能源科技與環境概論

太陽能電池導論

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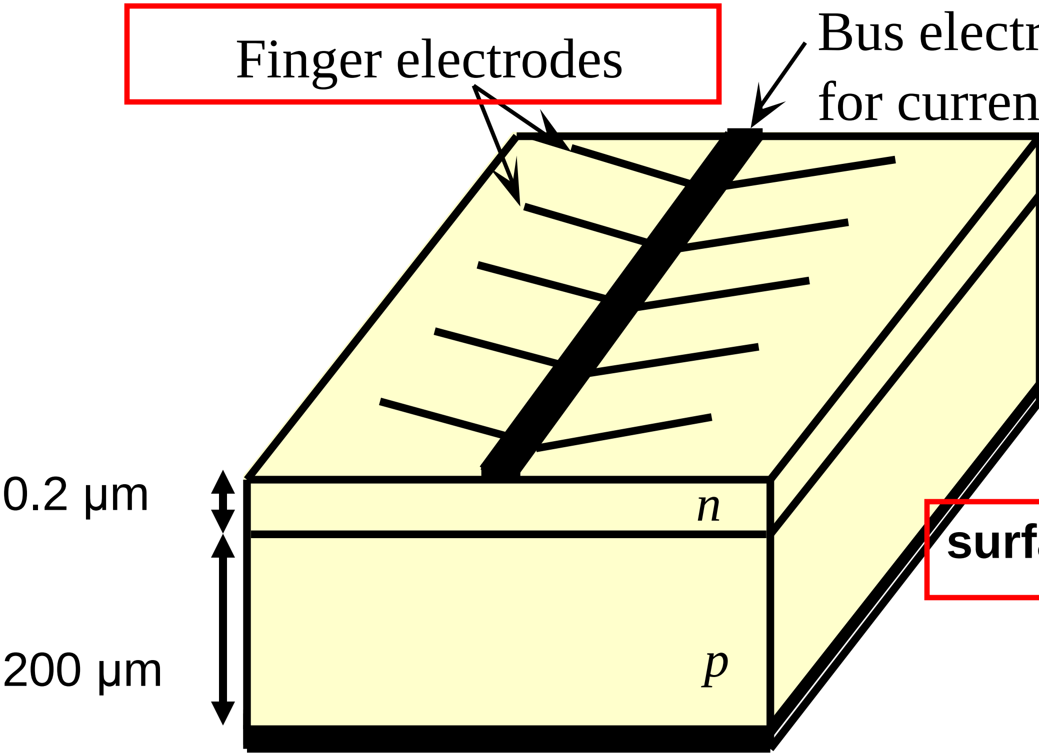
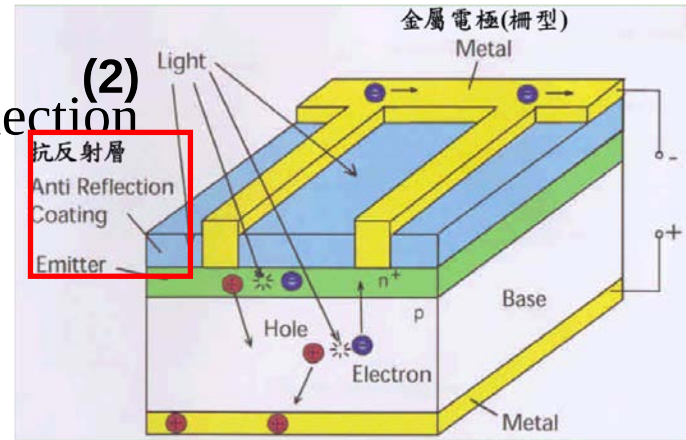
Device structure of a Si solar cell

(1)

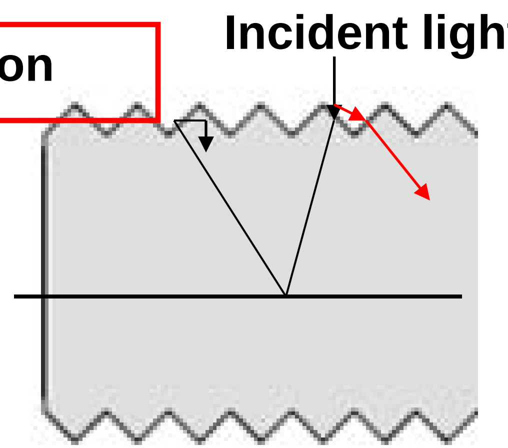


(2)



(3)

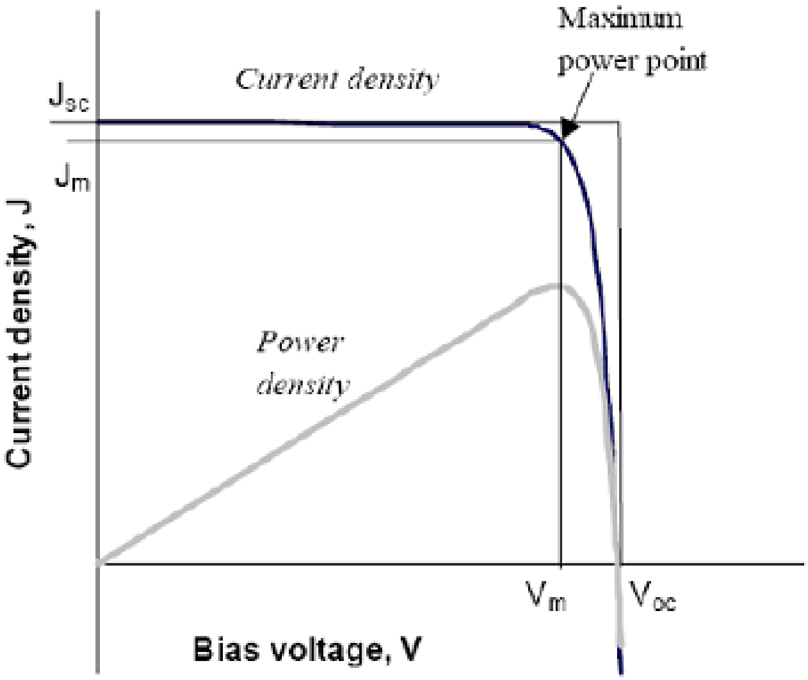
surface texturization



In order to capture more light

- finger electrodes were made to allow light pass through the device
- a thin antireflection coating on the surface reduces light reflection and allow more lighte to enter the device
-surface texturization to for multiple light reflection and increase light path

IV curve of a solar cell



$$\eta = \frac{Maximum \quad PV \quad output \quad power(P_{mp})}{Incident \quad solar \quad power(P_{in})} \times 100\%$$

$$= \frac{V_{mp} \times J_{mp}}{P_{in}} \times 100\%$$

$$= \frac{V_{oc} \times J_{sc}}{P_{in}} \times \frac{V_{mp} \times J_{mp}}{V_{oc} \times J_{sc}} \times 100\%$$

$$= V_{oc} \times J_{sc} \times FF / P_{in} \times 100\%$$

$$P_{mp} = J_{mp} \times V_{mp}; FF = \frac{J_{mp} \times V_{mp}}{J_{sc} \times V_{oc}}$$

Voc (open circuit voltage)

-when output current approaches zero,
the voltage develops between two terminals
ideally Voc~Eg at 0K and inverse proportional
to temperature

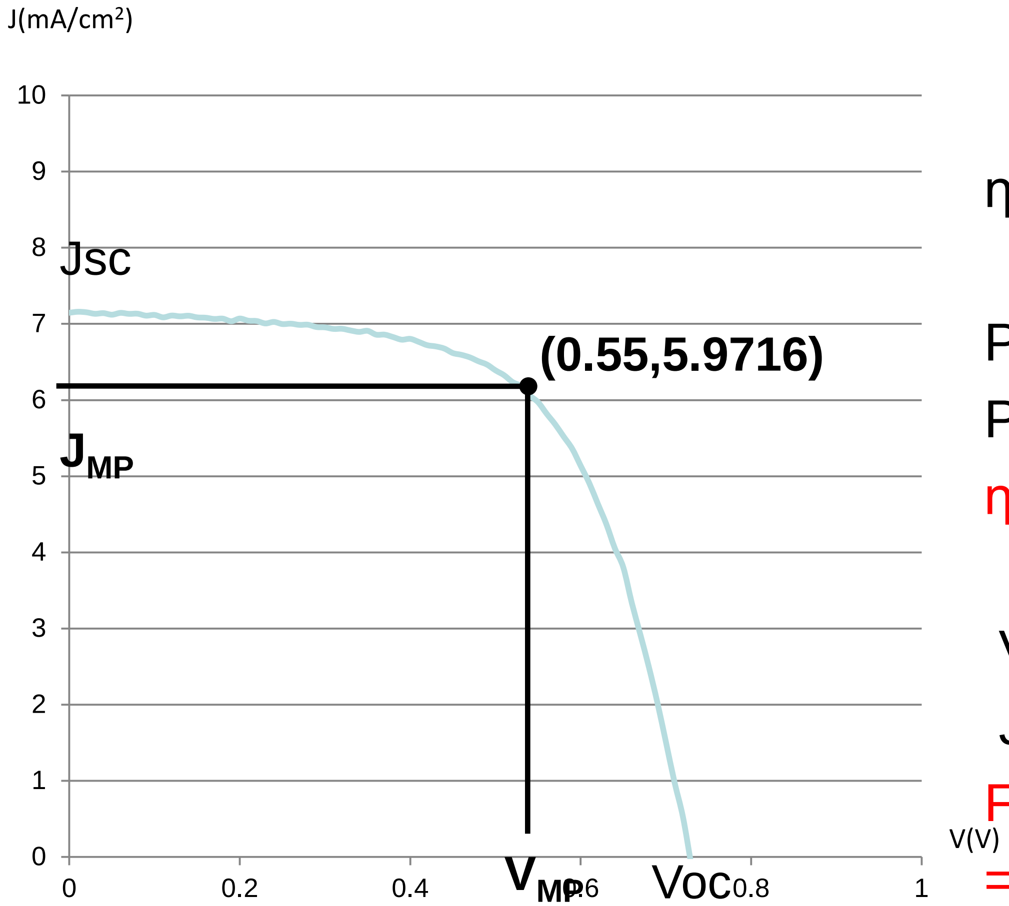
Jsc (short-circuit current)

-like the device connect the device with metal
close to photogenerated current

FF (fill factor): We want FF close to 1

η : Efficiency
Voc : Open Circuit Voltage
Jsc : Short Circuit Current Density
F.F. : Fill Factor
Pin : incident solar power (1000W/m² or 100mW/cm²)

Solar cell efficiency :an example



η and FF in this device ?

$\eta = P_{MP} / P_{in} \times 100\% = FF * V_{oc} J_{sc} / P_{in} \times 100\%$

（輸出電功率/入射光功率)

