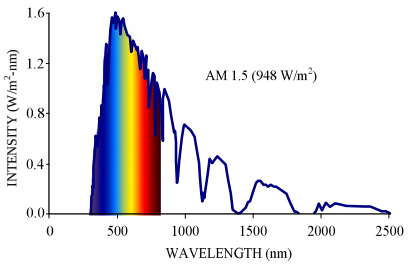
6.太陽能電池之基本原理

- 材料的光電特性
- 操作原理
- 太陽能電池的種類
- 太陽能電池的結構

6.太陽能電池之基本原理

6.1 材料的光電特性

- 光的吸收
- 吸收係數
- 表面效應



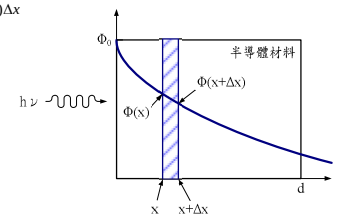
❑光的吸收

- 光的吸收

$$\Phi(x) - \Phi(x + \Delta x) = \alpha\Phi(x)\Delta x$$

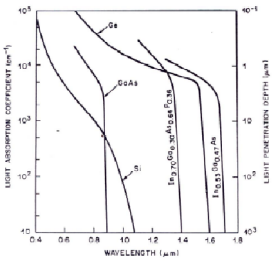
$$\frac{d\Phi(x)}{dx} = -\alpha\Phi(x)$$

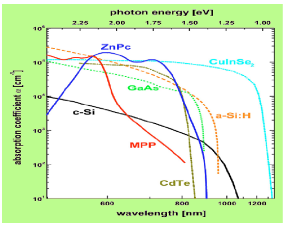
$$\Phi(x) = \Phi_0 e^{-\alpha x}$$



❑吸收係數

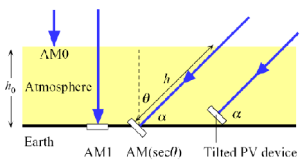
- 材料的光吸收係數

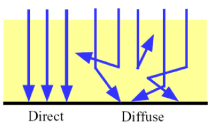




❑吸收係數

- 表面效應
  - 照射角度
  - 散射與反射





❖操作原理

- The basis for the solar cell is the photovoltaic effect
  - hν > Eg
  - Because of V_{bi} , it will induce photon current
  - Voltage is formed (across the pn junction)

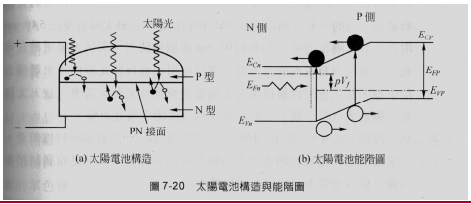
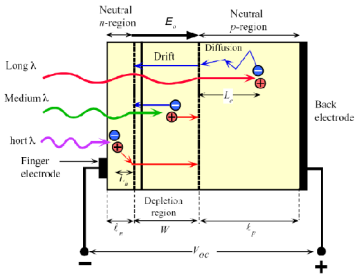


圖 7-20 太陽電池構造與能階圖

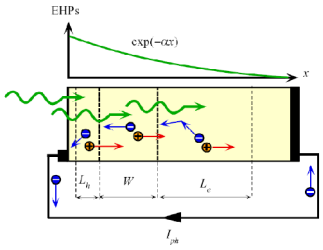
操作原理

- 波長



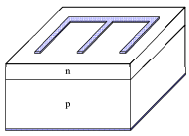
操作原理

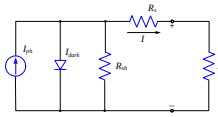
- 深度



❖操作原理

- Structure and Equivalent Circuit
  - R_{sh} - shunt resistance - represents current paths around junction
    - Surface leakage around cell edges
    - Diffusion spikes near dislocations
    - Fine metallic bridges
    - Microcracks
  - R_s - series resistance - represents impediments in current flow through junction
    - Resistance in base
    - Contact resistances
    - Resistance in emitter





