綠色能源時代--太陽能電池

賴 永 齡
國立彰化師範大學
機電工程學系暨顯示技術研究所
March 5, 2010

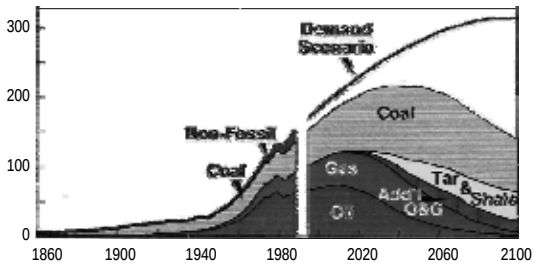
The Earth - Our Energy Challenge

Energy Challenge of World

- 石油儲藏量剩下1兆338億桶(Barrel)，尚可使用約43年
- 天然氣儲藏量剩下146兆立方公尺，尚可使用約62年
- 鈾儲藏量剩下395萬噸，尚可使用約64年
- 煤儲藏量剩下9,842億噸，尚可使用約230年
- 全世界至少有20億人口，目前仍無電可用！
- 不必等到石油耗盡，能源的價格將會飆漲到大家都無法承受！
- 目前地球的平均溫度比 20年前高了 0.2℃以上
- 1997年「京都環境會議」，制訂各工業國家CO2排放減量標準 (2005/2/16開始實施)
- 各國皆訂定達成再生能源比例 12%~15%之目標

World Energy

Millions of Barrels per Day (Oil Equivalent)



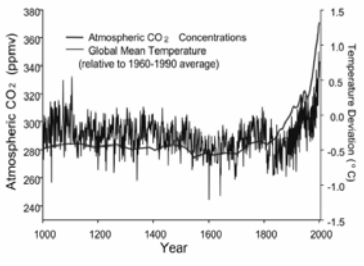
Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

Energy Challenge of Taiwan

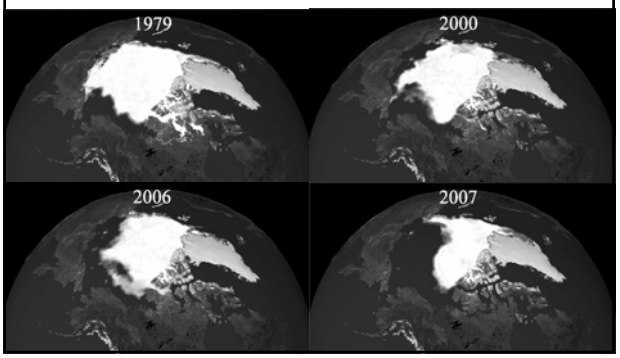
- 我國 98% 以上的能源仰賴進口。
- 水力的投資風險高且已飽和。
- 反核意識高漲。
- 發展使用符合環保、循環再生，並取之不盡之再生能源已是刻不容緩。
- 我國訂定再生能源比例之目標為 10% @2010
  - 2010年再生能源發電裝置總容量目標:513.9萬瓩，其中風力:215.9 萬瓩 、水力:216.8萬瓩、太陽光電:2.1萬瓩、地熱:5.0萬瓩、生質能:74.1萬瓩

Increasing CO_2 Emissions

- A rise in
  - Atmospheric CO_2
  - Global Temperature



North Pole

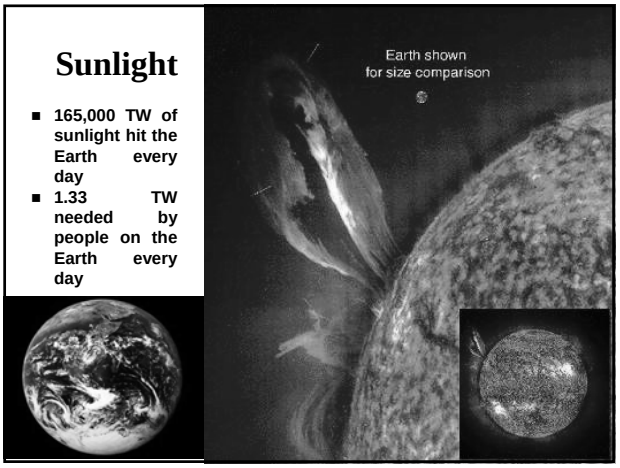


太陽是能源之母

- 太陽是地球上所有能源的源頭，目前已知的能源幾乎都直接或間接來自太陽(核能、地熱除外)。
  - ◆石油、煤、天然氣、水力、太陽能、風力、光合作用、海洋能等等 。
- 太陽光照射整個地球表面 1小時內的能量(~5×1020 J)，約可供全人類使用 1 年(2005)。
- 太陽還可以繼續發光 50 億年以上。