$P_{in} = 100\ mW/cm^2$

$P_{MP} = V_{MP} * J_{MP} = 0.55 * 5.9716 = 3.28 mW/c$

$\eta = 3.28/100*100\% = 3.28\%$

$V_{oc} = 0.72\ V$

$J_{sc} = 7.1464\ mA/cm^2$

$FF = V_{MP} * J_{MP} / V_{oc} * J_{sc}$

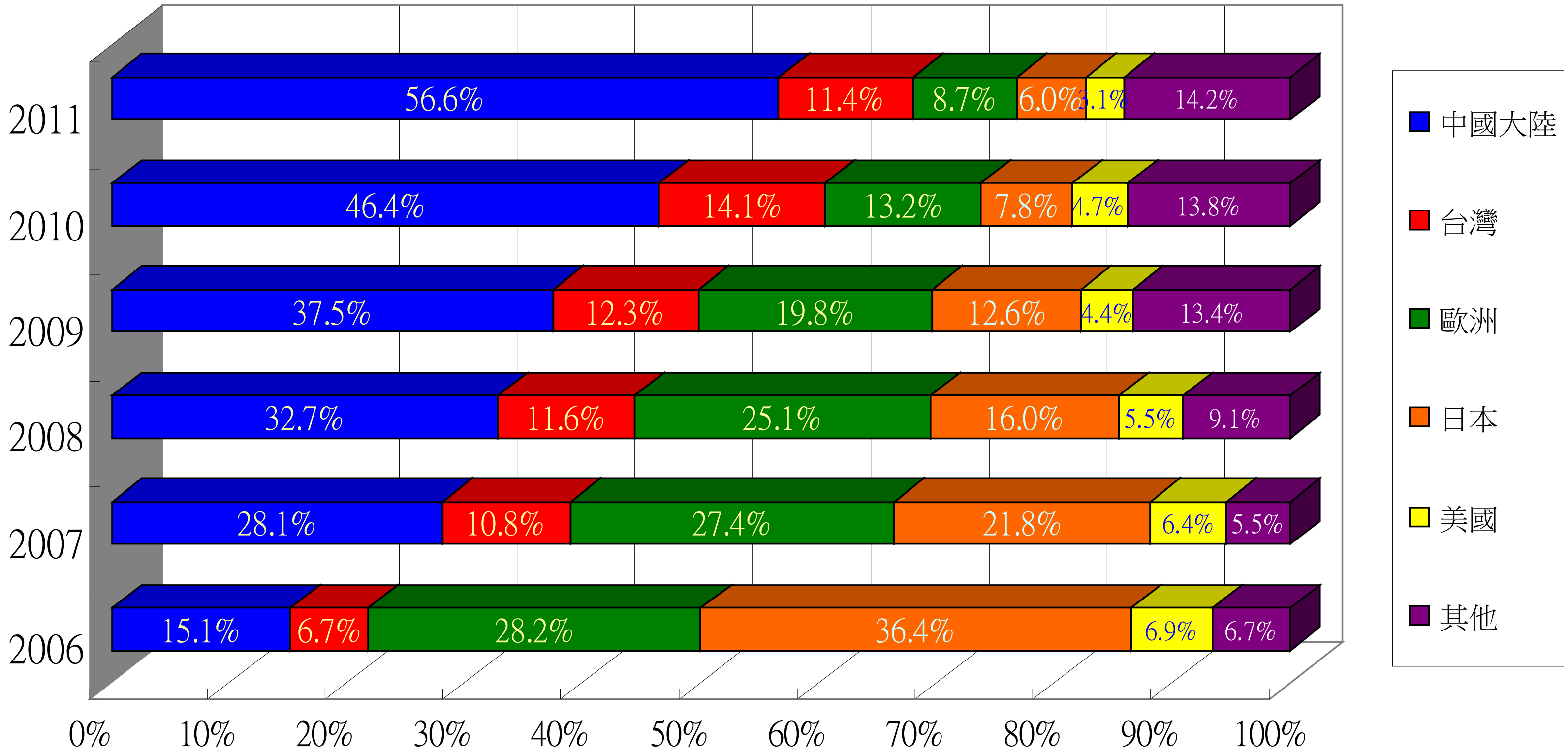
$= 3.28/(0.72*7.14) = 0.63$

Voc: 開路電壓 (open circuit voltage), 當輸出電流趨近於零，相對太陽電池兩電極端點沒有連接所得到的電壓

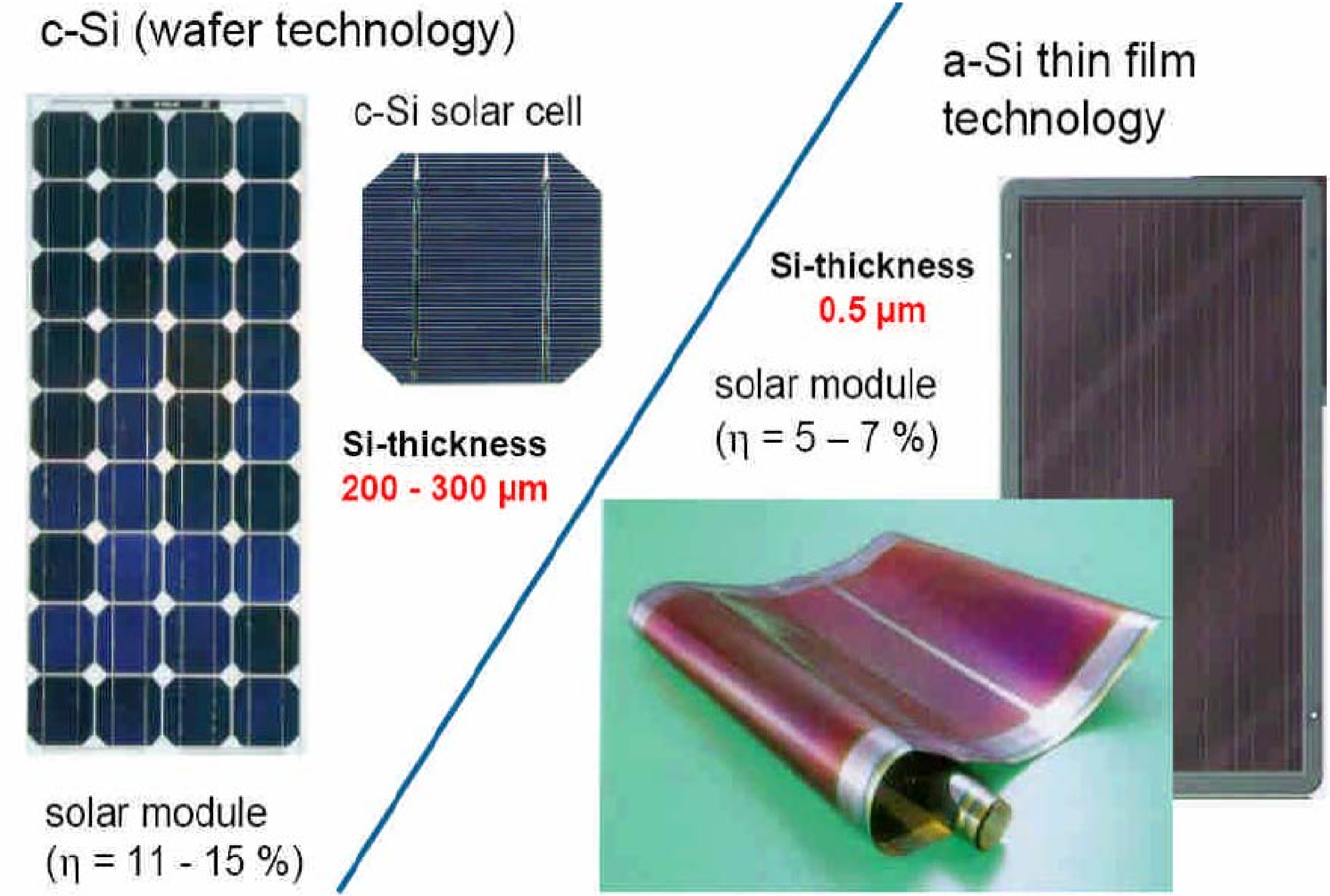
Jsc:短路電流(short circuit current)

如將照光的pn二極體兩端的金屬電極用金屬線連接, 造成短路, 此短路電流等於光電流

- 歐洲與日本之電池產量由**2006**年市占率約**30%**下降至**2011**年的**10%**以下。
- 太陽光電生產基地持續向亞洲移動趨勢不變，中國大陸與臺灣生產比例近全球**70%**。
- 大陸挾其成本優勢與政策支持，成為全球最大製造國，**2011**年產值達**2536**億元人民幣。



Thin film solar cell: use Si as an example



- required thickness of thin film solar cell is around 0.5 µm, 1/500 of that of wafer based solar cell
- material cost is very low

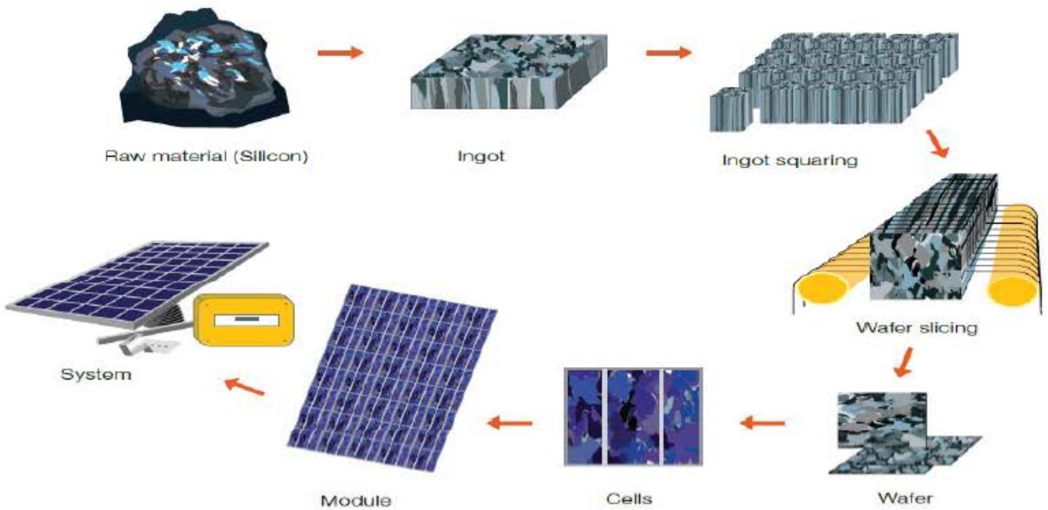
Advantages of thin film solar cells

1. low raw materials are required for fabrication
2. light transmission is better
3. more competitive price (CdTe, US$1 per watt ; First Solar, stock price is US$180)
4. frameless design
5. Ideal for BIPV(building integrated photovoltaic)

Advantage of Thin-Film

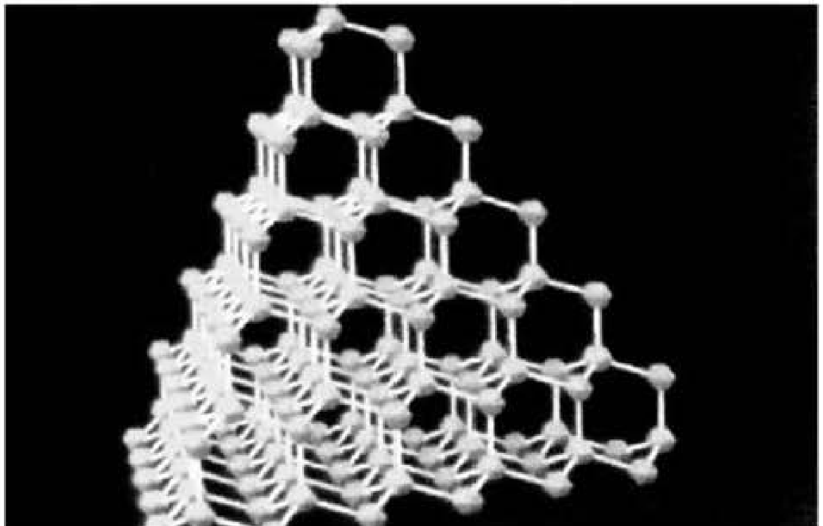
Thin-Film

Crystalline Si

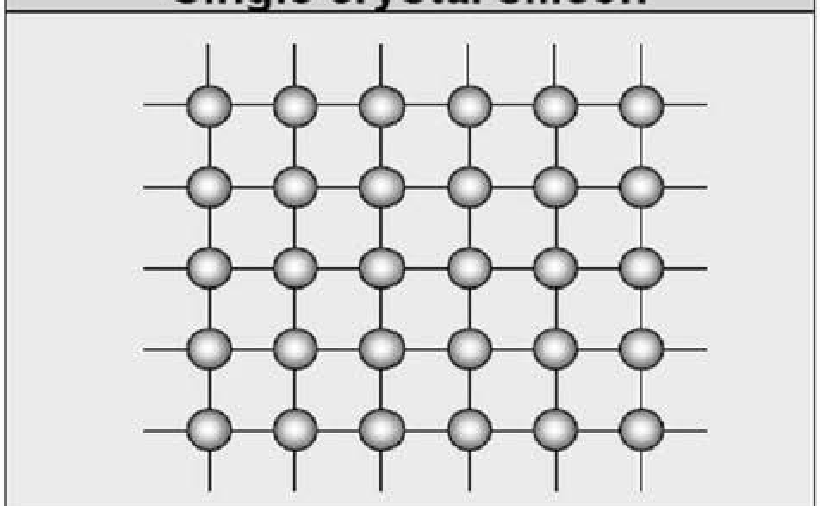


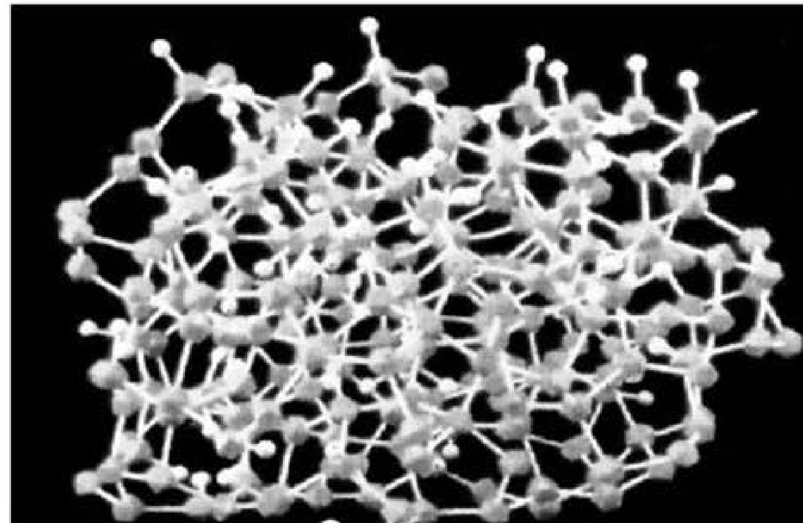
- Thin-film solar cells required a shorter value chain
- Long value chain presents difficulties with reaching grid parity.

Comparison of Atomic Structure of c-Si and a-Si:H

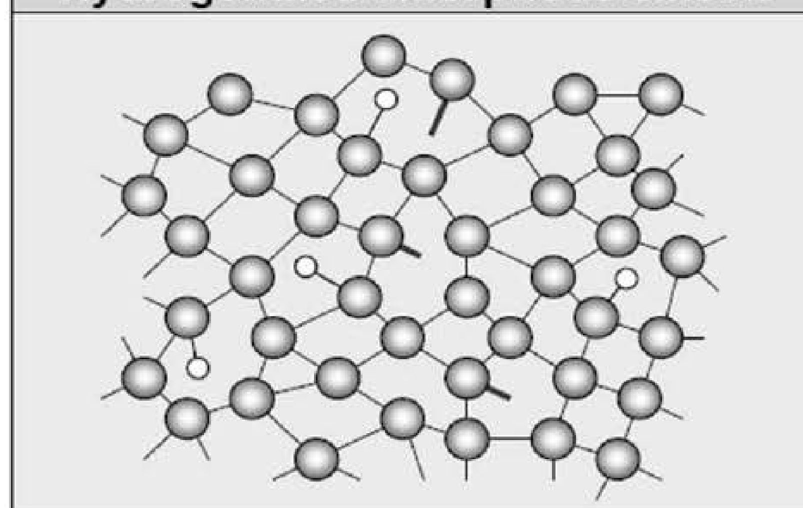


Single crystal silicon





Hydrogenated amorphous silicon



Device structure of amorphous Si solar cell

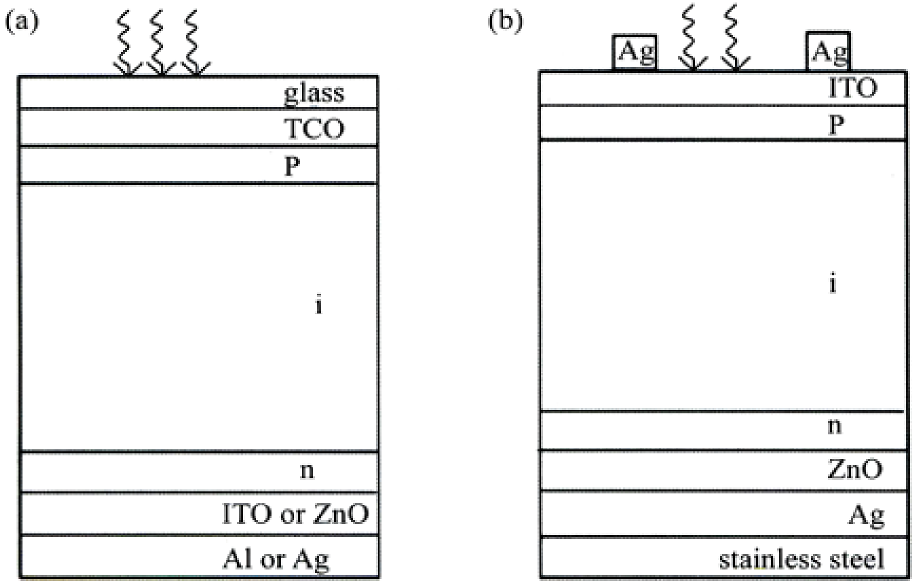
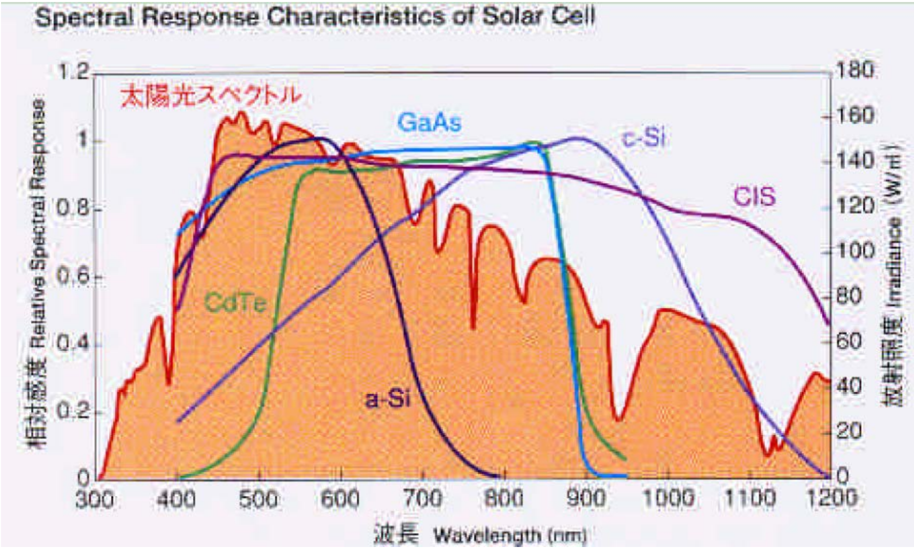


