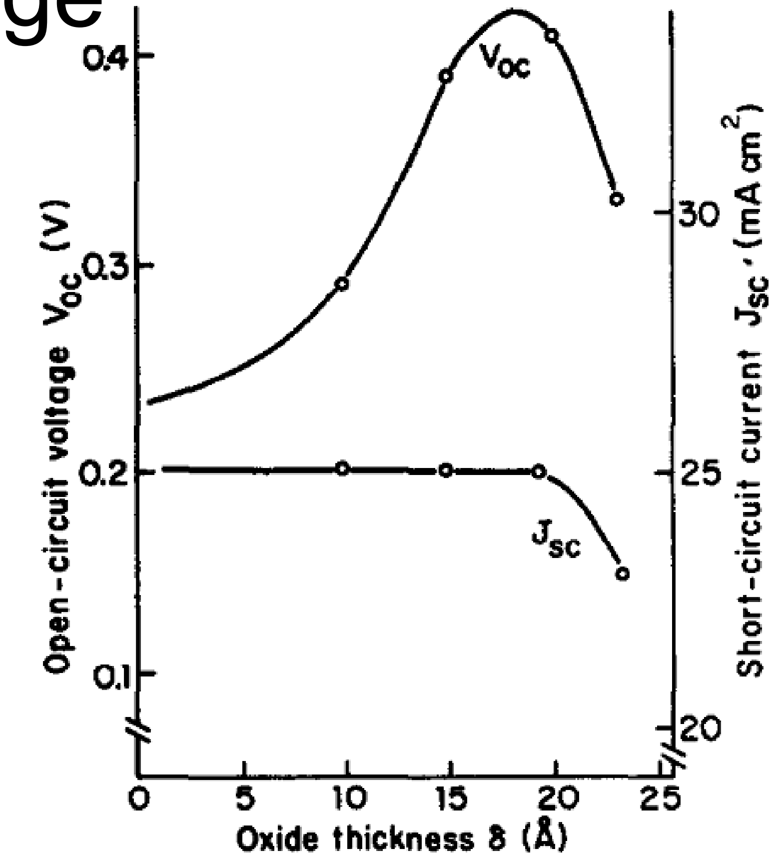
Unique to Schottky cells!



$$I = I_{0,T}(\exp(qV/kT) - 1)$$

Current paths

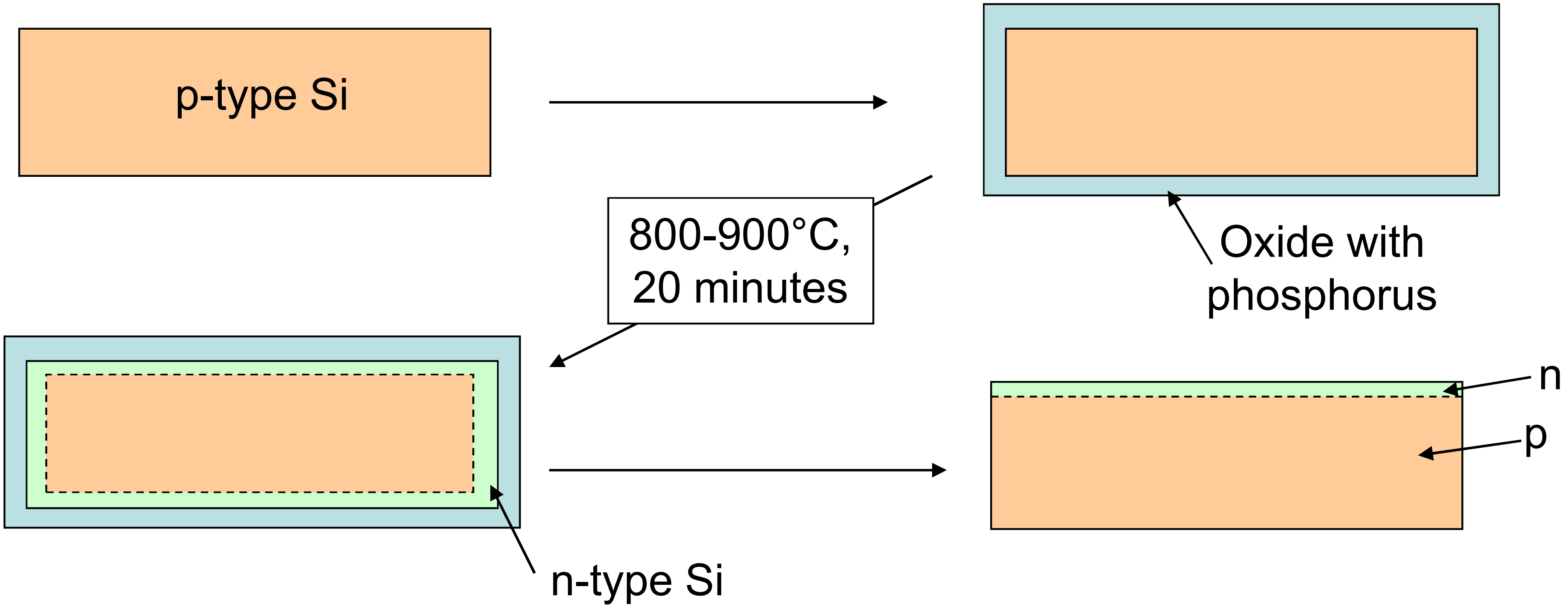
- Net result is a diode with saturation current $I_0 = I_{0,T} + I_{0,R}$.
- With no insulator, $I_{0,T}$ is large and limits efficiency.
- The insulator lowers $I_{0,T}$ without much affecting I_{sc}.



