Edmond Becquerel: A passion for Light

200th Birth Anniversary, 7th December 2020, Paris

The Grand History and Future of Silicon Solar Cells

Martin Green, UNSW Sydney

21st IEEE Photovoltaic Specialists Conference, Kissimmee, FL, May 21-25, 1990.

PHOTOVOLTAICS: COMING OF AGE

Martin A. Green

University of New South Wales
Kensington, Australia, 2033

1. Introduction

It is a pleasure to have been asked to deliver the keynote address at this, the 21st Conference in this series. In Australia, when a young person reaches 21 years, a large party is held to celebrate the "coming of age". This age used to coincide with the young person legally becoming an adult with rights to vote and partake in other Australian customs, such as going to the pub to order a beer. All this happens much sooner nowadays. At the party to celebrate the "coming of age", a relative with the "gift of the gab" would give a speech reminiscing about bouncing young John or Mary on his or her knee, referring to the milestones in the young person's life, and making some mention of expectations for the future.

Given that this is also our 21st, I will follow a similar format in my address. I will start by reviewing the history of photovoltaic development, then outline the future potential of the technology as I see it, and explain why I think photovoltaics will fulfil this potential.

2. Early History [1,2,3]

Edmond Becquerel appears to have been the first to demonstrate the photovoltaic effect [4,5]. Working in his father's laboratory as a young nineteen-year-old,

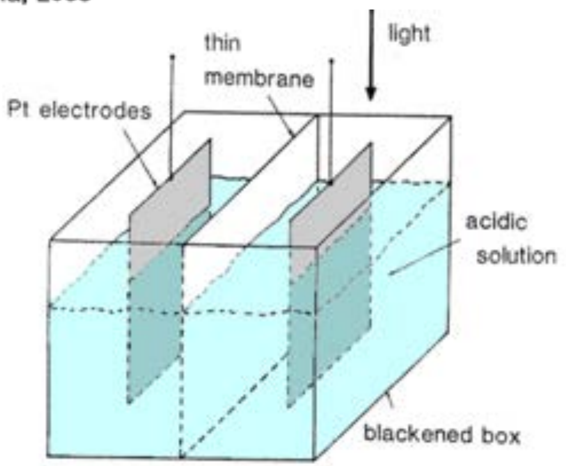

Figure 1: Diagram of apparatus described by Becquerel (1839)

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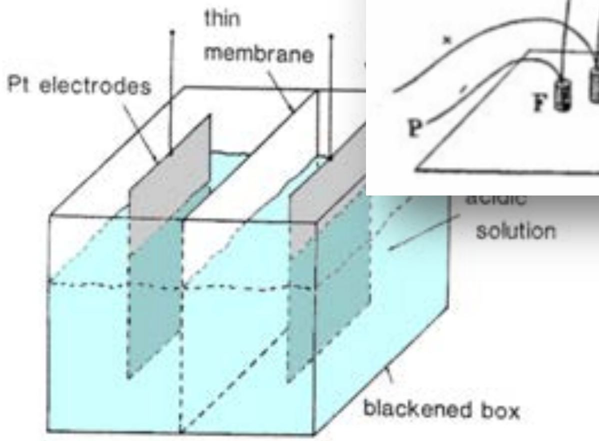

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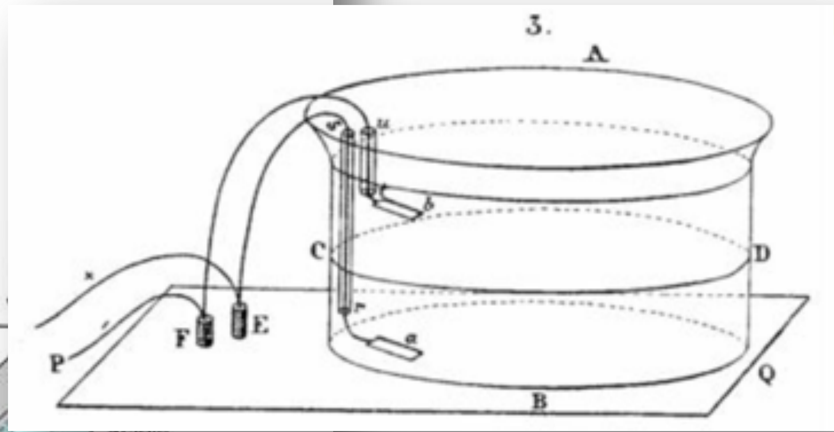

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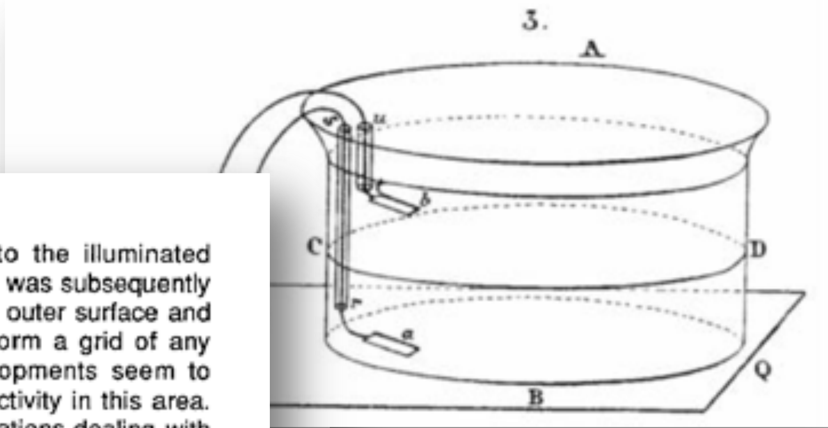


photovoltaic devices. These devices were quite large, approximately 30 cm^2 in area.

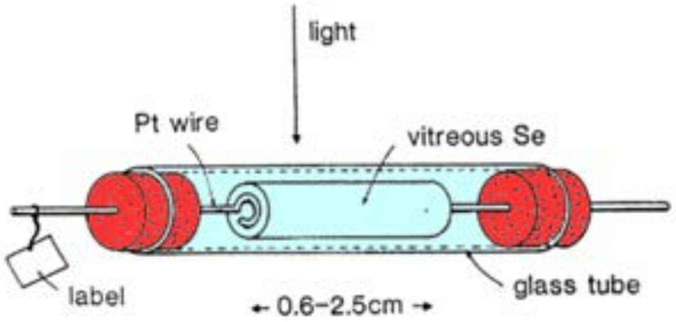
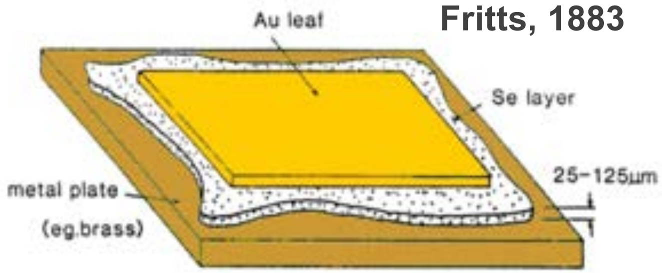


Figure 2: Sample geometry used by Adams and Day (1876) for the investigation of the photoelectric effects in selenium.

Fritts, 1883



is used to give a grid contact to the illuminated surface of the cell. This approach was subsequently refined by sputtering metal on the outer surface and removing a part of it so as "to form a grid of any desired fineness". These developments seem to have stimulated a great deal of activity in this area. Grondahl [8] documents 38 publications dealing with copper-cuprous oxide photovoltaic cells over the period 1930-32.

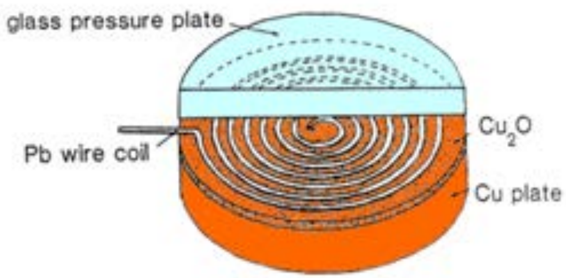
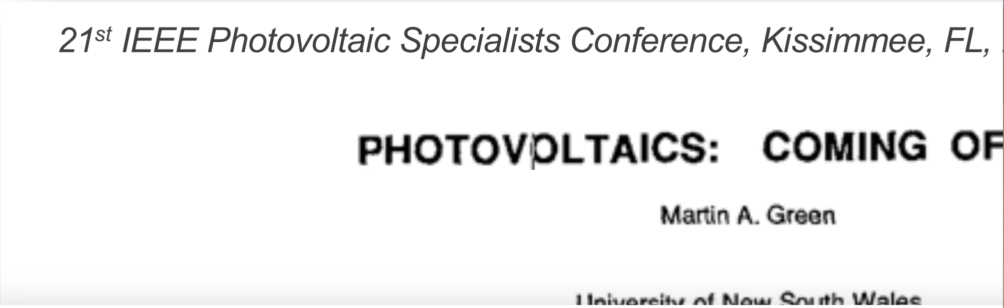


Figure 4: Early Grondahl-Geiger copper-cuprous oxide photovoltaic cell (circa 1927).

This activity also seems to have reawakened interest in selenium as a photovoltaic material. In particular, Bergman [9] reported improved selenium devices in 1931. These proved superior to the copper-based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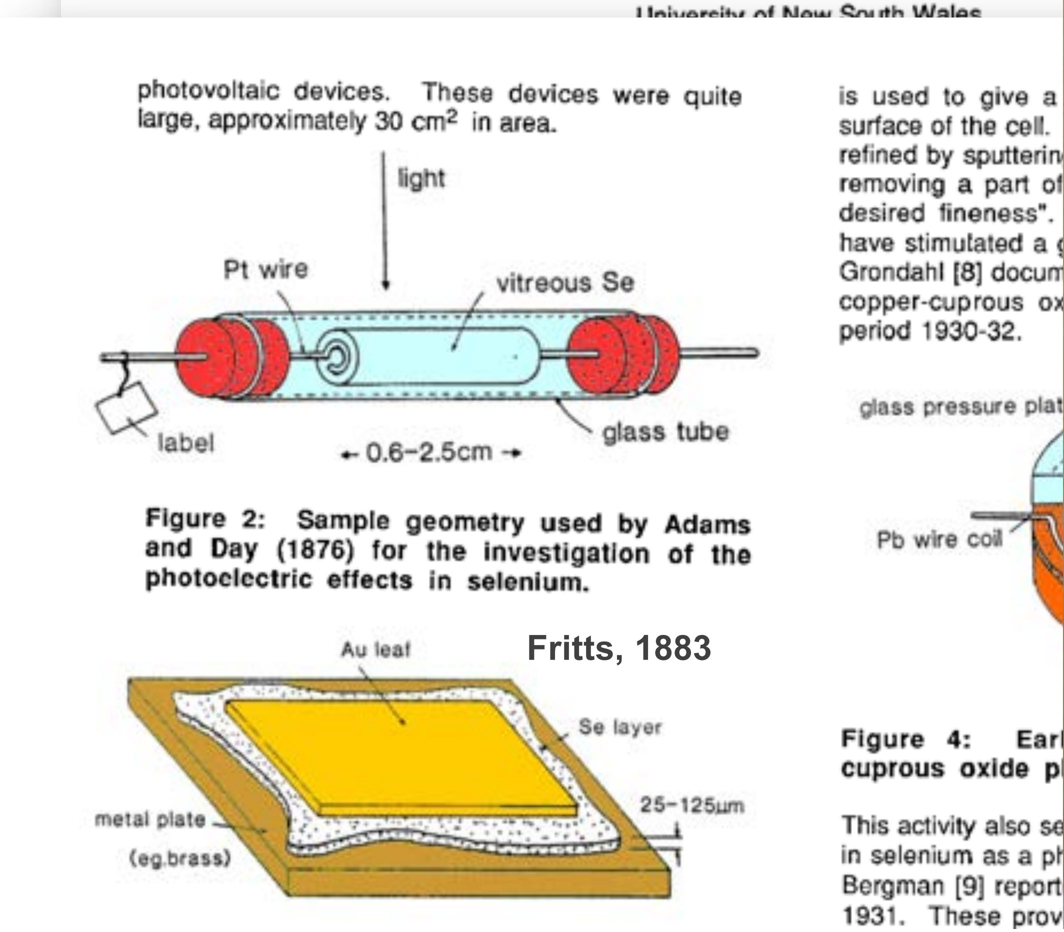
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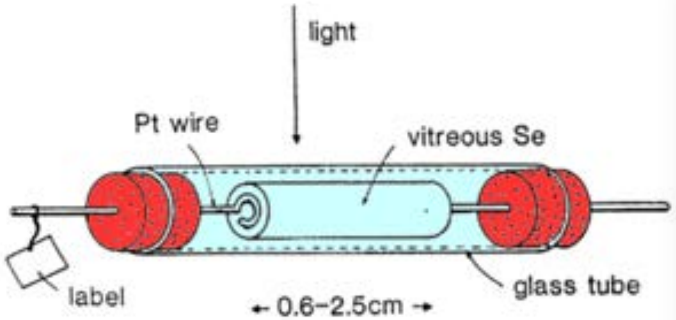

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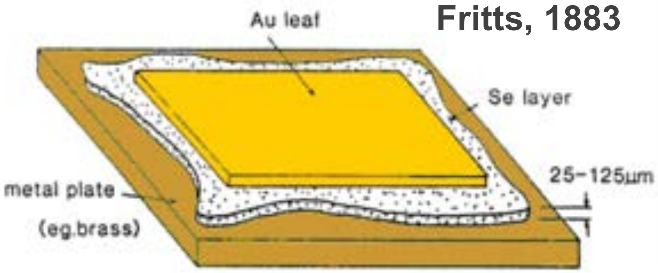