圖 6.7 典型 a-Si:H p-i-n 單接面太陽電池

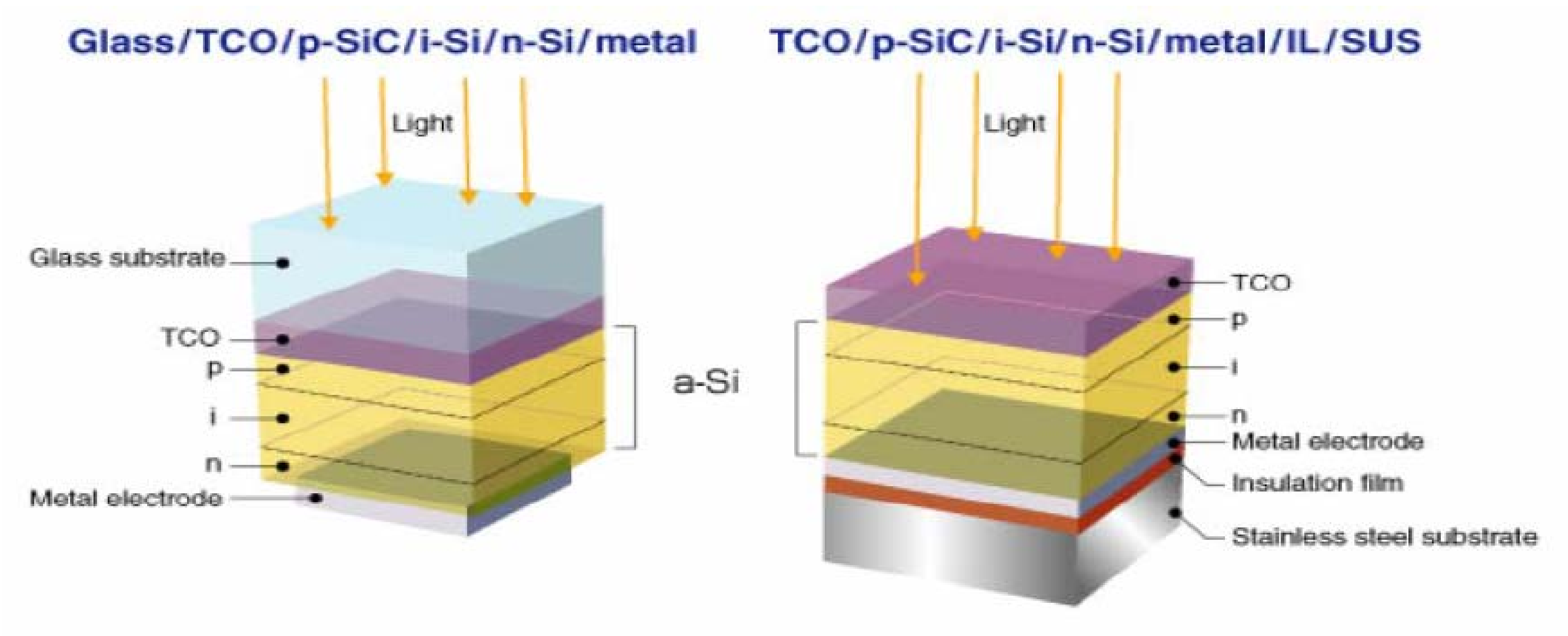
(a)superstrate 型式，(b) substrate 型式



-a-Si’s absorption coefficient at visible light is one order of magnitude than c-Si , so only 10-30 nm is needed to capture most photon in the visible region

-thickness of p and n type are around 10-30nm, thickness of i layer is less than 500 nm

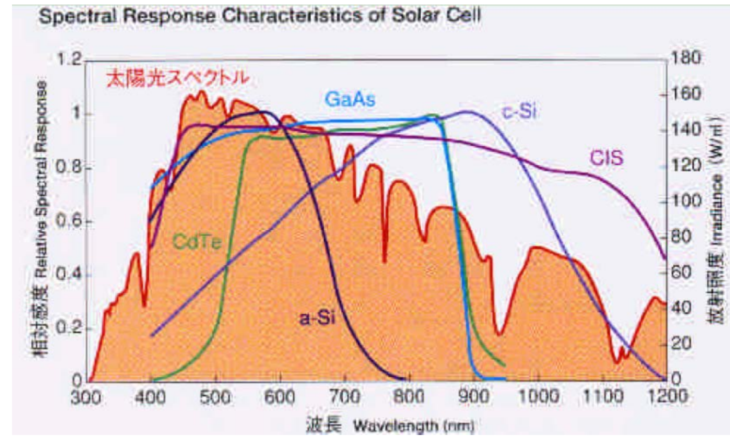
Structure of an amorphous Si solar cell



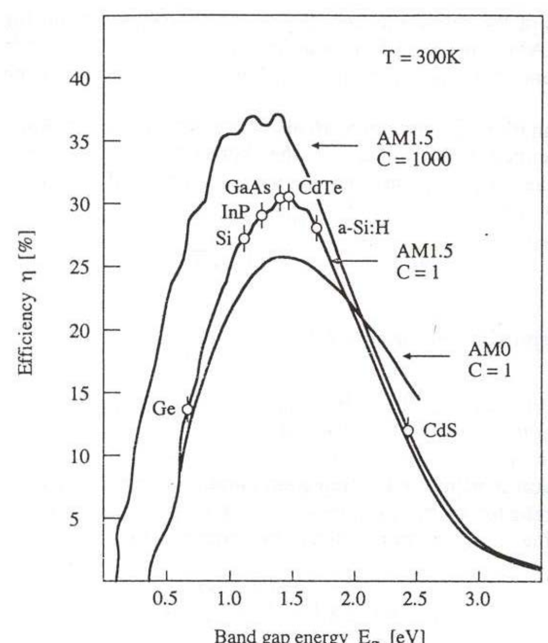
II-VI compound solar cell: CdTe

Abbreviated periodic table

I	II	III	IV	V	VI
		B	C	N	O
		Al	Si	P	S
Cu	Zn	Ga	Ge	As	Se
Ag	Cd	In	Sn	Sb	Te



II-VI group as light harvesting materials



band gap of CdTe : 1.5 eV

Device structure of a CdTe solar cell

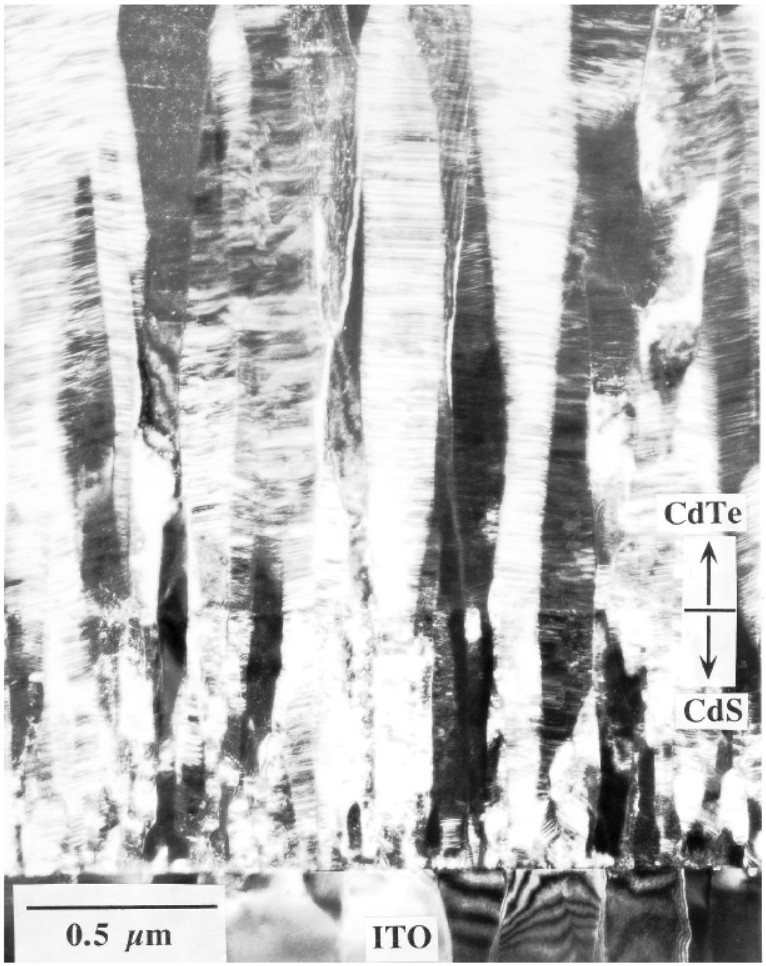
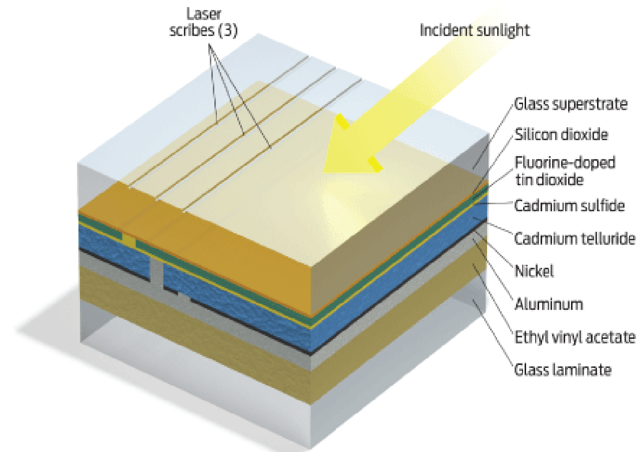


Figure 9 TEM micrograph showing the as deposited cross section of ITO/CdS/CdTe structure. Both CdS and CdTe are vapor deposited from the respective compounds.



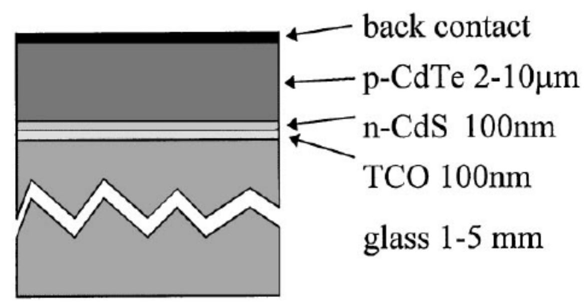


Fig. 1. The 'superstrate' configuration used for CdTe/CdS heterojunction solar cells.

P-type: CdTe
n-type: CdS

First solar

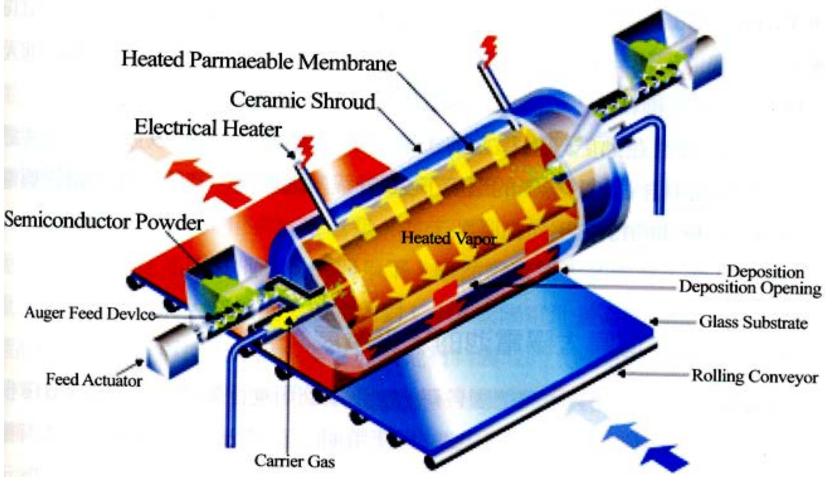


圖 7.8 First Solar 公司之量產型 CdTe 蒸氣輸送鍍膜示意圖

Pallas 綜合外電報導 / SolarExchange

美國太陽能廠商First Solar於去年第四季生產成本降到每瓦0.98美元

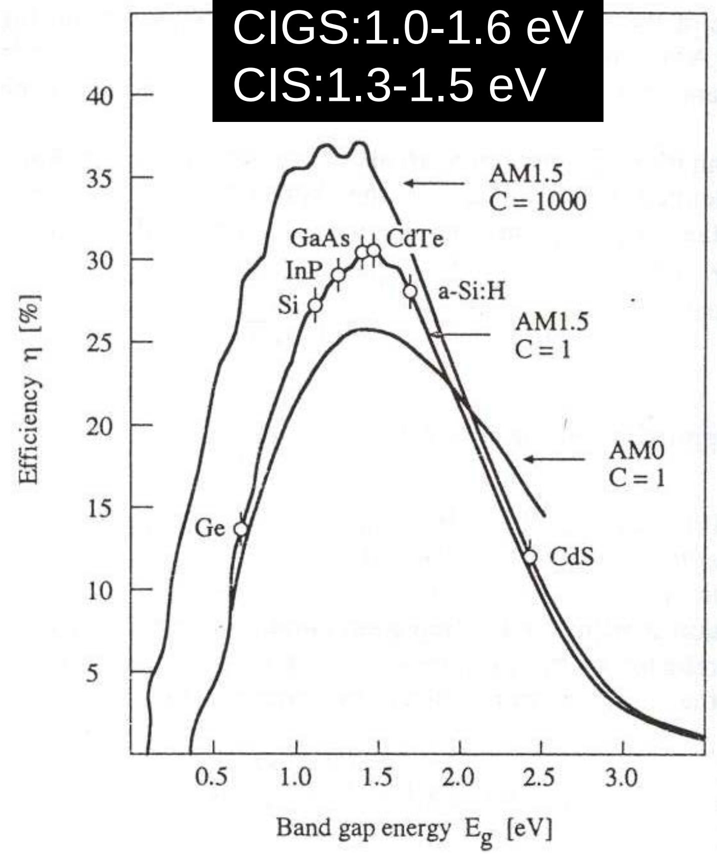
美國太陽能模組製造商First Solar（Nasdaq: FSLR）於24日宣布，
2008年第四季平均生產成本降到每瓦0.98美元，成為首家低於每瓦1美元的太陽能廠商。
美國太陽能模組製造商First Solar（Nasdaq: FSLR）於24日宣布，2008年第四季平均生產成本降到每瓦0.98美元，成為首家低於每瓦1美元的太陽能廠商。