❖操作原理

- Current-Voltage Characteristics

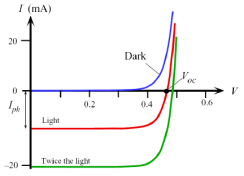
$$I = I_{ph} - I_{dark}$$
$$= qgA(L_n + L_p) - I_s\left(e^{qV/kT} - 1\right)$$
$$= qgA(L_n + L_p) - qA\left(\frac{L_n n_{p0}}{\tau_n} + \frac{L_p p_{n0}}{\tau_p}\right)\left(e^{qV/kT} - 1\right)$$

For the short-circuited diode, V=0:

$$I_{SC} = I_{ph} = -qgA(L_n + L_p)$$

For the open-circuited diode, I=0:

$$V_{oc} = \frac{kT}{q}\ln\left[1 + g\frac{L_n + L_p}{\frac{L_n}{\tau_n}n_{p0} + \frac{L_p}{\tau_p}p_{n0}}\right]$$
$$= \frac{kT}{q}\ln\left[1 + \frac{I_{ph}}{I_s}\right] \cong \frac{kT}{q}\ln\left[\frac{I_{ph}}{I_s}\right]$$



❖操作原理

- Output power

$$P = IV = I_{ph}V - I_sV\left(e^{qV/kT} - 1\right)$$

- Maximum power output P_m

$$\frac{dP}{dV} = 0 \quad or$$
$$V_m = \frac{kT}{q}\ln\left[\frac{1 + (I_{ph}/I_s)}{1 + (qV_m/kT)}\right] \cong V_{oc} - \frac{kT}{q}\ln\left(1 + \frac{qV_m}{kT}\right)$$
$$I_m = I_{ph} - I_s\left(e^{qV_m/kT} - 1\right) = I_s\left(\frac{qV_m}{kT}\right)e^{qV_m/kT} \cong I_{ph}\left(1 - \frac{1}{qV_m/kT}\right)$$

❖操作原理

- Maximum power output P_m (cont.)

$$P_m = I_mV_m \cong I_{ph}\left[V_{oc} - \frac{kT}{q}\ln\left(1 + \frac{qV_m}{kT}\right) - \frac{kT}{q}\right] = I_{ph}\left(\frac{E_m}{q}\right)$$

where

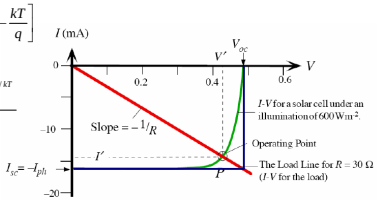
$$E_m = q\left[V_{oc} - \frac{kT}{q}\ln\left(1 + \frac{qV_m}{kT}\right) - \frac{kT}{q}\right]$$

- Conversion efficiency

$$\eta_c = \frac{P_m}{P_{inc}} = \frac{V_m^2 I_s\left(\frac{q}{kT}\right)e^{qV_m/kT}}{P_{inc}}$$

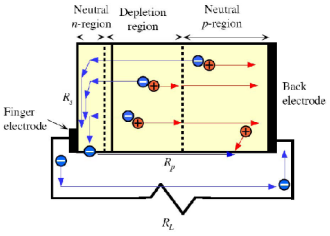
- Fill Factor

$$FF = \frac{I_mV_m}{I_{sc}V_{oc}}$$



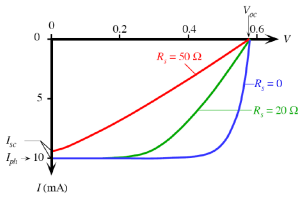
❖操作原理

- **Series and Shunt Resistance**
  - Effective series resistance *Rs*: carriers must travel through the neutral n- or p-regions to the electrodes.
  - Shunt or parallel resistance *Rsh*: a fraction of the photogenerated carriers can flow through the edges of the device or through grain boundaries in polycrystalline devices instead of flowing through the external load R_L.



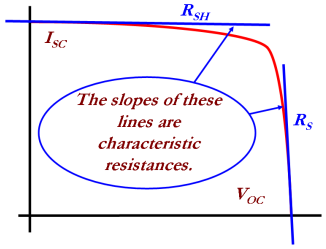
❖操作原理

- **Series and Shunt Resistance**
  - Both series and shunt resistances can significantly deteriorate the solar cell performance. The available maximum output power decreases with the series resistance.
  - In order to improve the cell efficiency, we need to reduce the series resistance and maximize the shunt resistance.