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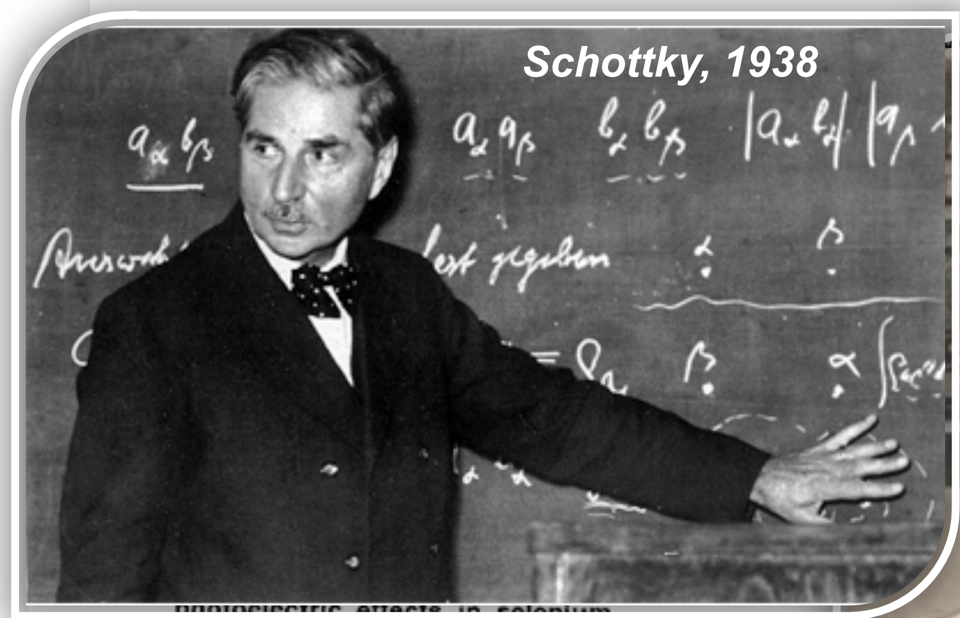

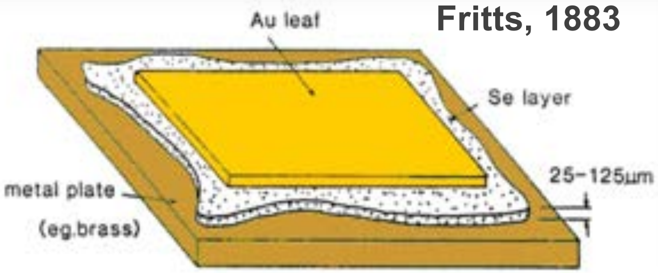

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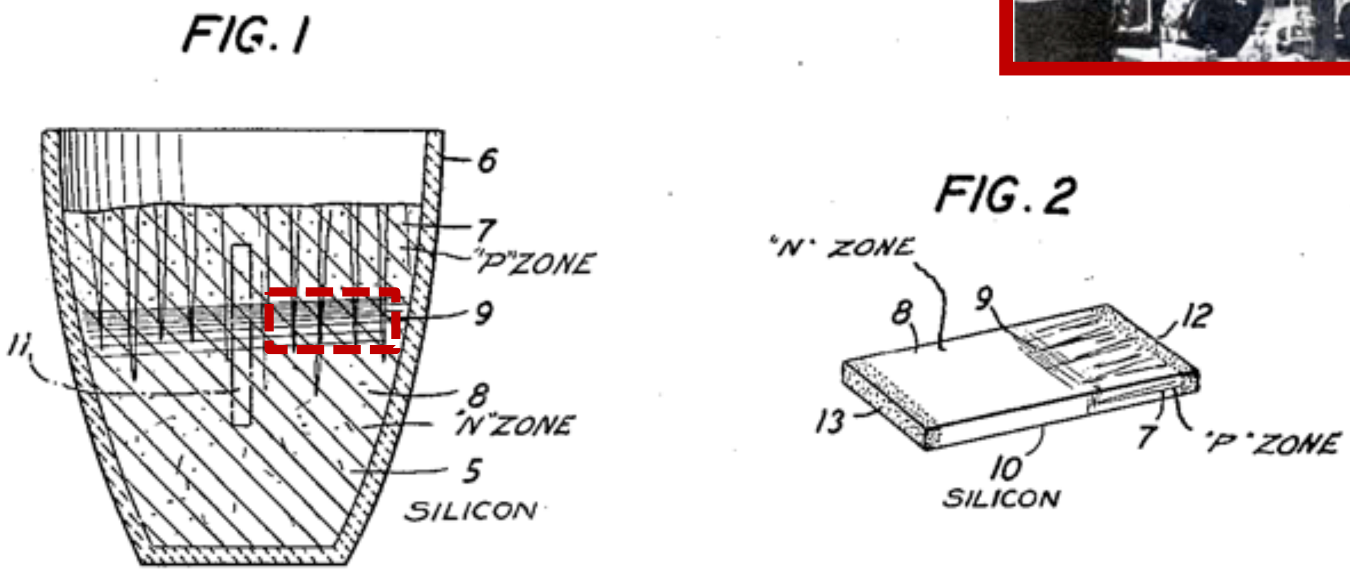
The first silicon pn junction cell
(Russell Ohl, Bell Labs,1941)



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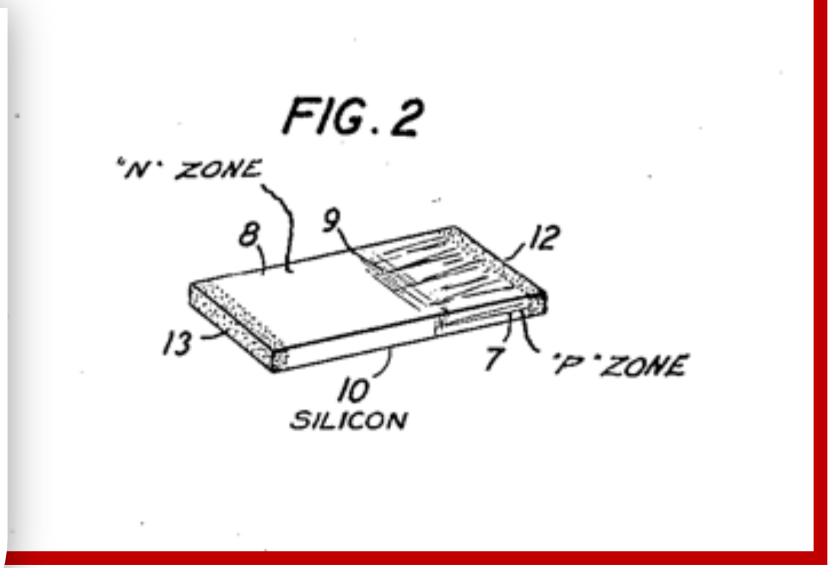
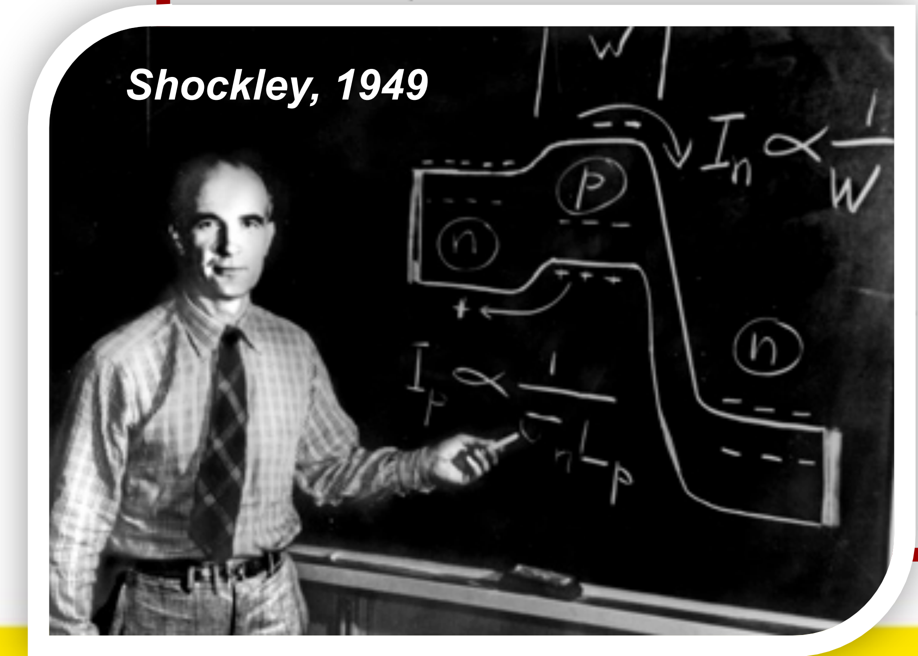
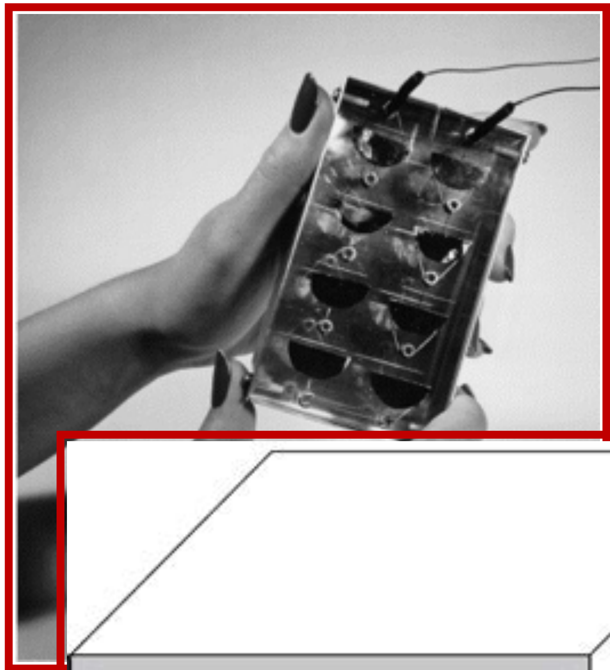
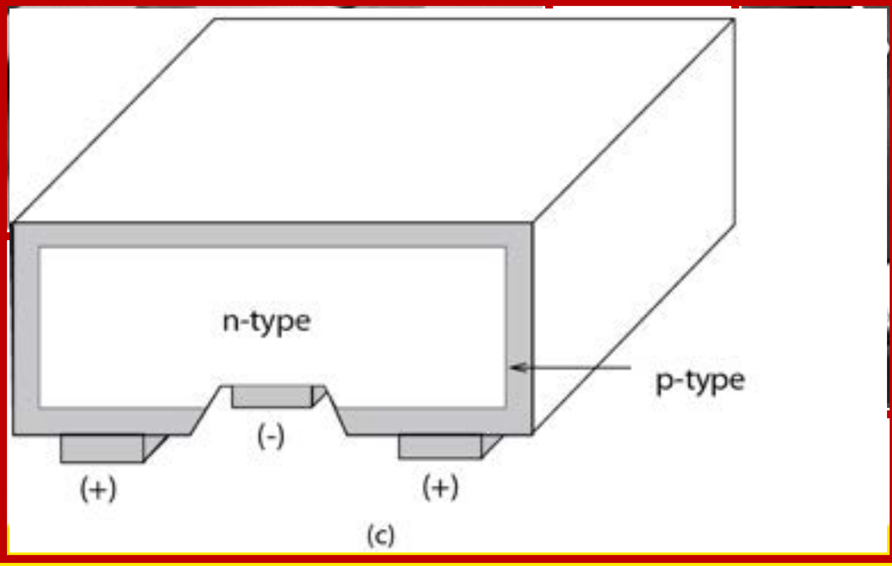


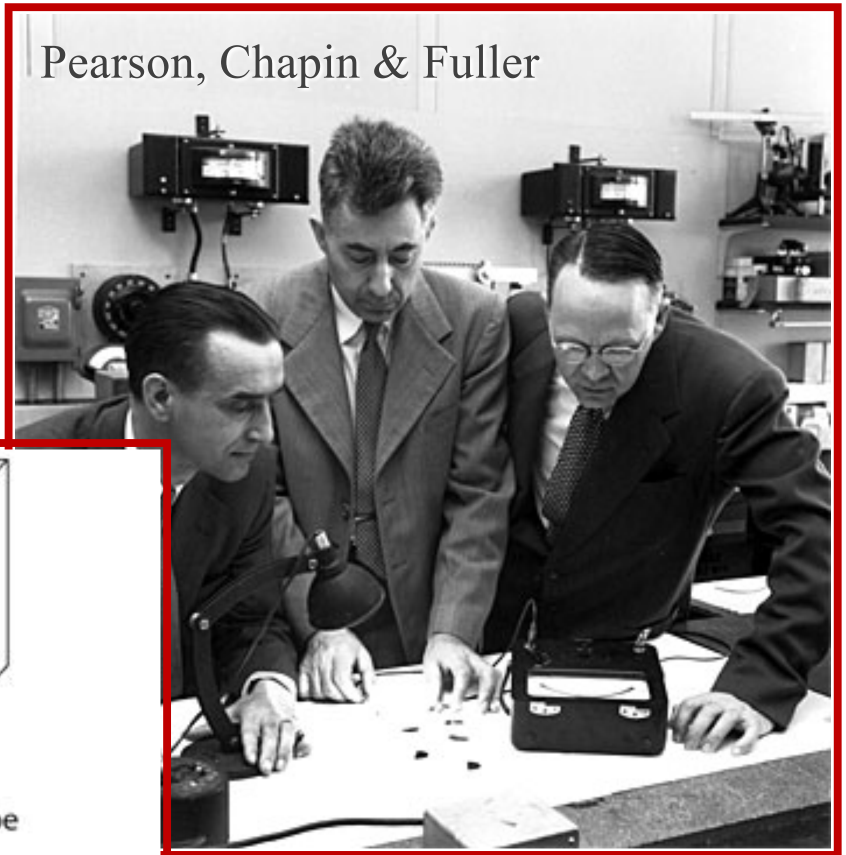


Shockley, 1949

The first efficient cells (1953/4)







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Vast Power of the Sun Is Tapped By Battery Using Sand Ingredient

Special to The New York Times.