Card, *Solid St. Electron.* **20**, 971 (1977)

Cell manufacturing process

- Classic Si p-n junction cell has high-temperature step for n-type doping



Green 1998, p109

Effect of top layer

- The top region in a traditional Si solar cell contributes significantly to saturation current I_0:
  - Auger recombination due to high doping
  - Crystal defects and phosphorus precipitates from high-temperature diffusion
  - Surface recombination
- As a result, Voc limited to typically ~600-630 mV

Green 1998, p153

Effect of top layer

- <u>By comparison…</u>
- In an MIS cell, no high-temperature diffusion
  - No loss of crystal perfection
  - Easy to get a rather high V_{OC} (e.g., 655 mV in 1979)
  - 35% lower energy input per cell

Green 1998, p181

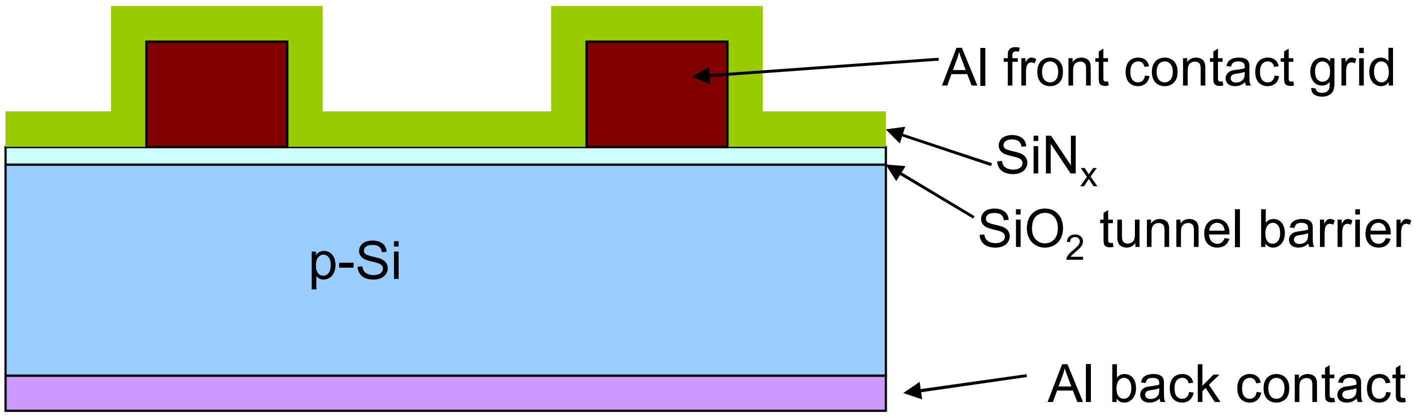
Godfrey and Green, *APL* **34** 790 (1979)