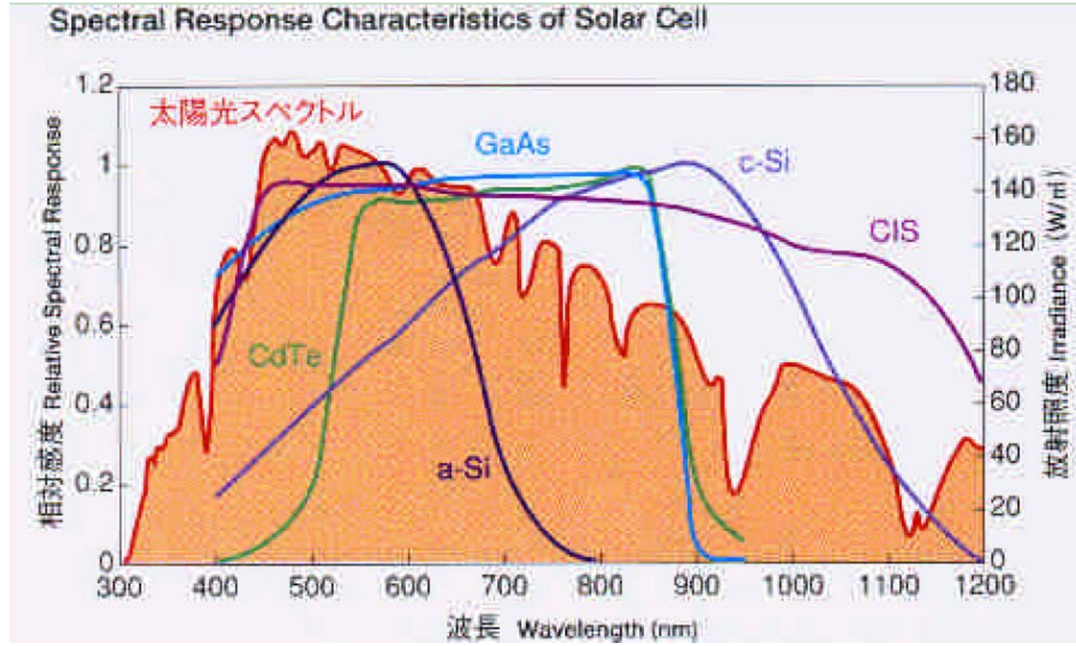
First Solar於2004年開始商業化生產以來，2008年產能成長約2500 % 達到500 MW。
2009年產能將再增加一倍，達到1GW。這相當於一般核電廠的規模。
這些成長率隨著成本迅速降低而提高。生產成本自2004年以來降了超過三分之二，從每瓦3美元降到每瓦1美元不到。First Solar有信心能基於First Solar未用盡的技術和製程的潛力，進一步再將成本降至更低。

Current production Cost of crystalline Solar cell is around US 2/Wp

Band gap and optical absorption of CIGS

$CISe_2$:1.0 eV
CIGS:1.0-1.6 eV
CIS:1.3-1.5 eV





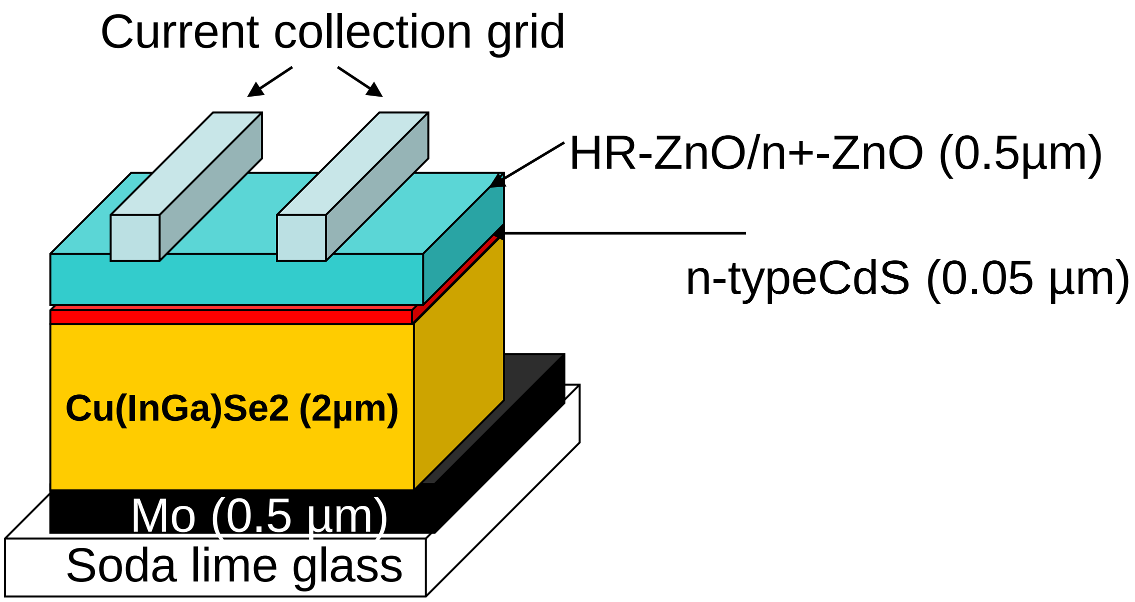
Muller, semiconductor for solar cells, 1993

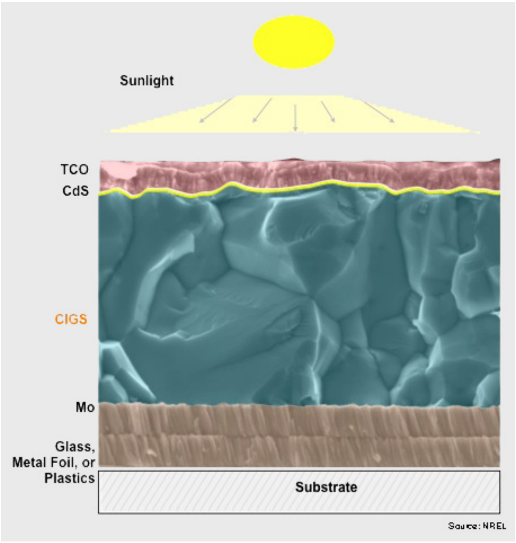
$$\text{Efficiency} = \frac{FFVocIsc}{Pin}$$

-CIGS's band gap is in the range of 1.1 to 1.5 ev

I-III-V_2 compound solar cell: (CIGS)

Schematic picture

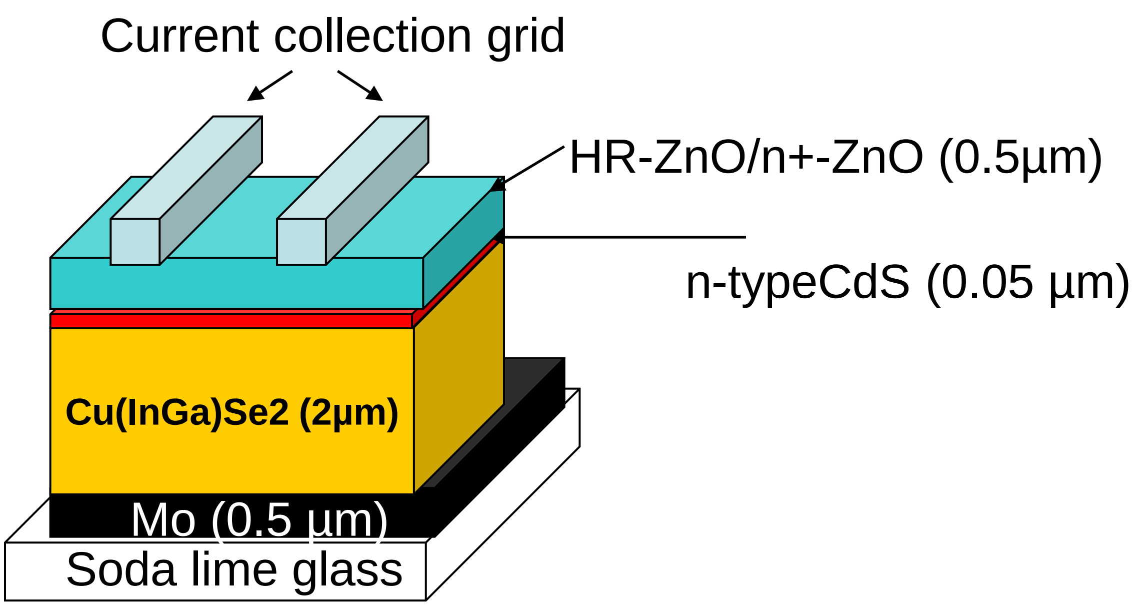




total device thickness less than 5 µm (Crystalline Si module~200 µm)

Compared to CdTe solar cells

Schematic picture



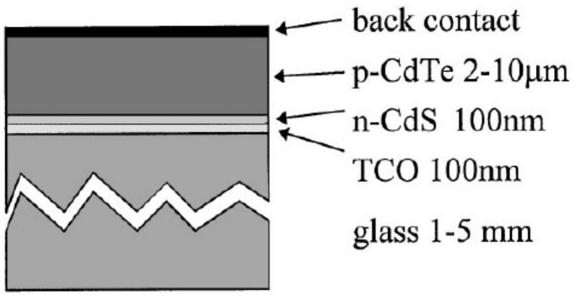
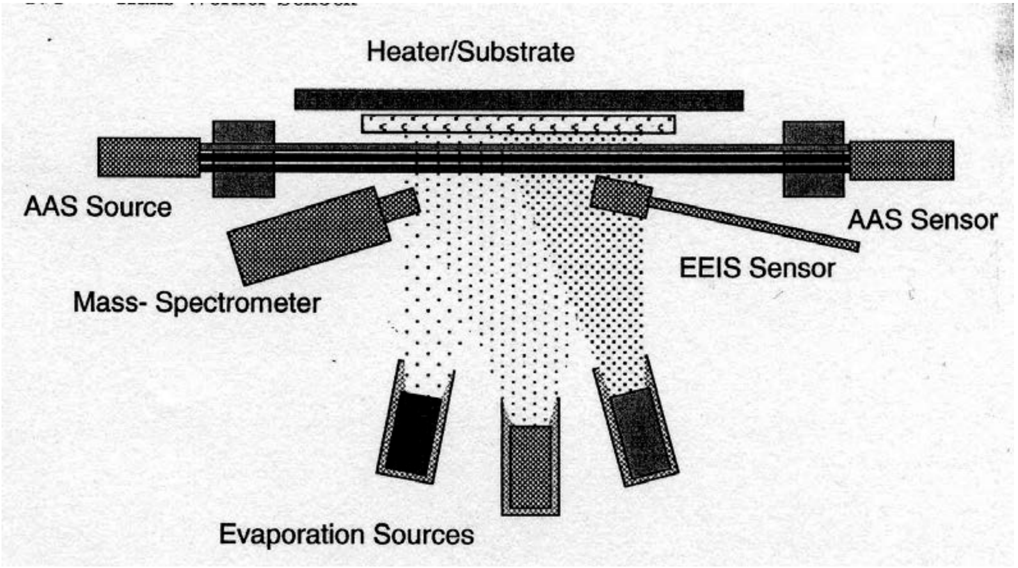
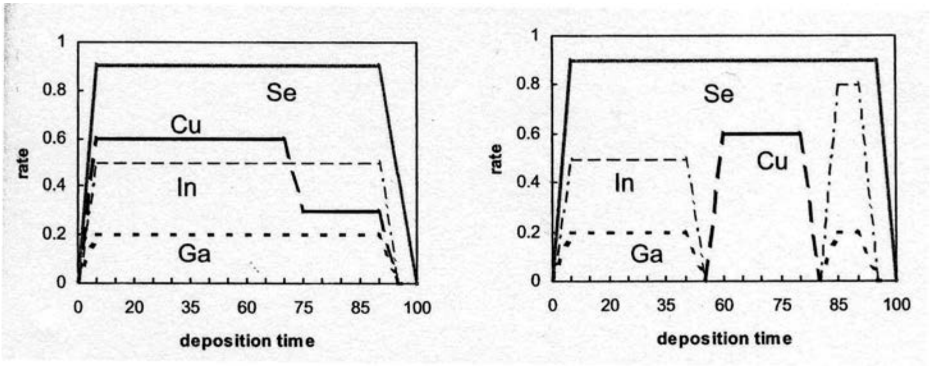


Fig. 1. The 'superstrate' configuration used for CdTe/CdS heterojunction solar cells.

Much less Cd required

An example of vaccum-based CIGS film deposition

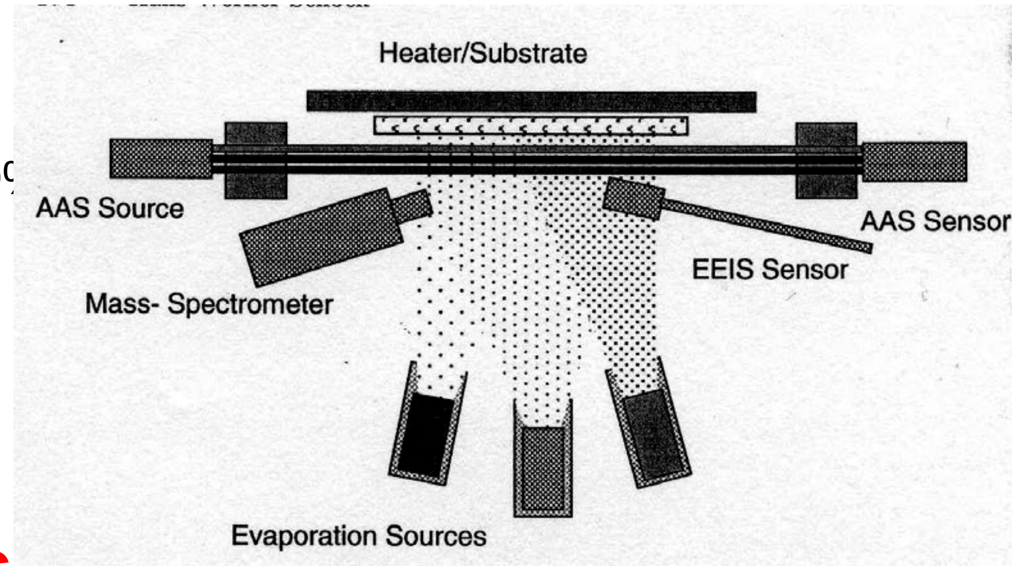




Y. Hamakawa Thin-film solar cells,

Vaccum-based CIGS film deposition

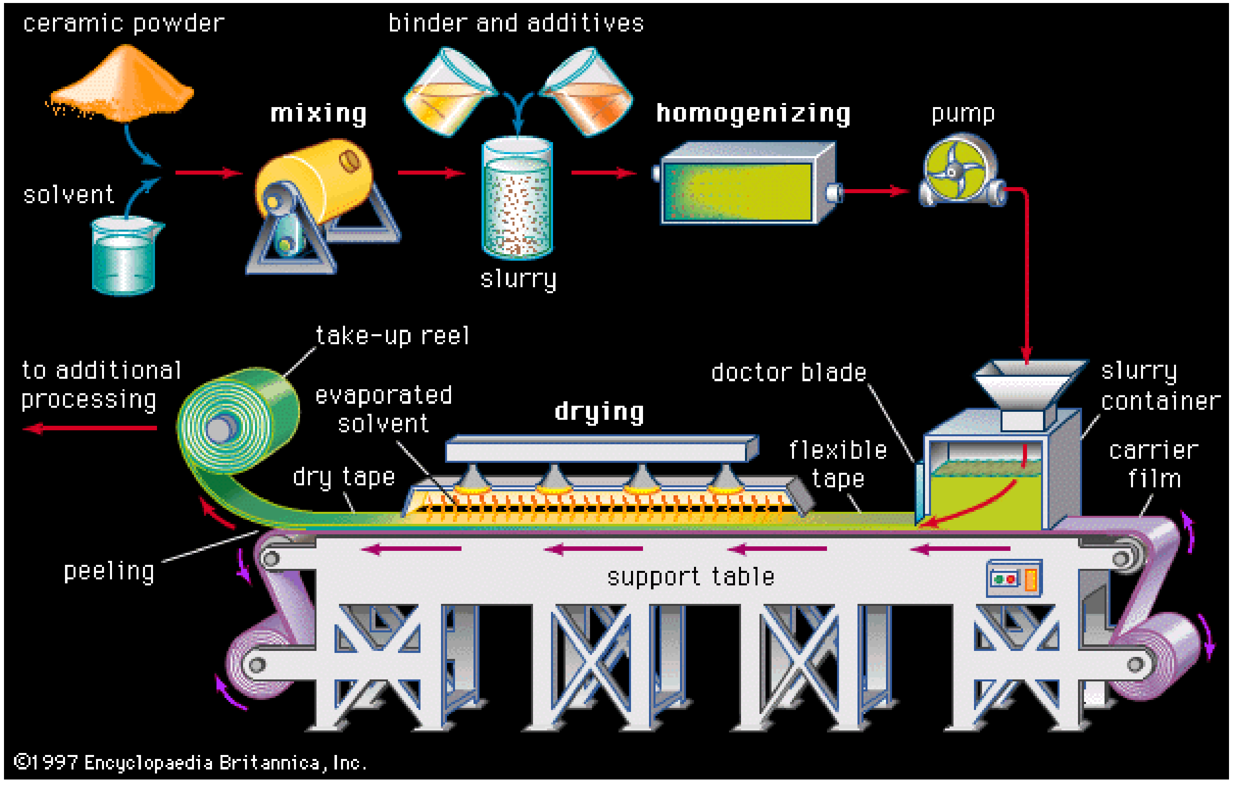
-Highest efficiency (lab scale: 18~20
-Usually UHV/MBE
-Cost prohibitive (but <cryst-Si)



