

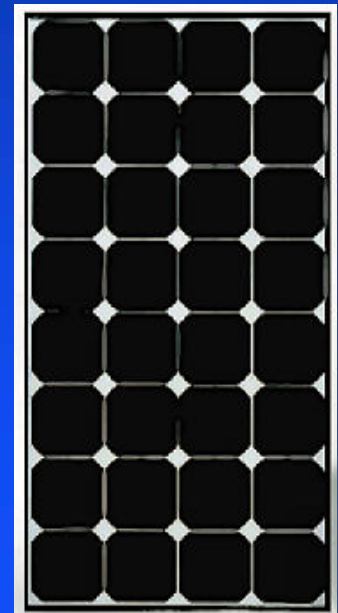


Australian Centre for Advanced Photovoltaics

“Evolution of High Efficiency Silicon Solar Cell Design”

Martin A. Green

University of New South Wales



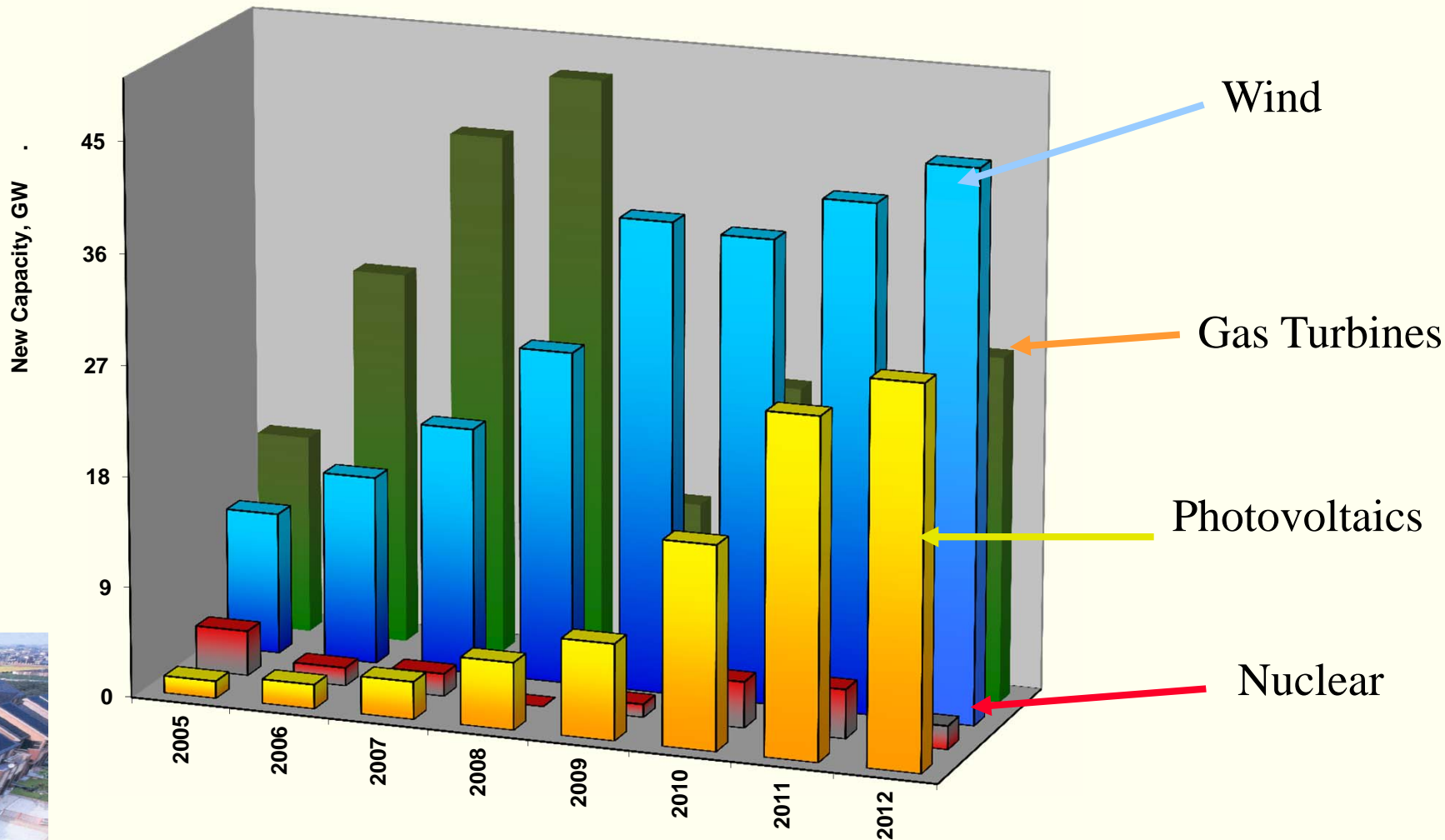


Outline –Lecture I

1. Recent developments
 2. Early PV history
 3. The first pn-junction
 4. Conventional space cells
 5. Key pointers pn junctions
 6. Enter the modern era
- Questions-



Annual capacity increase



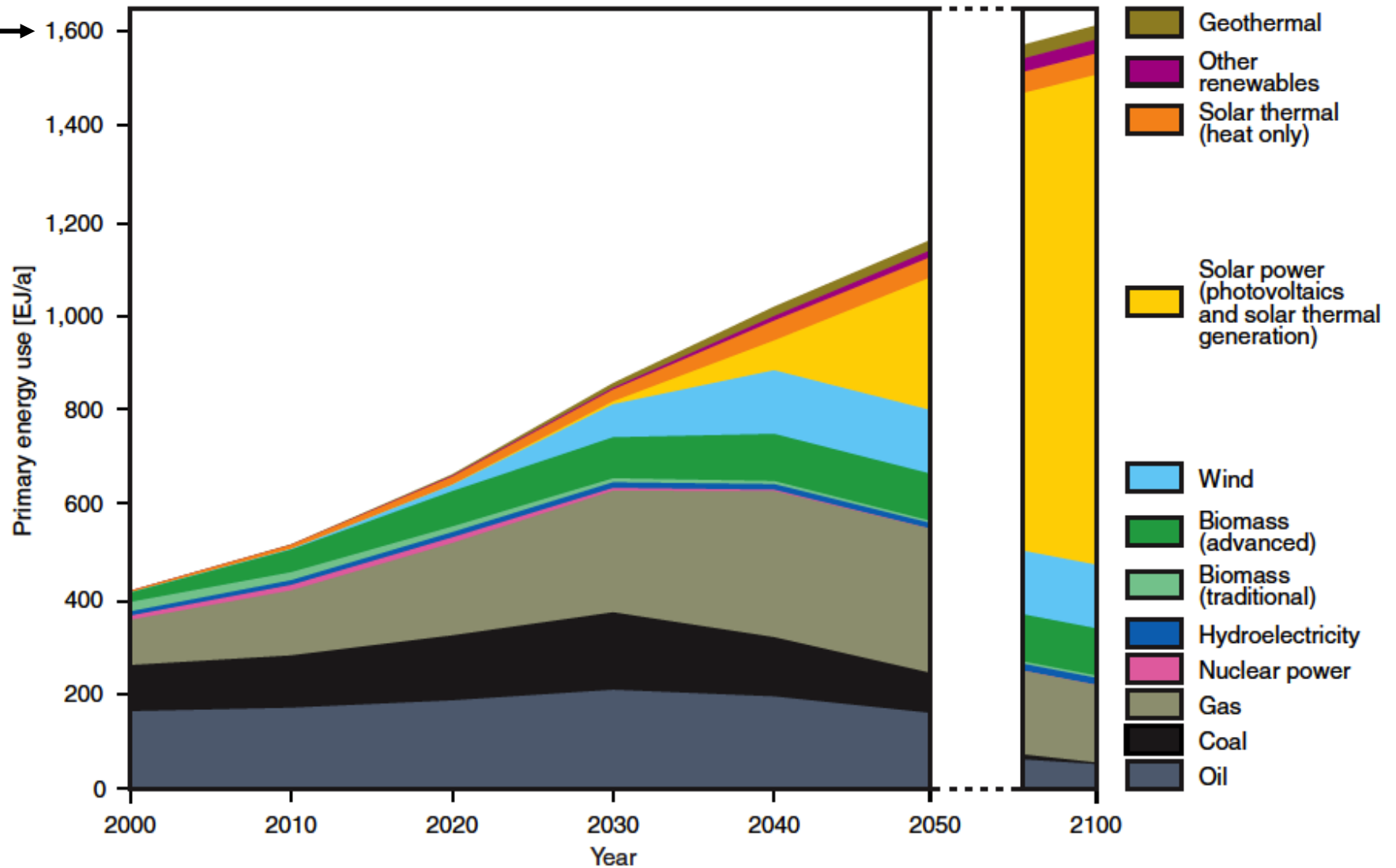
Sources: EPVIA, IAEA, GWEA



Ultimate potential?

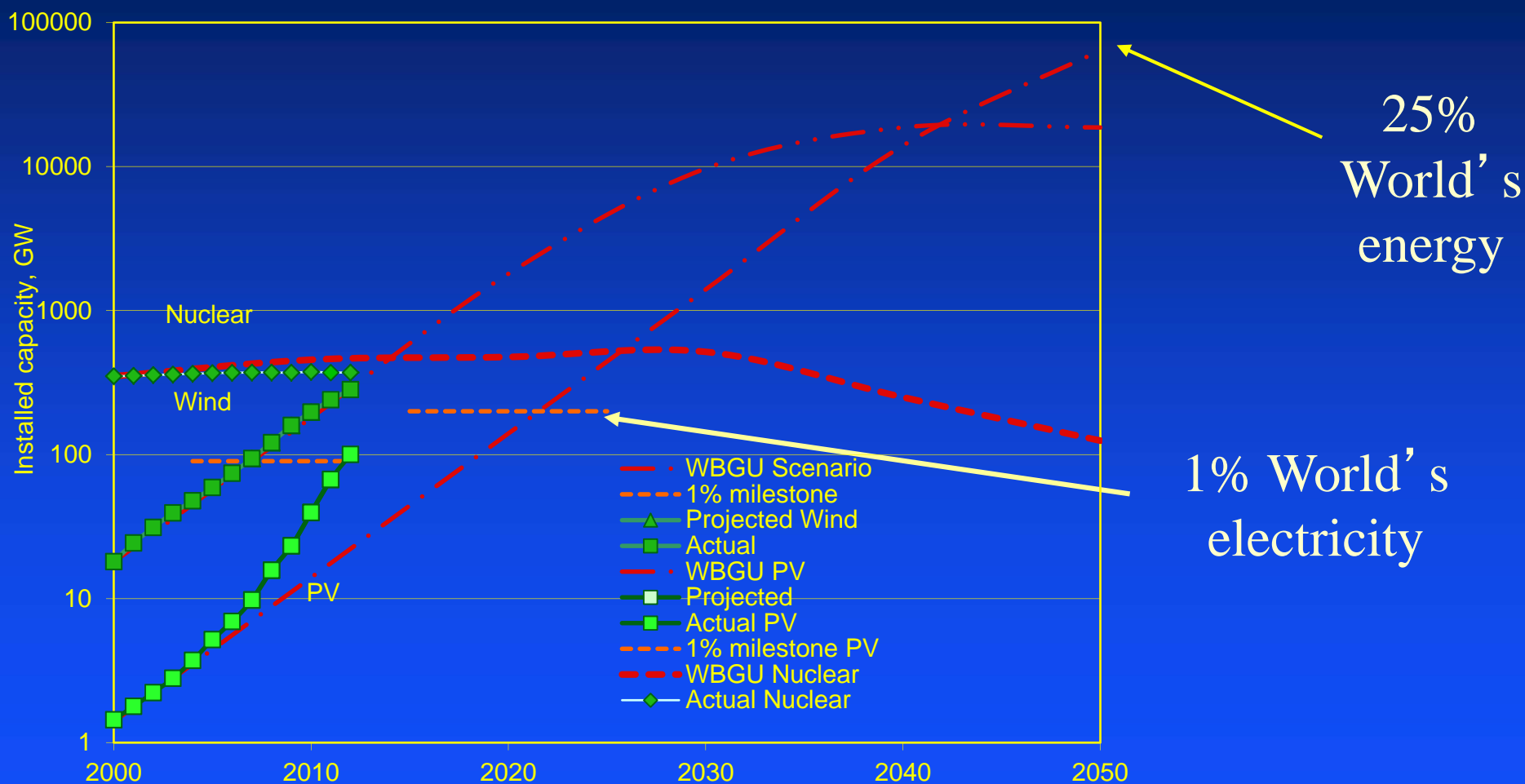
German Advisory Council
on Global Change
(WBGU) 2003

50.7 Terawatt





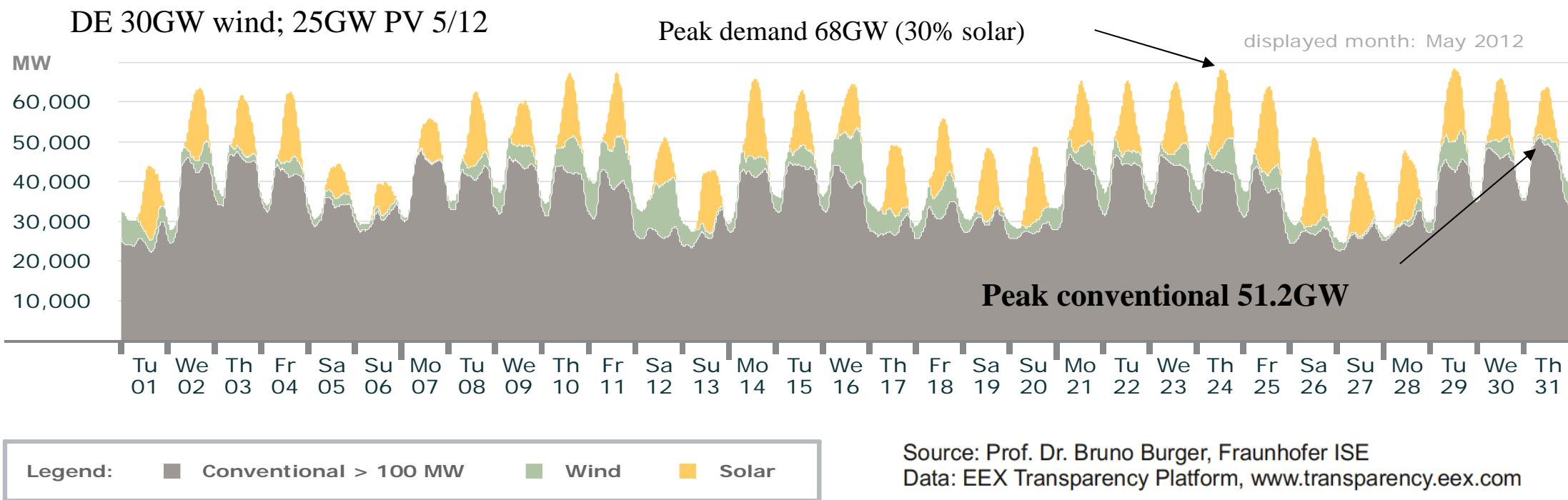
“Submerged” progress





German grid : May 2012

Actual production





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The beginning

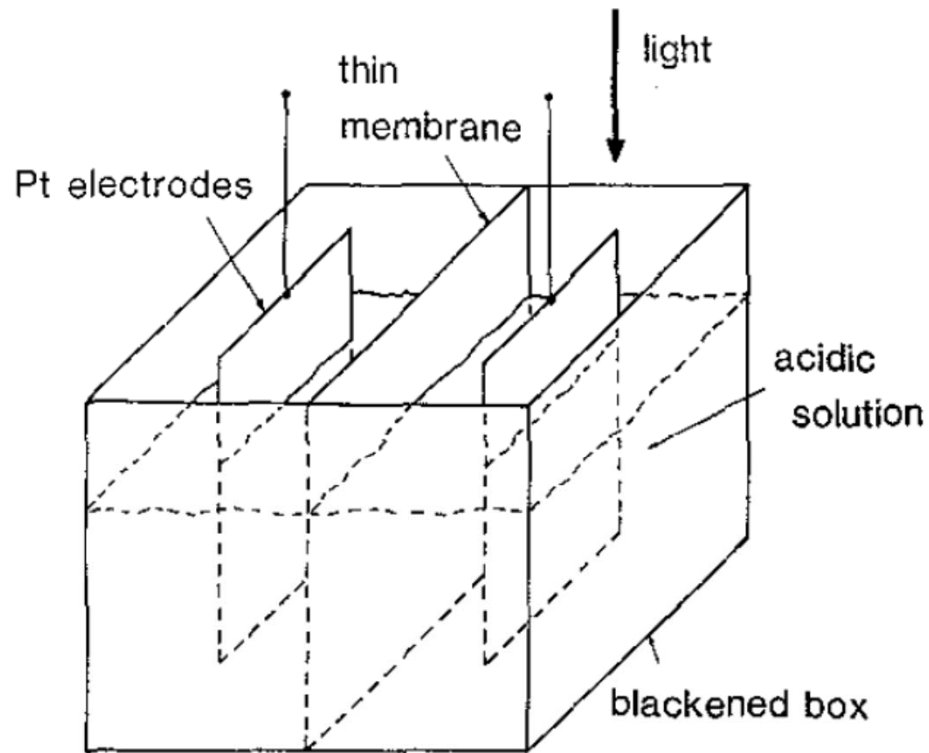
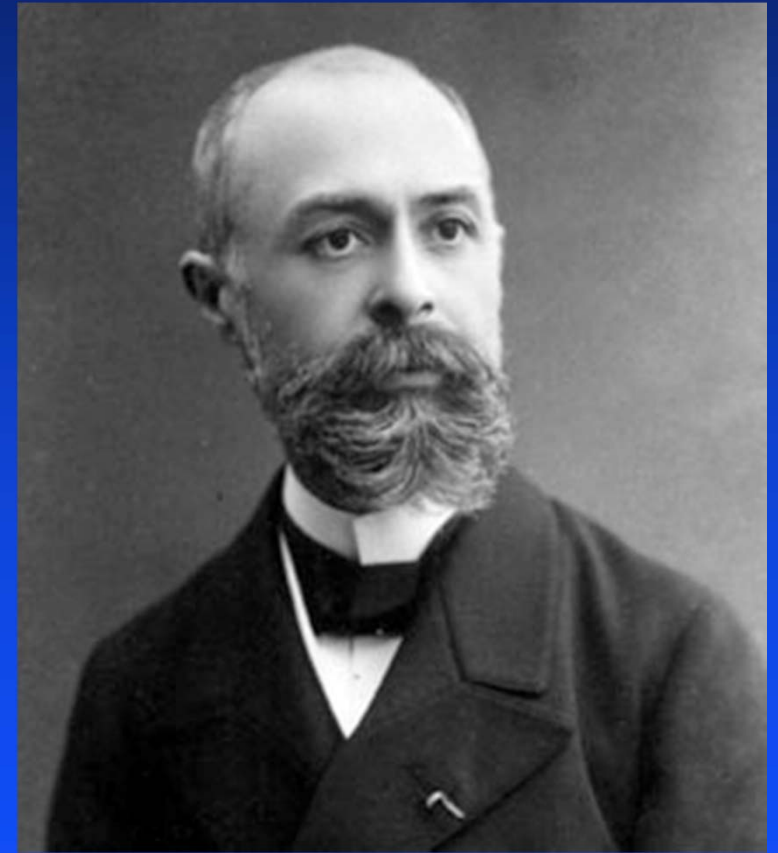


Figure 1: Diagram of apparatus described by Becquerel (1839)





The first solid-state cell

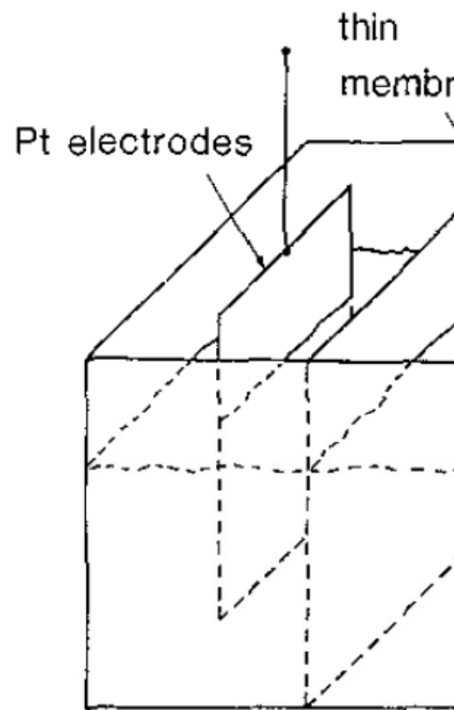


Figure 1: Diagram by Becquerel (1839)

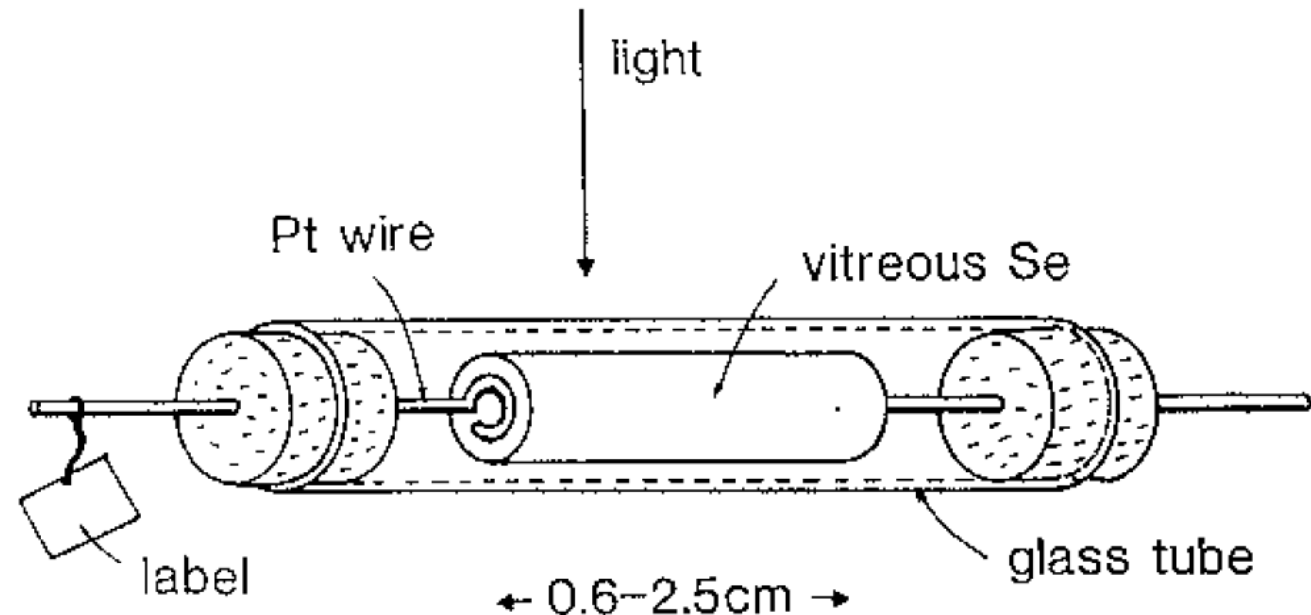


Figure 2: Sample geometry used by Adams and Day (1876) for the investigation of the photoelectric effects in selenium.