Sunlight

- 165,000 TW of sunlight hit the Earth every day
- 1.33 TW needed by people on the Earth every day

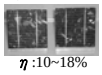


太陽光電(Photovoltaic)發電之特點

- 太陽電池(Solar Cell) 可將光能直接轉換為直流電能
- 無需燃料、無廢棄物與污染、無轉動組件與噪音。
- 太陽電池壽命長久，可達二十年以上 。
- 外型尺寸可隨意變化，應用廣泛(小至消費性產品--如計算機，大至發電廠)。
- 發電量大小隨日光強度而變，可以輔助尖峰電力之不足(併聯型)。
- 設計成阻隔輻射熱或半透光型模板，可與建築物結合(BIPV)。

太陽能電池種類

η :12~20%



η :10~18%

- Solar Cells
  - 矽 Silicon
    - 晶矽 Crystalline
      - 單晶矽 Single Crystalline
      - 多晶矽 Poly Crystalline
      - 多晶矽薄膜 Thin Film Poly.
    - 非晶矽薄膜 Amorphous Thin Film (Si:H, SiGe, SiC..) — η : 6~8%, 應用消費性產品、玩具等
  - 多元化合物 Compound
    - 單晶 Single Crystalline (GaAs, InP..) — η : 18-30 % (應用於太空或聚光型 PV 系統)
    - 多晶 Poly Crystalline (CdS, $CdTe$, $CuInSe_2$,...)
  - Nano & Organic — 如 TiO_2/染料、有機太陽電池，目前研發中

What are semiconductors

III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb

Elemental Semiconductors

Si, Ge

Binary Compounds

GaAs, InP, GaSb, GaN, InAs, AlAs, AlP

Ternary Compounds

AlGaAs, InGaAs, InGaP, AlGaP, InAlAs, GaAsSb

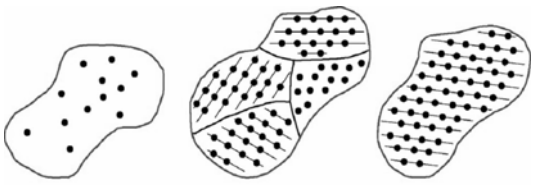
Quarternary Compounds

InGaAsP, AlGaAsP, InAlGaAs, AlInGaP

Silicon

Name	Silicon
Symbal	Si
Atomic number	14
Atomic weight	28.0855
Discoverer	Jöns Jacob Berzelius
Discovered at	Sweden
Discovery date	1824
Origin of name	From the Latin word "silicis" meaning "flint"
Bond length in single crystal Si	2.352 Å
Density of solid	2.33 g/cm^3
Molar volume	12.06 cm^3
Velocity of sound	2200 m/sec
Electrical resistivity	100,000 μΩ·cm
Reflectivity	28%
Melting point	1414 °C
Boiling point	2900 °C

Silicon



Amorphous Polycrystalline Single Crystal

From Sand to Wafer

- Quartz sand: silicon dioxide
- Sand to metallic grade silicon (MGS)
- React MGS powder with HCl to form TCS
- Purify TCS by vaporization and condensation
- React TCS to H_2 to form polysilicon (EGS)
- Melt EGS and pull single crystal ingot

From Sand to Wafer (cont.)

- Cut end, polish side, and make notch or flat
- Saw ingot into wafers
- Edge rounding, lap, wet etch, and CMP
- Laser scribe