R. Hezel, *Prog. Photovoltaics Res. App.* **5**, 109 (1997).

Standard design

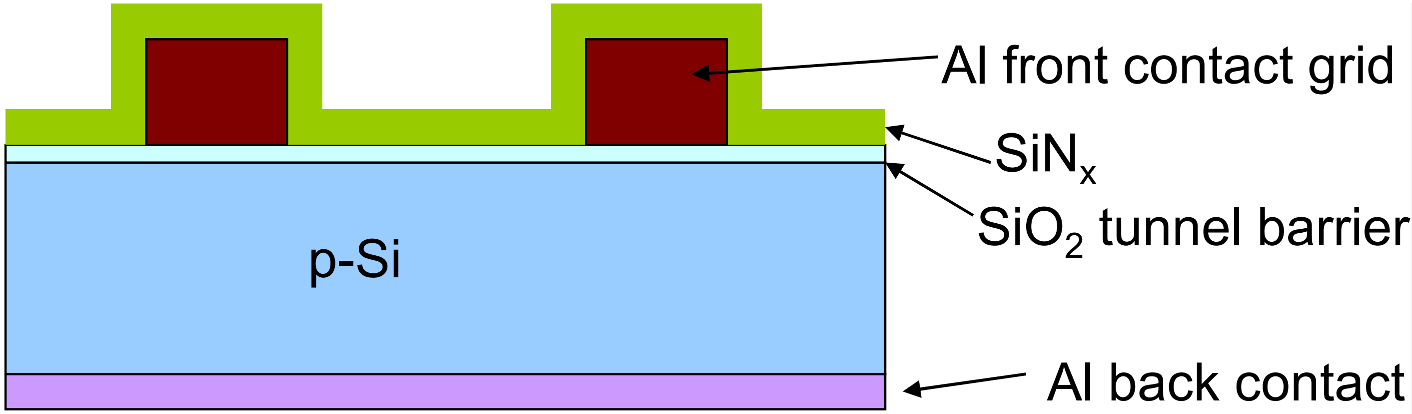
Markvart and Castañer 2003, p172.

- Usually called “MIS-IL” (MIS-inversion-layer).
- Advantageous for very-high-quality Si. For lower quality, you need high-temperature step anyway (to getter impurities).



Processing sequence

1. Surface texturing (physical and chemical)
2. Evaporate back-side Al metal contact
3. Heat, to sinter the Al and simultaneously grow the 1.5nm SiO_2 tunnel barrier
4. Put in front Al grid, by mask-evaporation
5. Dip in CsCl to fix positive charge, thereby increasing barrier height and inversion-layer conductivity
6. Deposit SiN_x by PECVD, to passivate, invert, and AR



Markvart and Castañer 2003, p172.

Grauvogl et al., *IEEE 25th PVSC*, 433 (1996)

Real-world status

- From 1994, MIS-IL cells produced by an industrial pilot plant
  - Manufactured >1 MW_p range
  - 15.3% efficient for 10x10cm CZ-Si, 15.7% for 2x2cm FZ-Si
- New ways to increase efficiency and lower costs
  - Lab efficiency up to 19.6% (in scaleable process)
  - Main ideas:
    - Alter processing to deposit SiN_x at higher temp.
    - Replace mask-evaporation by OECO.

Hezel, *Prog. Photovoltaics Res. App.* **5**, 109 (1997)

Grauvogl et al., *IEEE 25th PVSC*, 433 (1996)

Hezel, *Solar En. Mat. Solar Cells* **74**, 25 (2002)

Real-world status

- **Side note**: MIS contacts can be useful even in a p-n solar cell. (With accumulation layer at MIS junction.)
- e.g., can use cheaper aluminum front contacts, which would ordinarily degrade the junction.
- CZ-Si “OECO MIS-n^+p” solar cells have 20% efficiency for large-area cells, in a pilot production line using relatively cheap processing.

Hezel, *Solar En. Mat. Solar Cells* **74**, 25 (2002)

Future?

- MIS-IL is a good design; clear advantages over the “standard” single-crystal-Si solar-cell design, certainly in cost, perhaps even in efficiency.
- Promising candidate for the future of SC-Si solar cells.
- But keep in mind, today there are *tons* of clever and modern SC-Si designs to compete with.