The first thin films

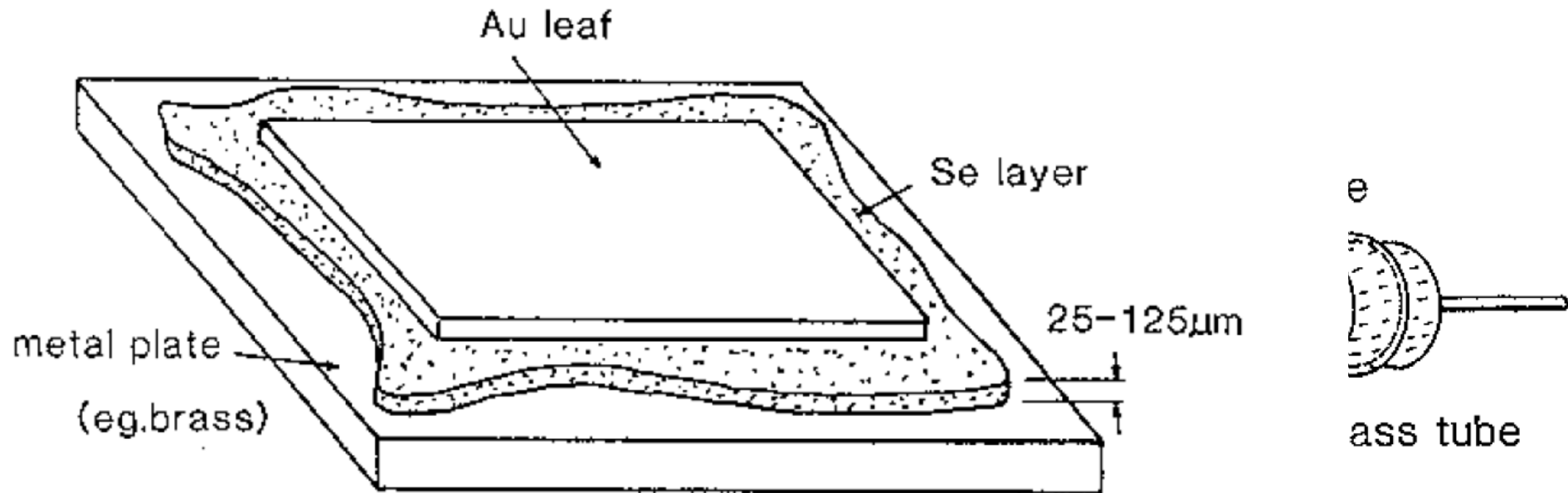
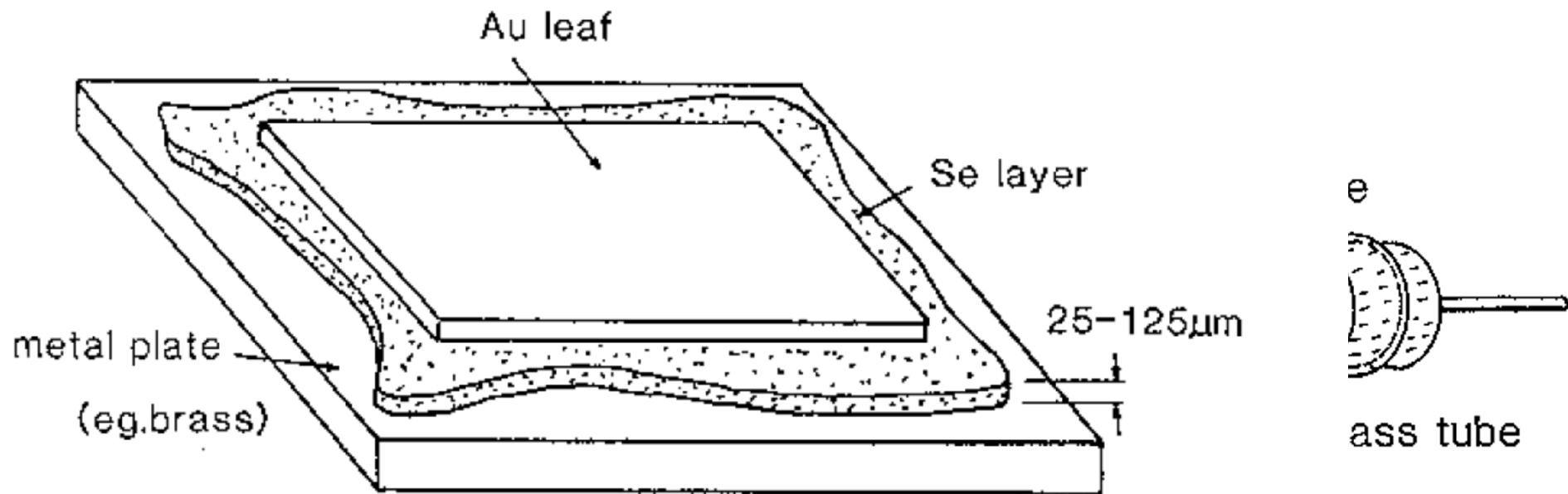


Figure 3: Thin film selenium cell demonstrated by Fritts in 1883.

by Adams
ion of the



The first PV visionary



"the current, if not wanted immediately, can either be "stored" where produced, in storage batteries ... or transmitted ... to a distance, and there used, or stored ..."



Cuprous oxide cells

Pt electrodes

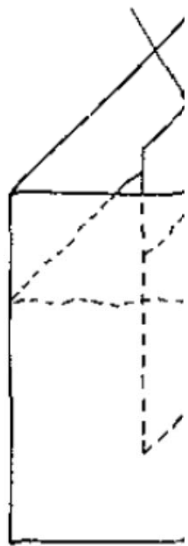
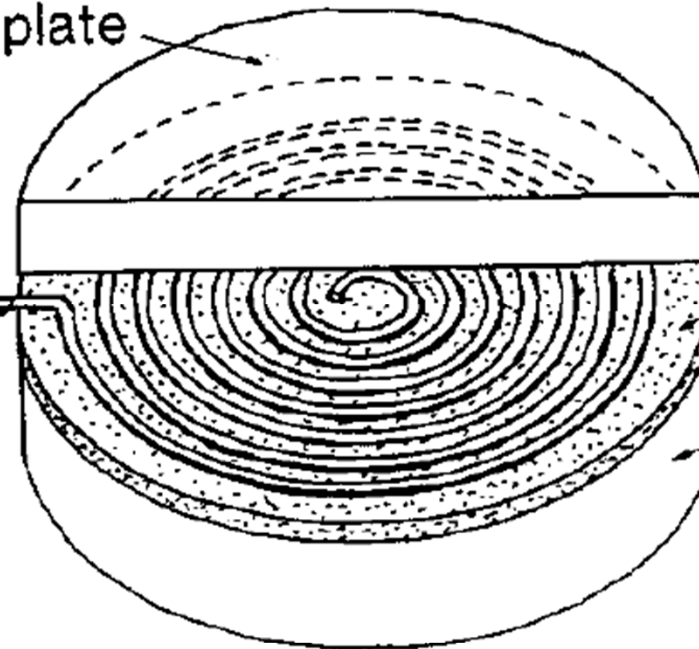


Figure 1: *l*
by Becquere

glass pressure plate

Pb wire coil



Cu_2O

Cu plate

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



Cuprous oxide cells

Pt electrodes

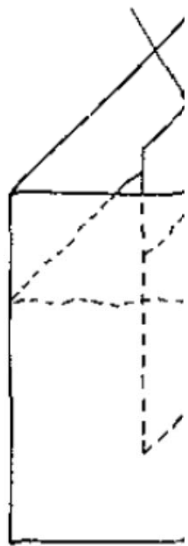
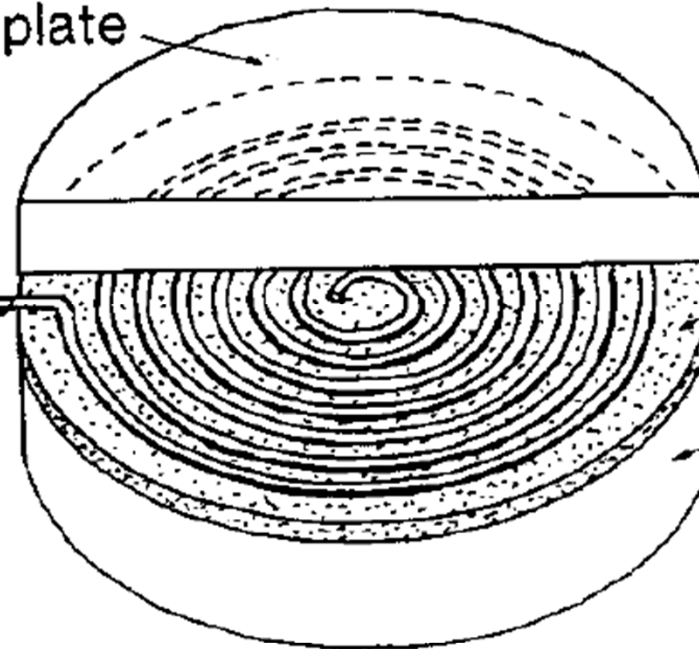


Figure 1: *l*
by Becquerre

glass pressure plate

Pb wire coil



Cu_2O

Cu plate

“spitting on a penny”

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



The 1930s

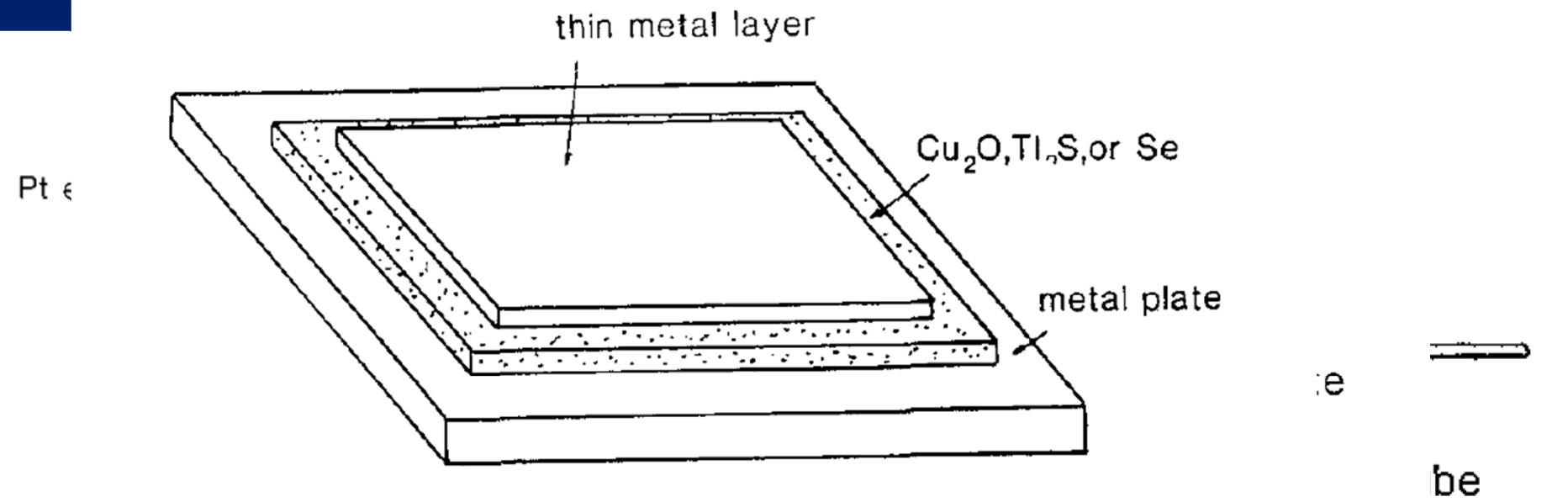


Figure 5: Structure of the most efficient photovoltaic devices developed during the 1930's.

Figure by E



The Theory of Electronic Semi-Conductors.

By A. H. WILSON, Emmanuel College, Cambridge.

(Communicated by P. A. M. Dirac, F.R.S.—Received June 18, 1931.)

Source: *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, Vol. 133, No. 822 (Oct. 1, 1931), pp. 458-491

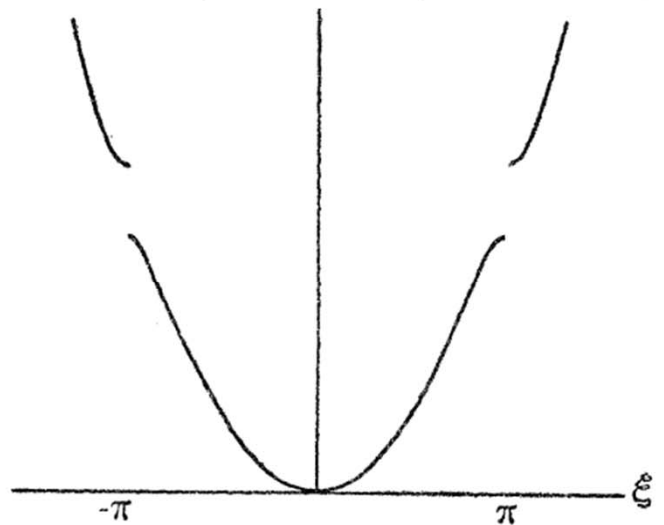
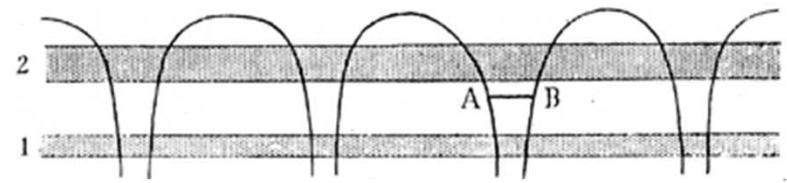


FIG. 1.





The 1930s

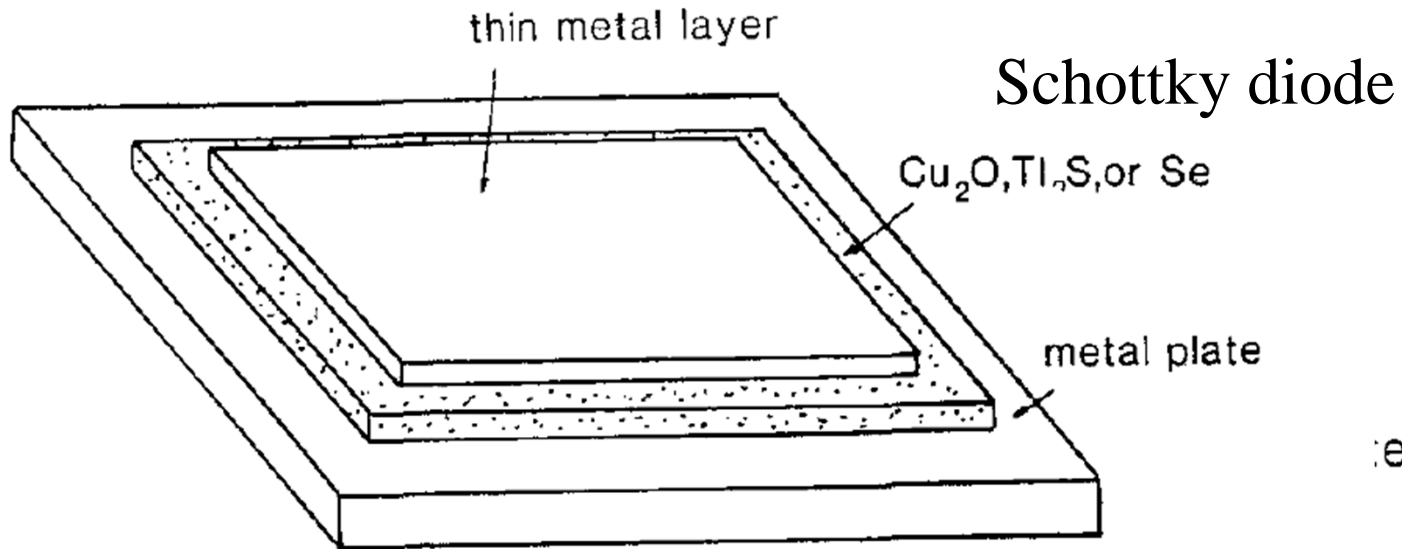
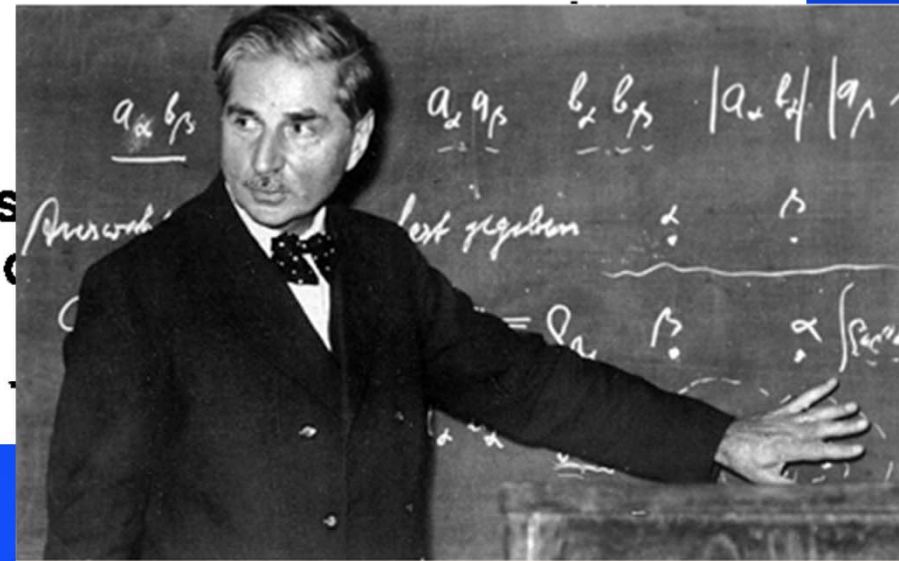


Figure 5: Structure of the most common photovoltaic devices developed in the 1930's.

Figure by E





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



FIG. 1

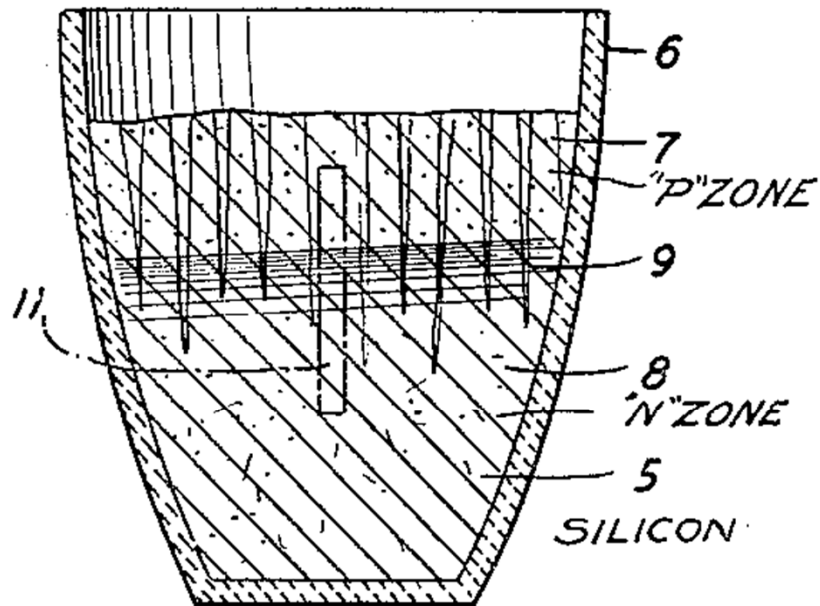
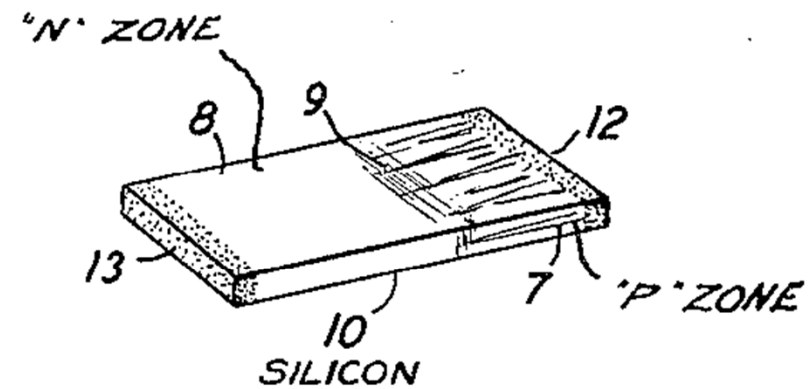