❖操作原理

- **Series and Shunt Resistance**



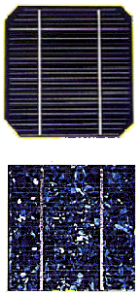
❖太陽能電池的種類

太陽電池種類		半導體材料	模組轉換效率
矽	結晶矽	單晶矽 (晶圓型)	13～20%
		多晶矽 (晶圓型、薄膜型)	10～15%
	非晶矽	a-Si、a-SiO、 a-SiGe	5～10%
化合物半導體	2元素	GaAs(晶圓型)	GaAs 18～30%
		CdS、CdTe (薄膜型)	7～10%
	3元素	CuInSe2(薄膜型)	8～10%
染料電池TiO_2 (Dye sensitized solar cell)			10%
有機半導體 (有機薄膜太陽電池)			1%

❖太陽能電池的種類

- **單晶矽太陽能電池**
- **多晶矽太陽能電池**

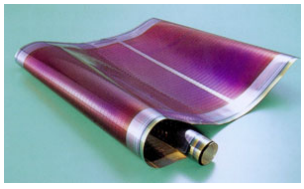
多晶矽太陽電池其光電轉換效率稍低於單晶矽太陽電池，但是材料製造簡便，節約電耗，生產成本較低。



❖太陽能電池的種類

- **非晶矽太陽能電池**

非晶矽太陽電池是1976年出現的新型薄膜式太陽電池，矽材料消耗很少，電量消耗更低，它的主要優點是在弱光條件也能發電。



❖太陽能電池的種類

- **CdTe-based Solar Cells**
  - Improve the understanding for the requirements of the CdS/CdTe junction using a thin CdS layer and how this interface can be manipulated by altering the cell processing.
  - Provide stability tests on CdTe cells and interpret the results found.
- **$CuInSe_2$-based Solar Cells**
  - Develop an understanding of the functioning and processing requirements for high-efficiency Cu(In,Ga)(S,Se)2 cells with bandgaps from 1.3 to 1.7 eV.
  - Explore and understand Cu(In,Ga)(S,Se)2 absorber formation limiting reaction temperatures to approximately 400 C.
  - Identify the critical requirements of all materials used in the device fabrication process (glass, Mo, CdS, surface modification of Cu(In,Ga)(S,Se)2, ZnO, etc.)

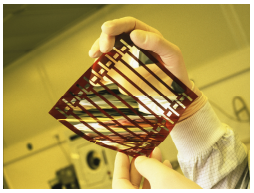
❖太陽能電池的種類

- **染料敏化太陽能電池 (Dye-Sensitized Solar Cells)**
  - 瑞士科學家Gratzel在1991年提出，以奈米結構電極材料及染料組成光電效率超過7%的光電池，後來稱為「染料敏化太陽光電池」。
  - 此類光電池的基本架構是透明導電基片、多孔奈米晶體二氧化鈦薄膜、染料光敏化劑、電解質溶液（含超敏化劑）和透明對電極所組成。其工作原理是以染料分子做為吸光的主要材料，在吸收到太陽光時轉換為激發態後提升到高能階層，再傳導至奈米二氧化鈦半導體的導電層，但激發態是在一個不穩定狀態下，所以電子必須以最快的速度注入到緊鄰的TiO2導帶，使染料分子所失去電子能在第一時間從電解質中得到回饋作用，在TiO2導帶中的電子能夠併入導電膜中，最終經由電極引至外部迴路產生光電流作用。



❖太陽能電池的種類

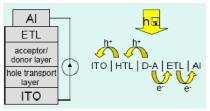
- **有機太陽能電池**
  - The discovery of metal-like electrical conductivity of polyacetylene in 1976 by Shirakawa with Heeger and MacDiarmid opened the field of research of polymers.
  - **Advantages of organic solar cells !**
    - Relatively cheap in production and purification.
    - Materials can be tailored for the demand.
    - Can be used on flexible substrate.
    - Can be shaped or tinted to suit architectural applications.
  - **Disadvantages of solar cells!**
    - Do not reach the energy conversion efficiency exceeding 24 % in inorganic materials.
    - Limited lifetime/ stability issue.