General drawbacks:

-Difficult to achieve controlled-stoichiometry over large device areas
-Manufacturing equipment is “very” expensive (> NT 0.1 billion)
-The deposition process is time-consuming
-Poor materials utilization (30-50%)
-Low throughput

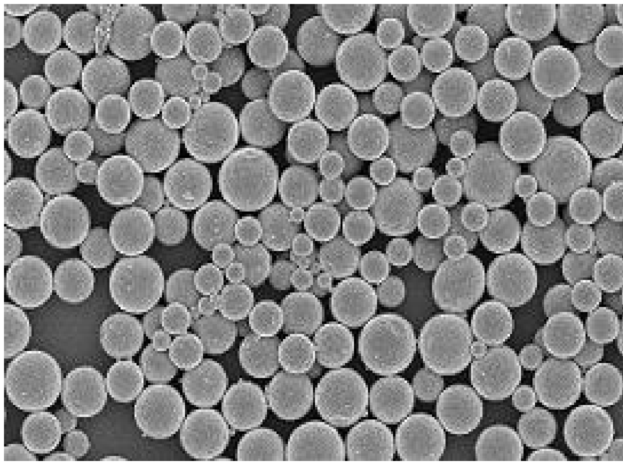
Non-Vacuum Processing



-Synthesize colloidal nanocrystals with controlled CIGS stoichiometry and deposit layer
-Roll-to-roll manufractruing process

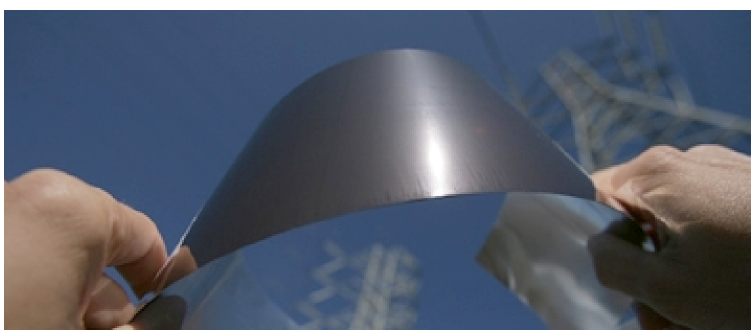
Nano solar- Nanoparticle as ink for printable solar cell

CIGS particle ink



Roll-to-roll processing

Flexible solar cell

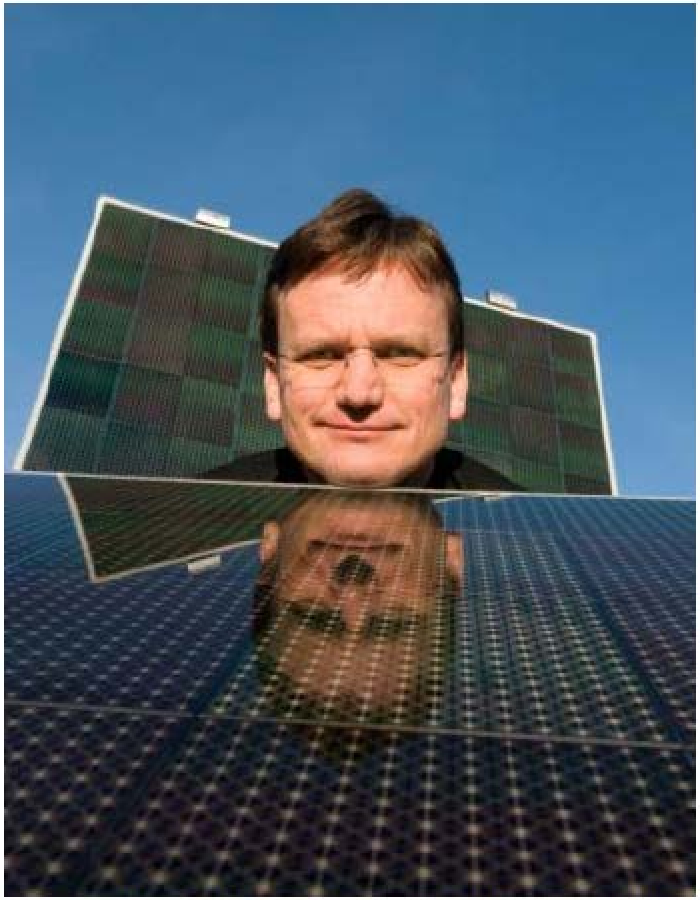


Add a video

has denmostrated a 1GW coater in a movie

	Silicon Wafer cells	Vacuum-based thin film	Roll-printed thin film
Process	Si wafer processing	High vacuum depositon	Roll-to-roll printing
Process Yield	Robust	Fragile	Robust
Materials Utilization	30%	30-60%	Over 97%
Throughput	1	2-5	10-25

Nanosolar Ships First Panels - Dec. 18,2007



Martin Roscheisen, CEO

首批的三片量產太陽能板一片將掛在公司裡做「精神堡壘」，一片捐贈給聖荷西的科技博物館，一片拿到 eBay 上拍賣，起價 0.99 美元，3天後叫價到13,000美元。

Nanosolar, Thin-Film Solar Hype Firm, Officially Dead

U.S. CIGS solar assets are being auctioned off after more than $400 million in VC investment.

by Eric Wesoff

July 12, 2013

CIGS Rocks! 2010/July

【時報記者沈培華台北報導】台積電 (2330) 新事業總經理蔡力行表示，
台積電將以CIGS薄膜產品進軍太陽能產業，以五年期間朝全球前五大廠邁進，
產能規模將達1GW規模，並看好此事業對台積電是有獲利與高成長潛力的新事業。
台積電今天舉行先進薄膜太陽能技術研發中心暨先期量產廠房動土典禮。
新事業總經理蔡力行表示，全球太陽能電池市場將持續成長，預期2009年至
2015年全球太陽能電池市場年複合成長率可望達23%；其中，銅銦鎵硒(CIGS)
因具有薄膜的低成本價格等優勢，成長率將最高，年複合成長率將達115%。
台積電因此將以CIGS薄膜產品為主力，進軍太陽能產業。
台積電先進薄膜太陽能廠第一期將投資約79.2億，預計2012年量產200百萬瓦(MW)
，終期產能為700百萬瓦(MW)。台積電董事長張忠謀並預估，2015年太陽能佔
台積電營收比重可望達10%。蔡力行表示，台積電三年內CIGS薄膜太陽能電池
模組轉換效率將達14%，產能規模將約300至500百萬瓦，預期3至5年轉換效率
將進一步提升至16%，產能規模將達1GW規模。

薄膜太陽能翻身　台積電產能衝3倍　全球龍頭廠轉盈　產業前景漸撥雲見日 2014/Feb

台積電旗下銅銦鎵硒(CIGS)薄膜太陽能廠目前年產能為40百萬瓦(MWp)，隨著整體市況轉佳、訂單滿載且技術獲得重大突破，台積電第4季CIGS年產能將擴增到120MWp，達到3倍規模，太陽能業者透露，以台積電在太陽能領域穩紮穩打風格來看，這次產能出現大躍進，凸顯CIGS接單情況明顯轉佳，業界紛預期台積電太陽能事業可望邁向獲利。不過，台積電發言體系表示，目前針對財務部分不予置評。

全球最具代表性的CIGS薄膜太陽能龍頭大廠是日本昭和殼牌石油旗下子公司Solar Frontier，年產能規模達900MWp，近年來一直陷入虧損困境翻不了身，然近期財報終於首度轉虧為盈，2013年旗下產能全數滿載，年營收暴增8成，並計劃在日本東北(Tohoku)擴增150MWp產能的CIGS新廠，預計2015年投產。

台積太陽能步上關廠 業界:成本難敵矽晶 2015/08/25 16:36

（中央社記者張建中新竹25日電）台積電100%持股子公司台積太陽能將於8月底結束工廠營運。業界人士認為，薄膜太陽能電池成本難敵矽晶太陽能電池，是迫使台積太陽能走向關廠的主因。

台積電新事業發展接連遭逢重大挫敗，旗下台積固態照明因較晚進入發光二極體（LED）產業，業界專利障礙與通路開發不易，考量短期難以轉盈，台積電今年初決定將台積固態照明全部股份賣予晶電。

台積電今天又宣布，旗下台積太陽能因是市場後進者，缺乏經濟規模，雖然轉換效率具領先優勢，但在成本上不具競爭力，即便執行最精進的成本減抑計畫，也將難以逆轉成本劣勢，將於8月底結束工廠營運。

台積電是於2009年成立新事業部，並陸續成立台積固態照明與台積太陽能，分別投入LED與太陽能產業，由前總執行長蔡力行領軍。隨著蔡力行轉往中華電信擔任董事長，台積固態照明與台積太陽能董事長由左大川接任。

台積太陽能成立之初，蔡力行曾表示，台積太陽能將以技術領先為主要策略。

碩禾電子材料 太陽能電池導電膠

碩禾 **(3691)** 股價560.0

碩禾導電漿在全球產業地位

項目	全球市占(%)	台灣市占(%)	挑戰目標(%)	產業地位	主要競爭者
背鋁	35	90	40	全球前2名	中國儒興
背銀	25~30	60	40	全球前3名	杜邦、中國中型廠
正銀	1	3~4	5	起步中	杜邦、賀利氏

註：背鋁及背銀目標為中期目標，為期2到3年；正銀目標為今年

資料來源：碩禾　簡永祥／製表

碩禾相關權證

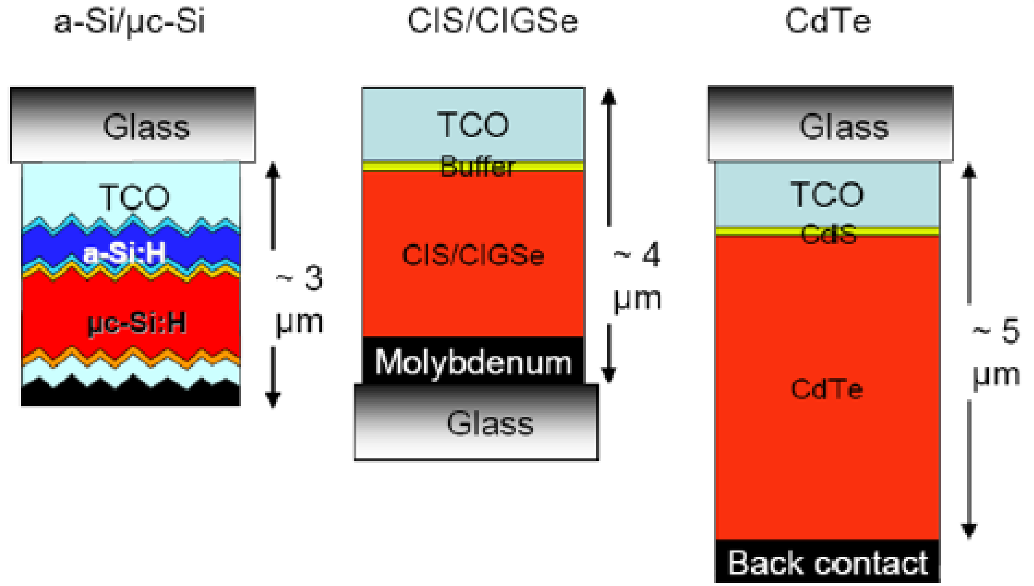
標的證券	權證代號	權證名稱	價內外(%)	權證單價(元)	剩餘天數	標的上漲1%、權證相對漲跌幅(%)
碩禾	706875	群益TK	內11.48	2.43	132	3.57

群益金鼎證券／製表

清大化工系友在光電業界的發展

三大上游材料，都是清大幫天下—清大幫創業公司表
公司名：晶電代表人物：董事長李秉傑畢業系級：1985年化工博士公司地位：台灣第一大LED磊晶廠
公司名：璨圓代表人物：董事長簡奉任畢業系級：1985年化工系公司地位：台灣第二大LED磊晶廠
公司名：上緯代表人物：董事長蔡朝陽畢業系級：1987年化工碩士公司地位：高性能樹脂材料大廠
公司名：碩禾代表人物：蔡禮全 化學工程
公司地位：太陽能導電膠大廠 副總經理