FIG. 2





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

FIG. 1

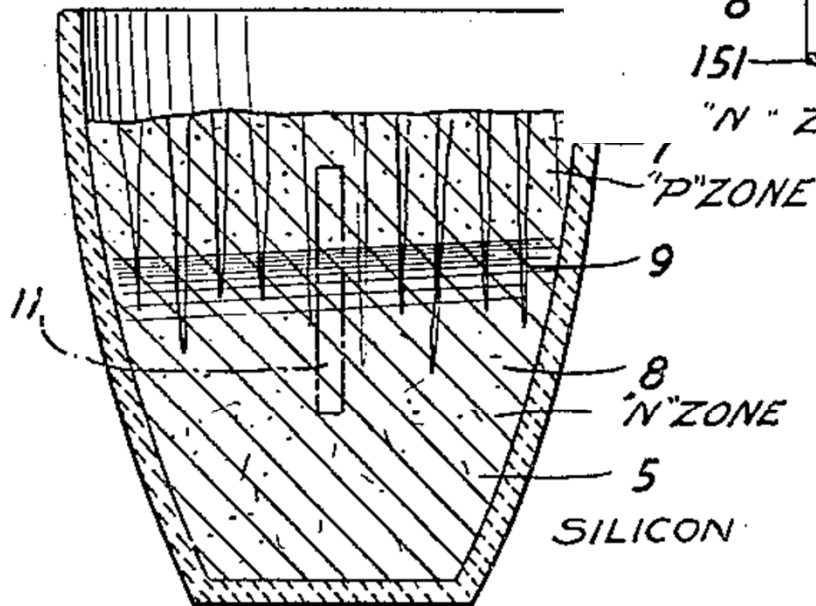


FIG. 26

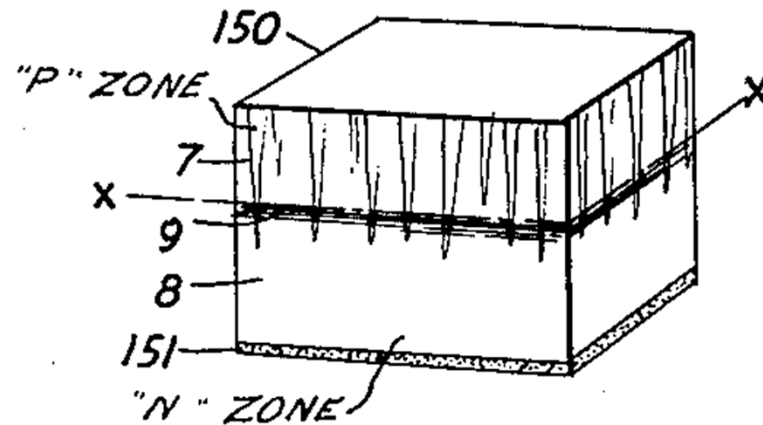
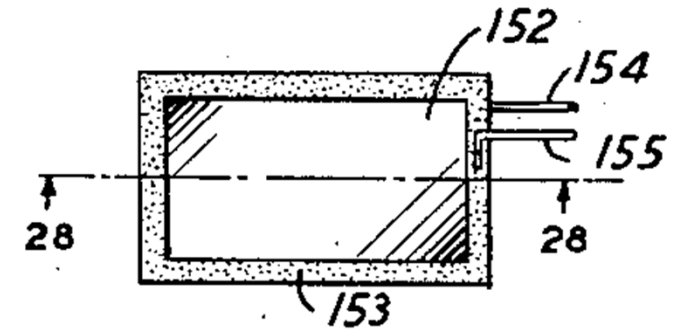
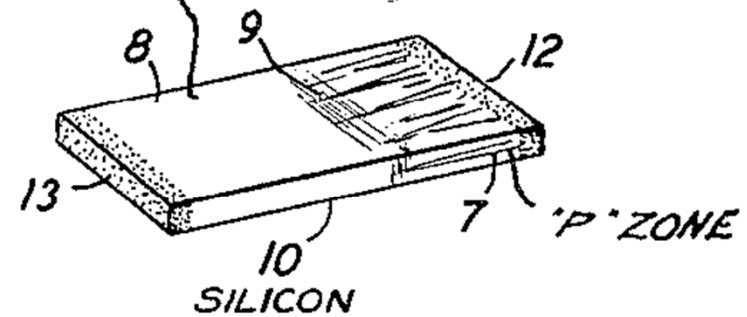


FIG. 27



"N" ZONE





The first silicon pn junction cell

(Russell Ohl, 1941)

FIG. 1

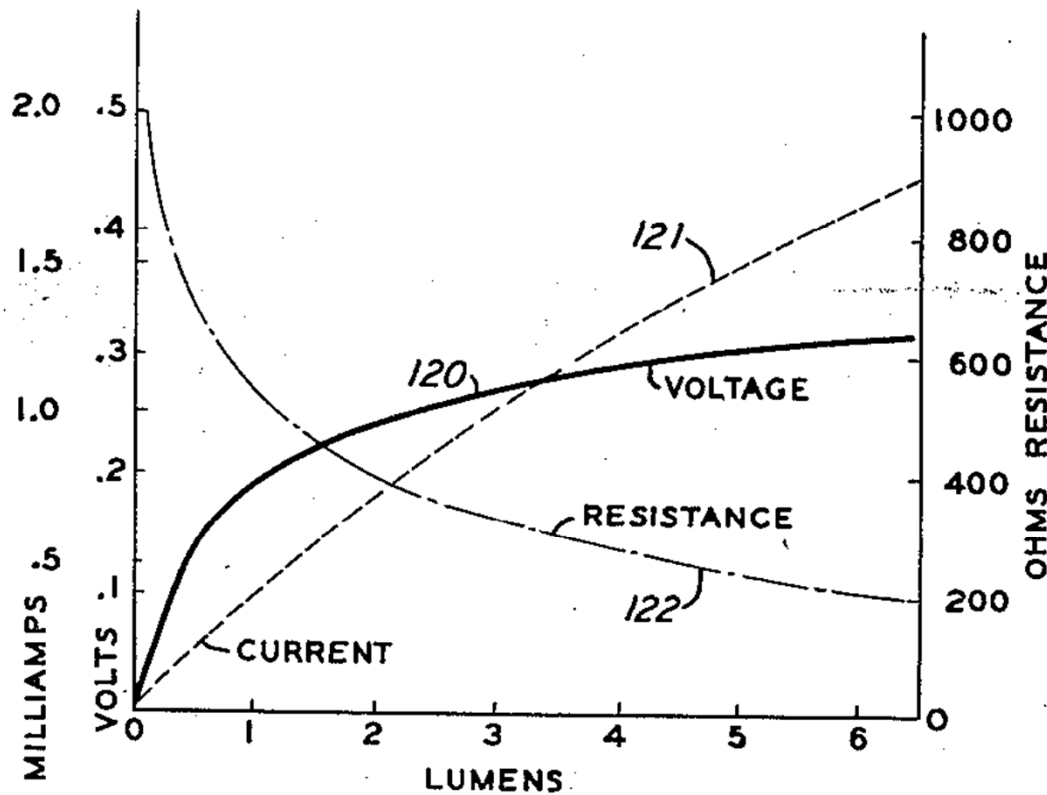
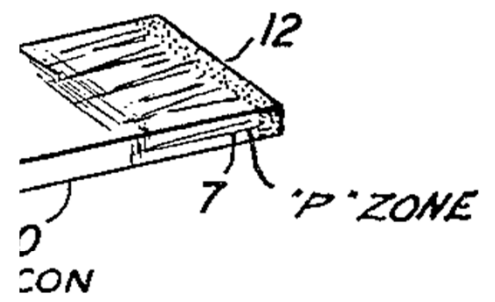
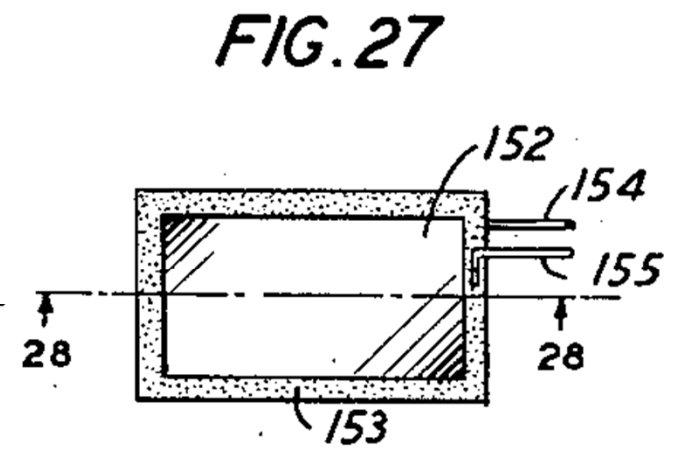
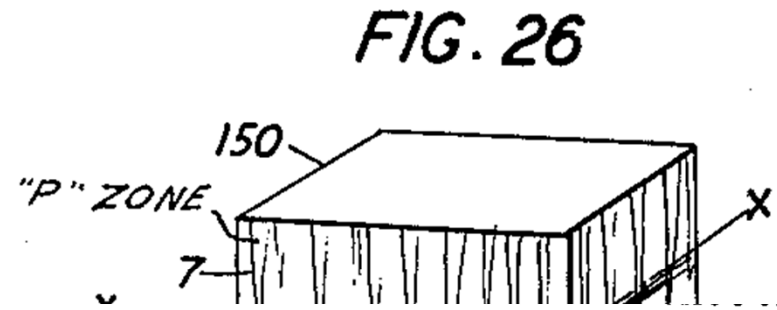


FIG. 21



The first silicon pn junction cell

William Shockley

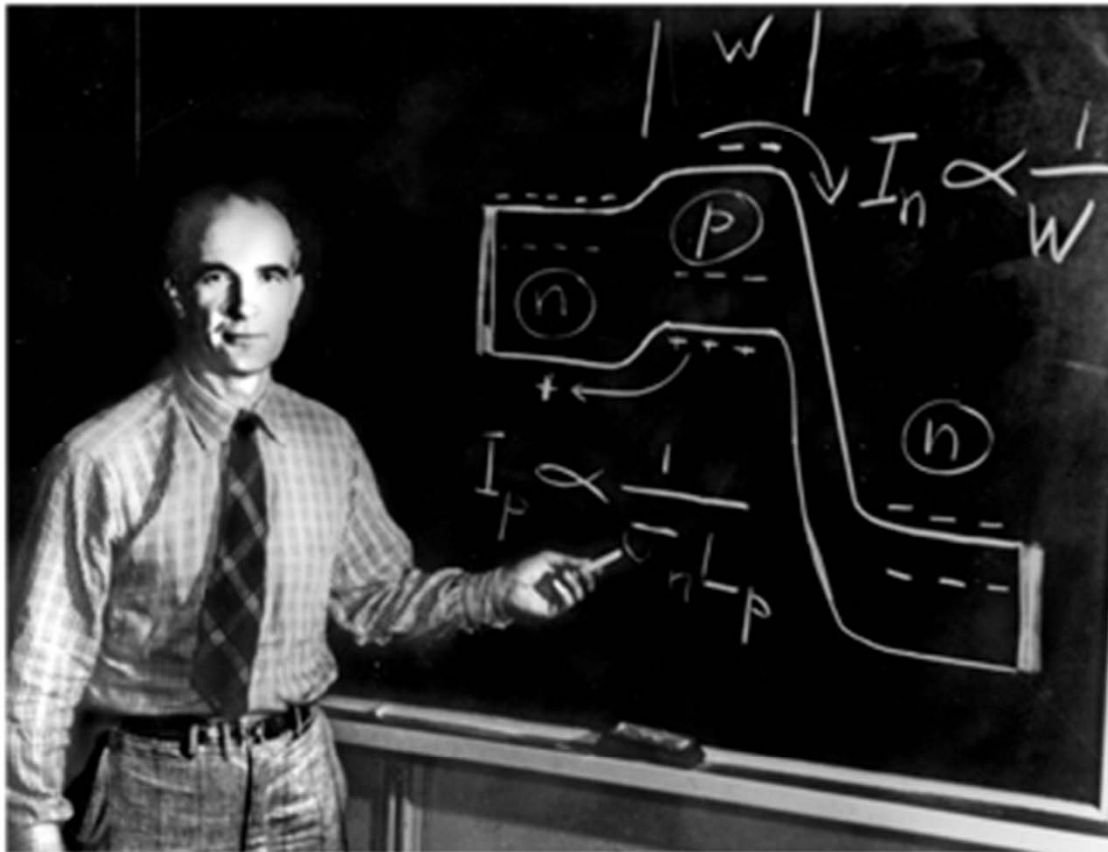
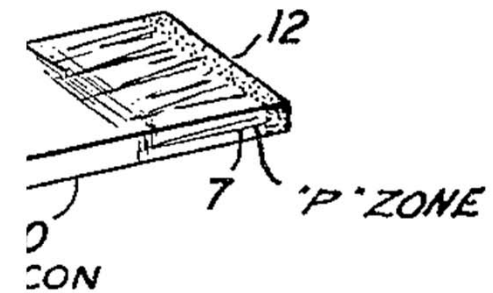
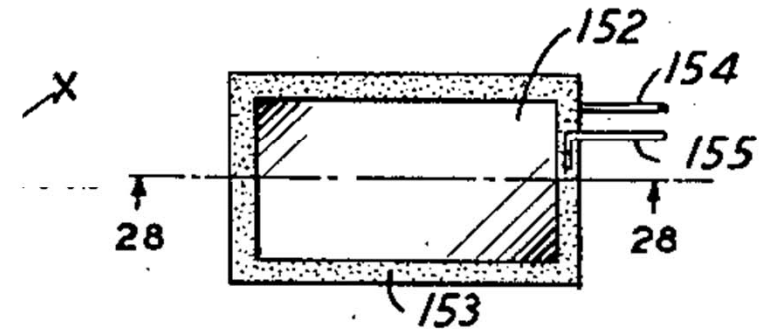


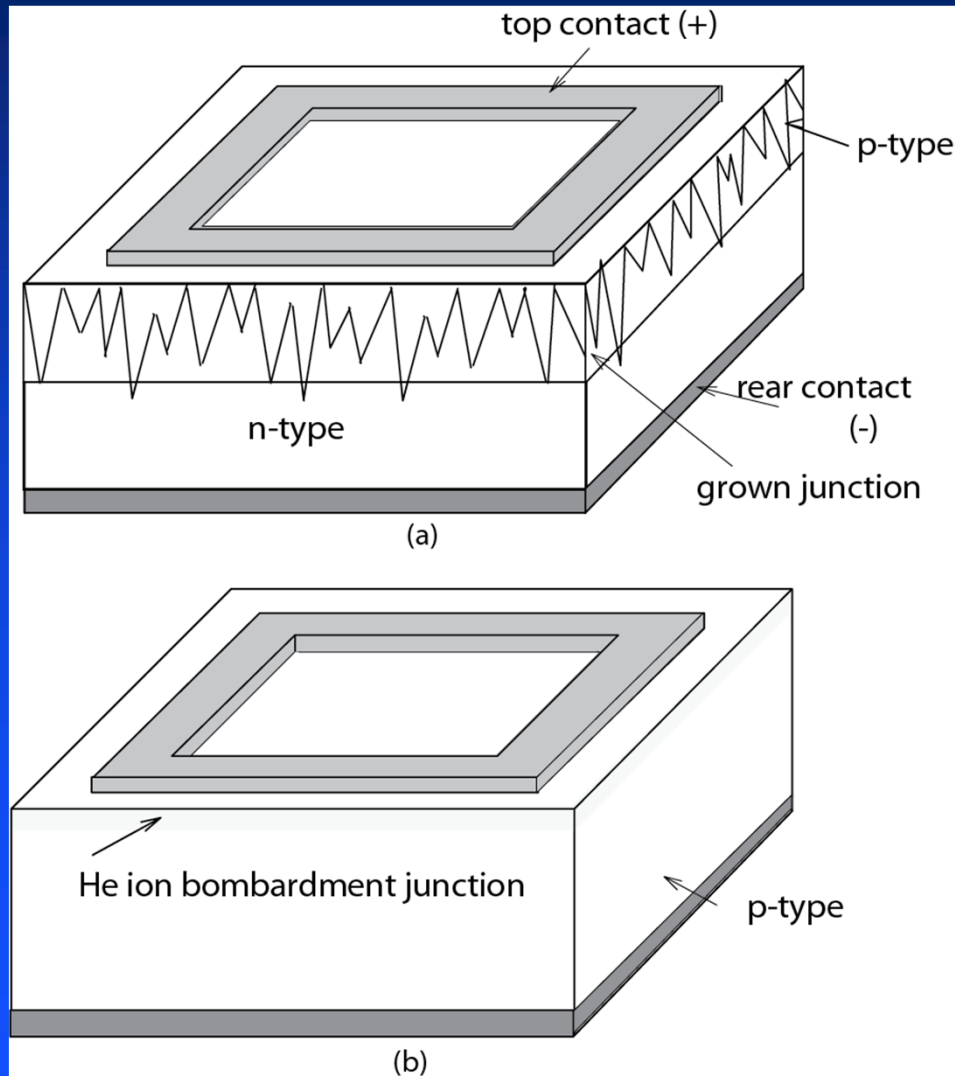
FIG. 4

FIG. 27



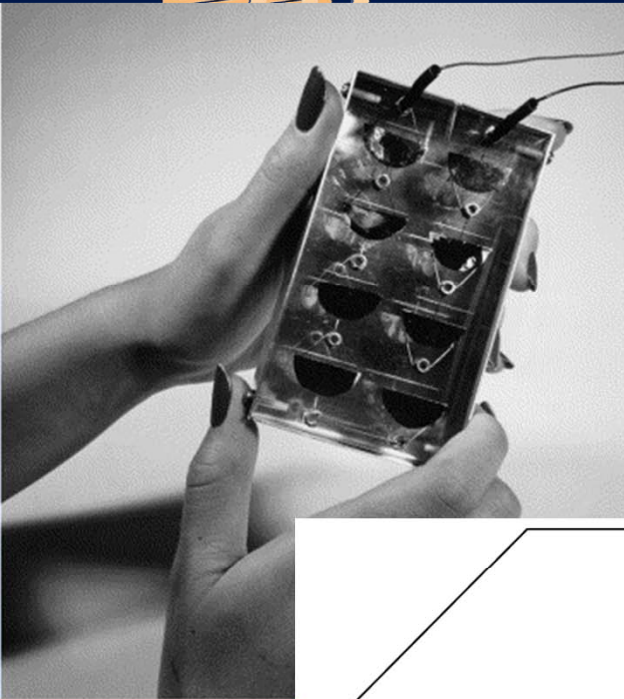


The first silicon pn junction cells (Russell Ohl, 1941 & 1951)

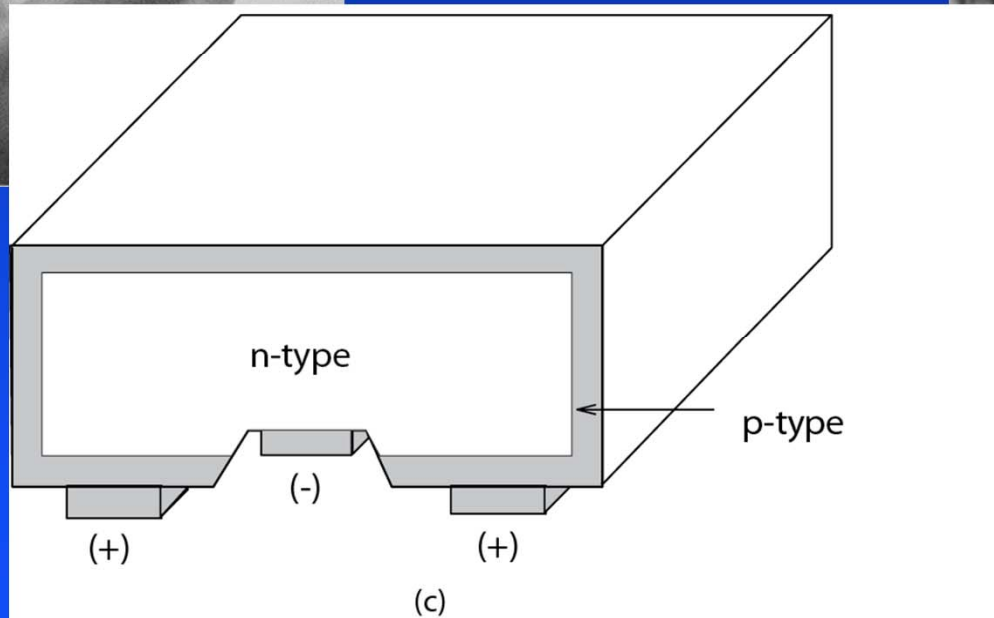




The first efficient cells (1953/4)



Pearson, Chapin & Fuller



WENSEL, REBUTTAL ACCUSES MCGARTHY OF 'MALICIOUS LIES'

Charges Attempt to Overt Subcomm.—Challenges Senator on Franco

LETTER QUICKLY REPLIED

Always Start to 'Rebuttal' Inquiry—Gleason Back on the Stand Today

By CLAYTON KENNEDY

WASHINGTON, April 25.—WENSEL, chairman of the Senate subcommittee on Franco, today sharply rebuffed a letter from the late Senator Joseph P. Kamp, who had accused Wensele of "malicious lies" in his report on Franco.

WENSEL STILL HINTS AT TIE-UP OF BUSES

Agrees to Seek Probe Today But Carries Over Vote

By HAROLD ARBEY

WASHINGTON, April 25.—WENSEL, chairman of the Senate subcommittee on Franco, today agreed to seek a probe today but carried over his vote on the matter.

AUSTRALIA SPURS MOSCOW'S DEMAND

Belongs to Hand Over, Peron and Roberts Say, French or Soviet's Decision

By E. L. KILGORE

WASHINGTON, April 25.—AUSTRIA'S demand today for the handover of Peron and Roberts, the Argentine and British spies, was a direct result of the Australian government's decision to extradite them.

IRAQ WILL RECEIVE U.S. MILITARY AID

Agreement Reached with Baghdad, Arms Shipment Used Only for Security

By W. H. AGRESTI

WASHINGTON, April 25.—IRAQ WILL receive a shipment of U.S. military aid today, according to a report from Baghdad.

3 Killed During Argentine Voting

Clear Victory for Peron Conducted

By EDWARD ARDRE

Buenos Aires, April 25.—THREE people were killed today during the voting in the Argentine presidential election.

Palau Vaccine Test Will Start Today

By WILLIAM L. LATHROP

WASHINGTON, April 25.—THE test of a vaccine against the mumps virus in Palau, a small island in the Pacific, will begin today.

Scientists See Harm In Monoclonal Inquiry

By FREDERICK BROWN

WASHINGTON, April 25.—SCIENTISTS today said they saw no harm in the government's inquiry into the possible effects of the atomic bomb on the environment.

FERGUSON ASSERTS HOUSING INQUIRY MAY DELAY FUNDS

Says Senate Action Findings In F.H.A. Standards—Wants Official in Investigation

By FREDERICK BROWN

WASHINGTON, April 25.—FERGUSON today asserted that the government's inquiry into the housing program might delay the release of funds to the Federal Housing Administration.

U. S. and British Leaders on Two Active Diplomatic Fronts

By W. H. AGRESTI

WASHINGTON, April 25.—U. S. and British leaders today were active on two diplomatic fronts, one in Europe and one in the Middle East.

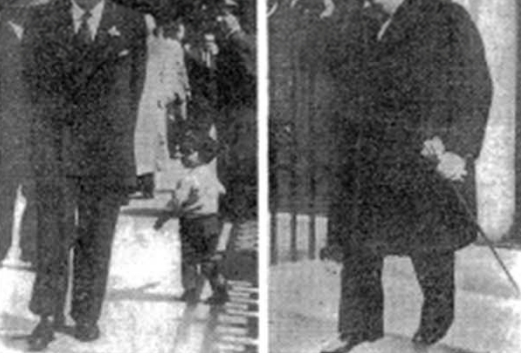
BRITAIN'S CABINET SEEMS WAY TO BAR AN ASIAN DISASTER

Political and Military Moves to Aid French in Indo-China Discussed by Ministers

By EDWIN BARRINGTON

LONDON, April 25.—BRITAIN'S cabinet today seemed to be on the way to barring an Asian disaster, according to a report from London.