(Siemens)

❖太陽能電池的種類

- **In three essential steps, light energy is transformed into electricity by organic solar cells.**
  - **Absorption of light**
  - **Charge carrier generation**
  - **Transport of the opposite charges to the opposite contacts.**



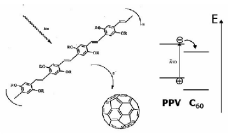


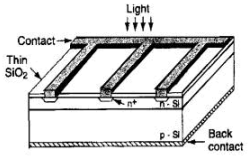
Illustration of the photoinduced charge transfer (left) with a sketch of the energy level scheme (right). After excitation in the PPV polymer the electron is transferred to the C_{60} due to its higher electron affinity.

❖太陽能電池的種類

- **有機太陽能電池**
- **There are 3 types of organic solar cells.**
  - Dye sentisized nanocrystalline TiO_2 solar cells.
  - Molecular organic solar cells.
  - Polymer solar cells.[Meissner, 1999]
    - Attracting great interest as photovolatic materials.
    - Breakthrough came with the introduction of the bulk heterojunction.

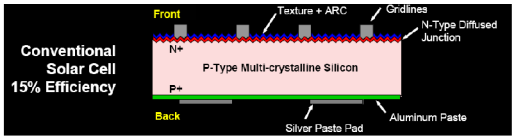
❖太陽能電池的結構

- **傳統太陽能電池**
  - 將電極作成手指狀(Finger)，以增加入射光的面積。



❖太陽能電池的結構

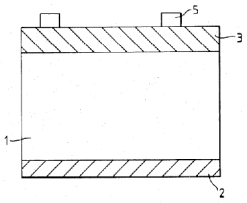
- **傳統太陽能電池**
  - **Texture+ARC**:將表面製成金字塔型的組織(Pyramid Texture)結構，並加入抗反射層，以減少光的反射量。
  - **Diffused junction**
  - **N+**
  - **P+**



❖太陽能電池的結構

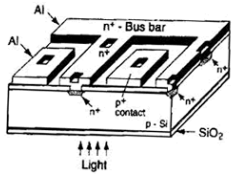
- **Metal-Insulator-NP (MINP)**
  - **United States Patent 4,404,422**
  - **Sep. 13, 1983**

The invention relates to a new-type of solar cell structure, and to a method of manufacturing same. The solar cell is designated as an MINP cell (Metal-Insulator-NP junction solar cell). Essentially, the MINP solar cell is an extremely shallow N-P junction cell with a MIS (Metal-Insulator-Semiconductor) type contact made to the top of the cell. Although combining features of the two technologies, no more processing steps are required than for a conventional P-N junction cell. The advantage of the MINP structure is its substantially improved efficiency.



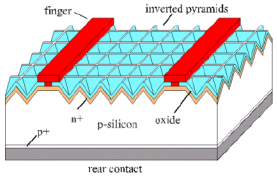
❖太陽能電池的結構

- **點接觸Solar Cell**



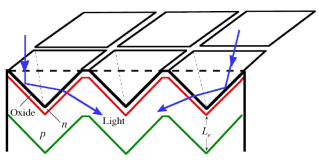
❖太陽能電池的結構

- **Passivated emitter solar cell structure (PESC)**



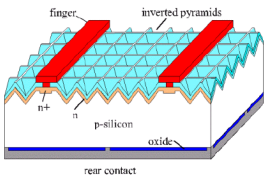
❖太陽能電池的結構

- **Inverted pyramid textured surface substantially reduces reflection losses and increases absorption probability in the solar cell device.**
- **Anisotropic etches to expose the slowly etching (111) crystallographic planes.**