MURRAY HILL, N. J., April 25—A solar battery, the first of its kind, which converts useful amounts of the sun's radiation directly and efficiently into electricity, has been constructed here by the Bell Telephone Laboratories.

The new device is a simple-looking apparatus made of strips of silicon, a principal ingredient of common sand. It may mark the beginning of a new era, leading eventually to the realization of one of mankind's most cherished dreams—the harnessing of the almost limitless energy of the sun for the uses of civilization.

The sun pours out daily more than a quadrillion (1,000,000,000,000,000) kilowatt hours of energy, greater than the energy content of all the reserves of coal, oil, natural gas and uranium in the earth's crust.

With this modern version of Apollo's chariot, the Bell scientists have harnessed enough of the sun's rays to power the transmission of voices over telephone wires. Beams of sunlight have also provided electricity for a transistor in a radio transmitter, which carried both speech and music.

The Bell scientists reported they had achieved an efficiency of 6 per cent in converting sunlight directly into electricity. This, they asserted, compares favorably with the efficiency of steam and gasoline engines, in contrast with other photoelectric devices, which have a rating of no more than 1 per cent.

With improved techniques the efficiency may be expected to be increased substantially, they added. They observed that nothing is consumed or destroyed in the energy conversion process and there are no moving parts, so the solar battery "should theoretically last indefinitely."

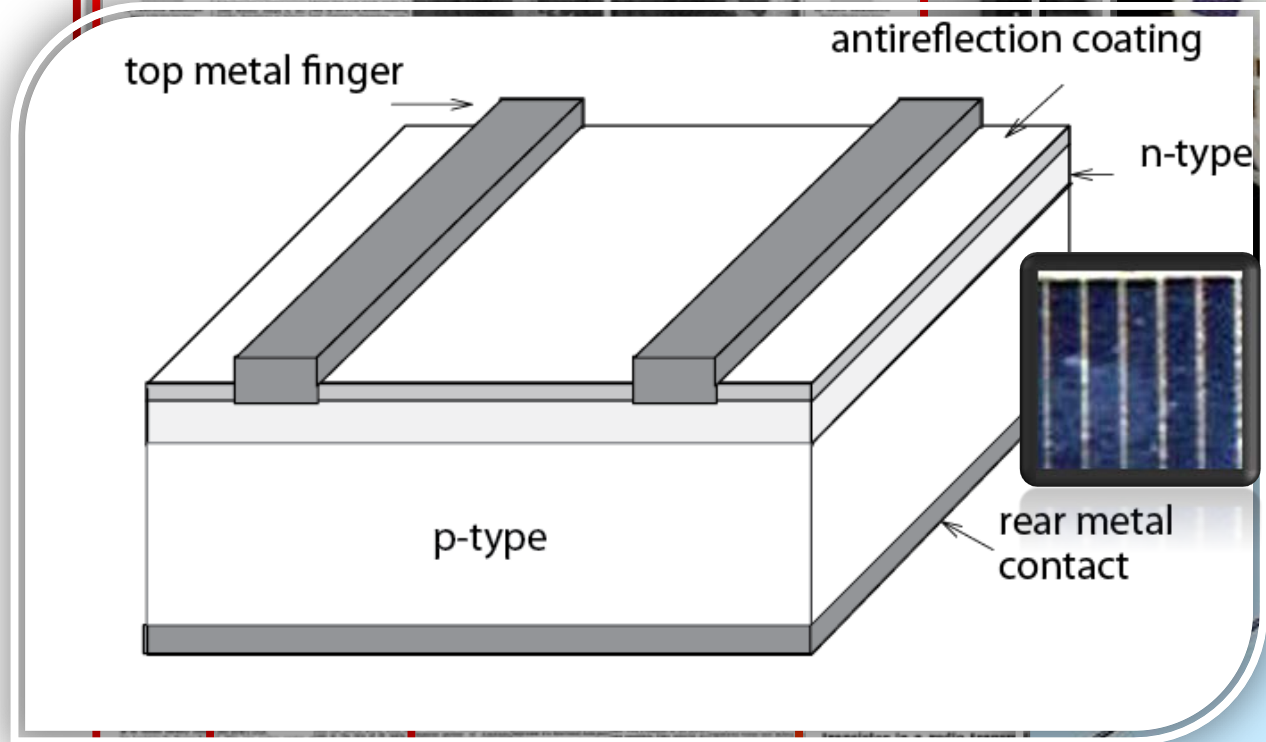
The experimental solar battery uses strips of wafer-thin silicon about the size of common razor blades. These strips are extremely sensitive to light. They can be linked together electrically and can deliver power from the sun at the rate of 50 watts a square yard of surface.

The atomic battery recently announced by the Radio Corporation of America delivers one-millionth of a watt. The new Bell solar battery thus delivers 50,000,000 times the power of the R.C.A. atomic battery.

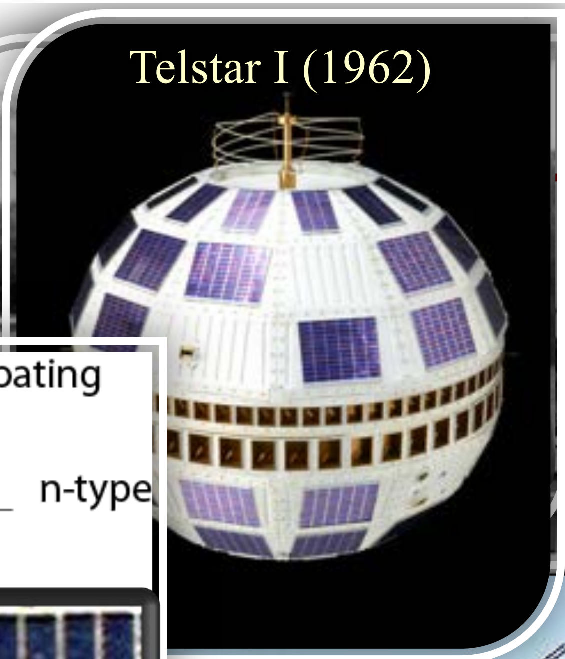
Silicon is a semiconductor,

Continued on Page 11, Column 4

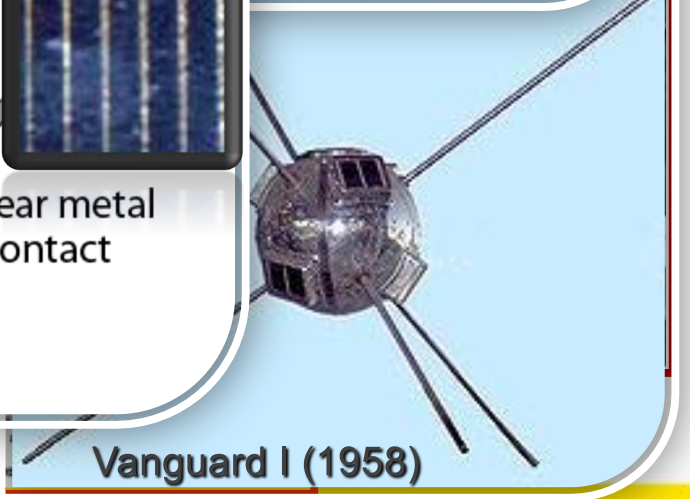
"All the News That's Fit to Print"
The New York Times.
LATE CITY EDITION
HENSEL REBUTTAL ACCUSES M'CARTHY OF 'MALICIOUS LIES'
FERGUSON ASSERTS HOUSING INQUIRY MAY DELAY FUNDS
U. S. and British Leaders on Two Active Diplomatic Fronts
BRITAIN'S CABINET SEEKS WAY TO BAR AN ASIAN DISASTER
which carried both speech music.
The Bell scientists



top metal finger
antireflection coating
n-type
p-type
rear metal contact

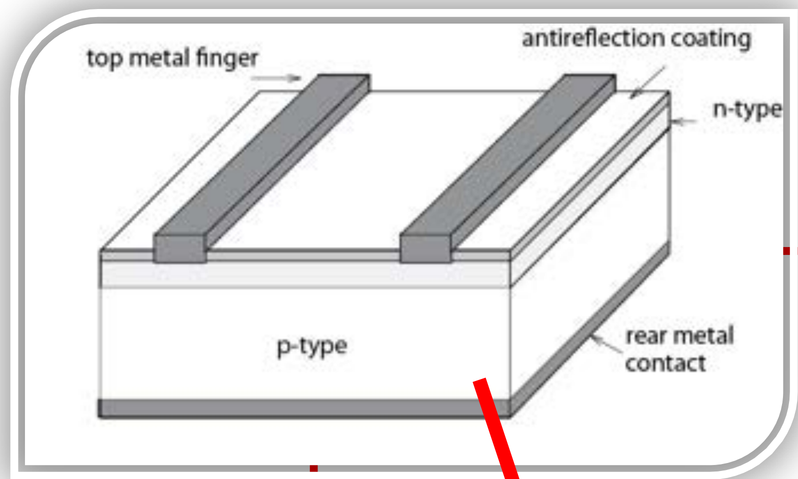


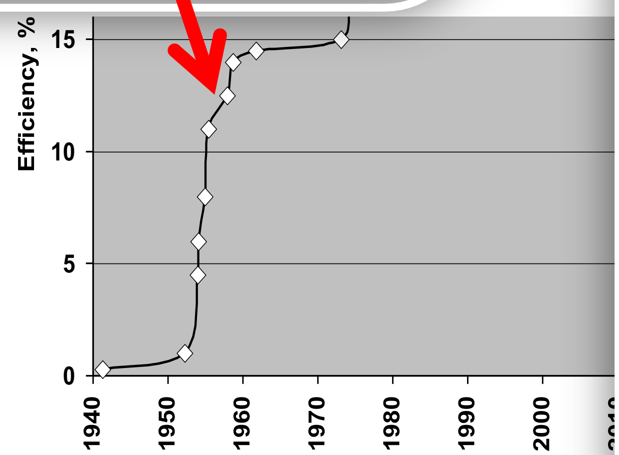
Telstar I (1962)

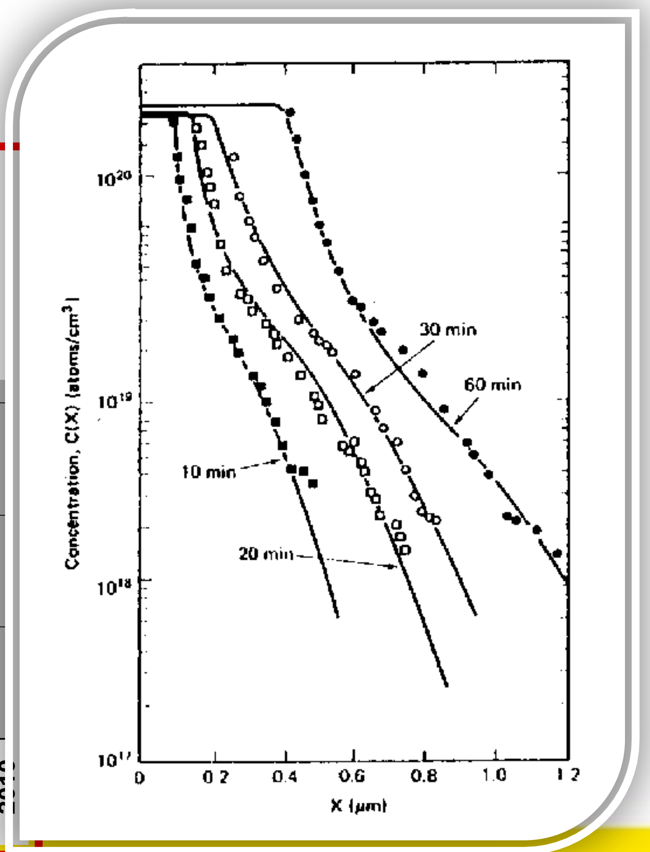


Vanguard I (1958)