U. S. and British Leaders on Two Active Diplomatic Fronts



John Foster Dulles, U. S. Secretary of State and chief delegate to the Geneva Conference, and Winston Churchill, British prime minister, were seen today walking down the steps of the British Embassy in Geneva. A side view taken by the Associated Press.

AUSTRALIA SPURS MOSCOW'S DEMAND

Belongs to Hand Over, Peron and Roberts Say, French or Soviet's Decision

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Political and Military Moves to Aid French in Indo-China Discussed by Ministers

ARMY HELP NOW DOUBTED

By EDWIN BARRINGTON

LONDON, April 25.—THE British cabinet today seemed to be on the way to doubting the need for British military aid to the French in Indo-China.

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Belongs to Hand Over, Peron and Roberts Say, French or Soviet's Decision

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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



Electricity from Sunlight

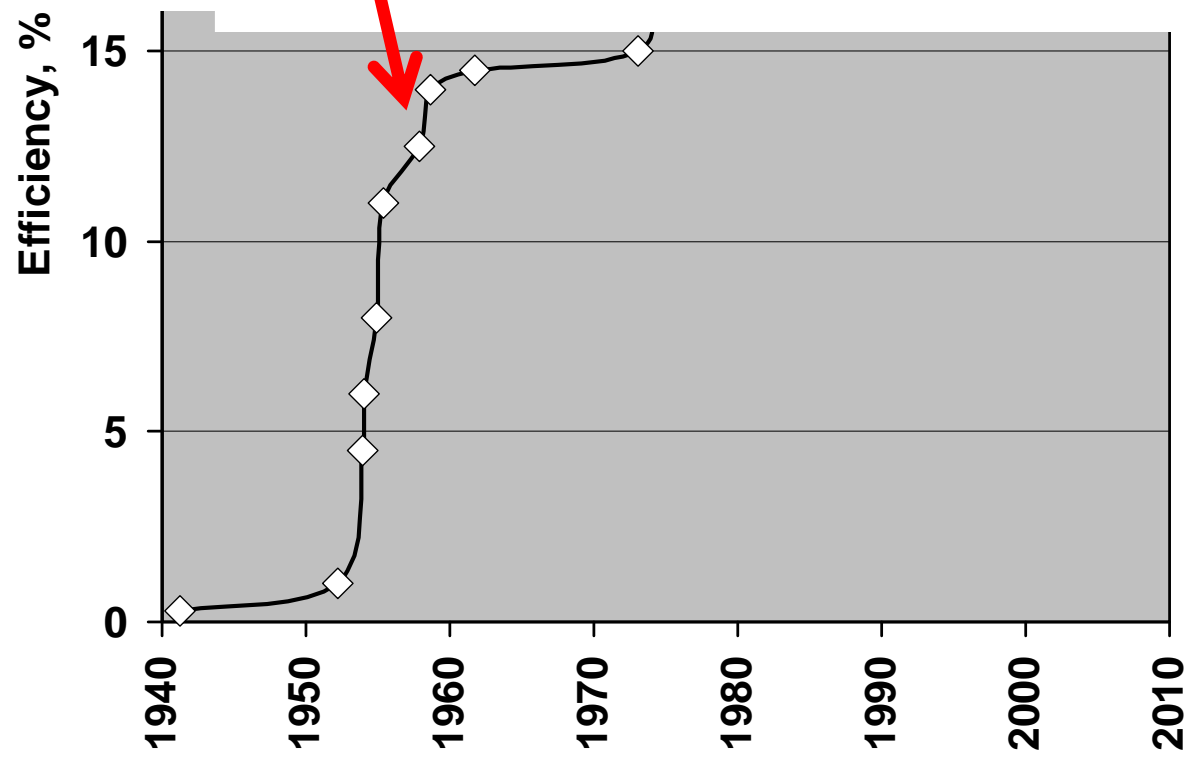
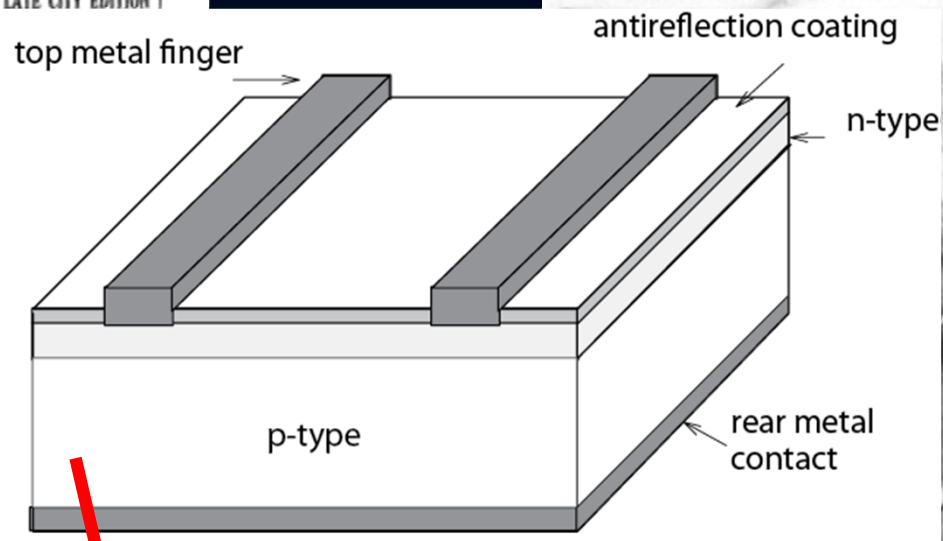


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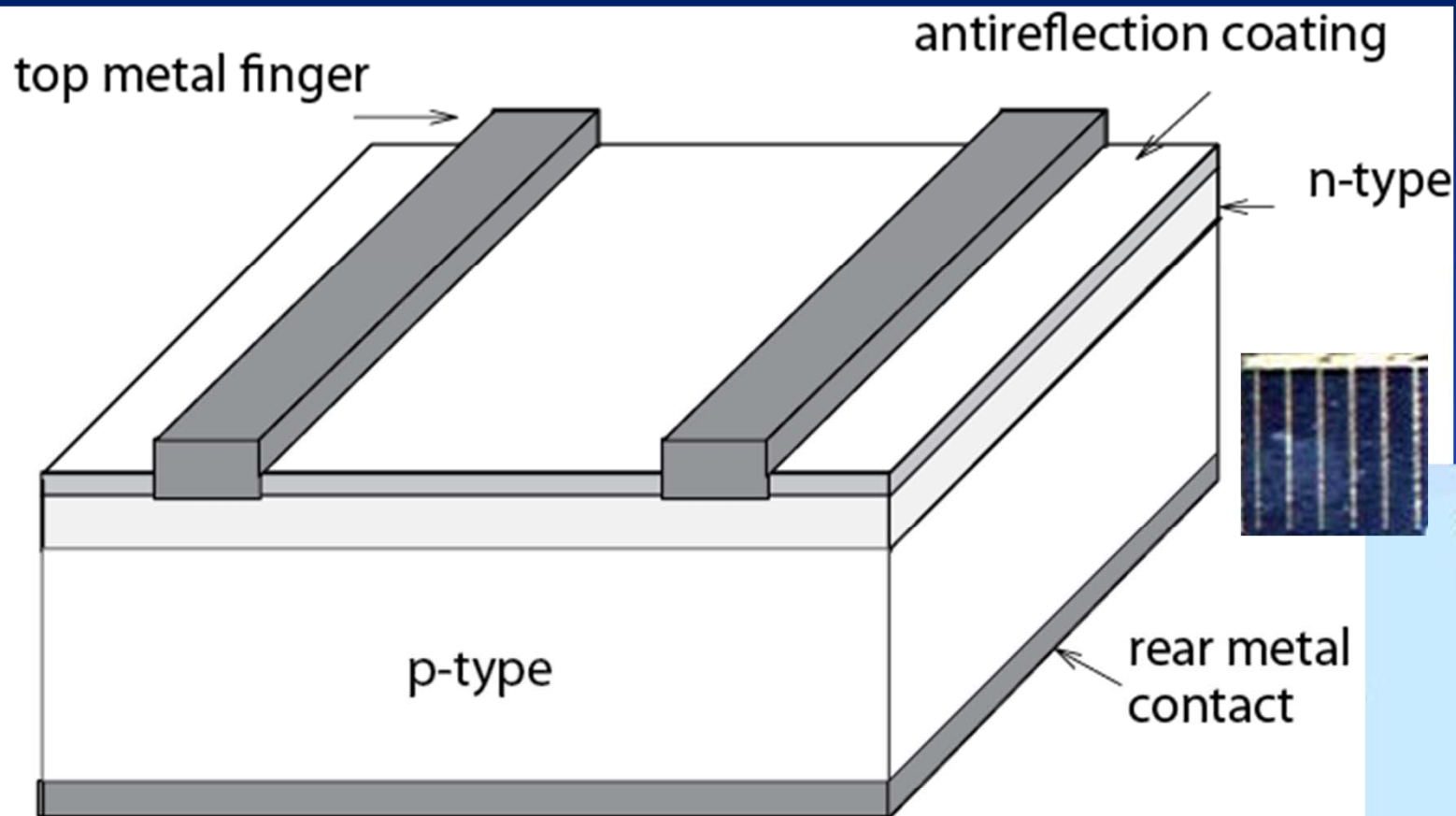
SCIENTISTS SEE HARM IN MONTHLY INQUIRY
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U. S. TO E
 U. S. to E...

Last Power of the Sun Is Tapped by Battery Using Sand Ingrid
 The last power of the sun...
Palio Vaccine Test Will Start Today
 Palio vaccine test will start today...
WILLIAM L. LUTHERICK
 William L. Lutherick...





Conventional space cell



Vanguard I (1958)



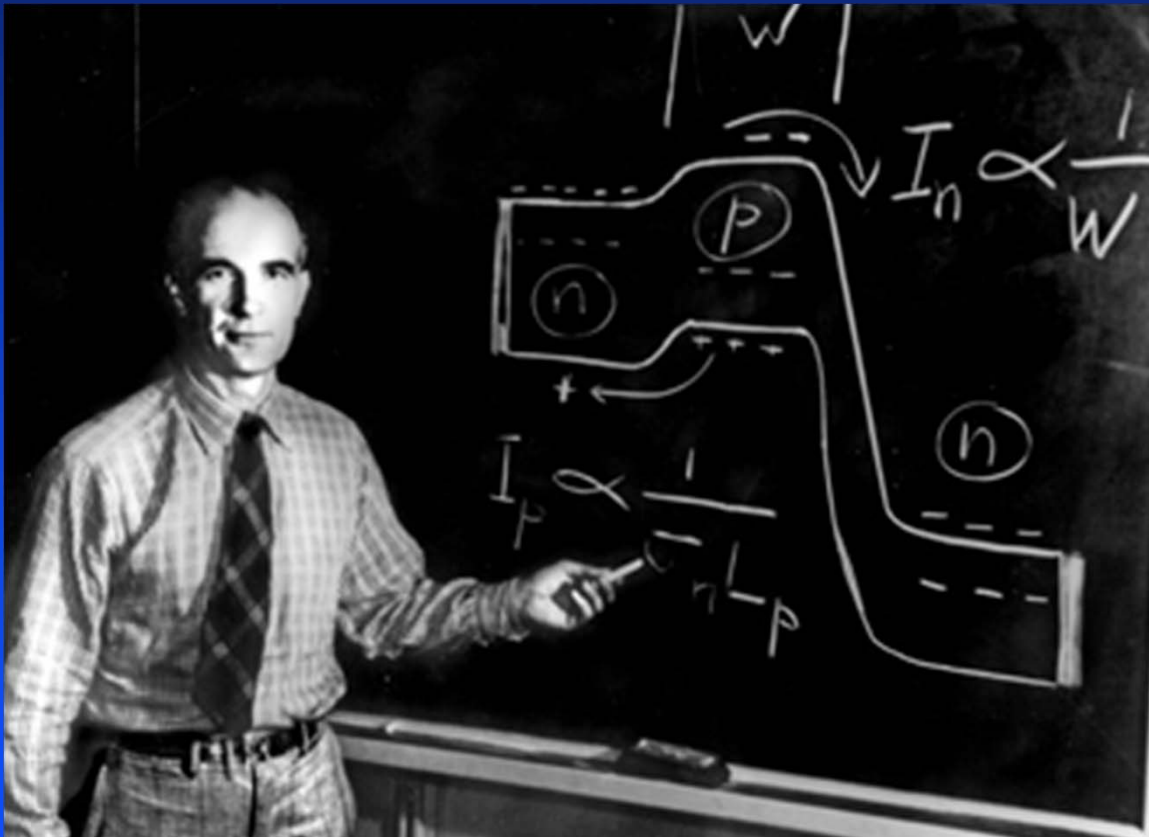


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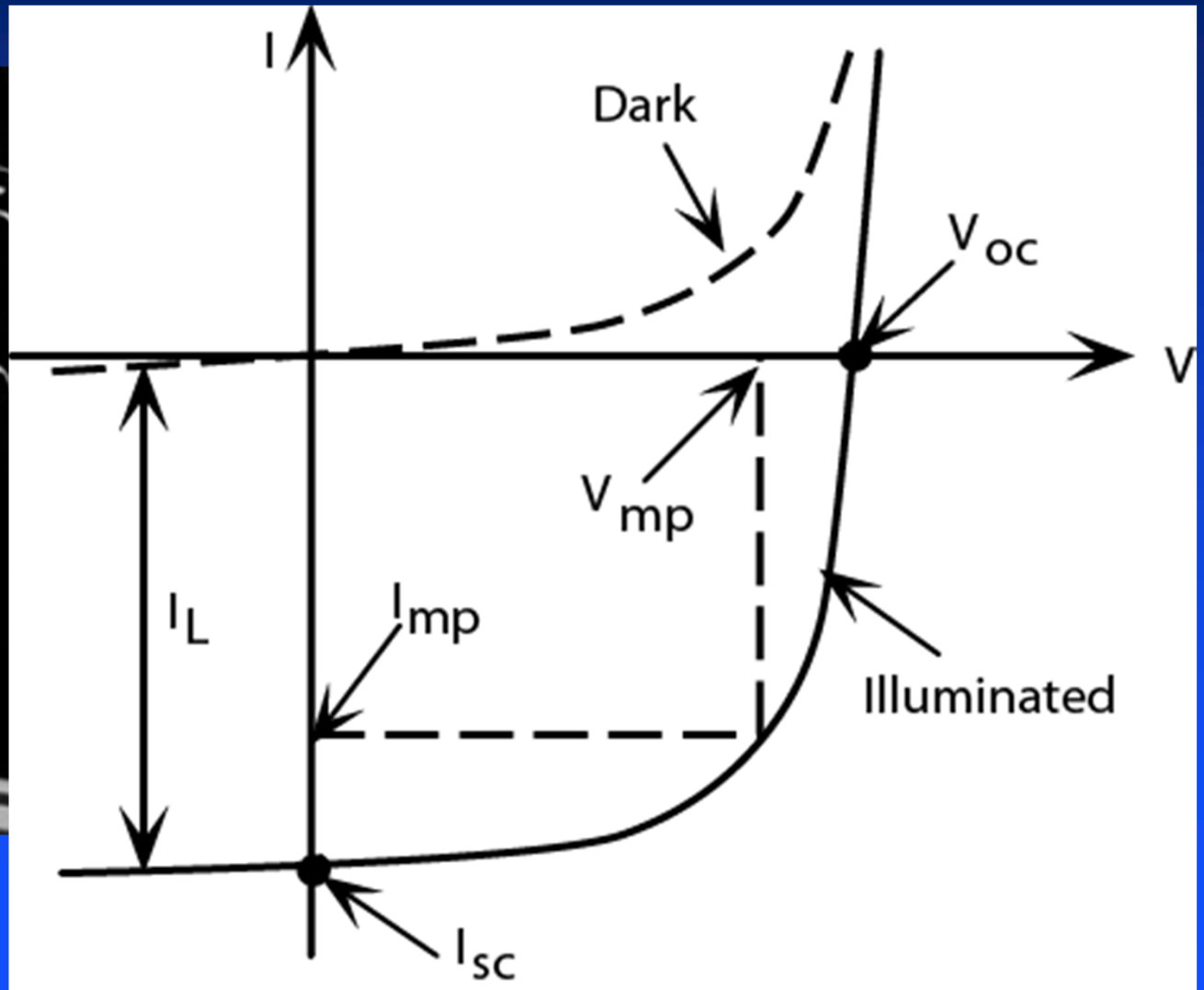
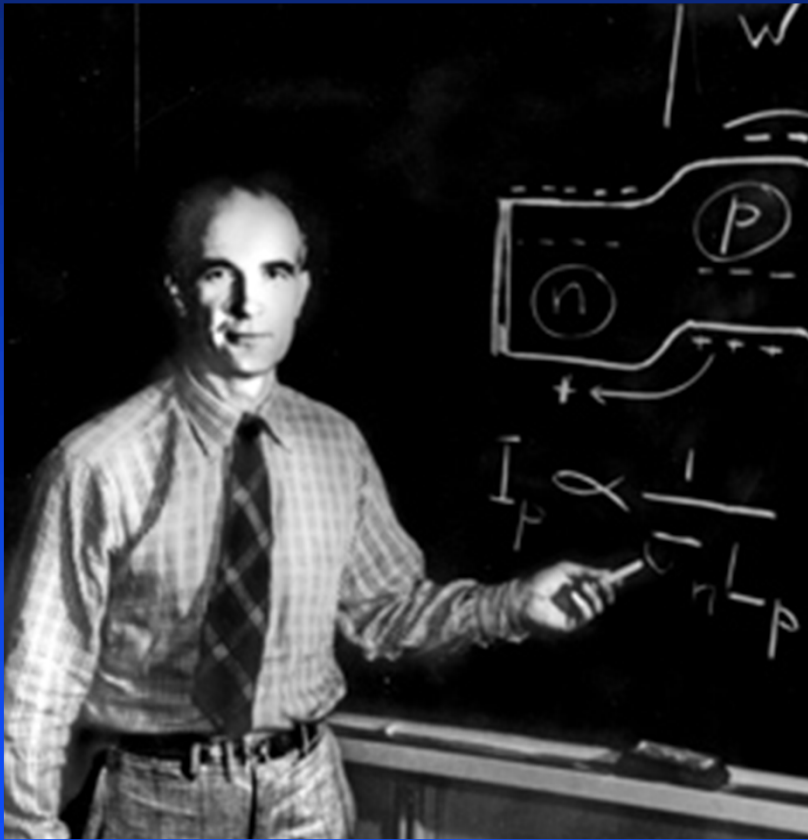


Re-cap: pn junction theory



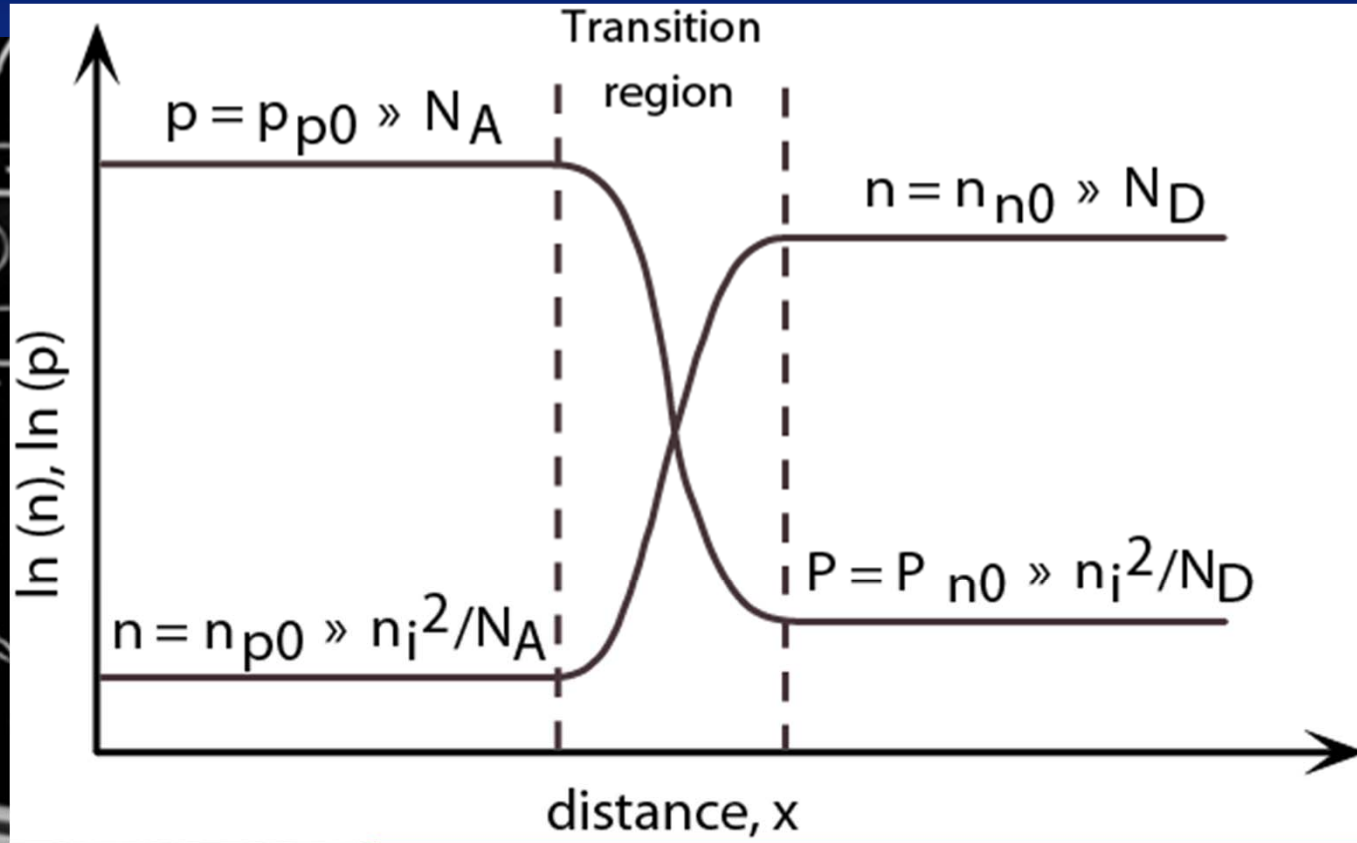
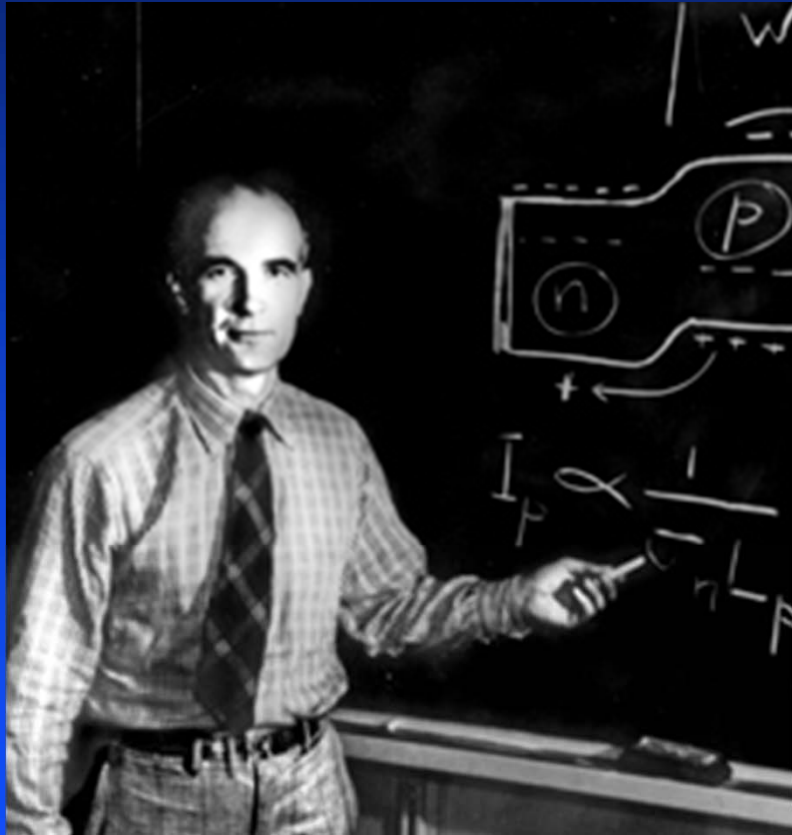