Comparison of three thin film solar cells

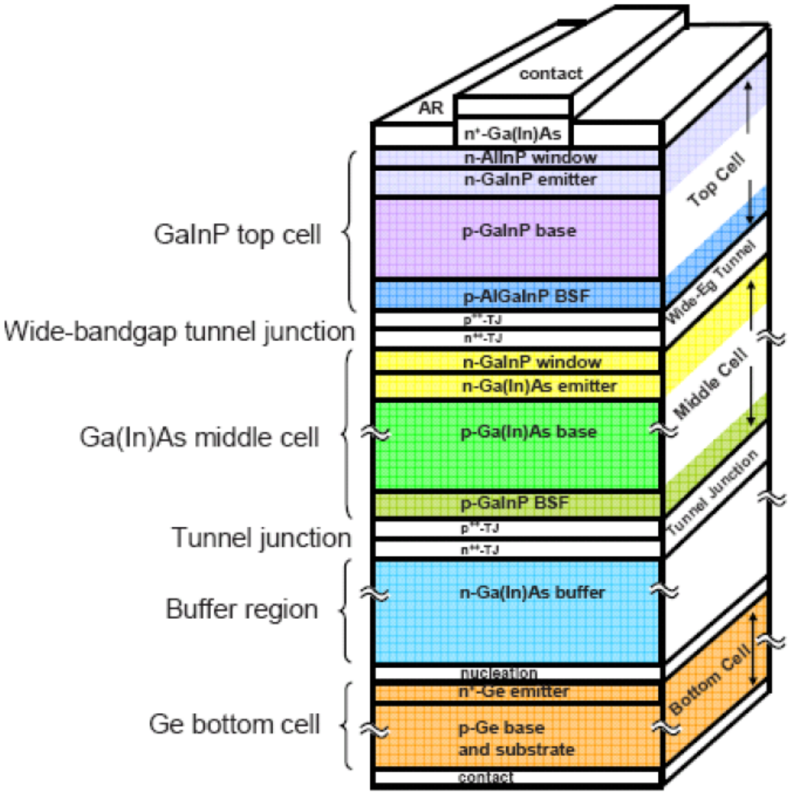


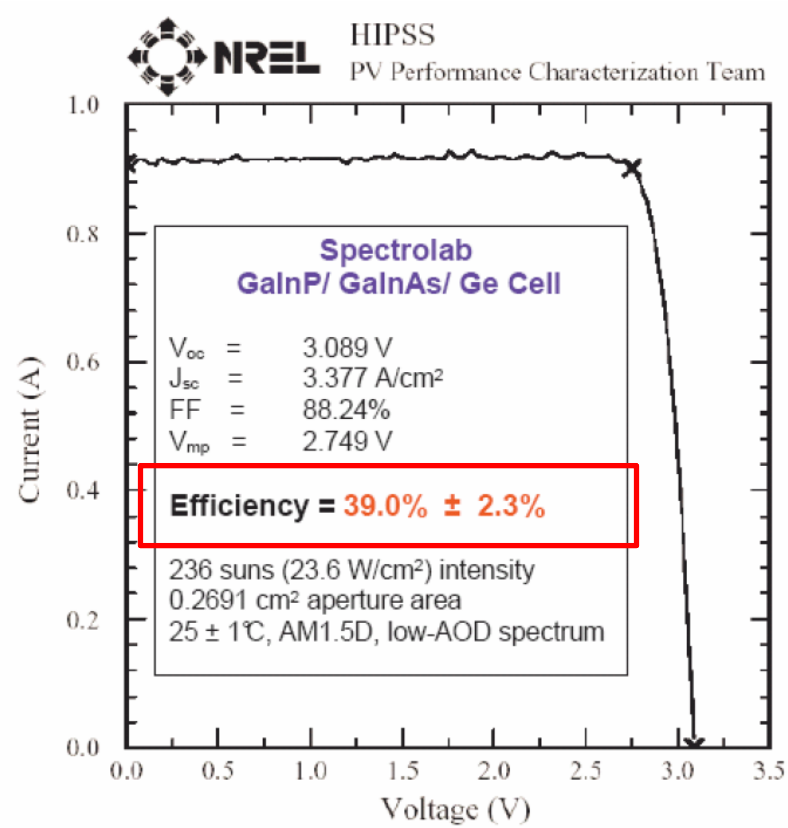
	a-Si/μc-Si	CIGS	CdTe
Junction	p/i/n, Si	p/n, CIGS/CdS	p/n, CdTe/CdS
Absorber	i-Si	P-CIGS.	P-CdTe
TCO	Textured FTO, AZO,	AZO	FTO, ITO
Eff. % in prod. (Lab)	~8.5 (~13)	10~11.5 (19.9)	8.5~10 (16.5)

Semiconductor Taiwan 2008

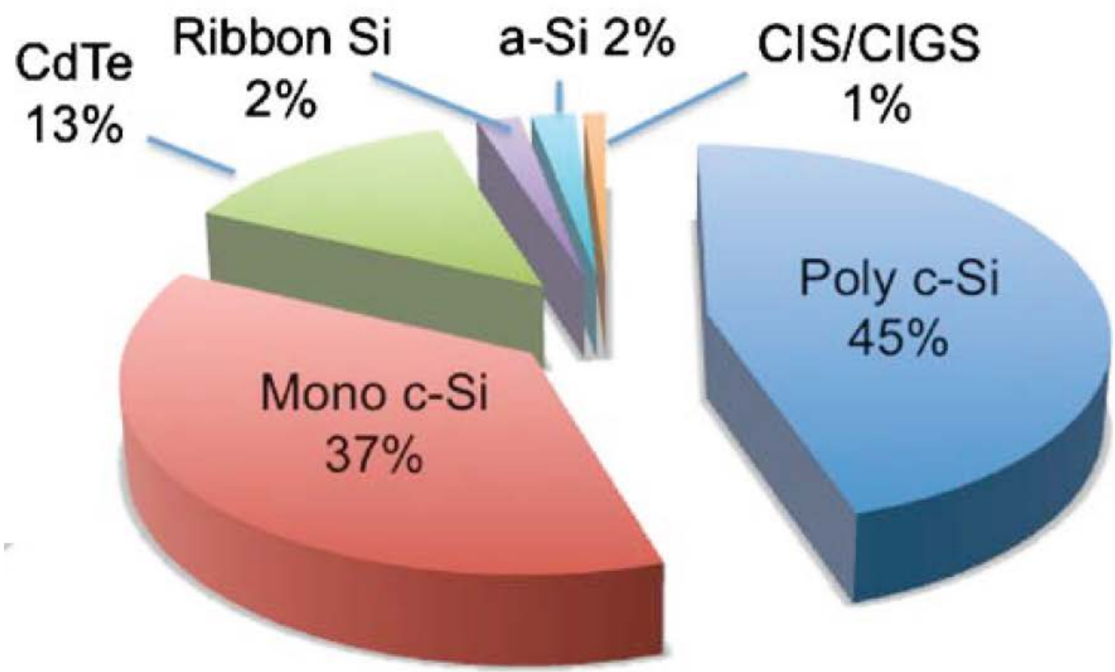
Tandom Junction Solar cells

GaInP/GaAs/Ge Triple Junction Cell





Market distribution in 2009



Total of 7.86 GW

- Both poly-Si and mono-Si combined a total 82%
- First Solar's CdTe was the first company to exceed 1GW/yr production, captured 13% market share.
- CIS/CIGS only has 1% market share.

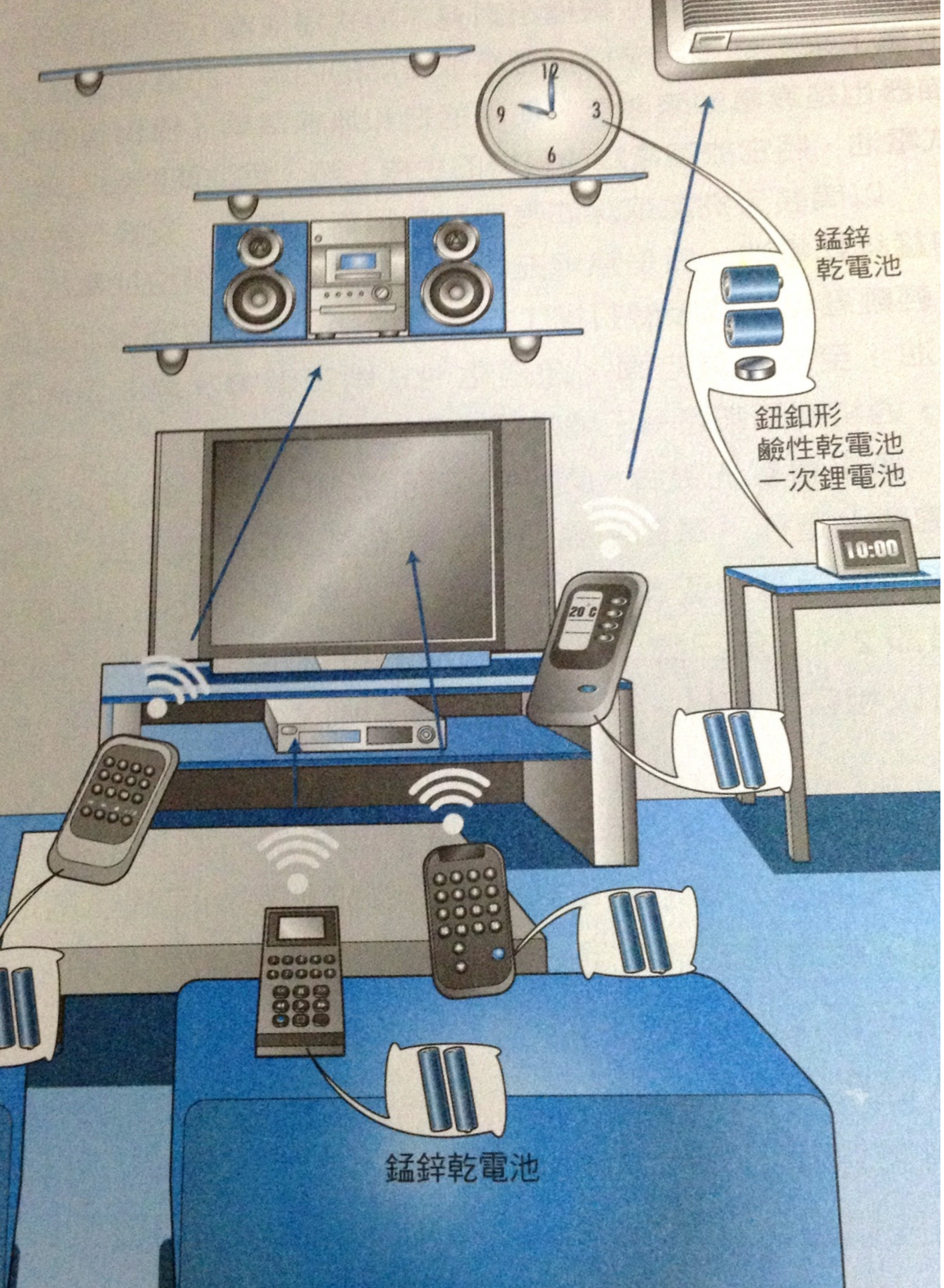
Batteries

- Definition: devices that transform chemical energy into electricity
- Every battery has two terminals:

positive cathode (+) and the negative anode(-)

- Procedure to produce electricity

Device plug in →chemical reaction started →electron produced →electron travel from (-) to (+)→electrical work is produced