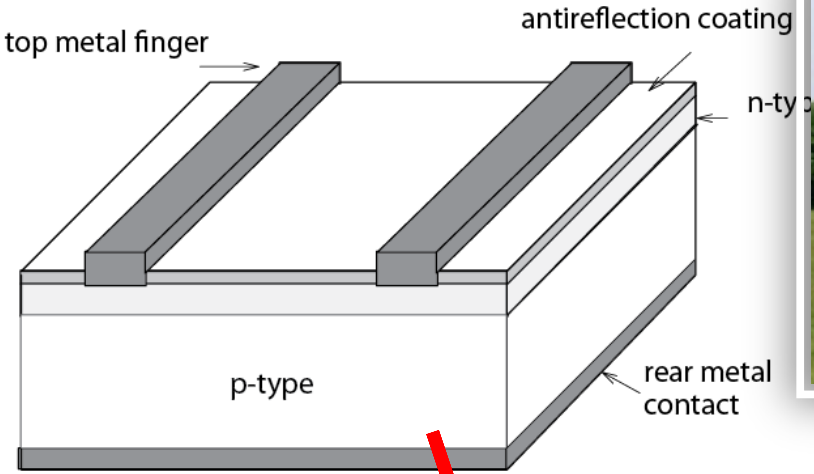
Conventional space cell

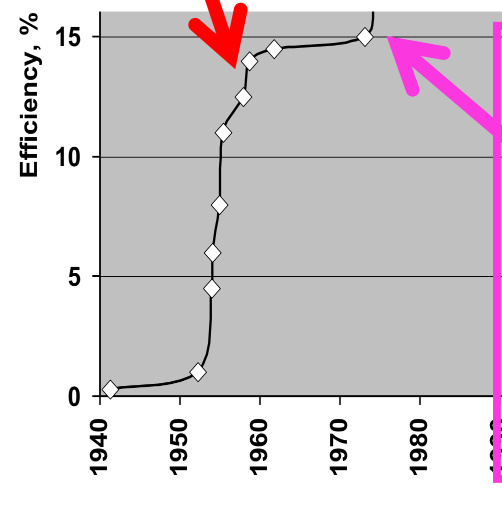


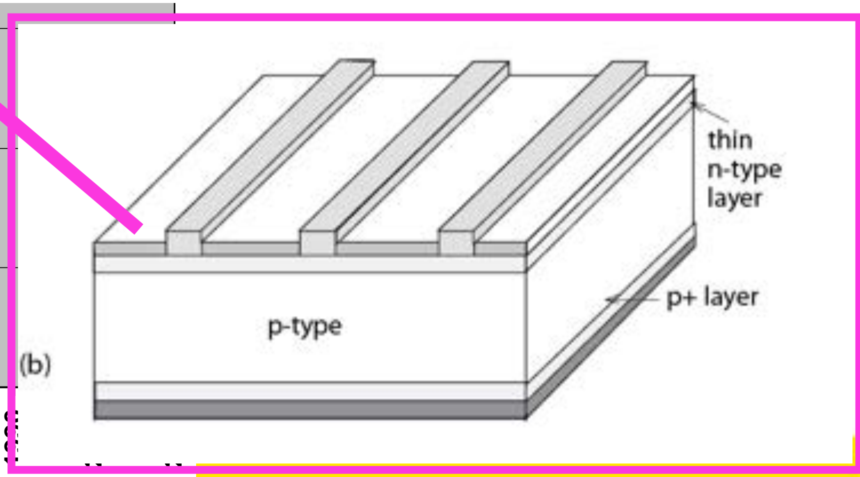




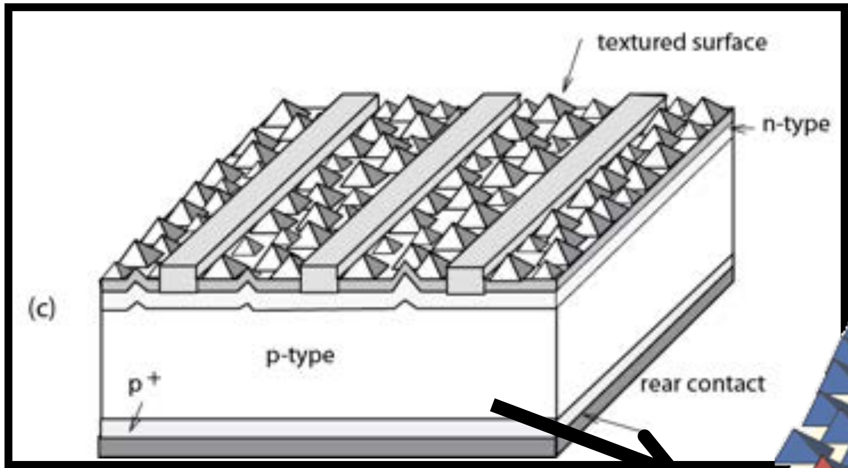
Violet cell (COMSAT 1972)



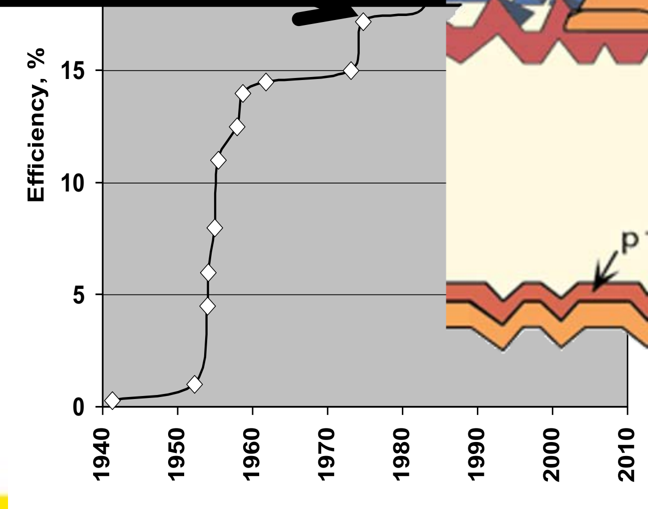


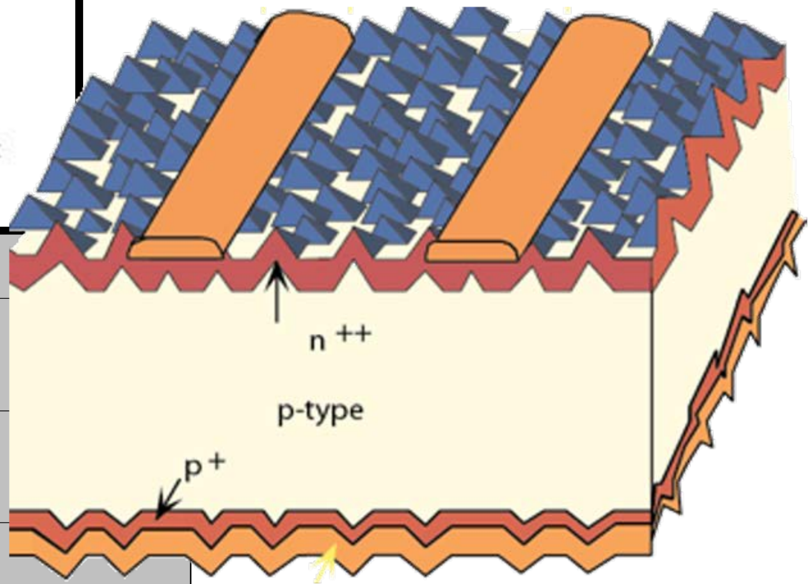


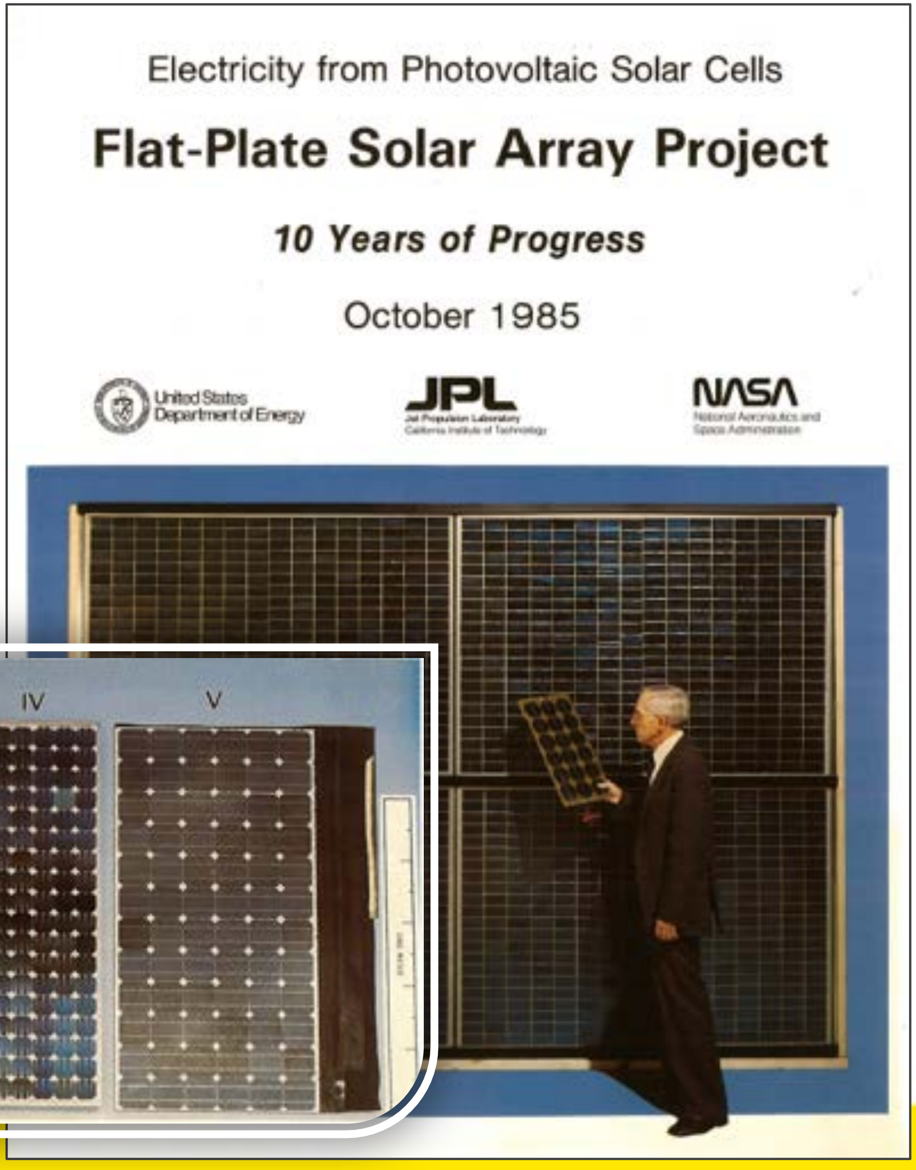
Black cell (COMSAT 1974)

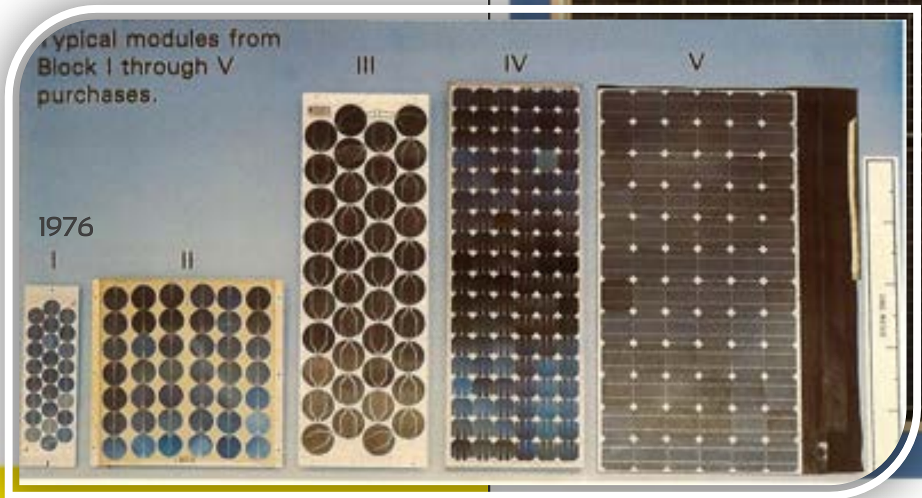


Al Back Surface Field (Al BSF)






Electricity from Photovoltaic Solar Cells
Flat-Plate Solar Array Project
10 Years of Progress
October 1985
United States Department of Energy
JPL
NASA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Block I through V
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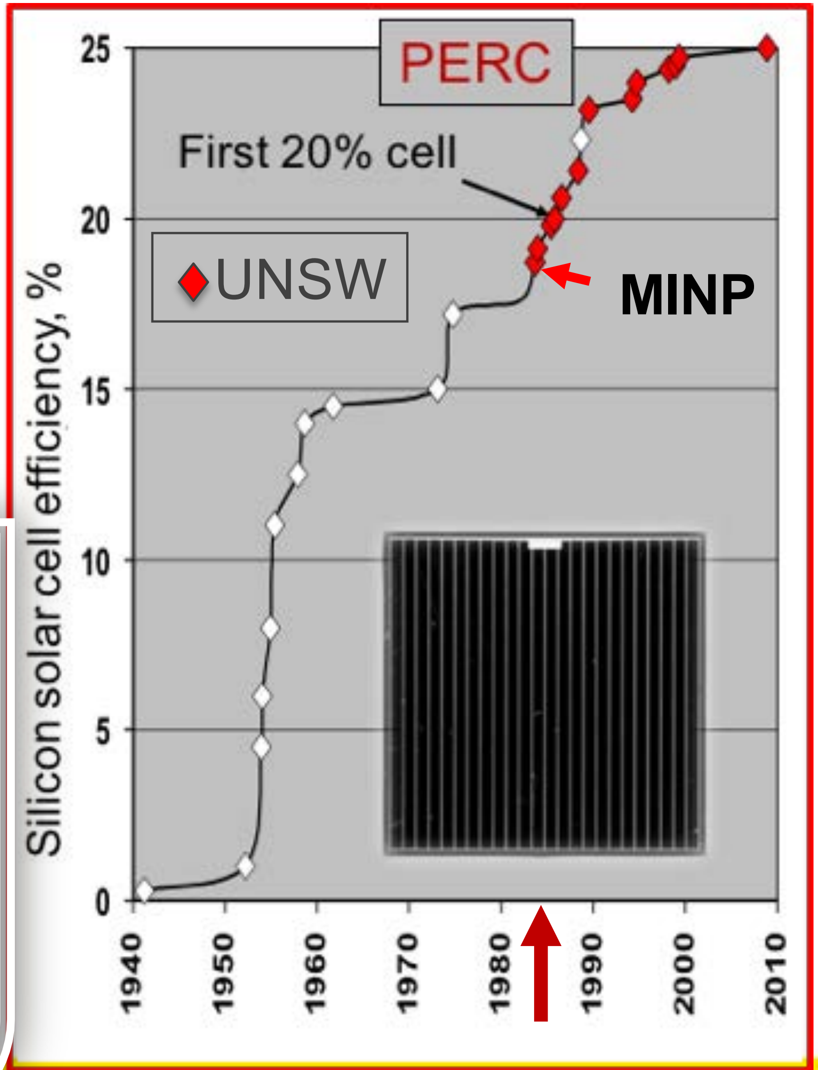
1976
I
II
III
IV
V