Re-cap: pn junction theory



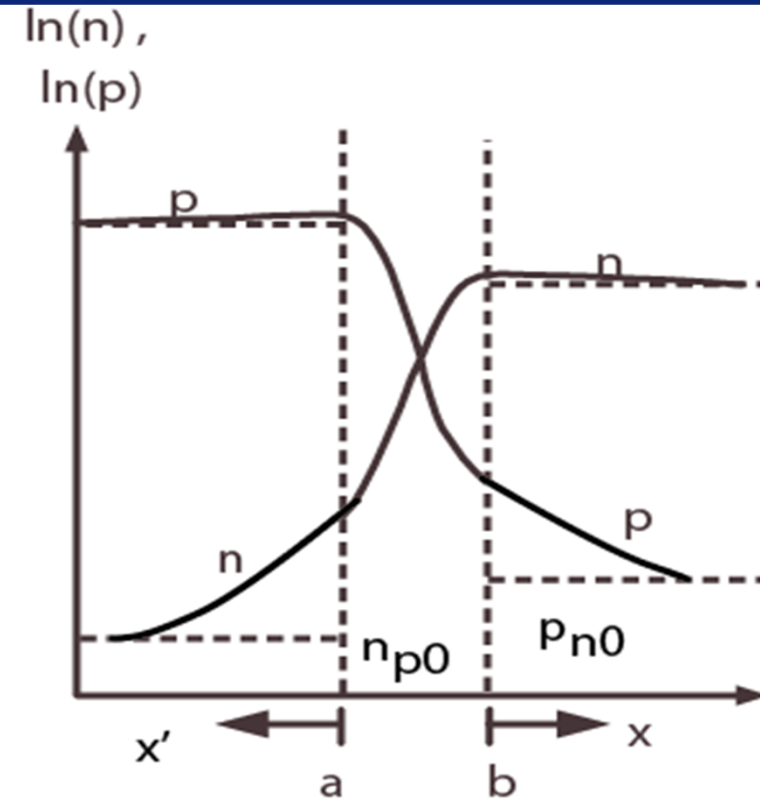
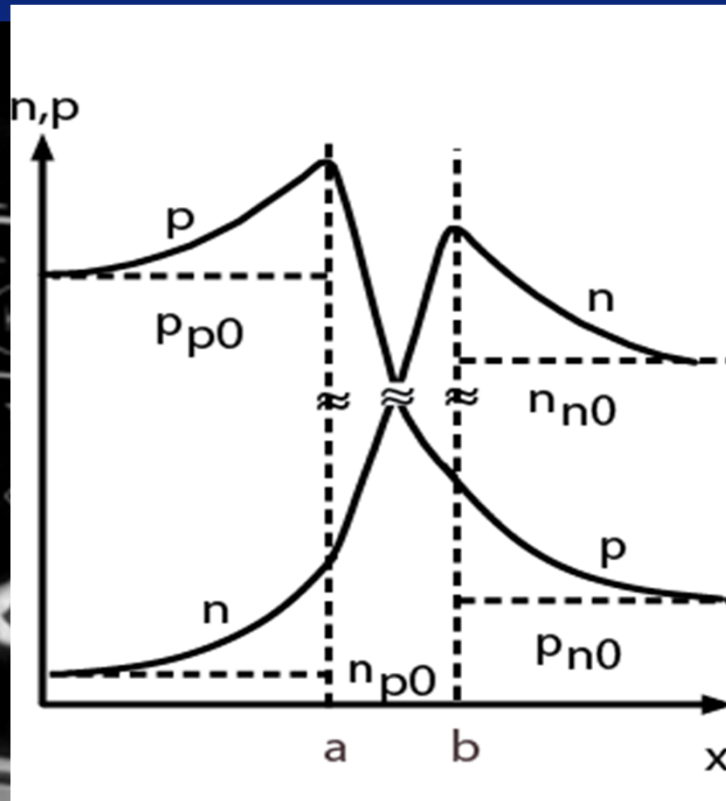
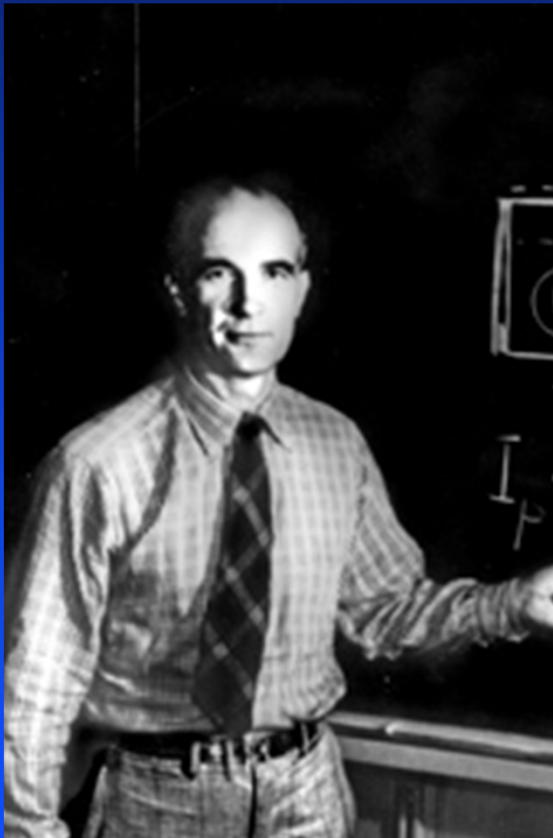


Re-cap: pn junction theory



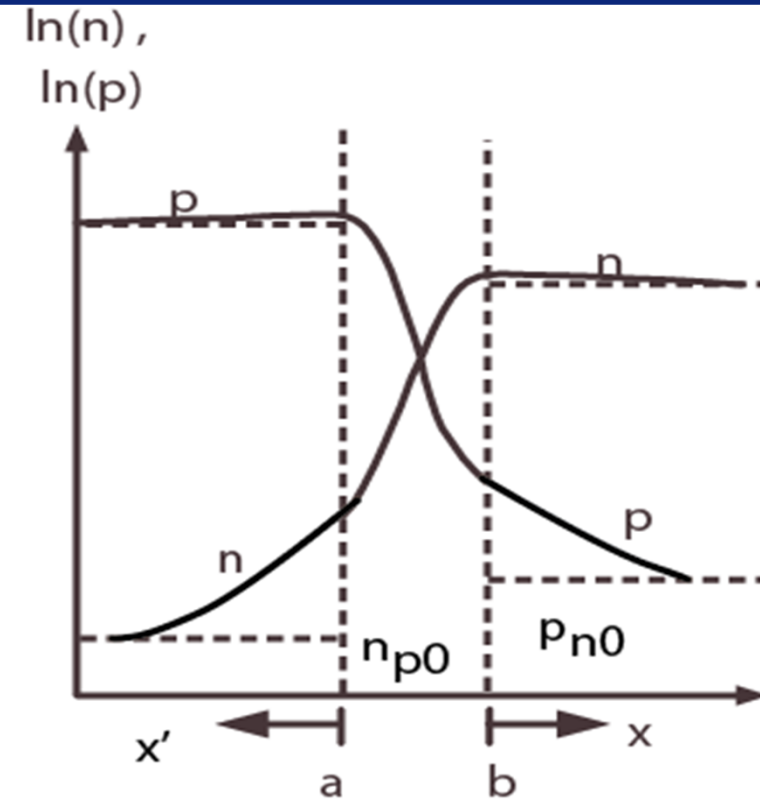
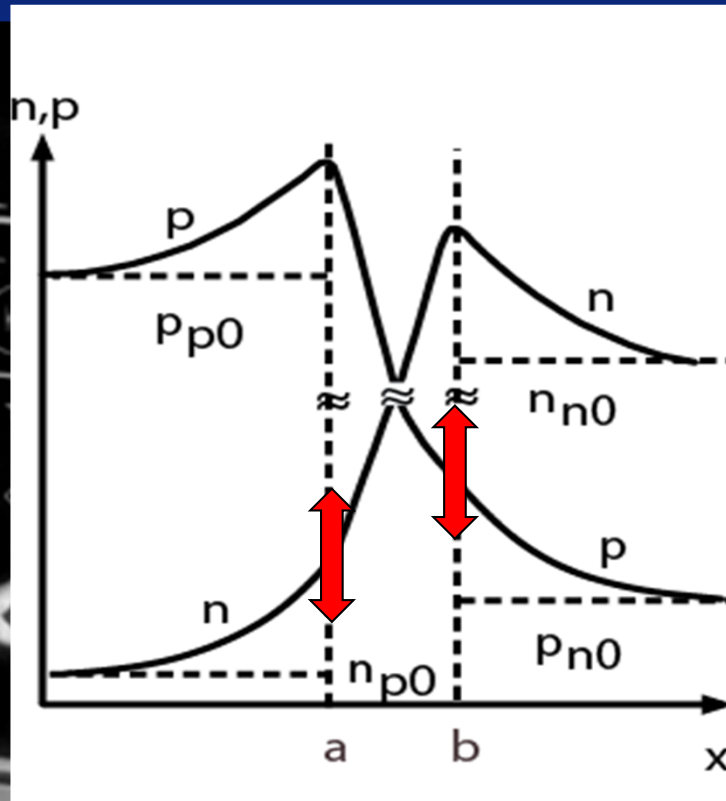
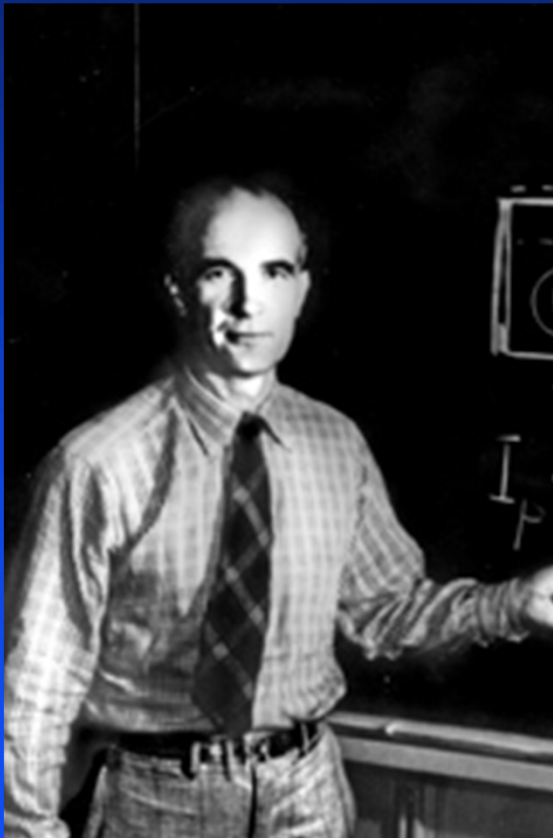


Re-cap: pn junction theory



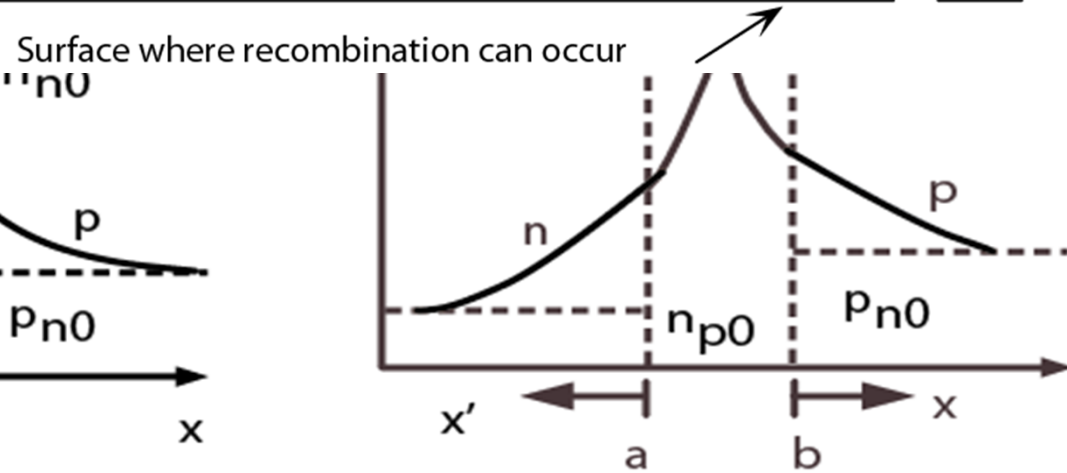
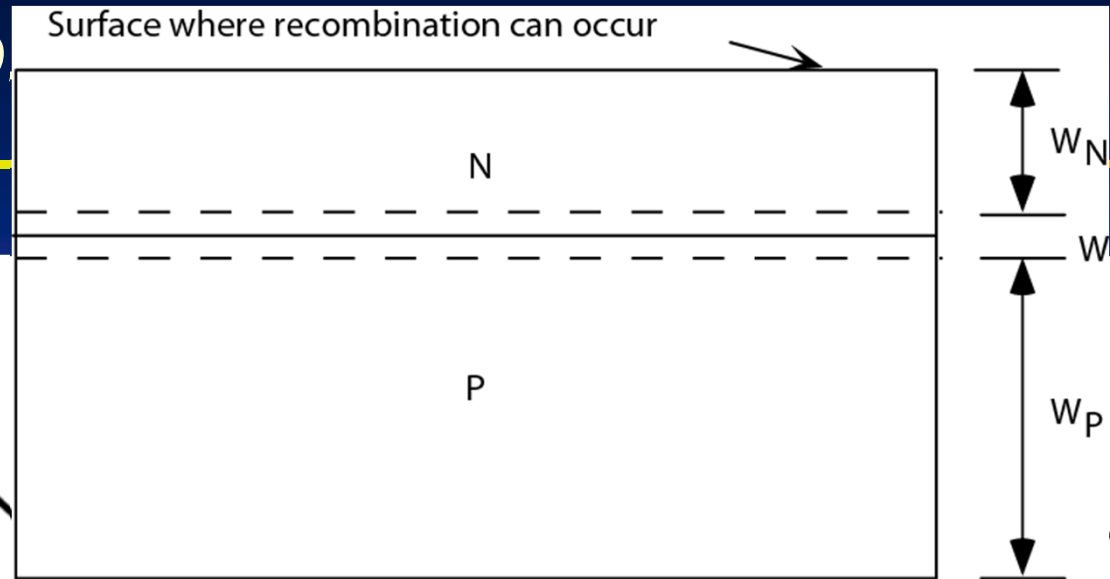
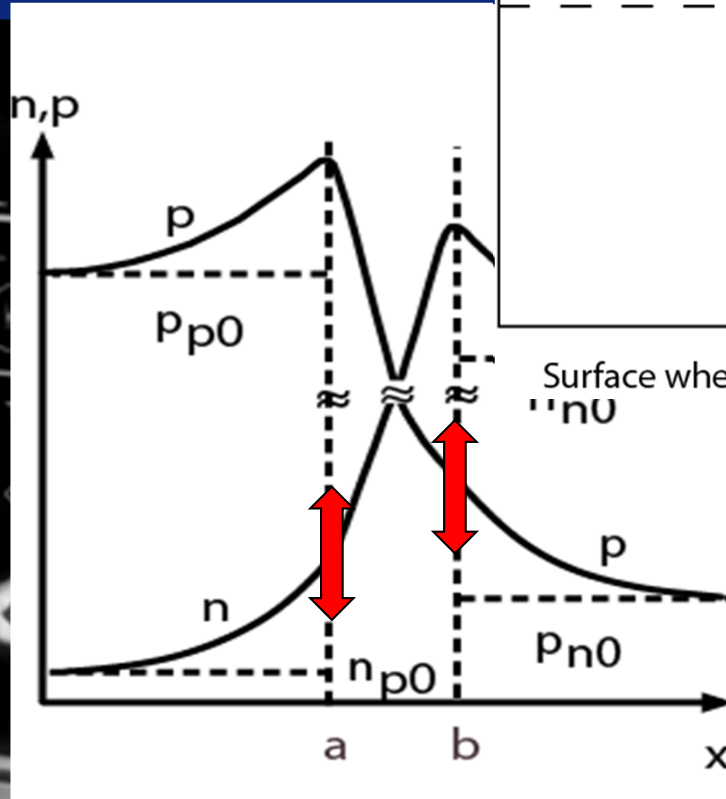
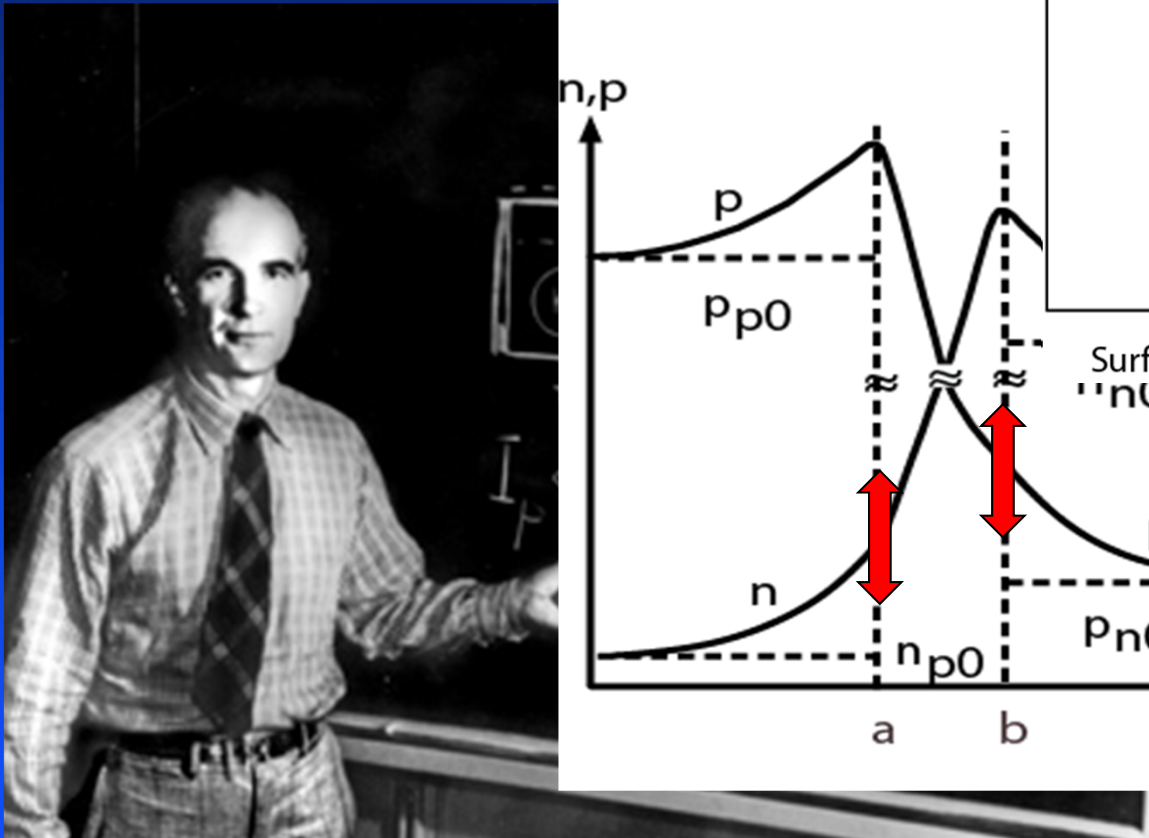