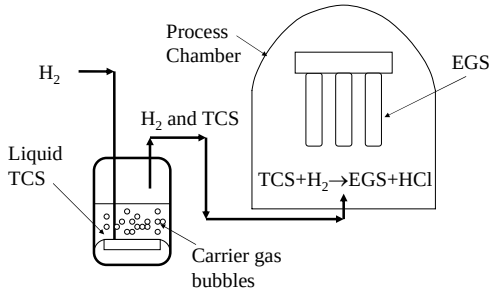
- Epitaxy deposition

Polysilicon Deposition, EGS

$$SiHCl_3 + H_2 \xrightarrow{\text{Heat (1100}^\circ\text{C)}} Si + 3HCl$$

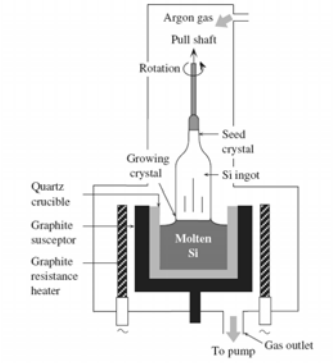
TCS Hydrogen EGS Hydrochloride

Silicon Purification II

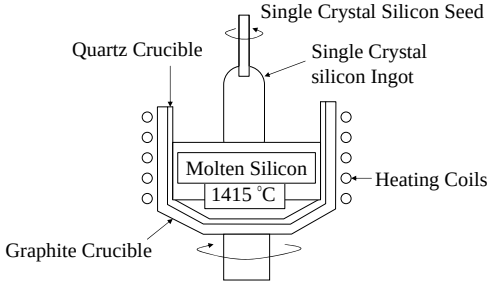


Electronic Grade Silicon

Growth of Silicon



Crystal Pulling: CZ method

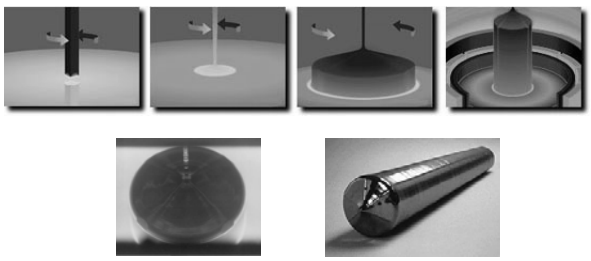


CZ Crystal Pullers

Mitsubish Materials Silicon

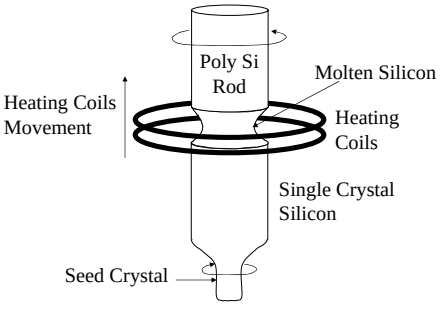
Source: http://www.fullman.com/semiconductors/_crystalgrowing.html

CZ Crystal Pulling



Source: http://www.fullman.com/semiconductors/_crystalgrowing.html

Floating Zone Method



Comparison of the Two Methods

- CZ method is more popular
  - Cheaper
  - Larger wafer size (300 mm in production)
  - Reusable materials
- Floating Zone
  - Pure silicon crystal (no crucible)
  - More expensive, smaller wafer size (150 mm)
  - Mainly for power devices.

Silicon

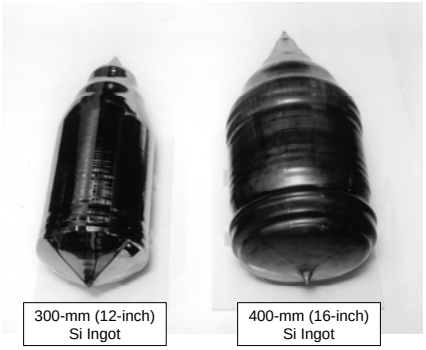
A silicon ingot is a single crystal of Si. Within the bulk of the crystal, the atoms are arranged on a well-defined periodical lattice. The crystal structure is that of **diamond**.

Silicon (cont.)

Left: Silicon crystal ingots grown by the Czochralski crystal drawers in the background