1983: First 18% Si cell



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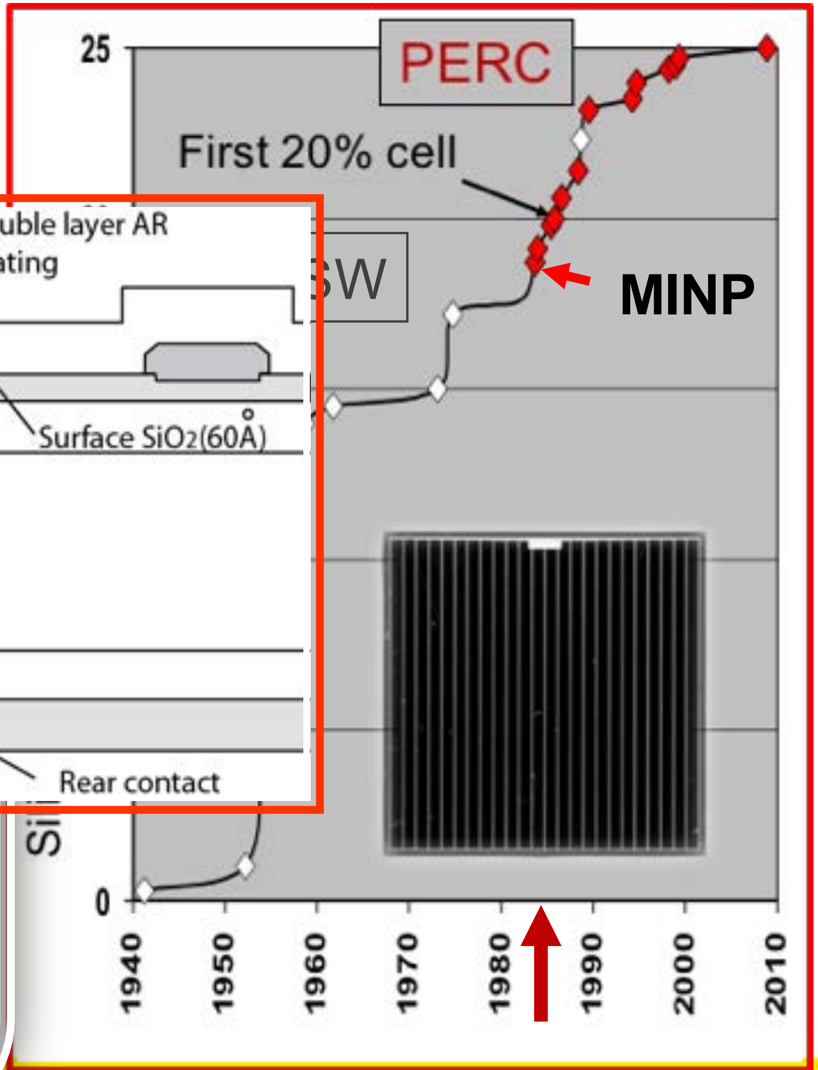
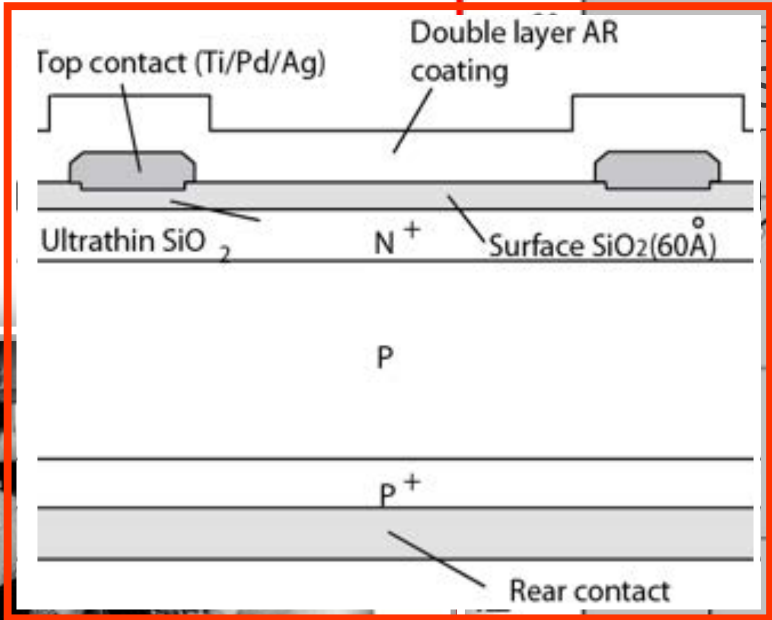
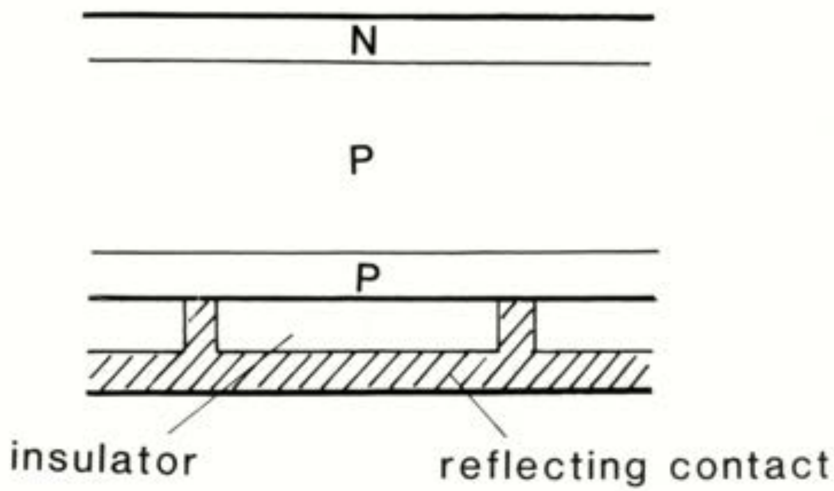




PERC solar cell invented (1983)

Passivated Emitter and Rear Cell



M.A. Green et al., "Ultimate Performance Silicon Solar Cells", Final Report, NERDDP Project 81/1264, Jan. 82 - Dec. 83 (dated Feb. 1984).

M.A. Green, "High Efficiency Silicon Solar Cells", Proposal in response to RFP RB-4-04033, SERI (now NREL), March 1984.

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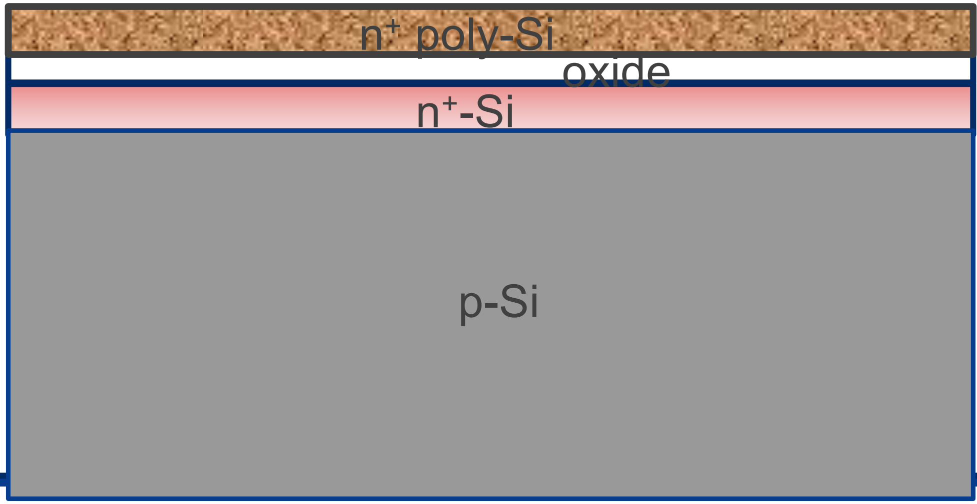
Passivated Emitter and Rear Cell

First TOPCon solar cell reported (1983)



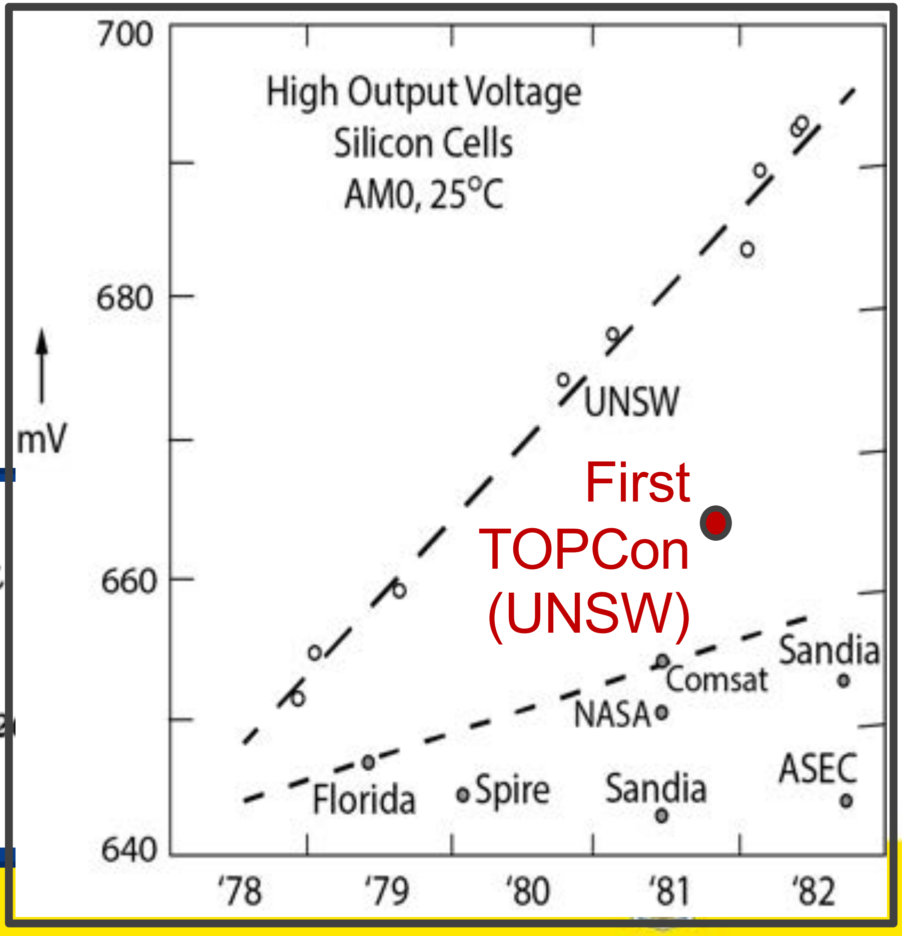
Solar Cells, 8 (1983) 3 - 16

ADVANTAGES OF METAL–INSULATOR–SEMICONDUCTOR STRUCTURES FOR SILICON SOLAR CELLS

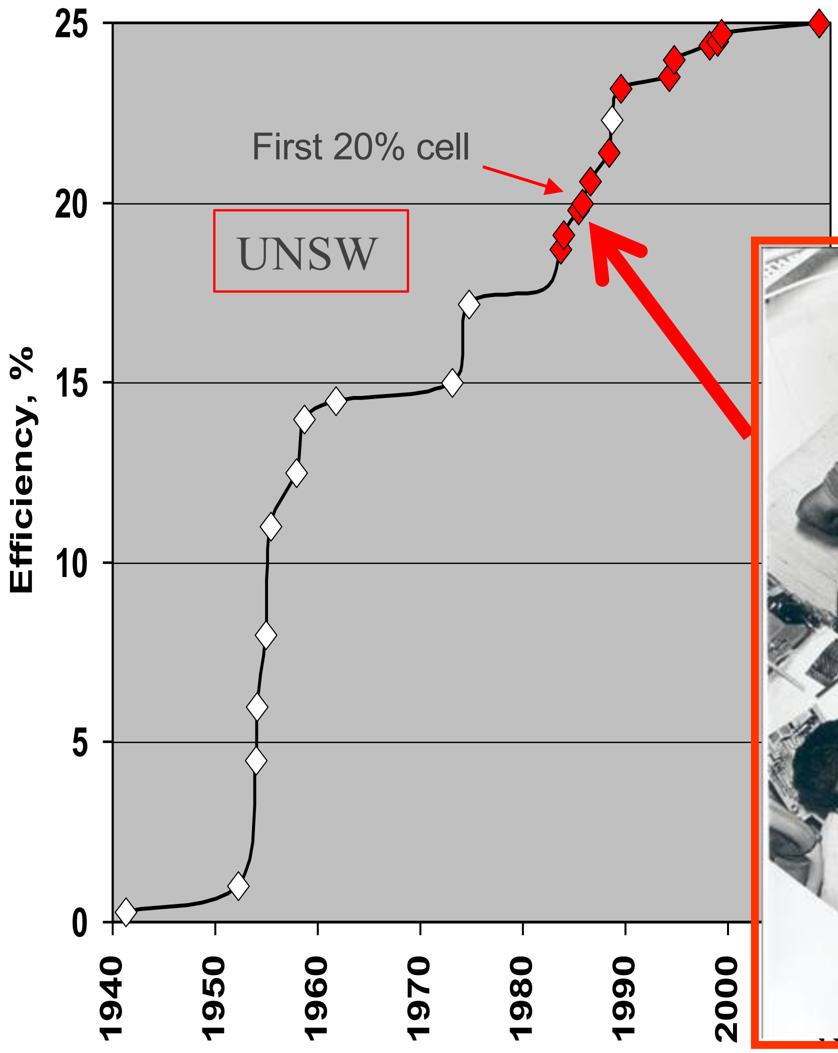
M. A. GREEN and A. W. BLAKERS

Solar Photovoltaic Laboratory, University of New South Wales, Kensington 2
(Australia)