Re-cap: pn junction theory



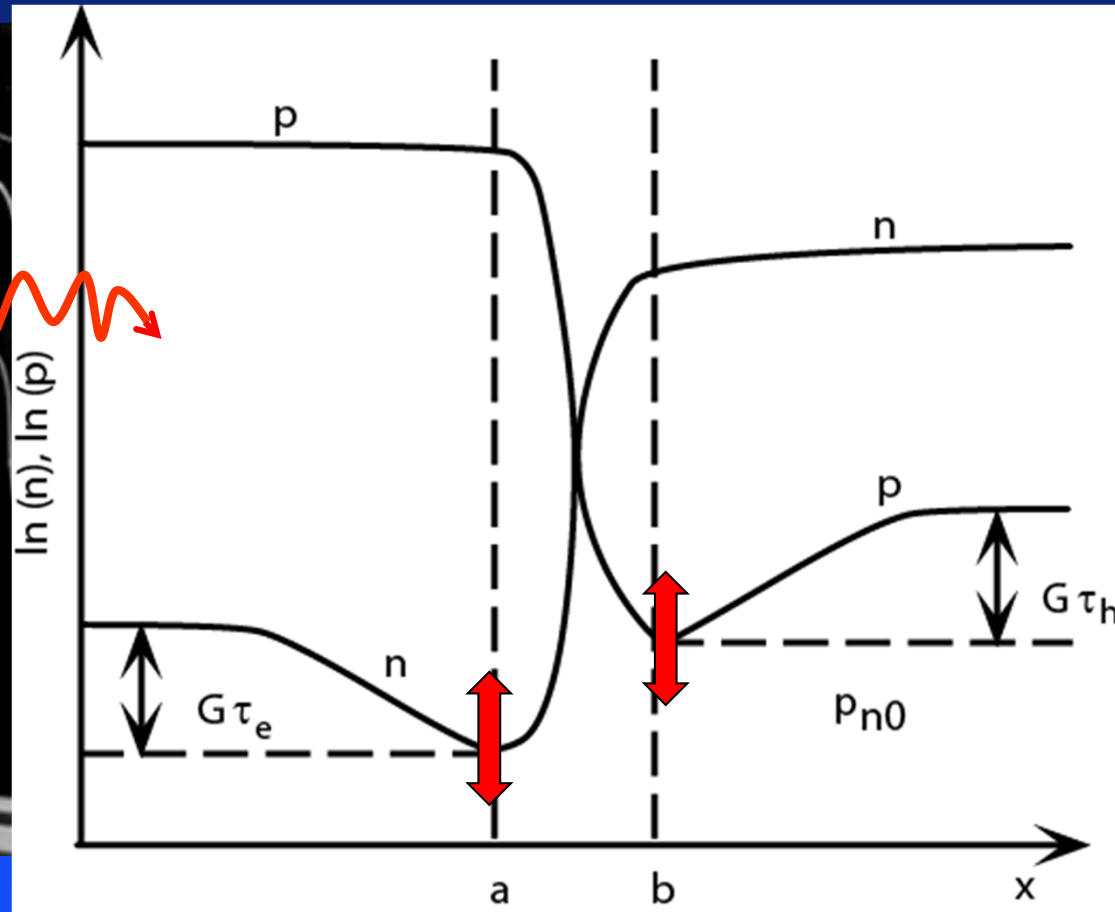
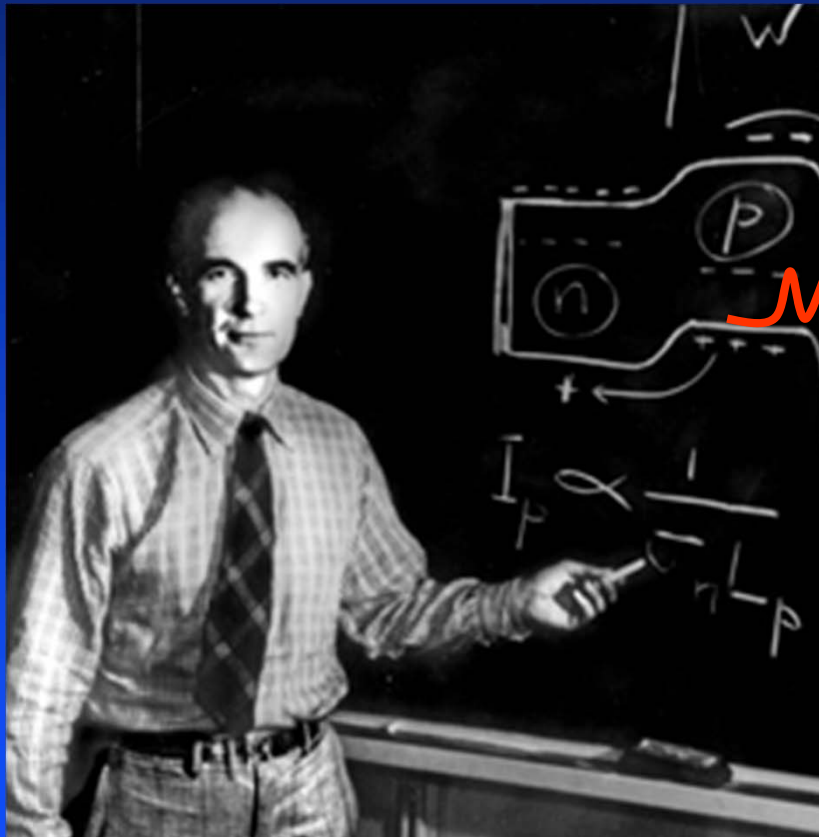


Re-cap



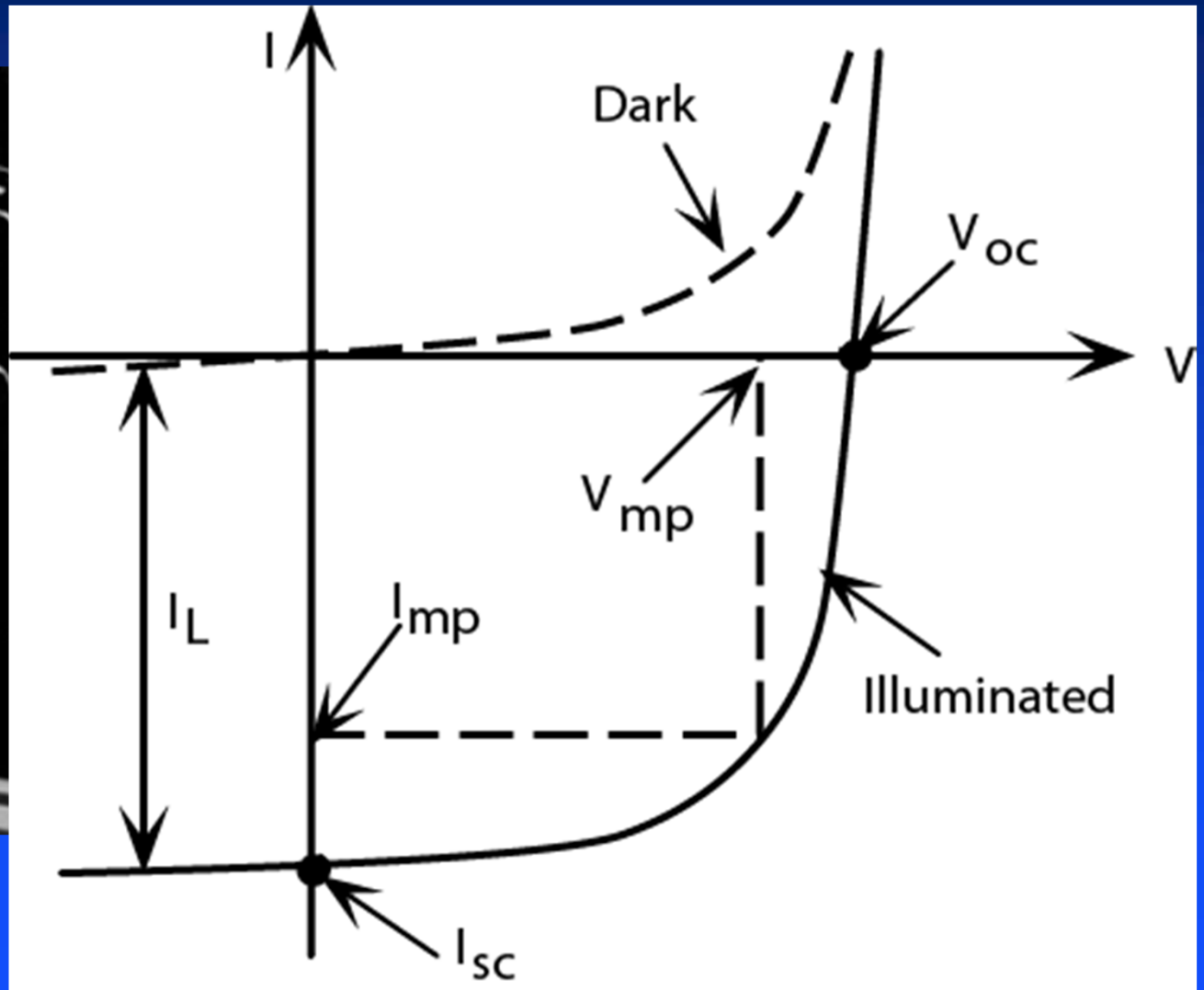
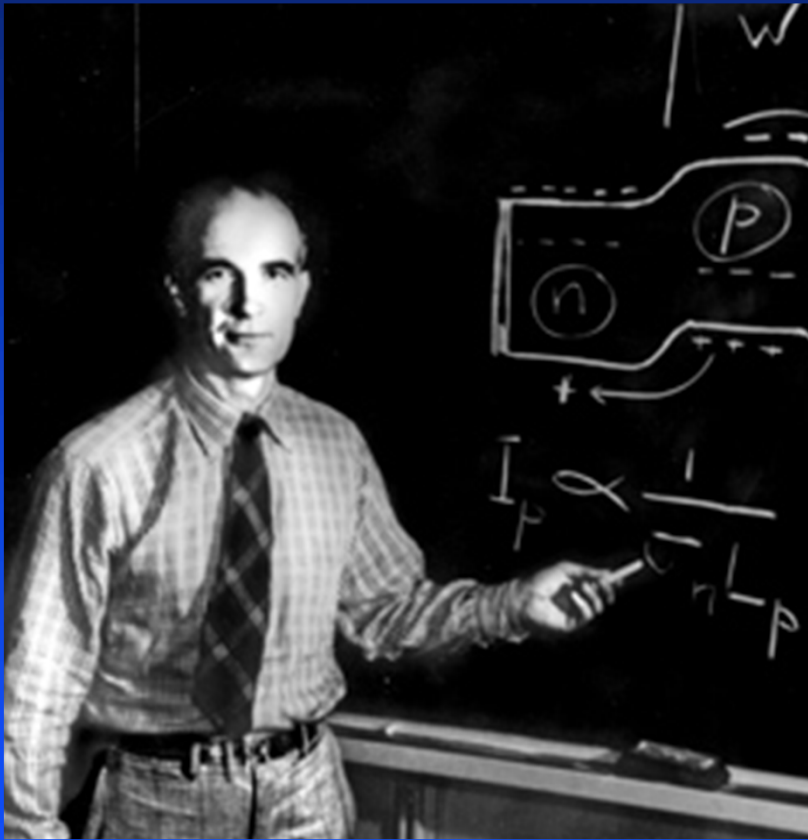


Re-cap: pn junction theory



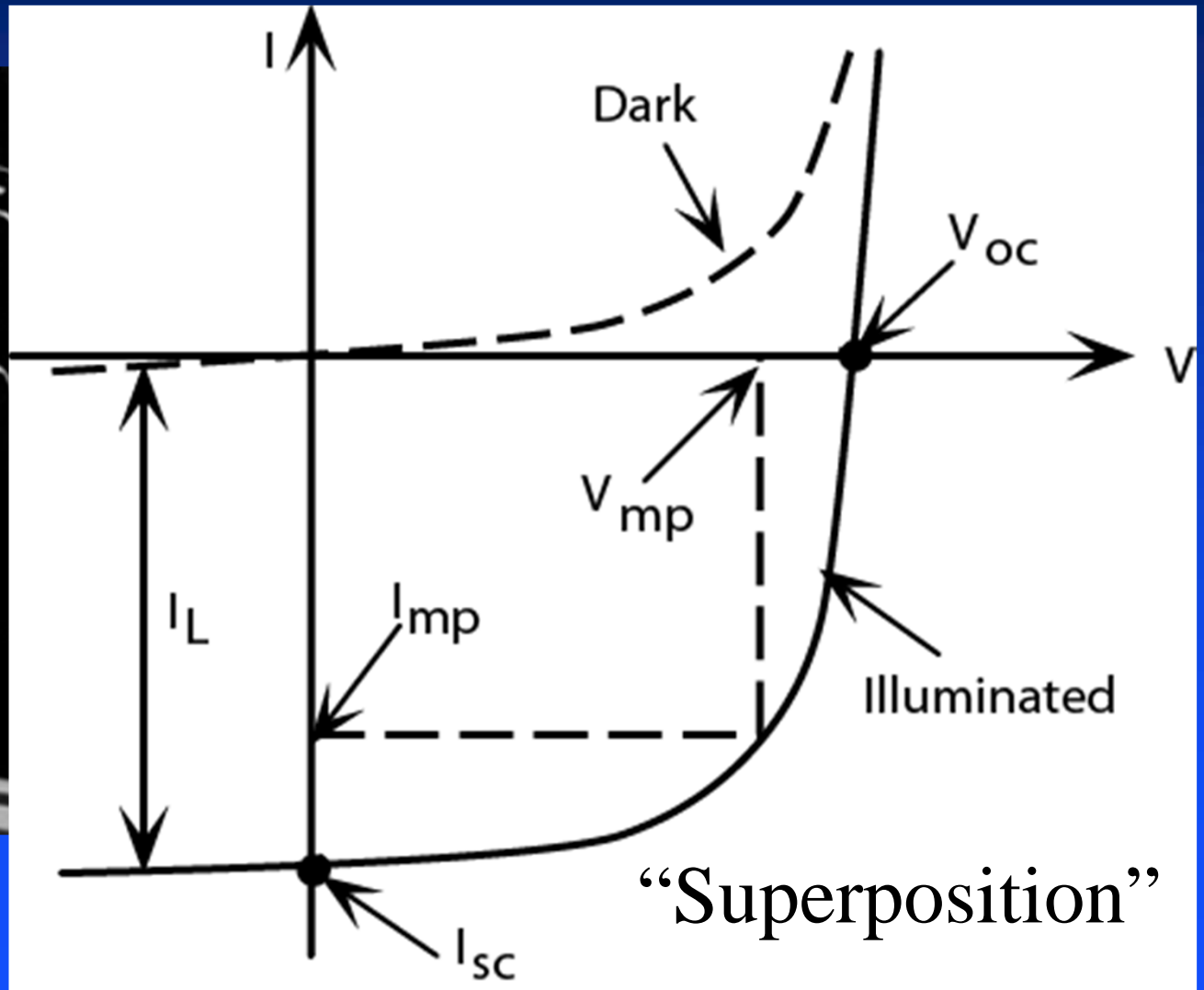
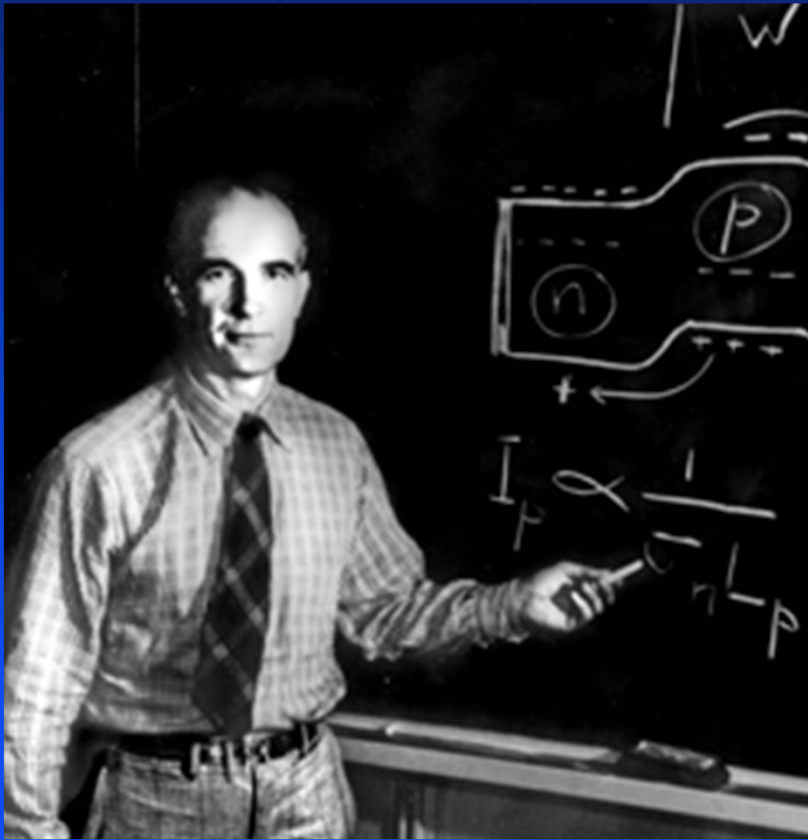


Re-cap: pn junction theory





Re-cap: pn junction theory

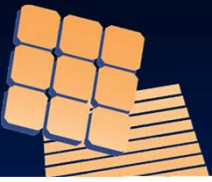




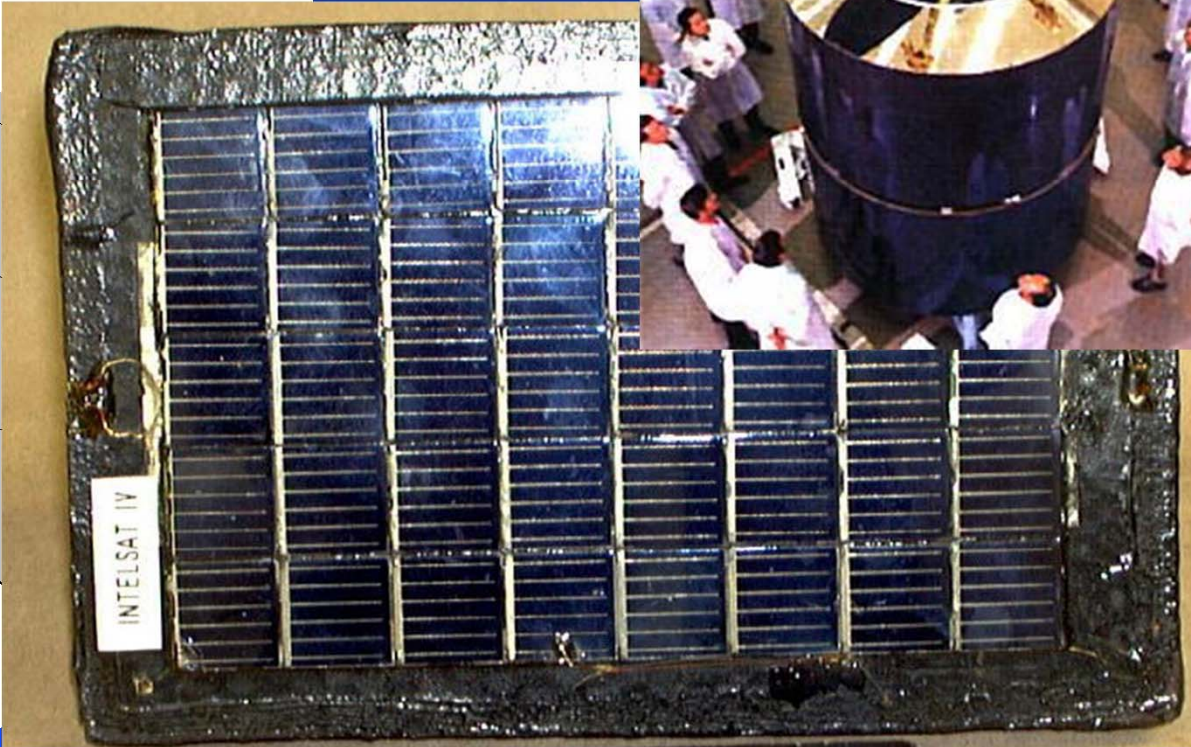
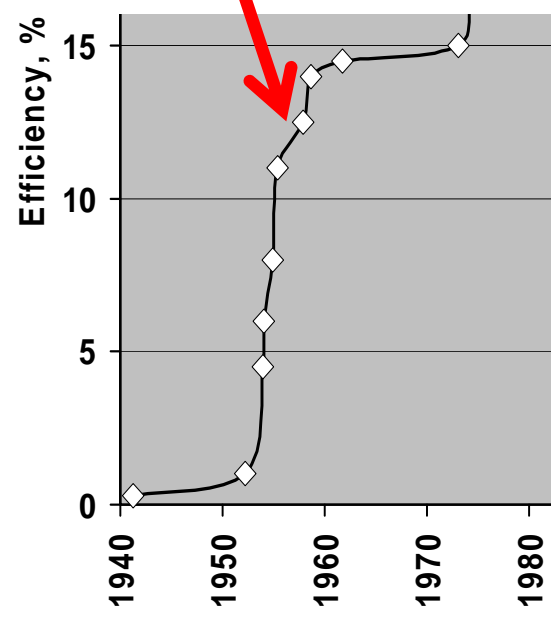
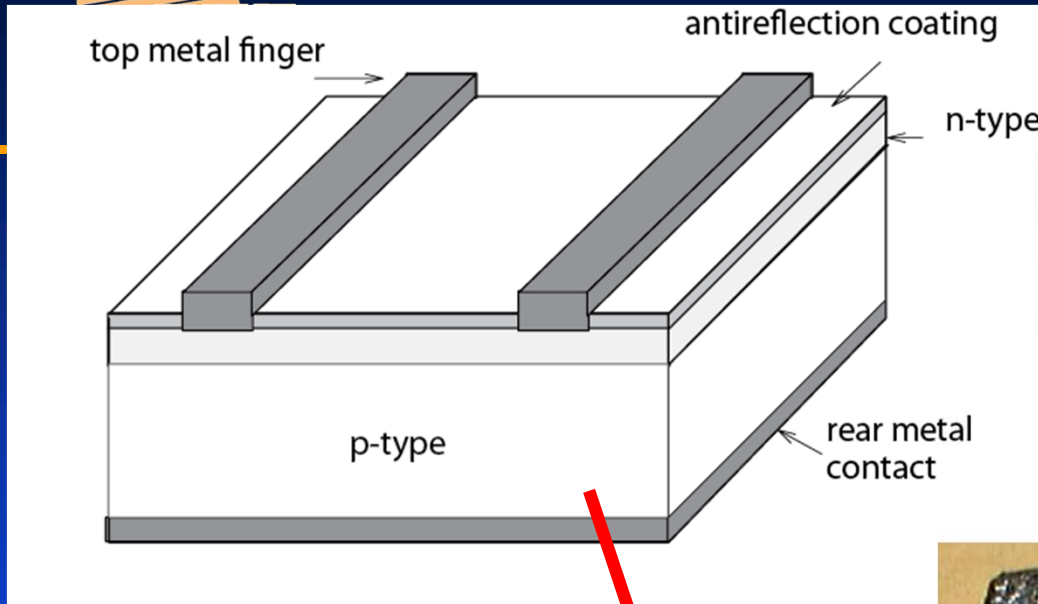
Outline –Lecture I

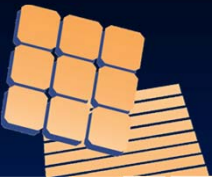
1. Recent developments
2. Early PV history
3. The first pn-junction
4. Conventional space cells
5. Key pointers pn junctions
6. Enter the modern era