客廳

家用電話
和暖爐設備

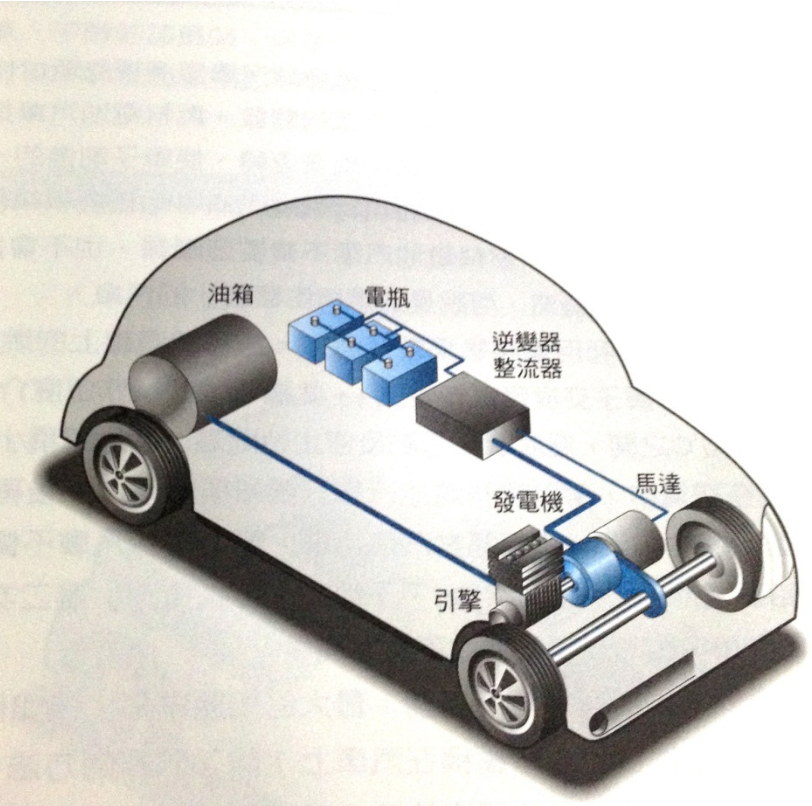
洗臉台等場所使用的電池設備

Mobile

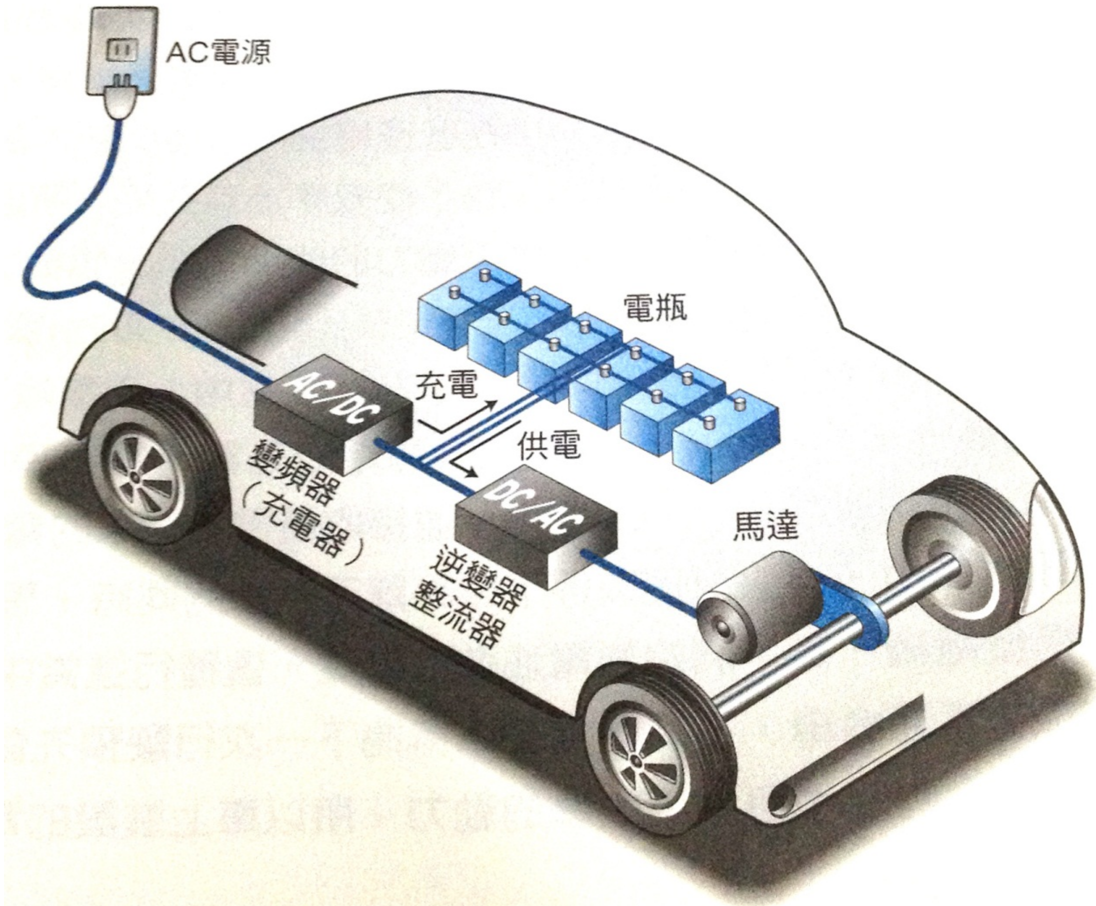
- Mostly Lithium-ion batteries

Hybrid car

- 行進過程，引擎本身附有大型發電機，除了驅動汽車，也會產生電力，為電池充電。

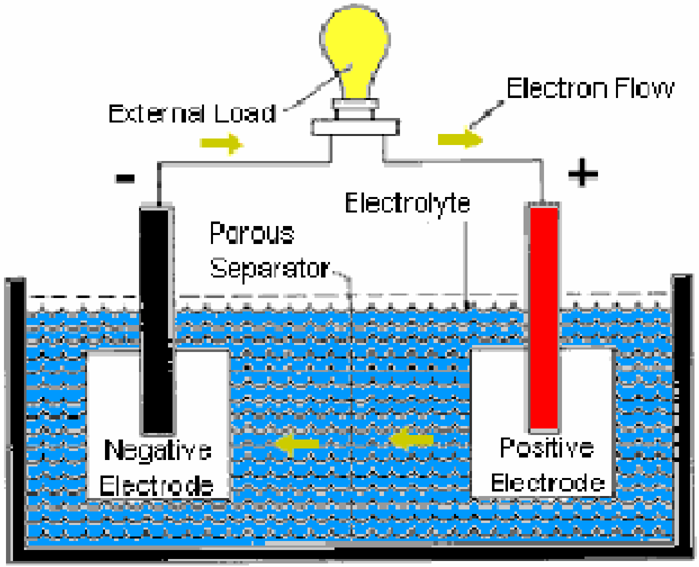


Electrical car



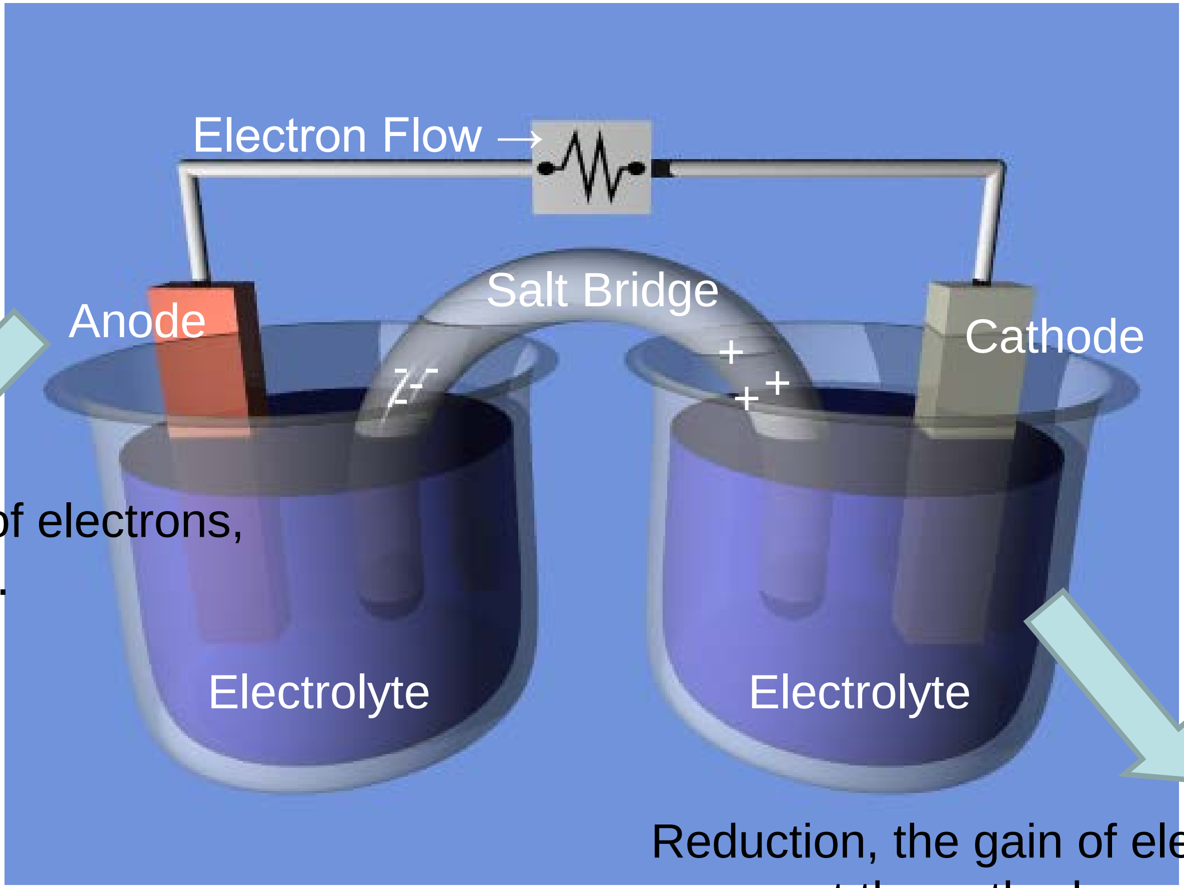
Electrochemical Cell

- An electrochemical cell :
  - a negative electrode to which anions (-) migrate – donates electrons to the eternal circuit as the cell discharge (anode)
  - A positive electrode to which cations migrate (cathode)
  - Electrolyte solution containing dissociated salts, which enable ion transfer between the two electrodes, providing a mechanism for charge to flow between positive and negative electrodes.
  - A separator which electrically isolates the positive and negative electrodes.



How Electrochemical Batteries Work

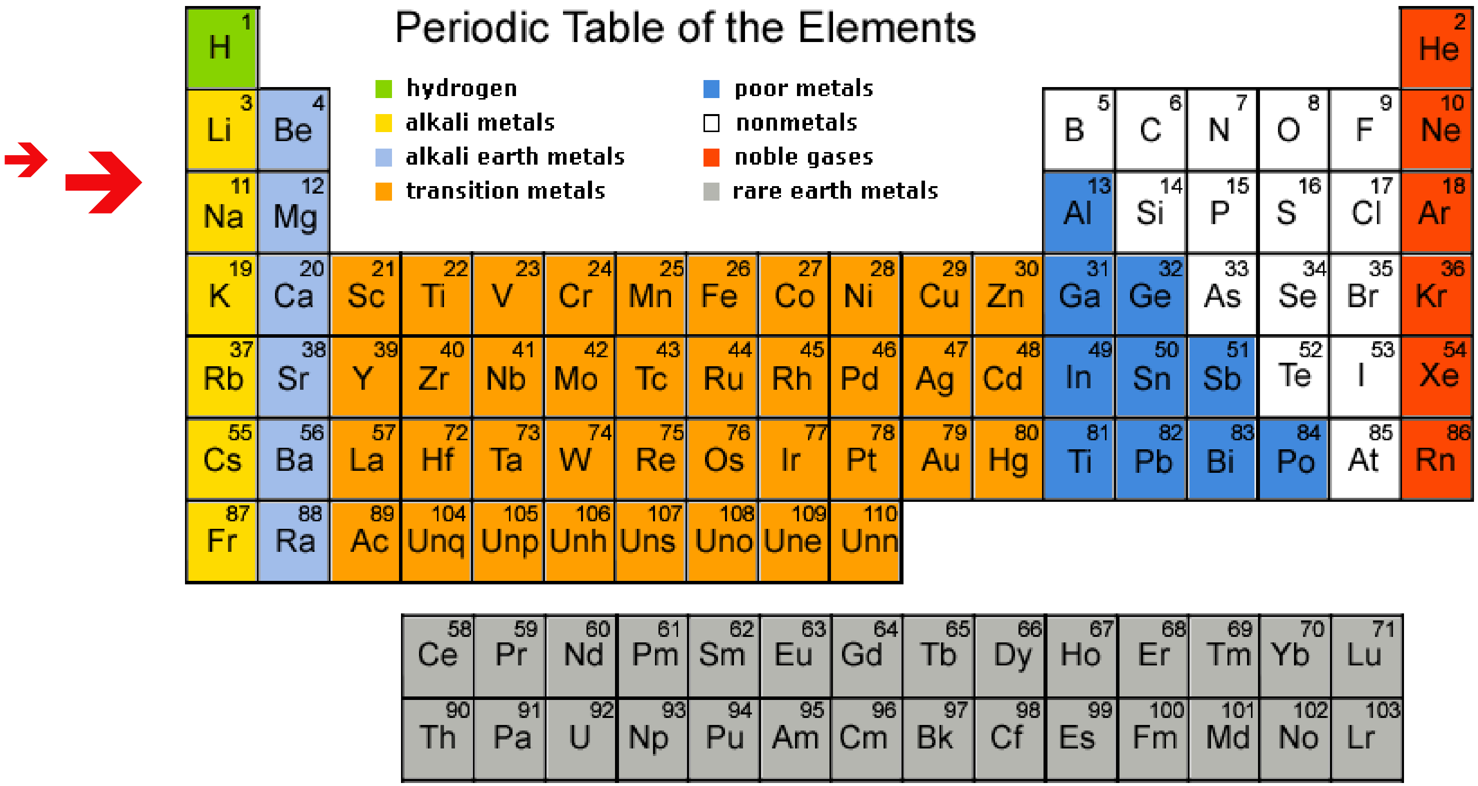
- REDOX Reaction



Oxidation, the loss of electrons, occurs at the anode.

Reduction, the gain of electrons, occurs at the cathode.

The Periodic Table: choose the electrode

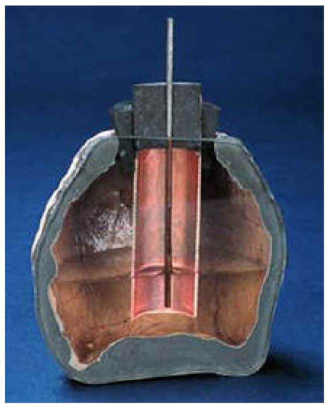


Combination of electrodes to make a variety types of batteries:
lithium ion battery、nickel-zinc、zinc air、Nickel cadmium、Ni iron、Silver zinc、Mer
cell

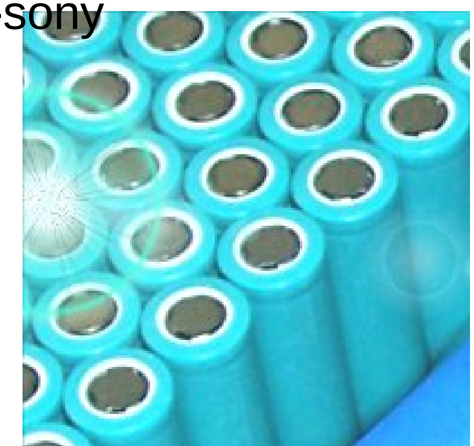
The History of Batter

Volta piles

Baghdad battery

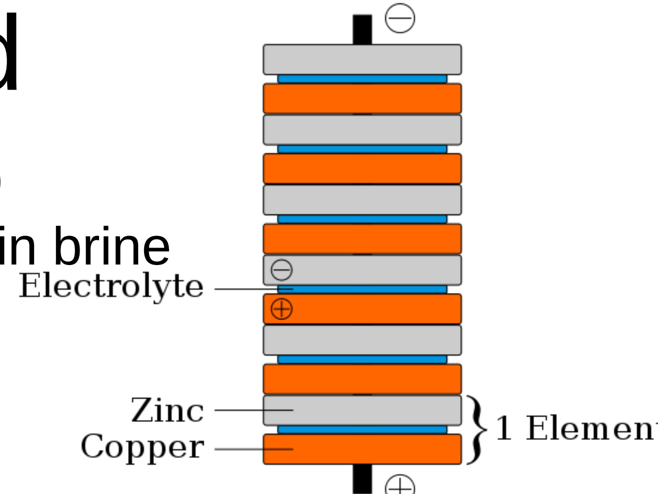


Lithium ion battery -sony

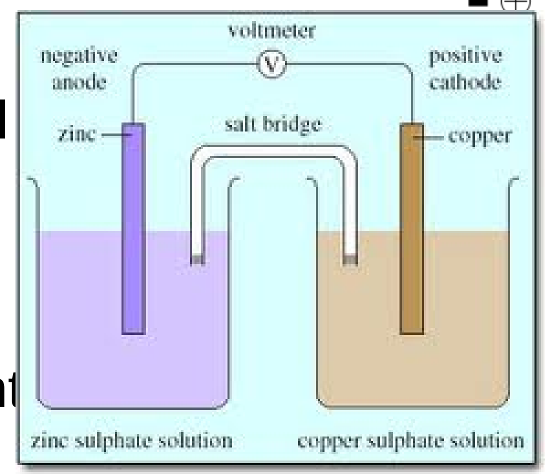


Time	Event	Name
200 B.C.	Baghdad battery	??
1791	Frog leg experiment	Galvani
1800	Voltaic piles	Volta
1802	Mass pr[illegible] battery	Cruickshank
[illegible]	Giant battery (2,000 cells)	Davy
1820	Electricity from magnetism	Ampere
1827	Ohm's law	Ohm
1833	Ionic mobility in Ag_2S	Faraday
1836	$Cu/CuSO_4$, $ZnSO_4/Zn$	Daniell
1839	Principle of the air cell	Grove
1859	Lead acid battery	Planté
1868	$Zn/NH_4Cl/C$ wet battery	Leclanché
1874	Telegraph	Edison
1878	Air Cell	Maiche
1880	High capacity lead/acid	Faure
1881	$Zn/NH_4Cl/C$ encapsulated	Thiebault
1885	Zinc-bromine	Bradley
1887	$Zn/NH_4Cl/C$ dry battery	Gassner
1891	Thermodynamics of dry cells	Nernst
1899	Nickel cadmium battery	Jungner
1900	Ni Storage batteries	Edison
1905	Ni iron batteries	Edison
1911	Automobile self-starter	Kettering
1927	Silver zinc	Andre
1930	Nickel-zinc battery	Drumm
1943	Cuprous chloride battery	Adams
1945	Mercury cell	Ruben
1950	Sealed mercury Cell	Ruben
1956	Alkaline fuel cell	Bacon
1959	Alkaline primary cell	Urry
1983	Lithium metal rechargeable	Moli
1991	Commercial lithium ion	Sony
1992	Reusable alkaline	Kordesch
1995+	Recent developments	..