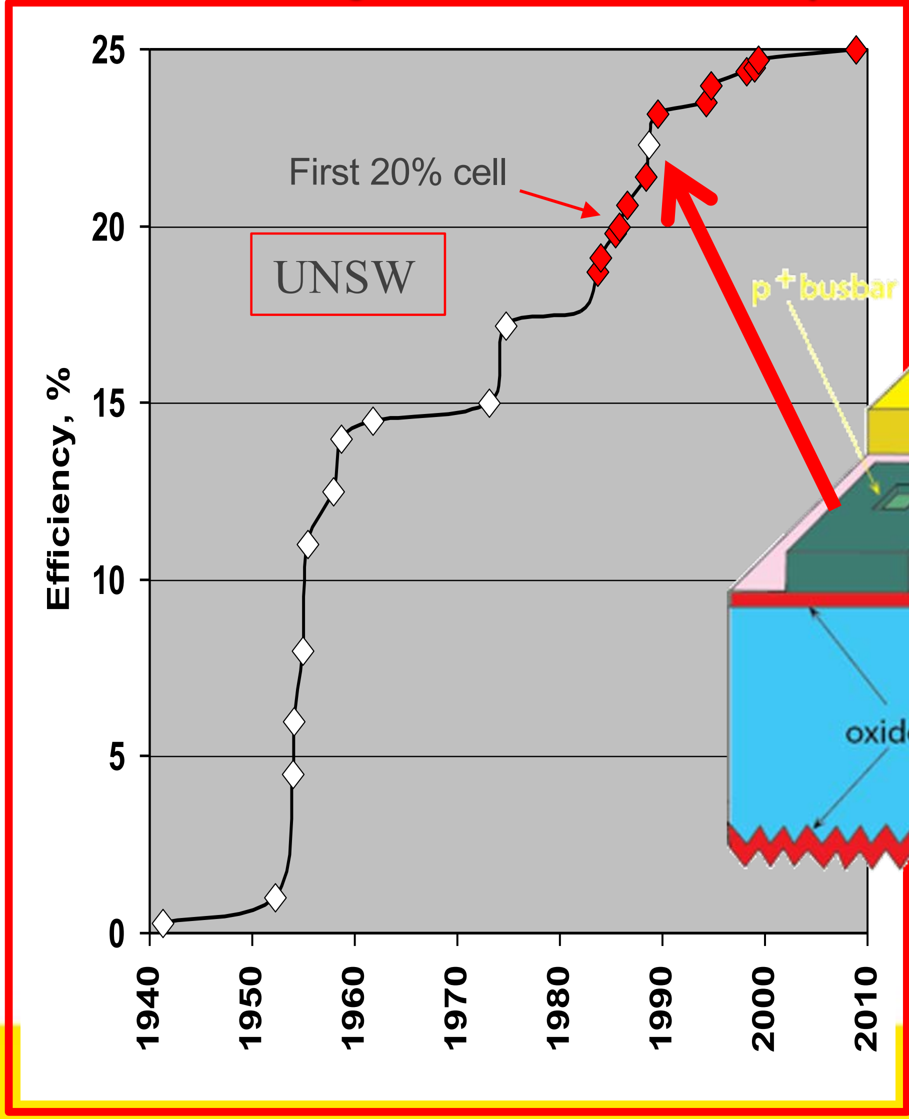
(Received January 26, 1982; accepted April 5, 1982)

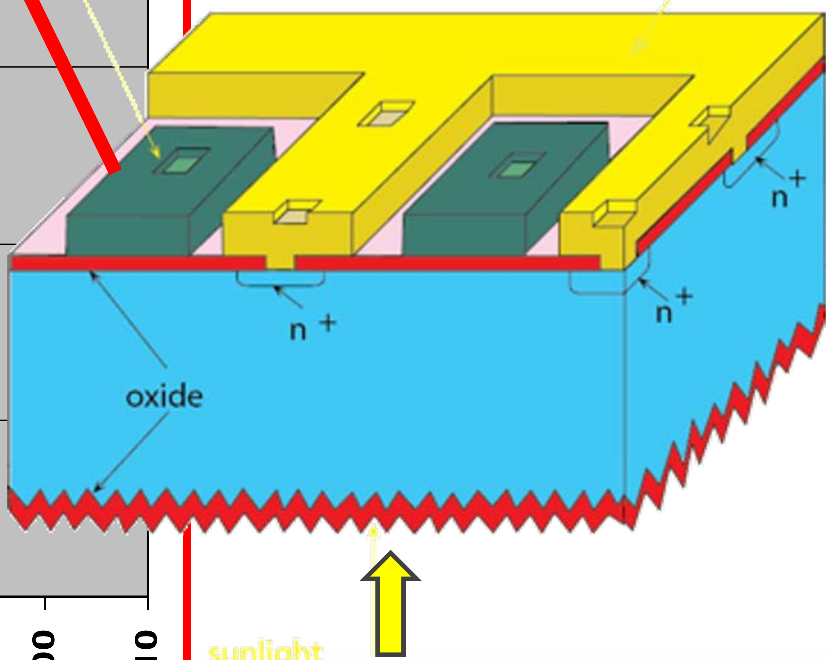


μg-PESC cell (UNSW 1985)

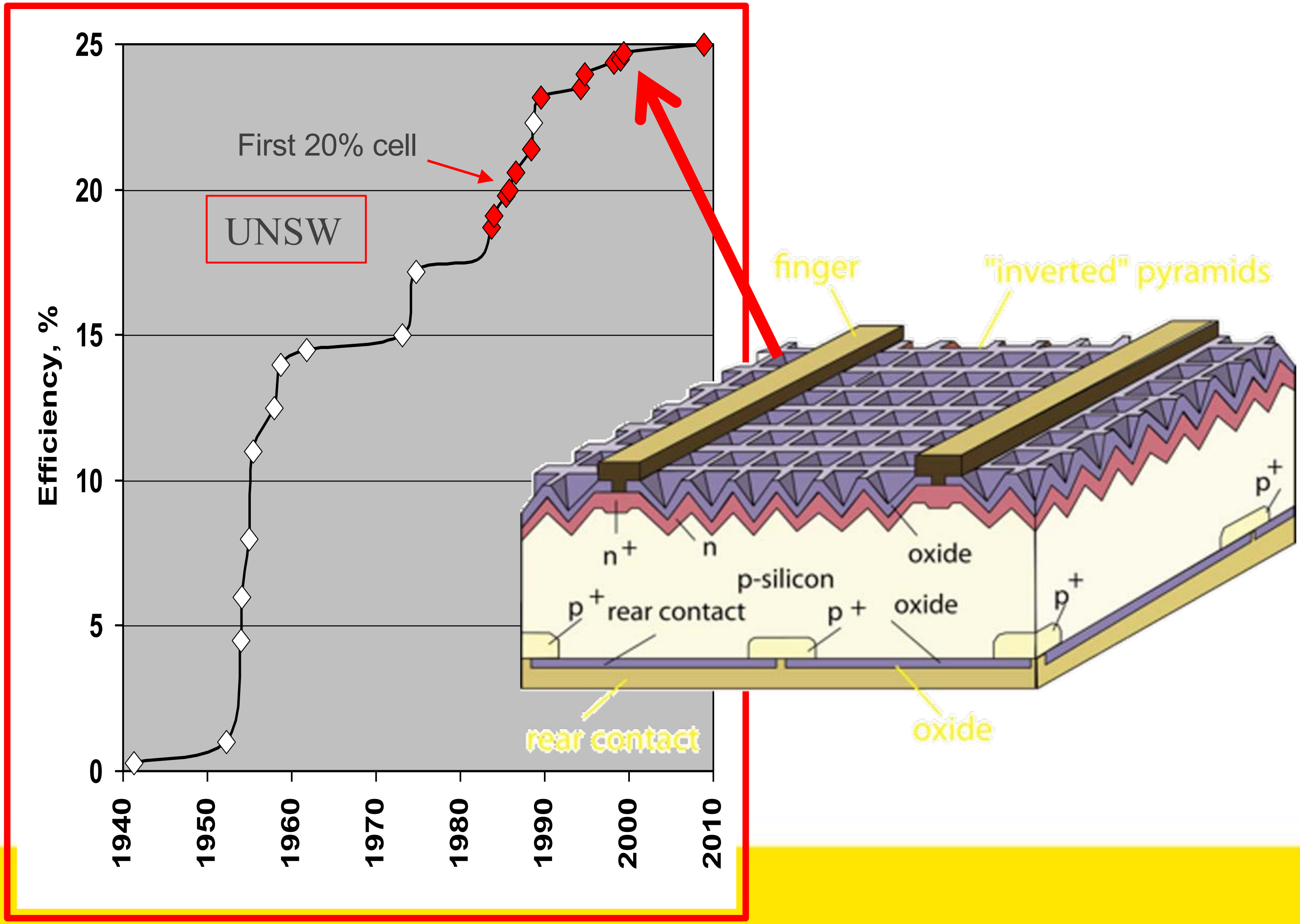


22% rear-junction cells (Stanford 1989)

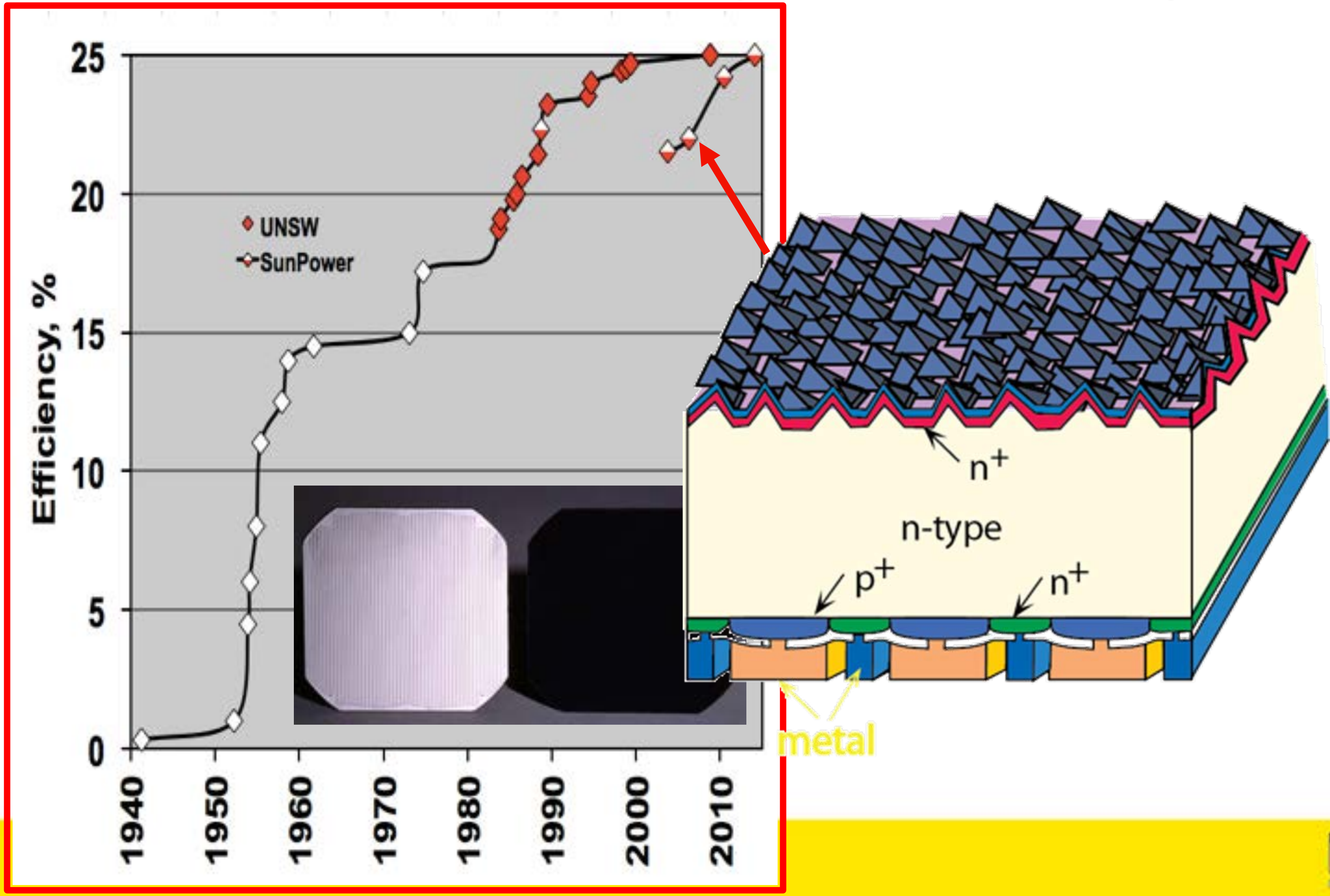




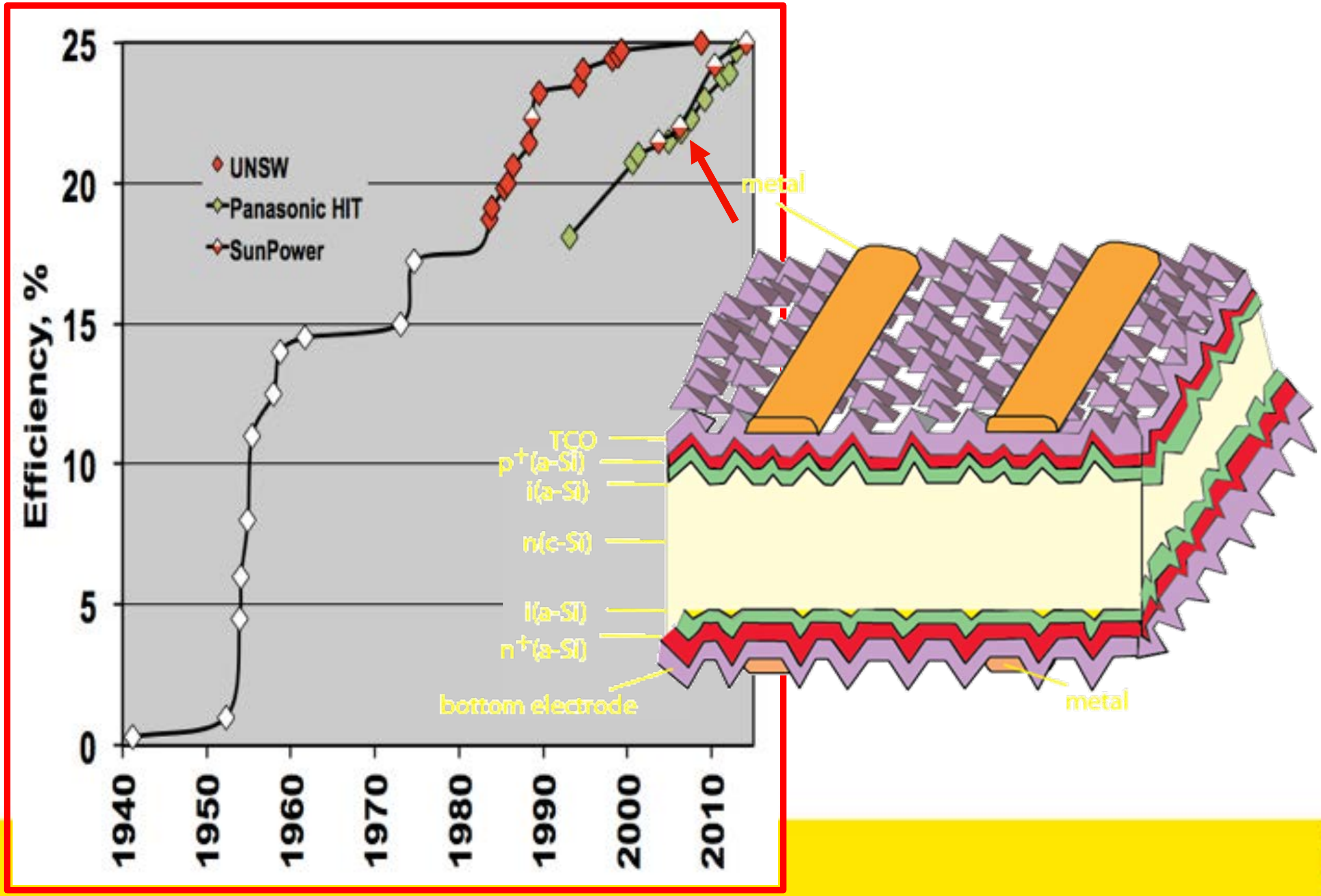
25% PERC/PERL cells (UNSW 1989/2008)