-Questions-

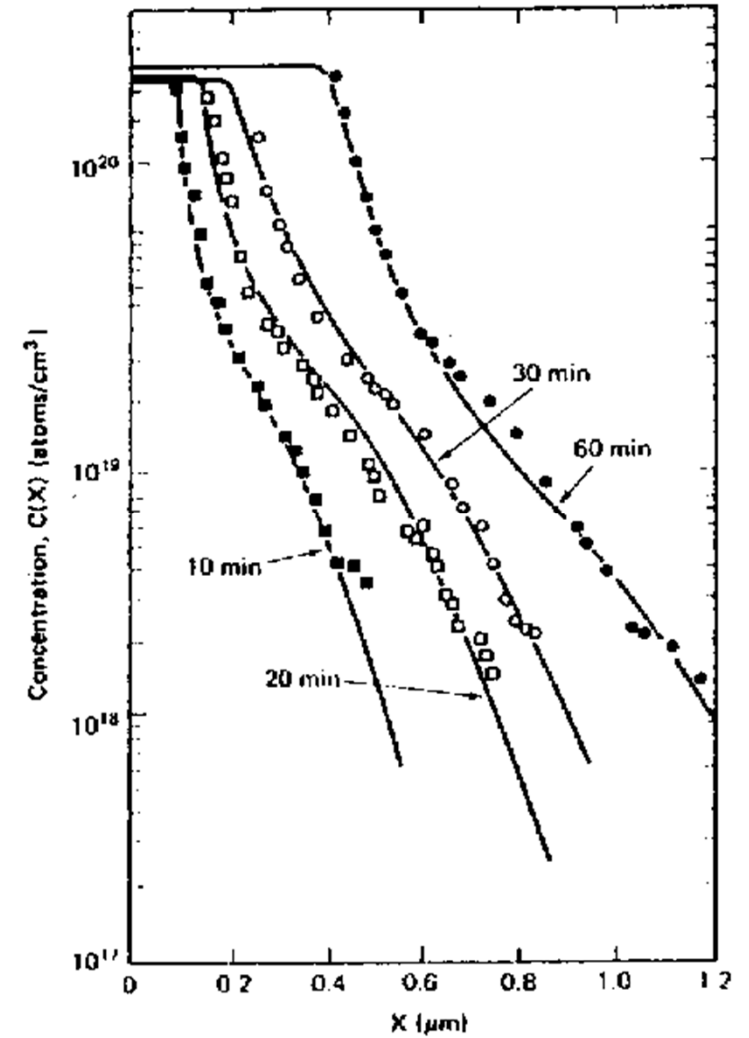
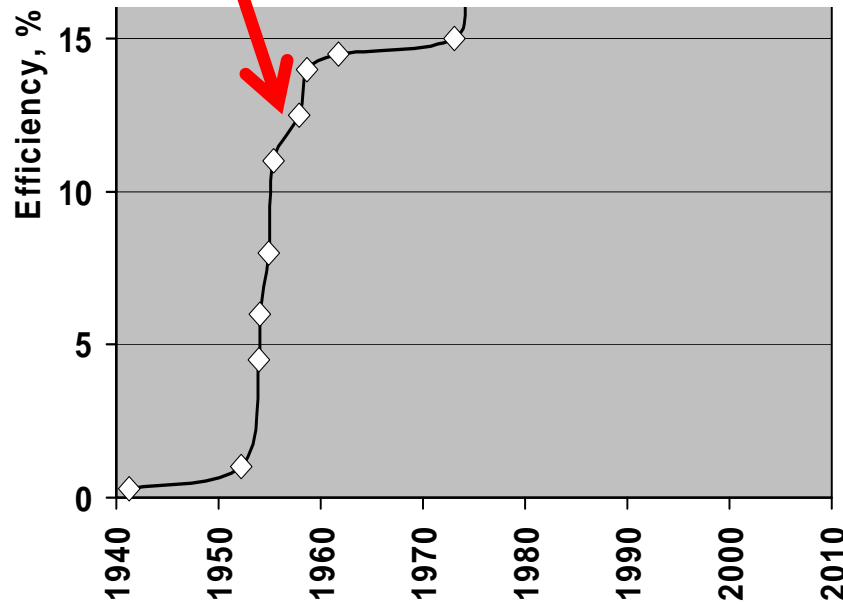
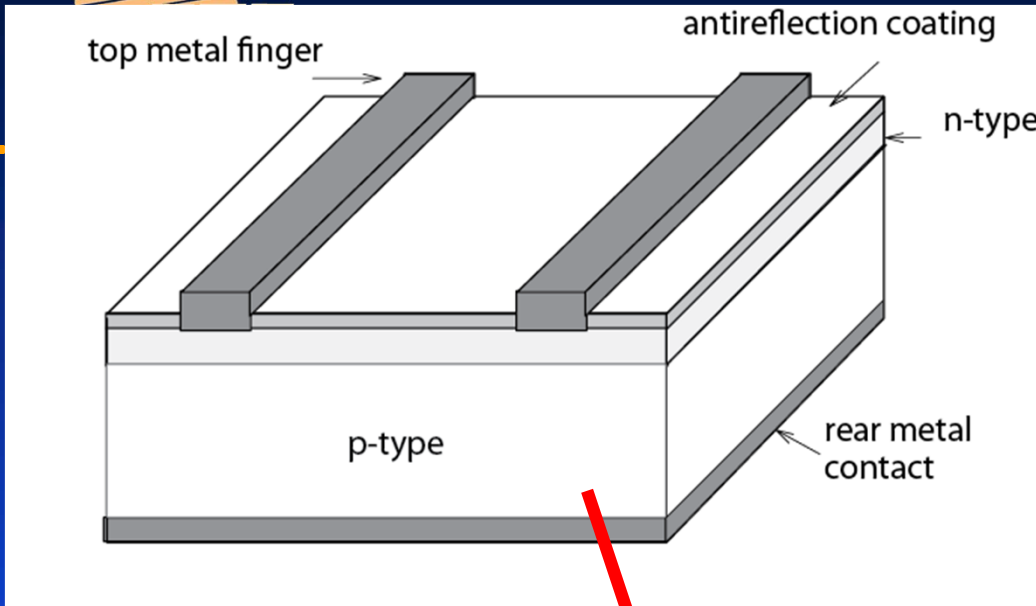


Conventional space cell



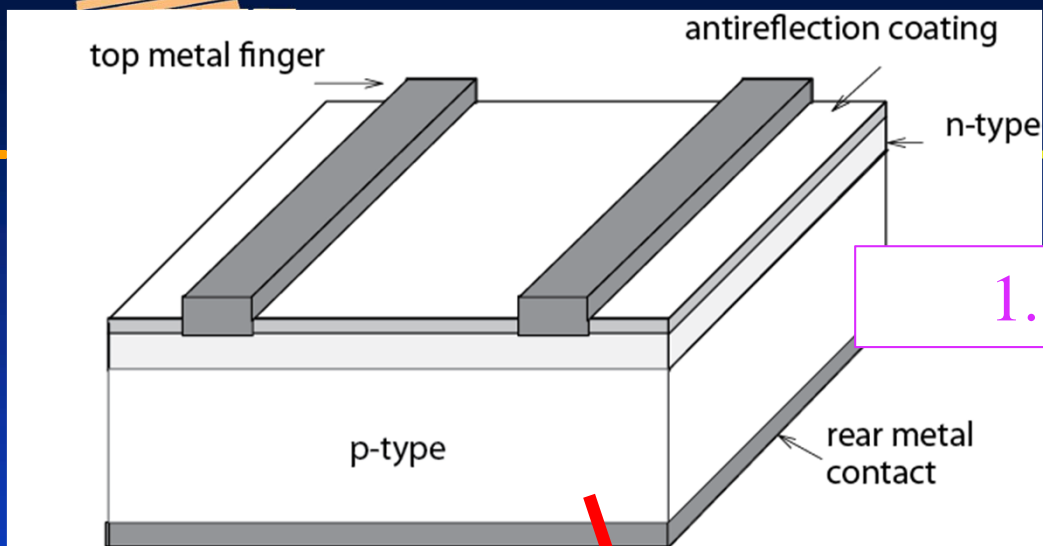


Conventional space cell

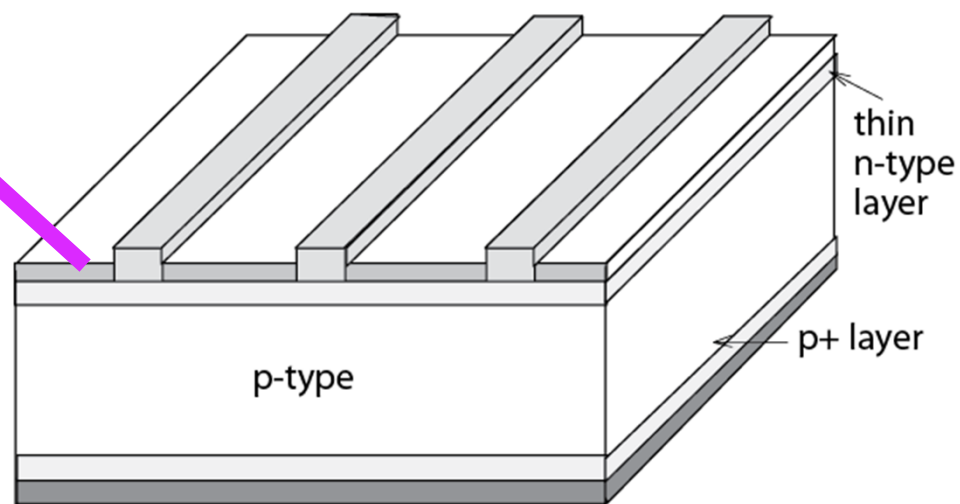
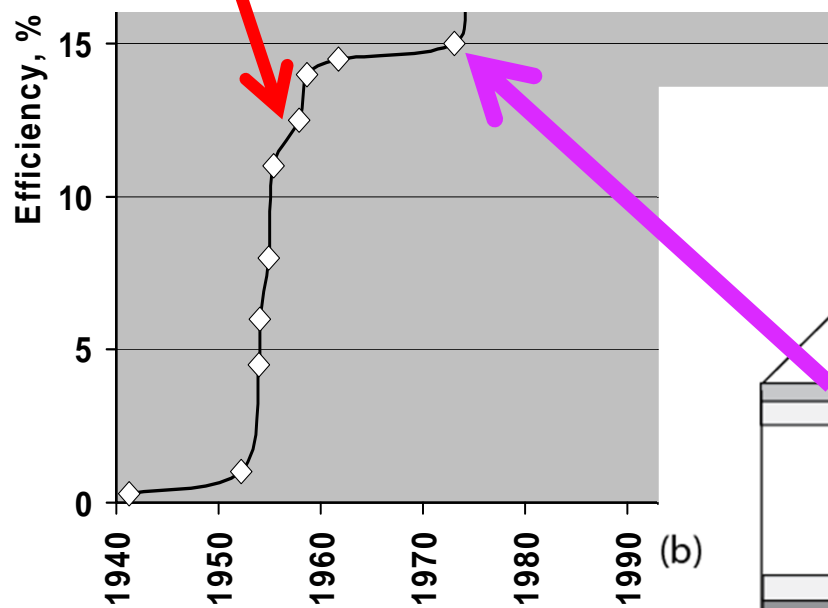




“Violet” cell (1972)

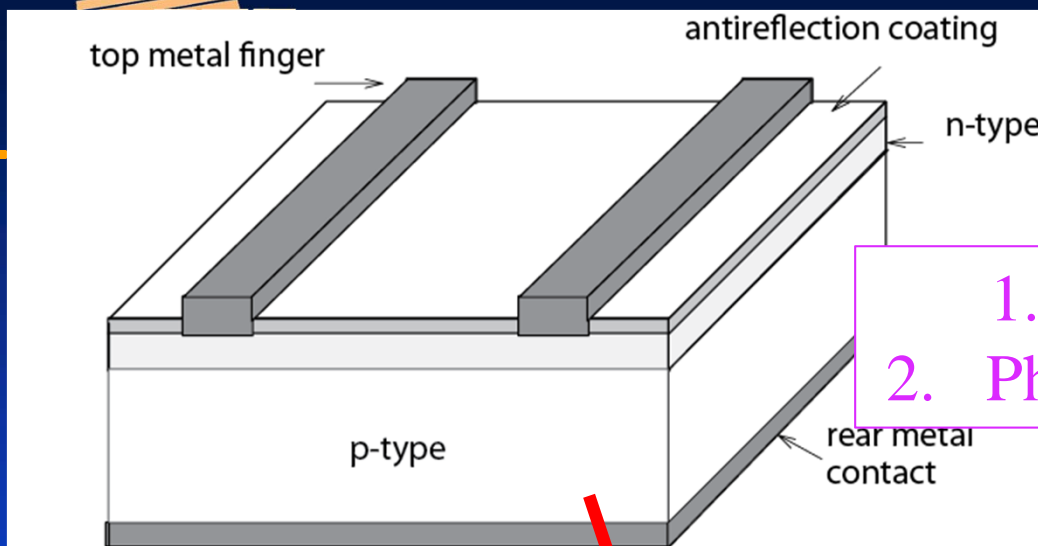


1. Light top diffusion (no dead layer)

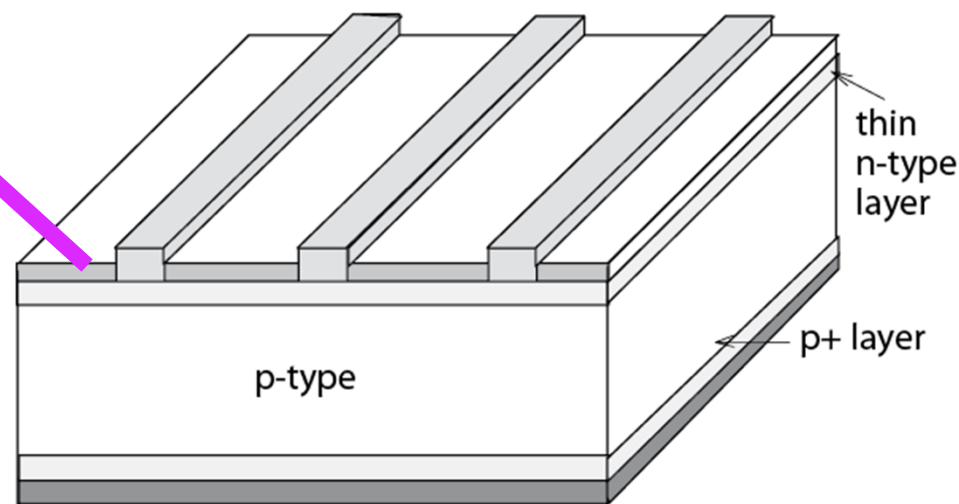
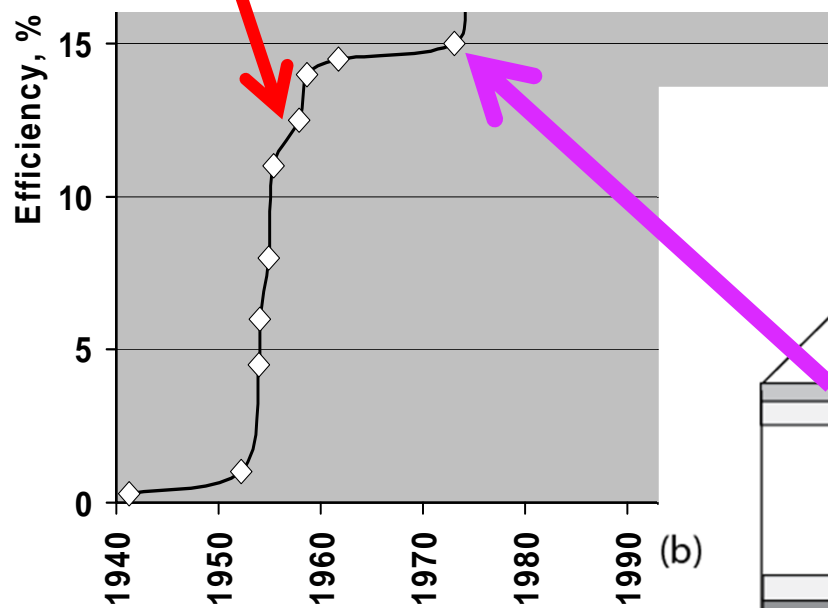




“Violet” cell (1972)

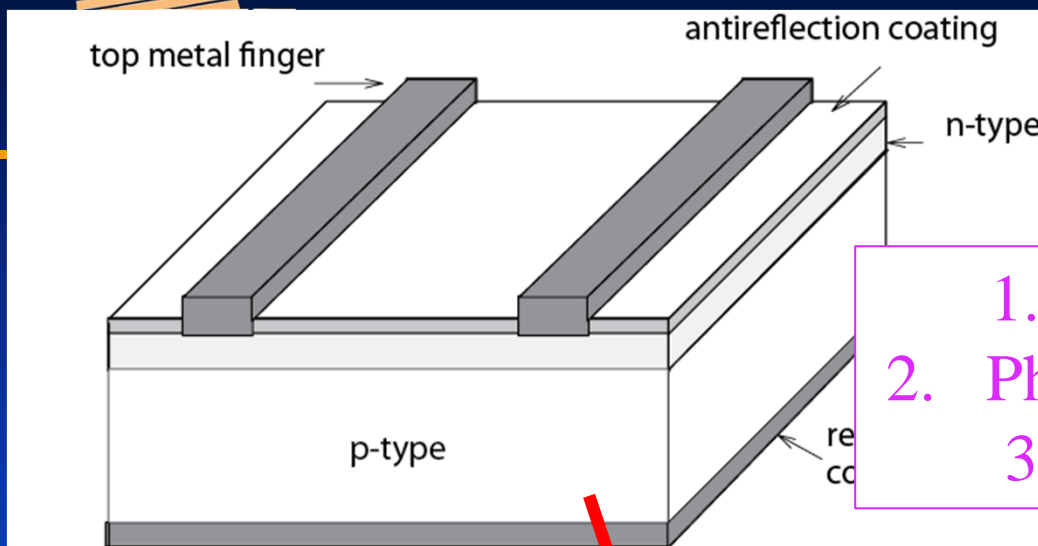


1. Light top diffusion (no dead layer)
2. Photolithographically defined top contacts

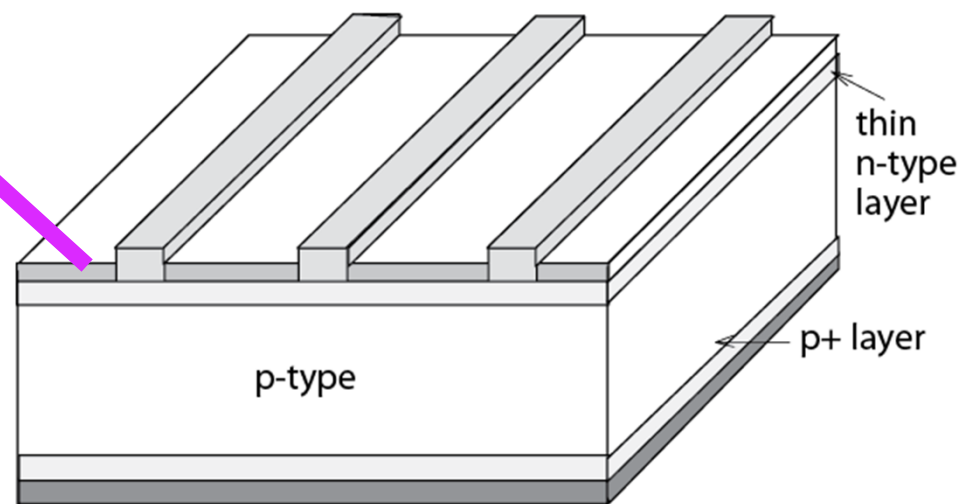
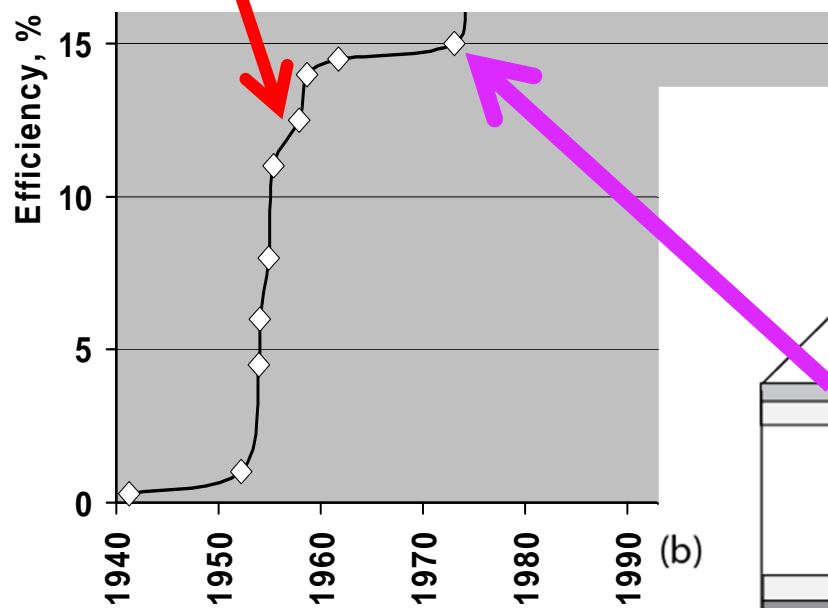




“Violet” cell (1972)