Electrochemical Battery History Cont'd



- The Voltaic Pile
  - Invented by Alessandro Volta in 1800
  - Zinc and Copper with a cloth soaked in brine
  - Technical Flaws:
    - Compressing of cloth created shorts
    - Short battery life
- The Daniel Cell
  - Invented in 1836 by John Daniell



- The lead-acid cell
  - Invented in 1859 by Gaston Plant
  - First rechargeable battery
- The zinc-carbon cell
  - Invented in 1887 by Carl Gassner

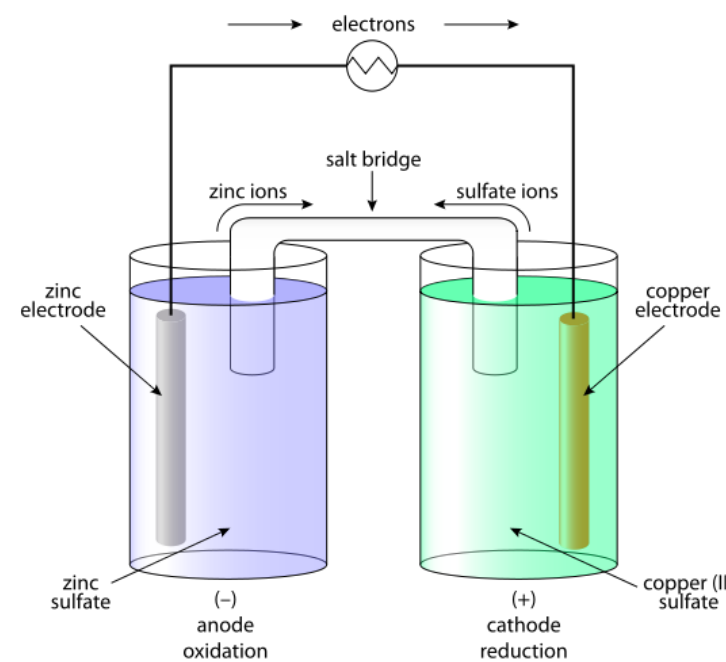
Electrochemical Battery History Cont'd

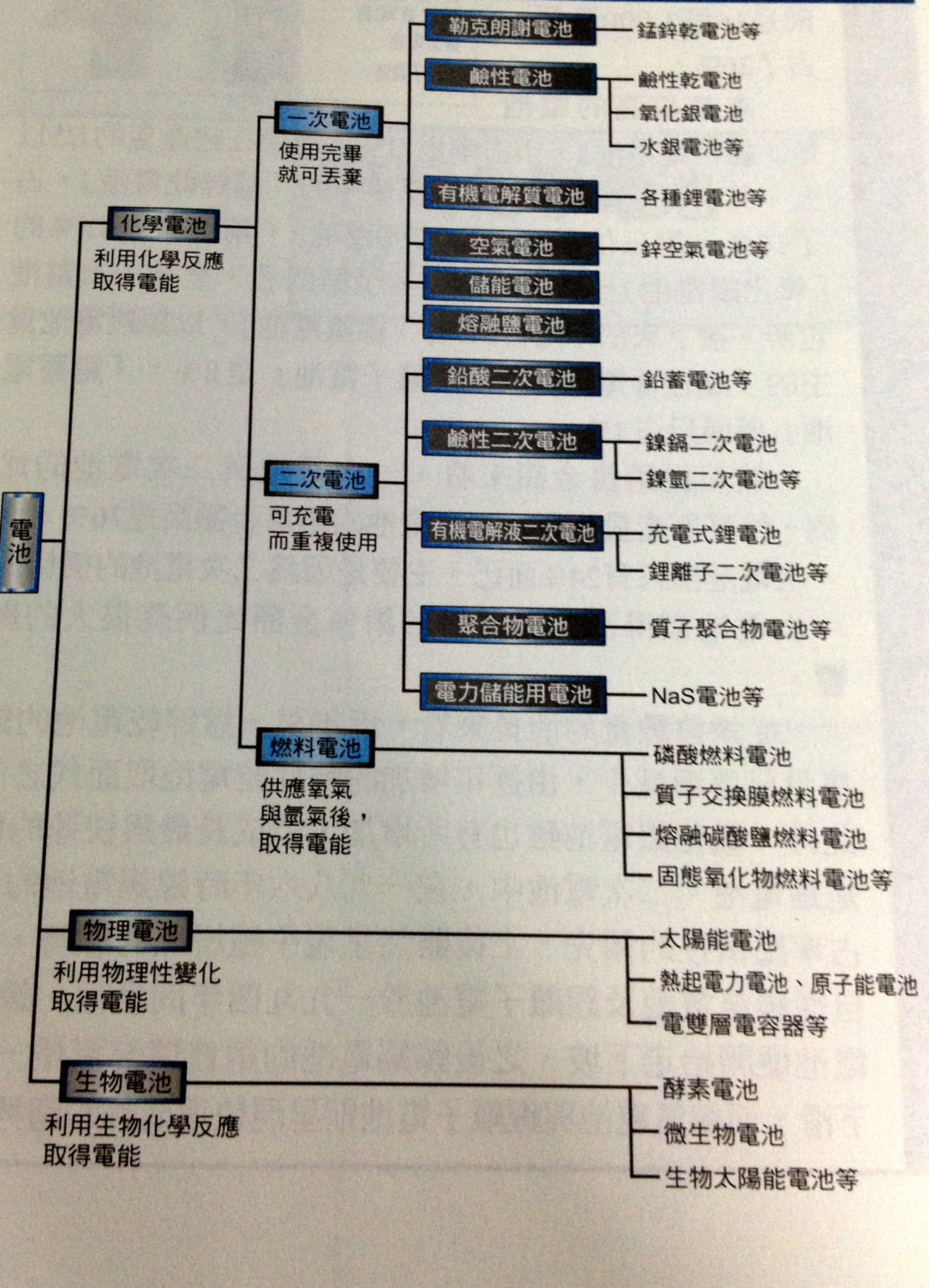
- The Nickel-Cadmium Battery
  - Invented in 1899 by Waldmar Jungner.
- The common Alkaline Battery
  - Invented in 1955 by Lewis Urry
- The Nickel Metal-Hydrid Battery
  - NiMH batteries for smaller applications started to be on the market in 1989.
- Lithium and Lithium-ion Batteries
  - First lithium batteries sold in the 1970s
  - First lithium-ion batteries sold in 1991 → portable electronic devices
  - First lithium-ion polymer batteries released in 1996

伏特電池的原理

- 在稀硫酸中插入銅板和鋅版兩種電極
- 鋅金屬變成鋅離子溶出Zn+2 鋅變成負電
- 銅板不會融化，但因電子
  被H+帶走帶著一點正電

以導線連接鋅版和銅板則會
產生電流，直到
鋅版耗盡。





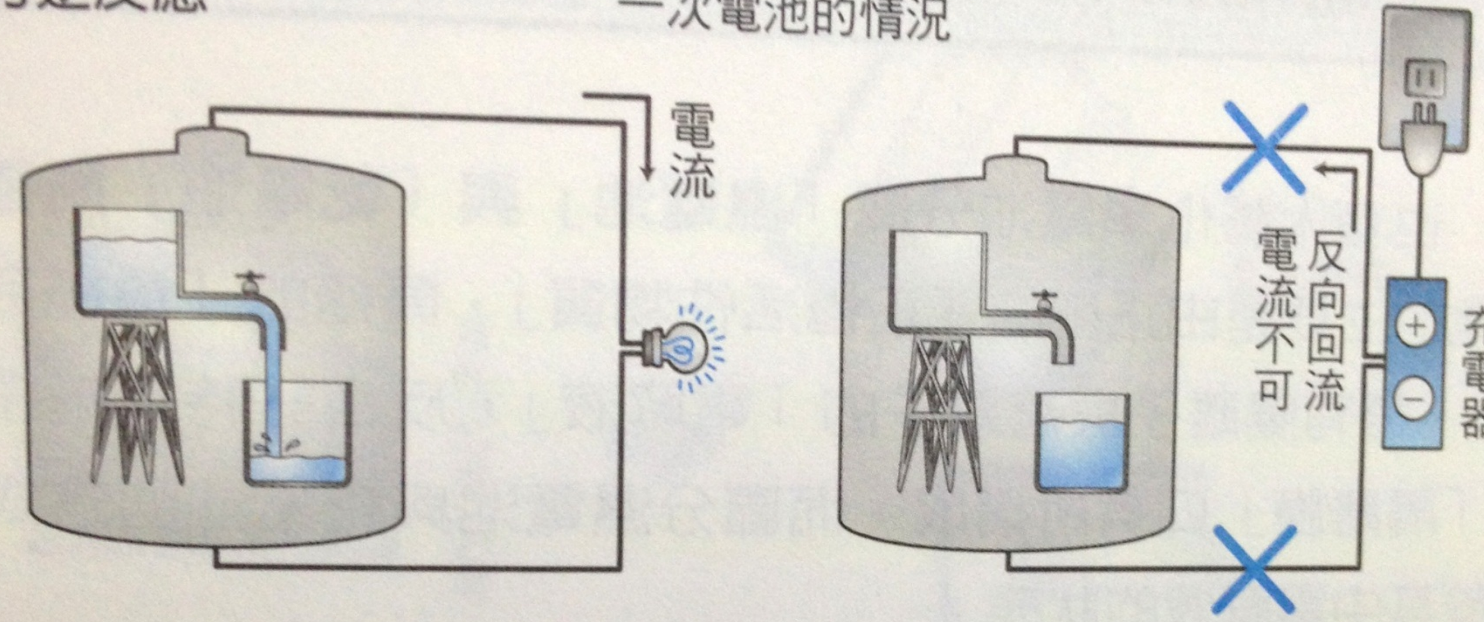
Various kinds of batterie

Primary vs. Secondary Batteries

- Primary batteries are disposable： their electrochemical reaction cannot be reversed.
- Secondary batteries are rechargeable, because their electrochemical reaction can be reversed by applying a certain voltage to the battery in the opposite direction of the discharge.

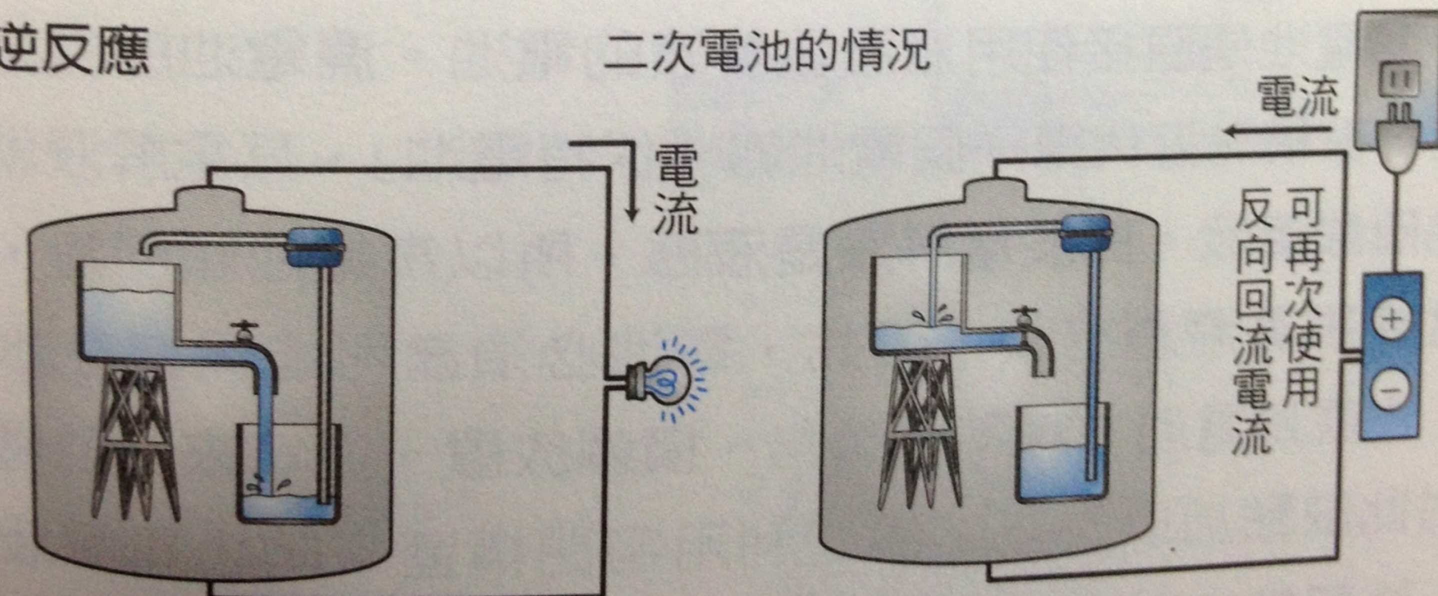
不可逆反應

一次電池的情況



可逆反應

二次電池的情況



Terminology and Units

- Primary Batteries – Disposable
- Secondary Batteries – Rechargeable
- emf – Electromotive force, voltage
- Ampere·hour (Ah) = 3600 coulombs, a measure of electric charge
- Watt ·hour (Wh) = 3600 joules, a measure of energy
- Ah = (Wh) / emf

Theoretical Cell voltage

- Anode (oxidation potential)+ cathode (reduction potential)=standard cell potential

$Zn+Cl_2 \rightarrow ZnCl_2$

$Zn \rightarrow Zn^{+2} +2e$ -(-0.76 V)

$Cl_2 \rightarrow 2Cl^{-}$ -2e 1.36V

E^o = 2.12 V $\rightarrow$ theoretical voltage

Theoretical capacity

- Zn + Cl2 → ZnCl2

0.82 Ah/g 0.76 Ah/g

1.22g/Ah 1.32g/Ah = 2.54 gAH or 0.394/Ah/g

Primary Alkaline Batteries

- Can lose 8 – 20% charge every year at room tempurature.
- Discharge performance drops at low temperatures.

	AAA	AA	9V	C	D
Capacity (Ah)	1.250	2.890	0.625	8.350	20.500
Voltage	1.5	1.5	9	1.5	1.5
Energy (Wh)	1.875	4.275	5.625	12.525	30.75

Secondary Alkaline Batteries

- Self-discharge more quickly than primary batteries

	Low-Capacity NiMH (1700-2000 mAh)	High-Capacity NiMH (2500+ mAh)	NiCd
Charge Cycles	1000	500	1000

- Must not overcharge because that will damage the batteries. Quick charges will also damage the batteries.
- Must not over-discharge.
- NiCd has “memory effect.”
- NiCd is better for applications where current draw is less than the battery’s own self-discharge rate.
- NiMH have a higher capacity, are cheaper, and are less toxic than NiCd.

Recharge-ability & the “memory effect”

- Recharge-ability: basically, when the direction of electron discharge (negative to positive) is reversed, restoring power.
- the Memory Effect:

- The battery appears to "remember" the smaller capacity
- the term 'memory' came from an aerospace nickel-cadmium application in which the cells were repeatedly discharged to 25% of available capacity by exacting computer control, then recharged to 100% capacity **without overcharge**. This long-term, repetitive cycle regime, with no provision for overcharge, resulted in a loss of capacity beyond the 25% discharge point. Hence the birth of a "memory" phenomenon, whereby nickel-cadmium batteries purportedly lose capacity if repeatedly discharged to a specific level of capacity.

Source: wiki

Types of Batteries

- Zinc-Carbon: used in all inexpensive AA, C, and D dry-cell batteries. The electrodes are zinc and carbon, with an acidic paste between them serve as the electrolyte (disposable)

- Alkaline: Curalcell or Energizer cell batteries. The electrodes are zinc and manganese-oxide, with an alkaline electrolyte (disposable)

Modern batteries

- Lead-Acid: used in cars: the electrodes are lead and lead-oxide, with an acidic electrolyte (recha

- Lithium-ion batteries

  - rechargeable and no memory effe

- Fuel cells

碳鋅電池

- 電壓：1.5V
- 正極：二氧化錳
- 負極：鋅
- 電解液：NH_4Cl、$ZnCl_2$

Battery Aspects

- Energy Density: total amount of energy that can be stored per unit mass or volume →how long will your laptop run by a fully-charged cell.
- Power Density: Maximum rate of energy discharge per unit mas or volume. Low power: laptop, ipod high power car
- Safety: could sustain at high temperatures
- Life: stability of energy density and power density with repeated cycling is needed for the long life required in many applications.
- Cost: Must compete with other energy storage technologies