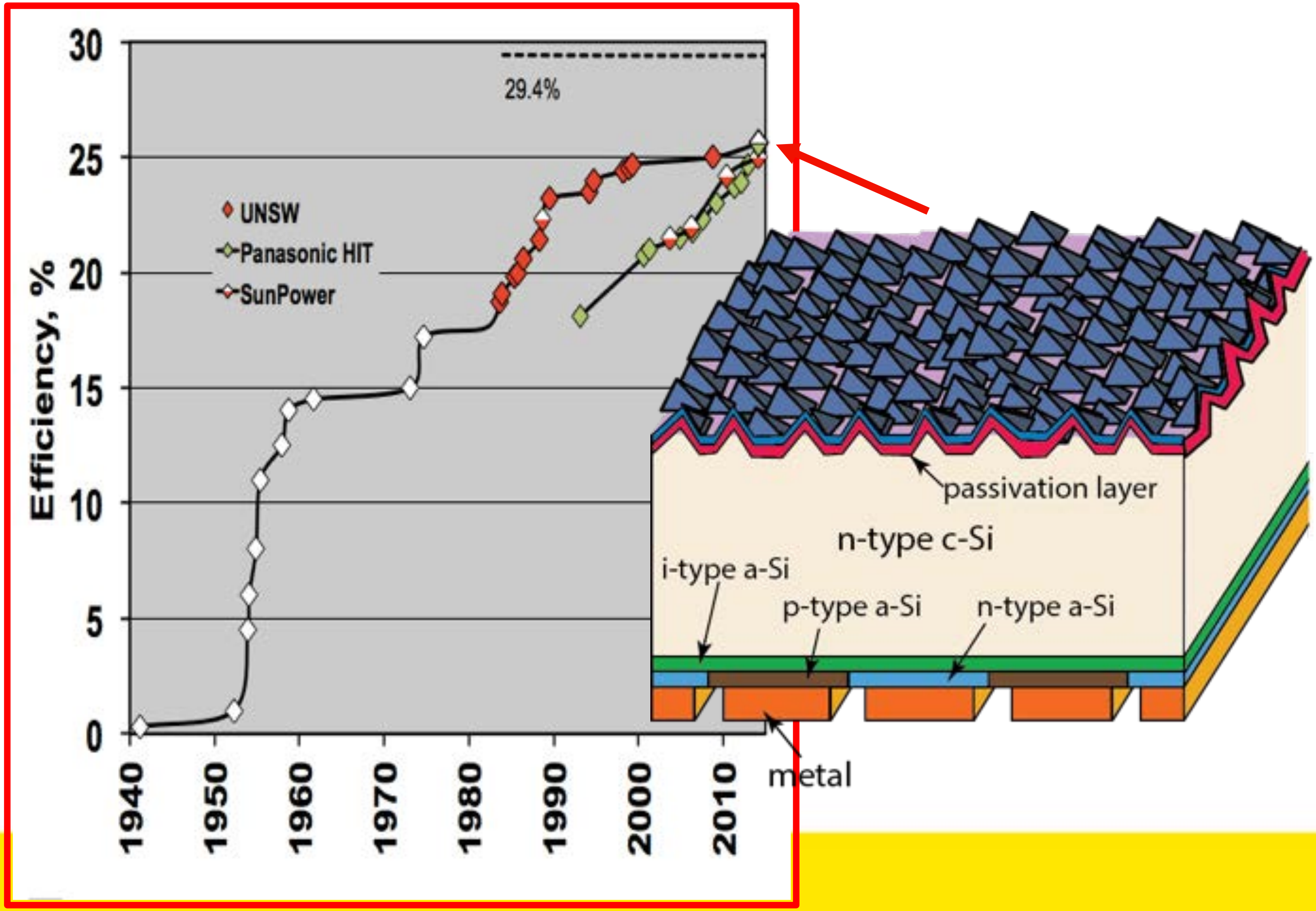
25% rear-junct. IBC cells (SunPower 2014)



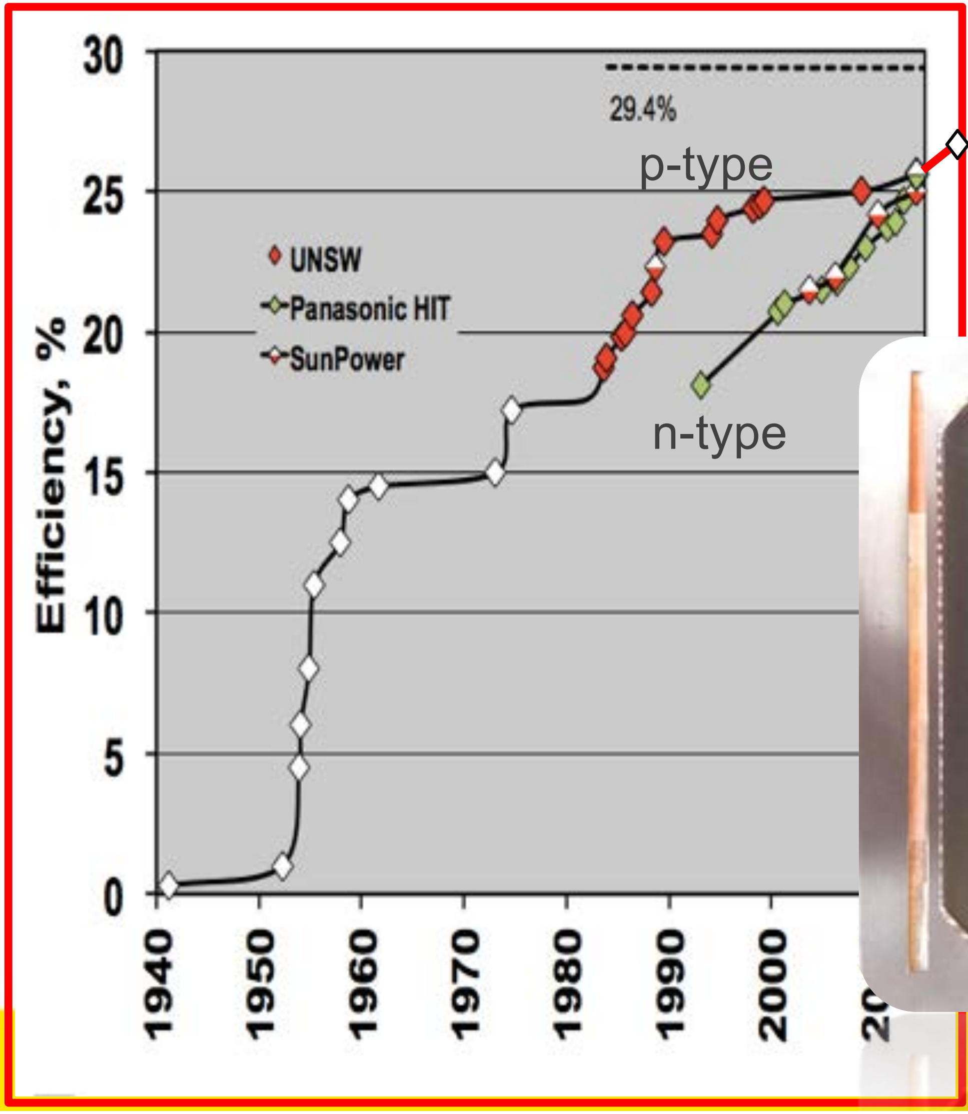
24.7% bifacial heterojunction HJT (Panasonic 2012)

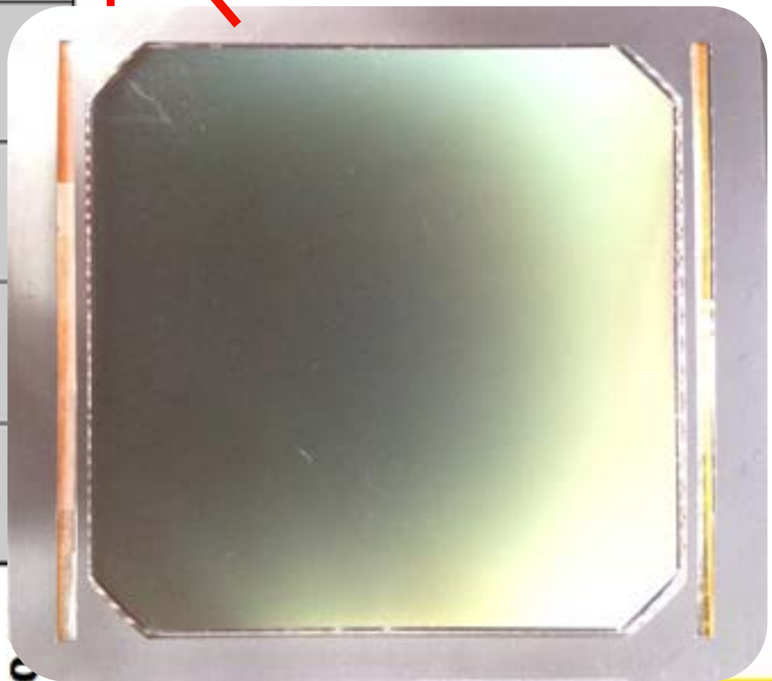


25.6% rear-junct.HJT (Panasonic 2014)



26.7% rear-junction HJT (Kaneka 2017)