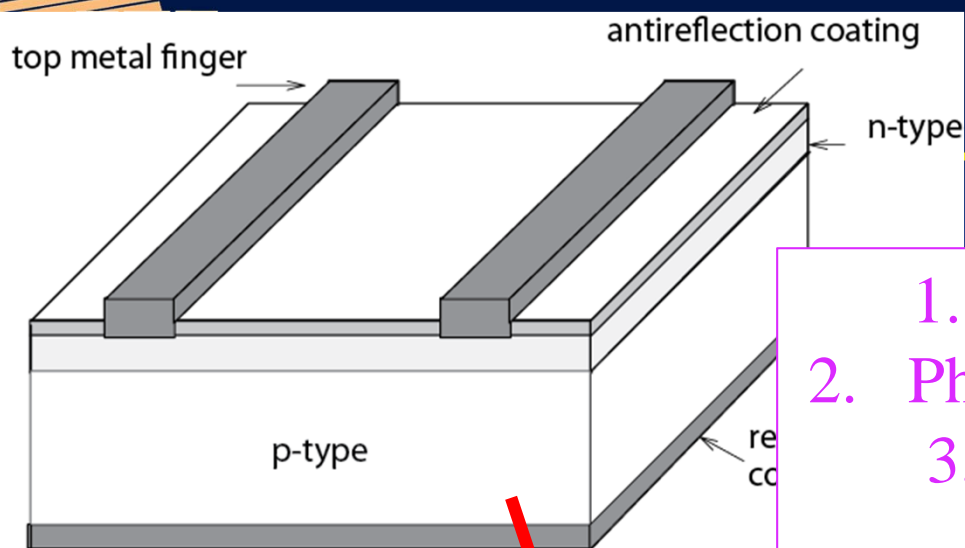


1. Light top diffusion (no dead layer)
2. Photolithographically defined top contacts
3. Rear Al BSF (back surface field)

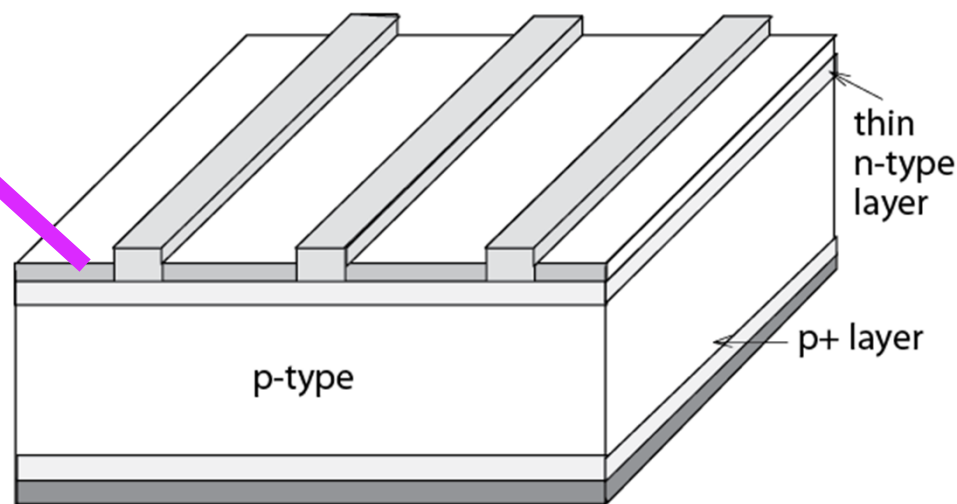
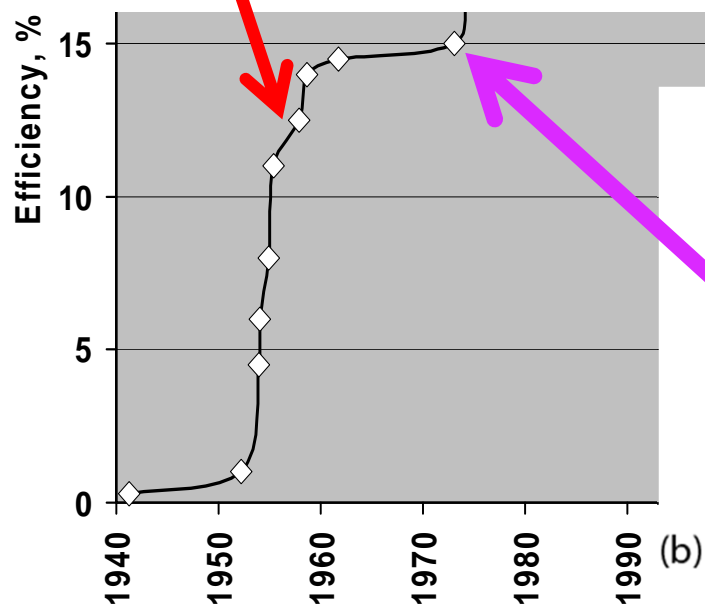




“Violet” cell (1972)

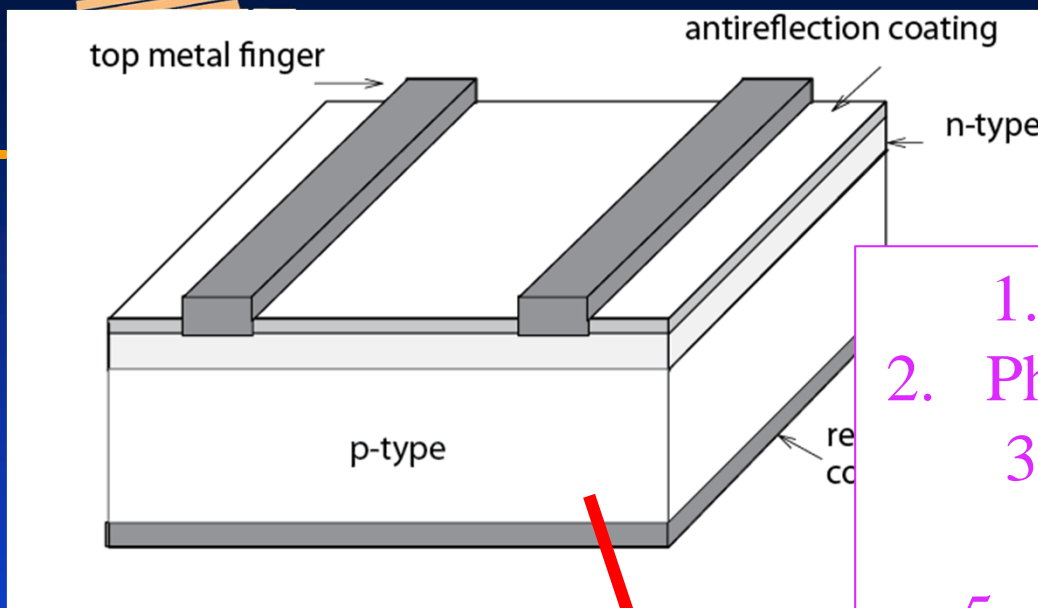


1. Light top diffusion (no dead layer)
2. Photolithographically defined top contacts
3. Rear Al BSF (back surface field)
4. Higher index AR coating

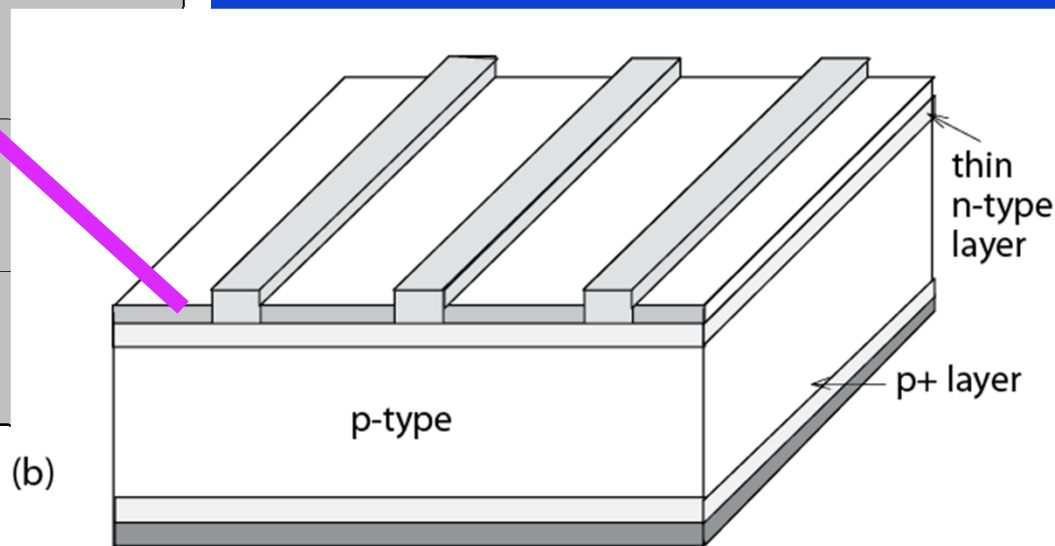
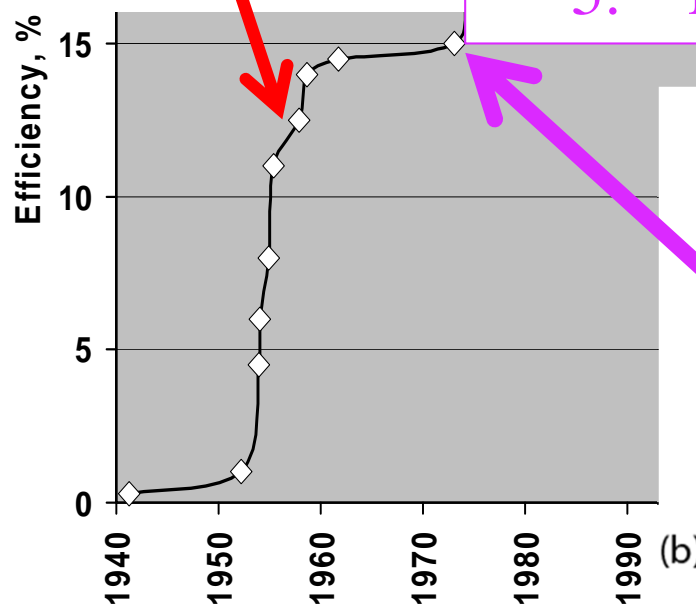


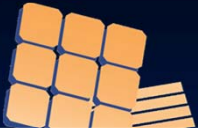


“Violet” cell (1972)

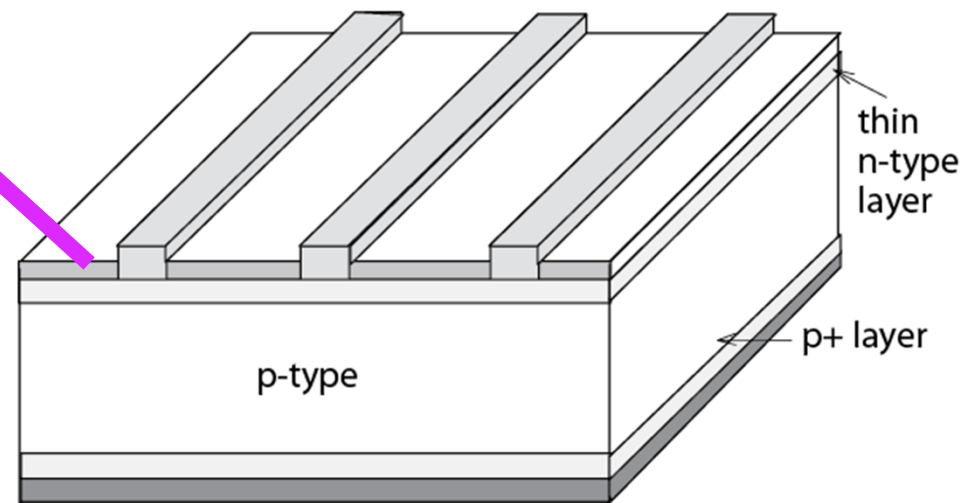
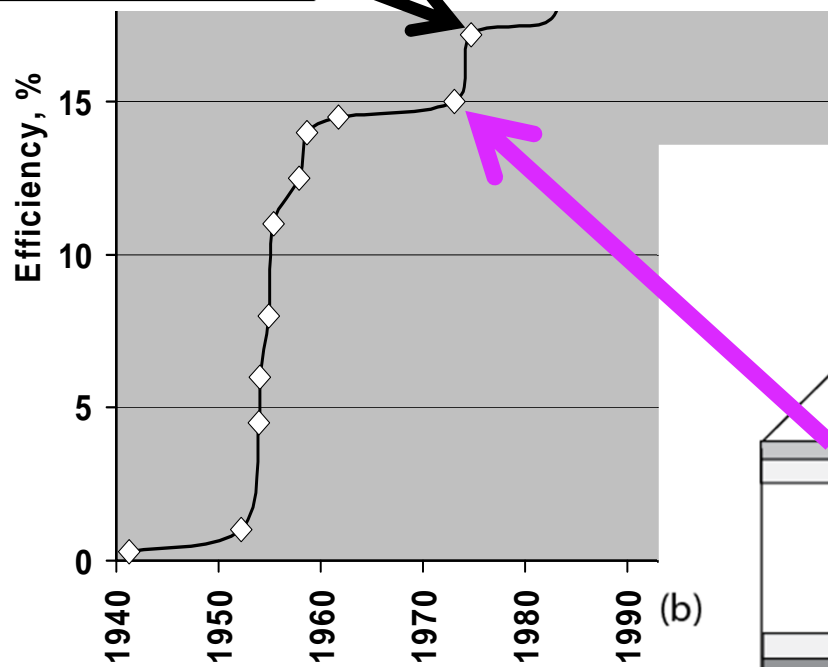
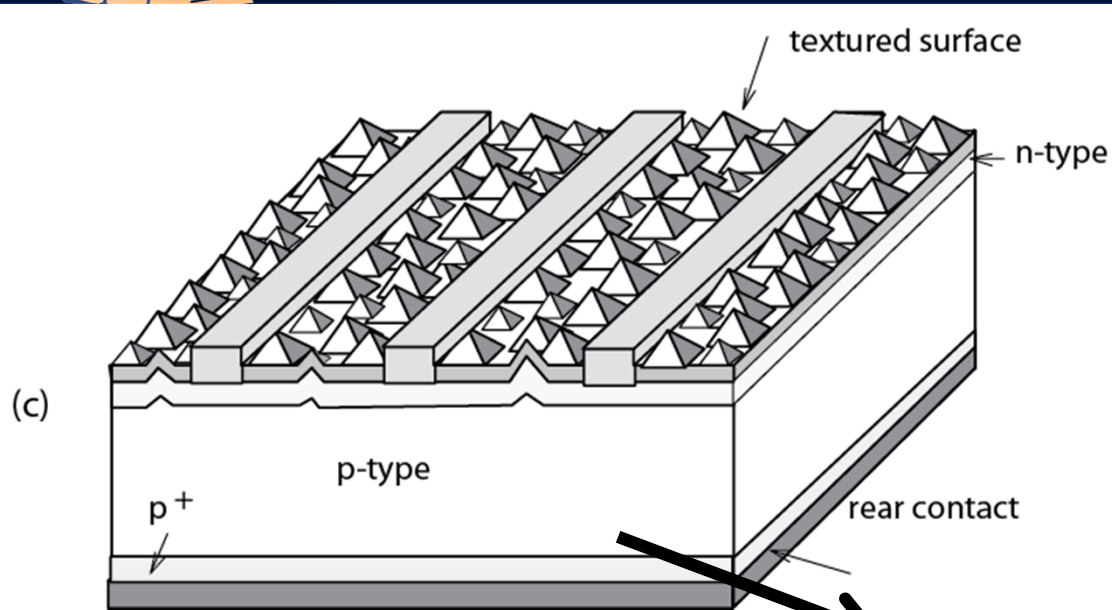


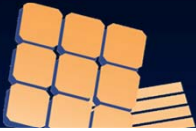
1. Light top diffusion (no dead layer)
2. Photolithographically defined top contacts
3. Rear Al BSF (back surface field)
4. Higher index AR coating
5. Higher doped substrate (2 ohm_{cm})



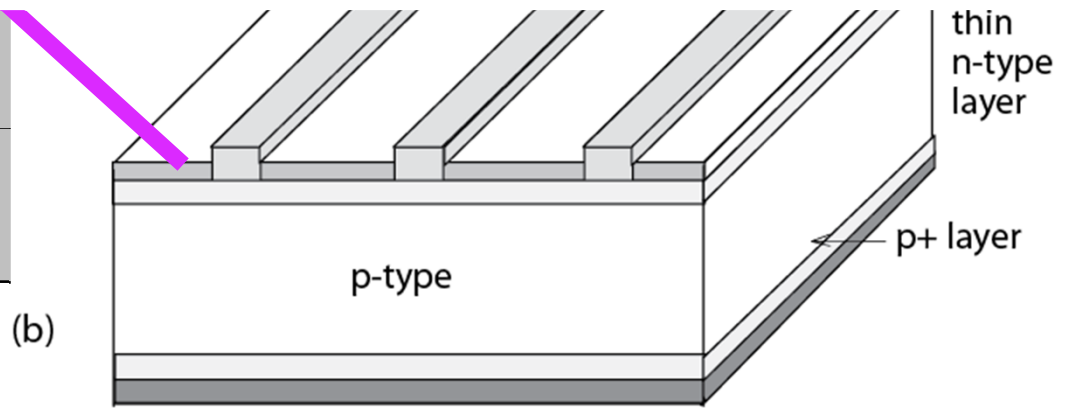
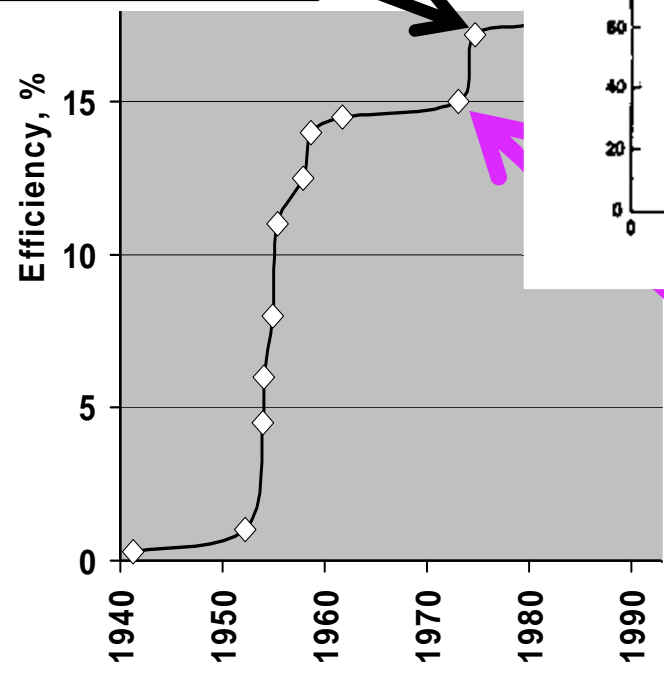
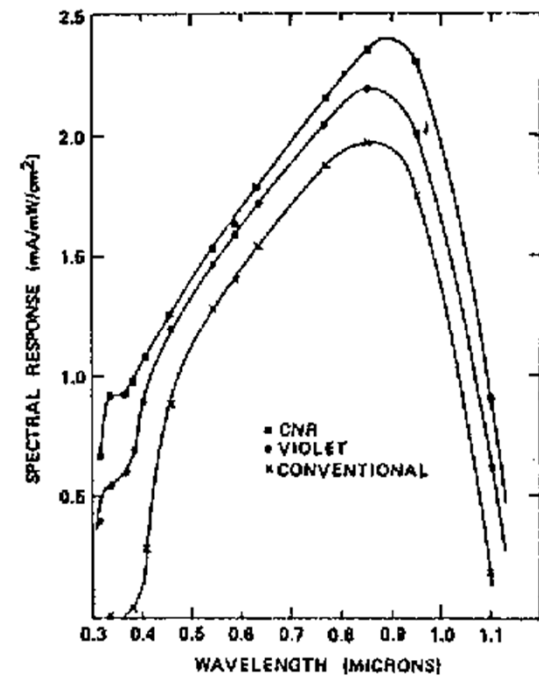
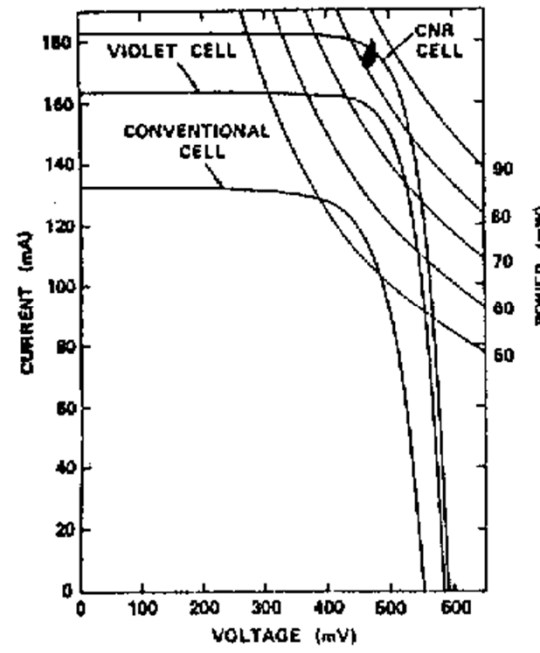
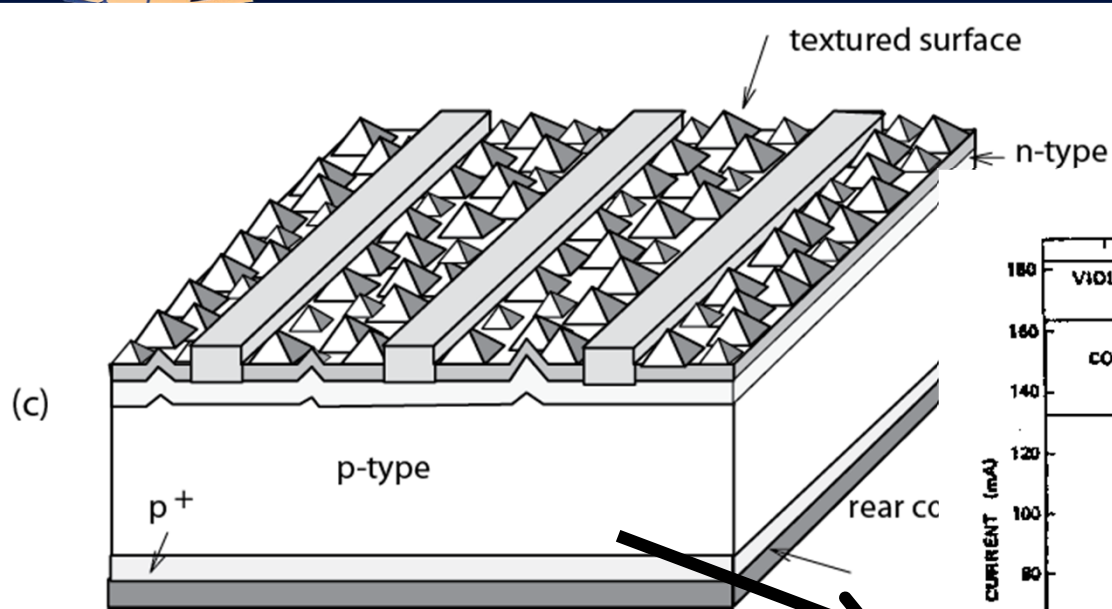


"Black" cell (1974)





"Black" cell (1974)





Outline –Lecture I

1. Recent developments
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- Questions-