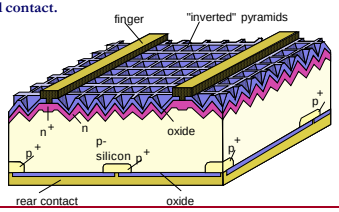
❖太陽能電池的結構

- **Passivated emitter rear cell structure (PERC)**



❖太陽能電池的結構

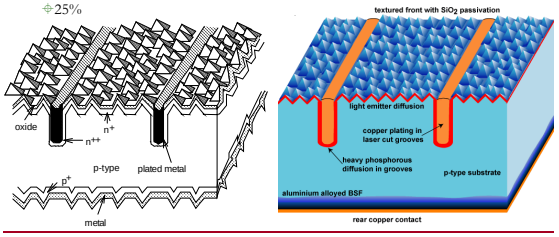
- Passivated emitter rear locally diffused solar cell structure (PERL)
- 澳大利亞新南威爾斯大學設計和製造。
- Using micro-electronic techniques to produce cells with efficiencies approaching 25% under the standard AM1.5 spectrum. The *passivated emitter* refers to the high quality oxide at the front surface that significantly lowers the number of carriers recombining at the surface. The rear is *locally diffused* only at the metal contacts to minimize recombination at the rear while maintaining good electrical contact.



❖太陽能電池的結構

Buried contact cell

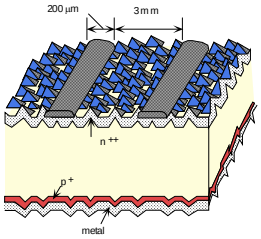
- 八十年代中期，新南威爾斯大學(UNSW)發明了“埋入式電極太陽能電池(Buried contact cell)”。
- 將金屬電極埋入基板中，以減少串聯電阻。
- Overcomes many of the disadvantages associated with screen-printed contacts.
- 25%



❖太陽能電池的結構

UNSW buried contact solar cell

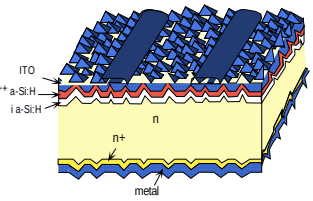
目前國際上大多數晶體矽太陽能電池生產廠家都採用絲網印刷技術。這一技術是在七十年代形成的。這一技術對單晶矽和多晶矽都適用。右圖描述了這一電池的結構。



❖太陽能電池的結構

HIT Solar Cell

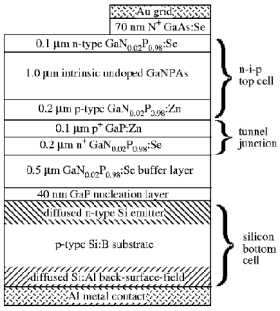
2000年，日本三洋公司（Sanyo）提出一種新型的HIT (Heterojunction with Intrinsic Thin Layer) 結構的高效太陽能電池。此種電池基於一種n-型晶體矽材料，採用PECVD方法在n-型矽片基板上沉積本質層i-和p-型非晶矽薄膜，從而形成n-型矽和非晶矽異質結構太陽電池，非晶矽（a-Si:H）材料的帶寬在1.7eV左右，遠大於晶體矽1.1eV的帶寬，因此此種HIT電池結構對於電池表面有很好的鈍化作用。同時，由於非晶矽幾乎沒有橫向導電性能，因此必須在矽表面澱積一層大面積的透明導電膜（TCO）以有效地收集電池的電流。這種電池的結構和技術製造出了21%轉換效率的單晶矽太陽電池，電池的開路電壓（Voc）達到719mV，接近世界紀錄，製造這種電池的溫度不超過300℃。
(22.3%, 2007/9/21)



❖太陽能電池的結構

Tandem Solar Cell

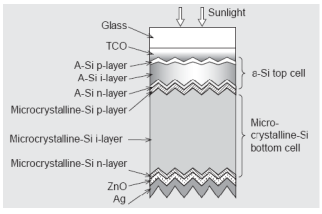
- III-V/Silicon Lattice-Matched Tandem Solar Cells