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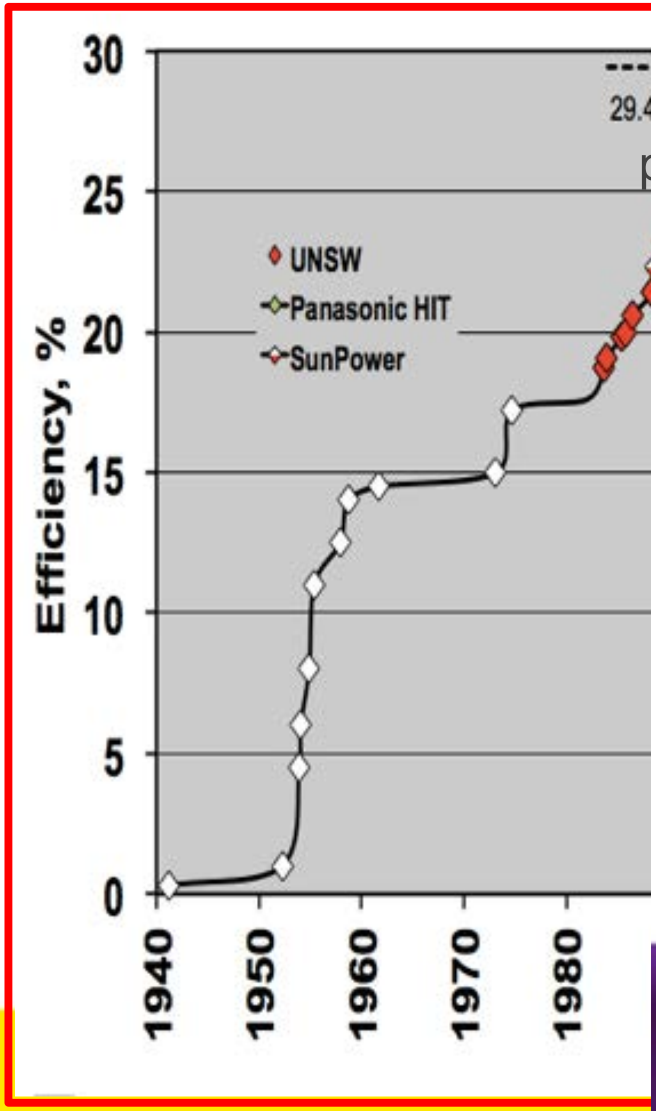
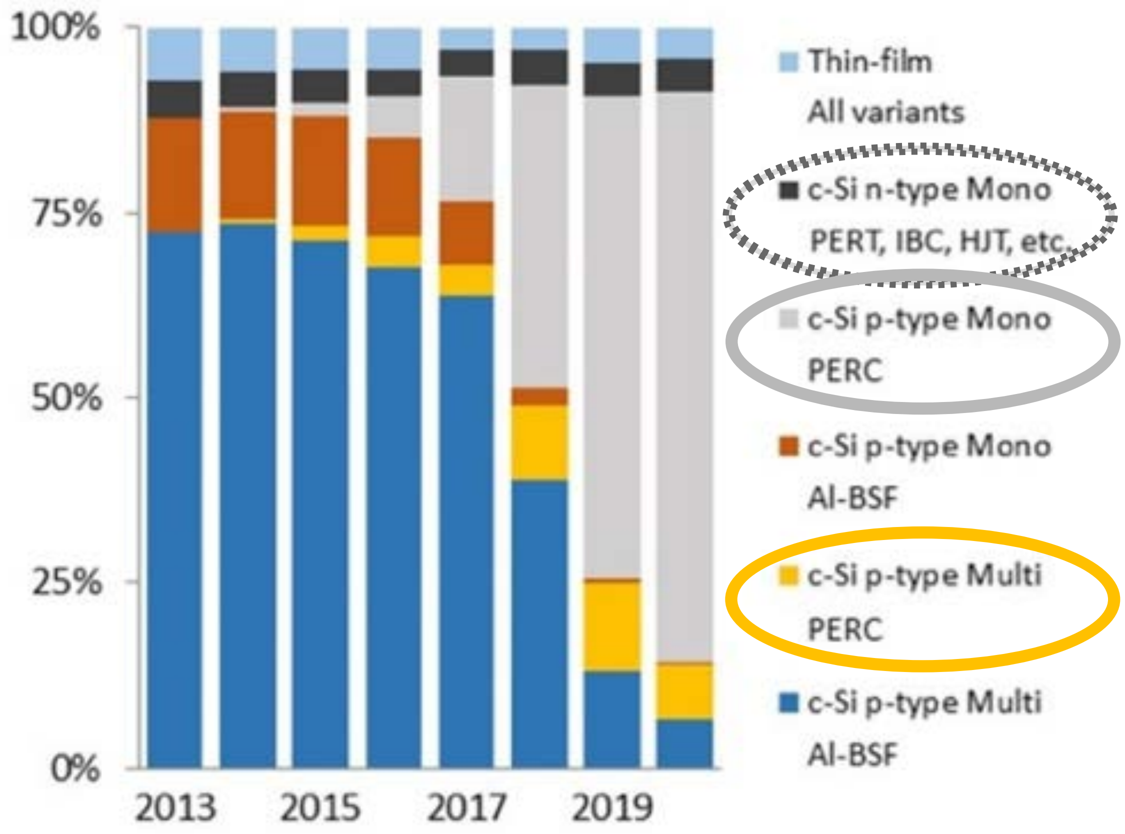
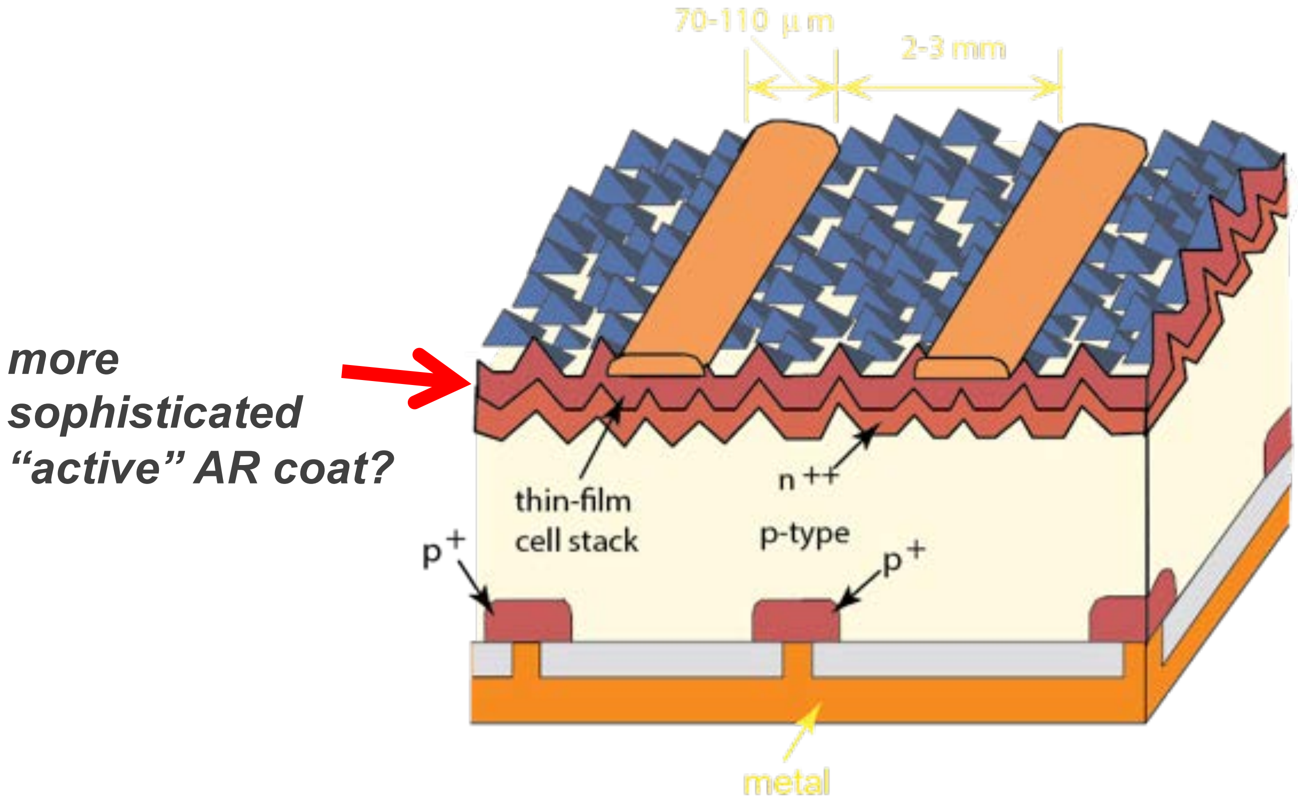
26.7% rear-juncti

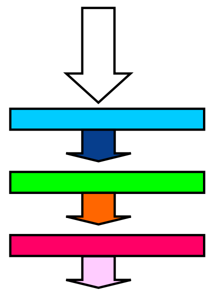


PV Technology Shares by Production



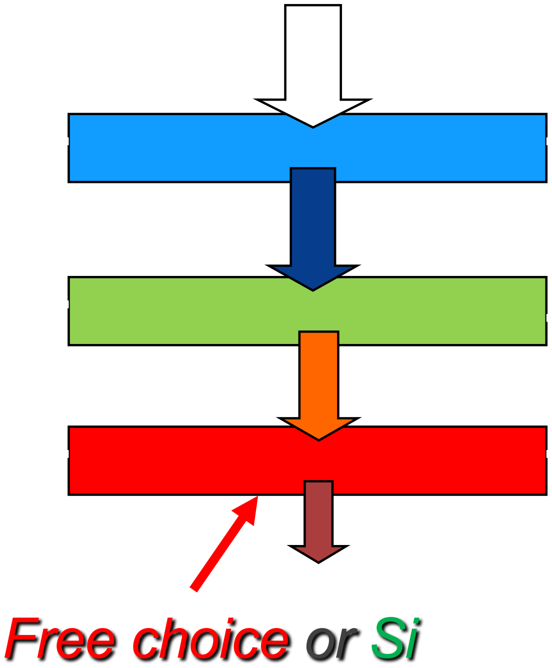
What comes after PERC?

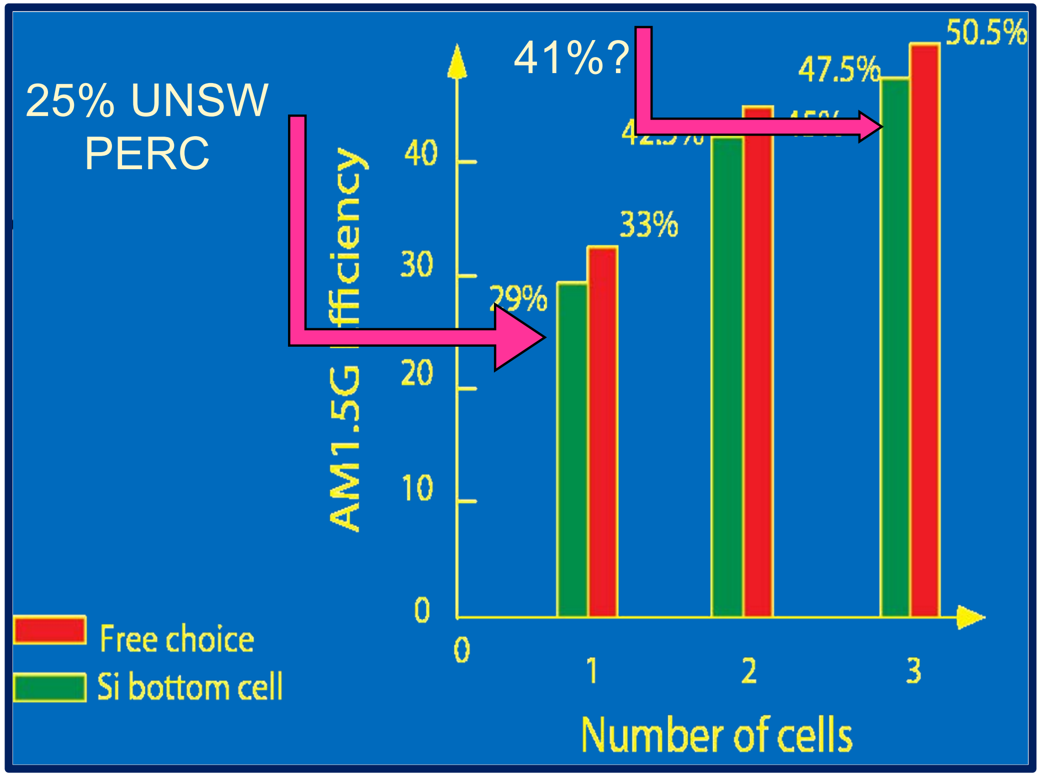




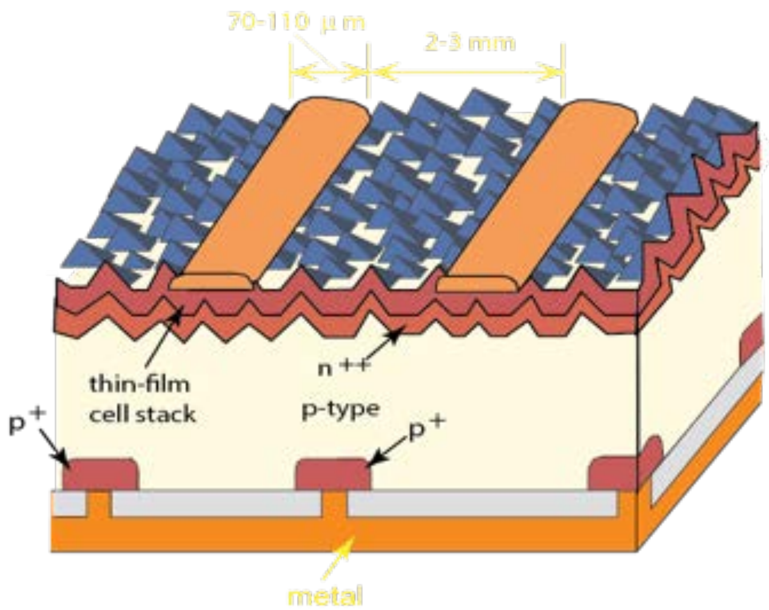
Supercharged tandem PERC?

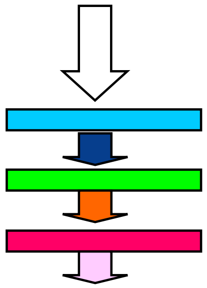
What comes after PERC?



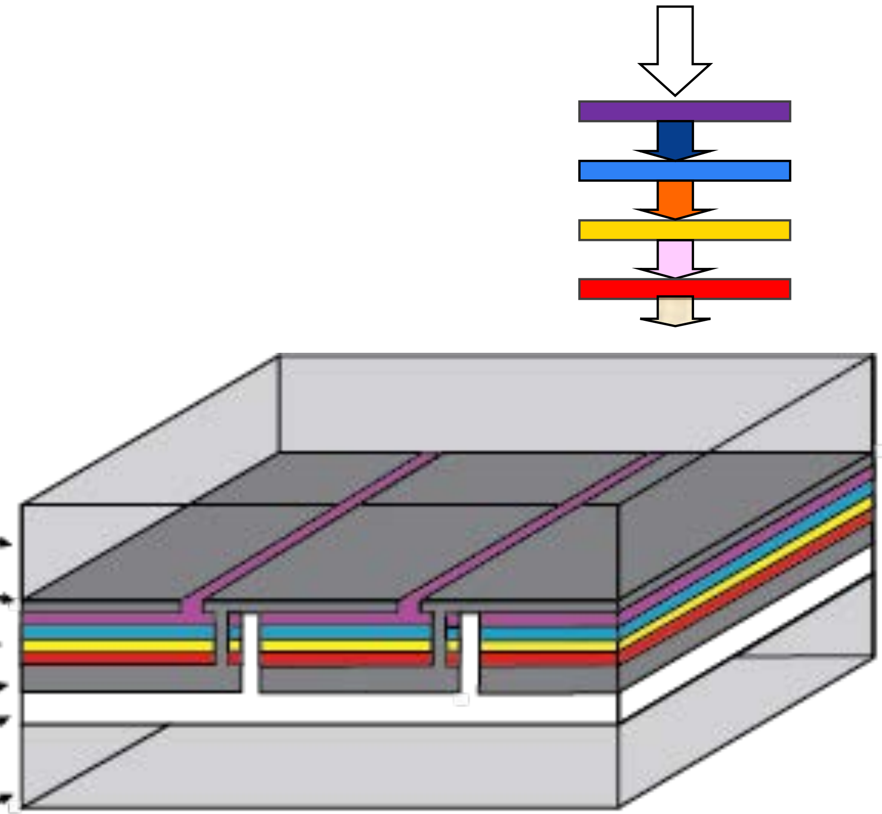


What then? – *the end for silicon?*





Si - 3 cell tandem



4-6 cell thin-film tandem