❖太陽能電池的結構

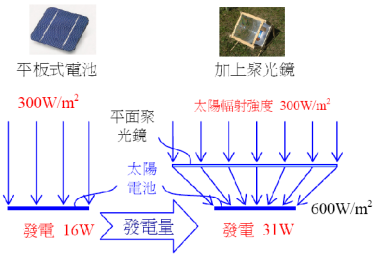
Tandem Solar Cell

- Development of a-Si/Microcrystalline-Si Tandem-type Photovoltaic Solar Cell



❖太陽能電池的結構

中聚光型 Solar Cell



❖太陽能電池的結構

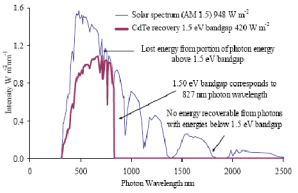
中集光型 Solar Cell

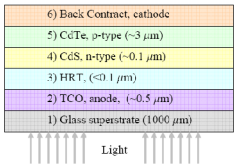


❖太陽能電池的結構

中Basic six layers for thin film CdTe solar cell

中Highly resistive transparent (HRT) layer

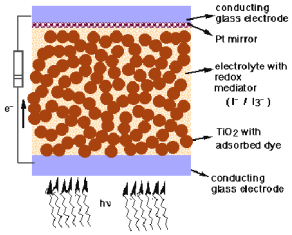




❖太陽能電池的結構

中 染料敏化太陽能電池 (Dye-Sensitized Solar Cells)

Dye sensitized Nanocrystalline Solar Cell (DYSC)



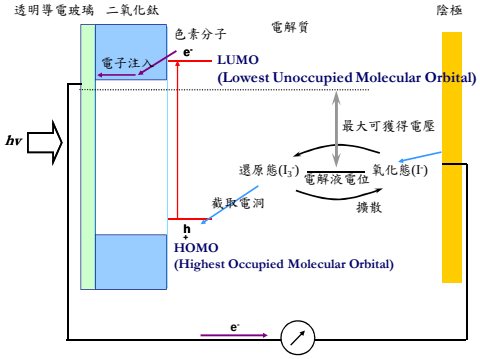
❖太陽能電池的結構

中 染料敏化太陽能電池 (Dye-Sensitized Solar Cells)

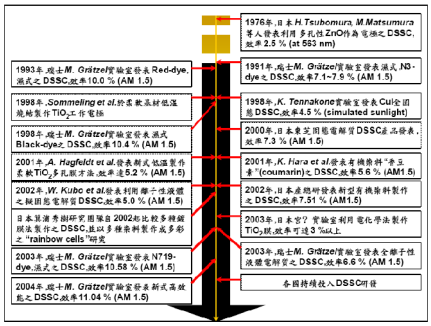
- 工作原理：

1. 染料分子吸收太陽光能後躍遷到激發態
   dye(S) + light → dye*(S*)
2. 激發態不穩定，電子快速注入到緊鄰的TiO2導帶
   dye*(S*) + TiO_2 → e⁻(TiO_2) + oxidized dye(S^+)
3. 染料中失去的電子則很快從電解質中得到補償
   oxidized dye(S^+) +3/2 I^-(A-) → dye(S) + 1/2I_3^-(A)
4. 進入TiO2導帶中的電子最終進入導電膜，然後通過外回路產生光電流。

1/2I_3^-(A) + e⁻(counter electrode) → 3/2I^-(A·)

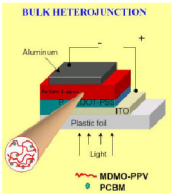


❖太陽能電池的結構



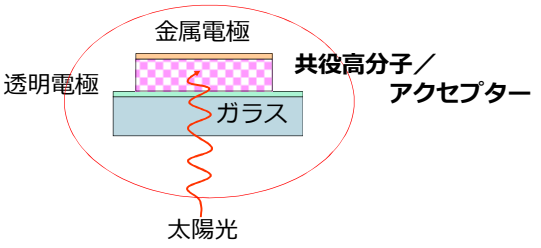
❖太陽能電池的結構

- 有機太陽能電池



ITO	Indium Tin Oxide
PEDOT:PSS	Poly (ethylene-dioxythiophene) doped with polystyrenesulphonic acid
MMDO-PPV	(poly-(2-methyloxy, 5-(3,7 - dimethyloctyloxy)) para phenylene-vinylene)
PCBM	([6,6]-Phenyl C61 butyric acid methyl ester

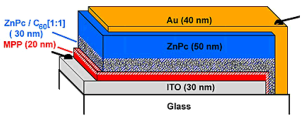
❖太陽能電池的結構



有機半導体太陽電池の断面模式図

有機太陽能電池

- ZnPc (Zn-phthalocyanine酞花青)(染料) → p-conducting materials
- MPP (methyl substituted perylene pigment) → n-conducting materials
- Buckminsterfullerene C_{60}



Structure of a sandwich organic solar cell consiting of substrate / ITO / MPP / ZnPc-C_{60}/ZnPc/Au