Right: 200 mm and 300 mm Si

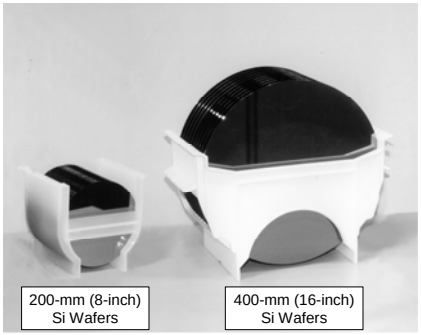
Silicon Ingot



300-mm (12-inch) Si Ingot

400-mm (16-inch) Si Ingot

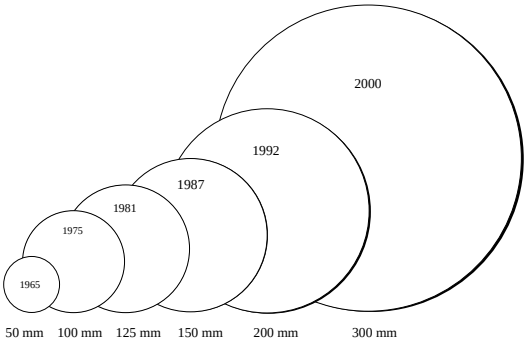
Wafers



200-mm (8-inch) Si Wafers

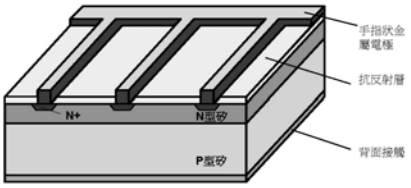
400-mm (16-inch) Si Wafers

Evolution of Wafer Size

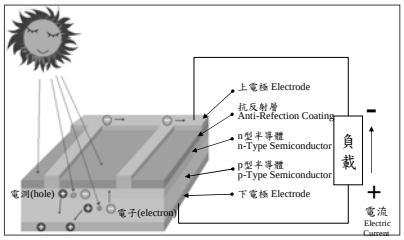


結晶矽太陽能電池基本結構

- **Substrate**
- **P-N Diode**
- **Antireflection**
- **Texturing**
- **Metal Contact**

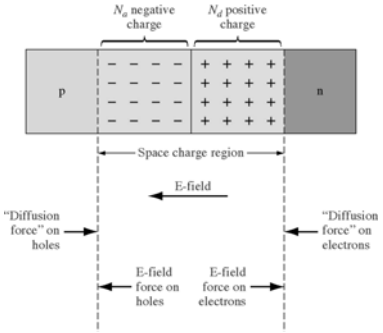


太陽電池之構造與發電原理

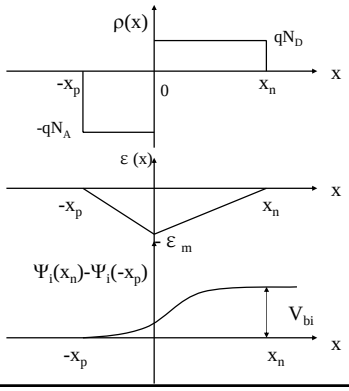


- 太陽電池是以 P 型與 N 型半導體材料接合構成正極與負極。
- 當陽光照射太陽電池時，陽光的能量會使半導體材料內的正、負電荷分離(產生電子-電洞對)。
- 正電荷-電洞(Hole)、負電荷-電子(Electron)會分別往正(P型)、負(N型)極方向移動並且聚集。
- 正、負極接上負載時，將有電流流出，可以對負載作功(燈泡會亮、馬達會轉)。

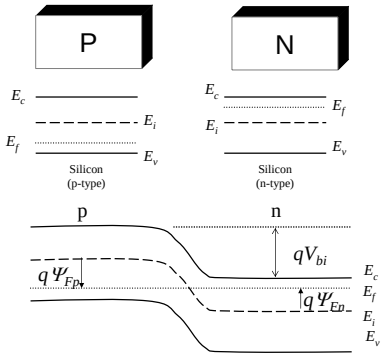
P-N Juction



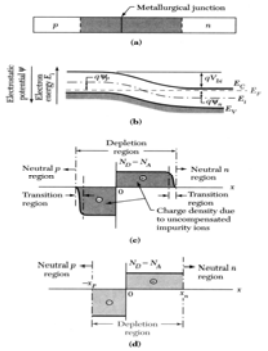
Built-in Potential



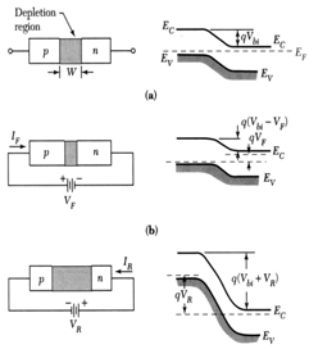
Energy Band



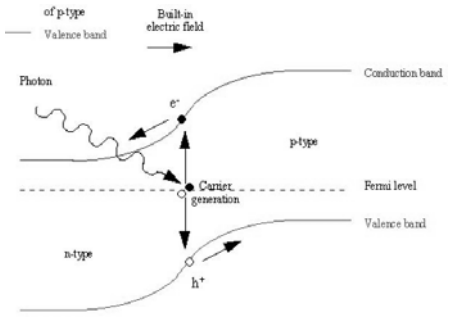
Principle



Biased Operation



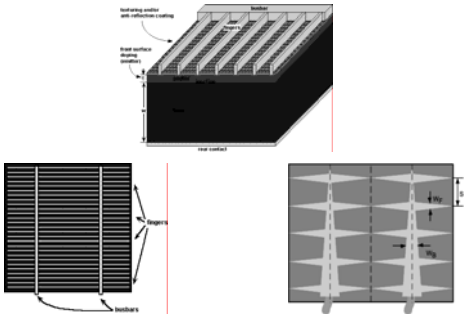
Photovoltaic Effect of P-N Junction



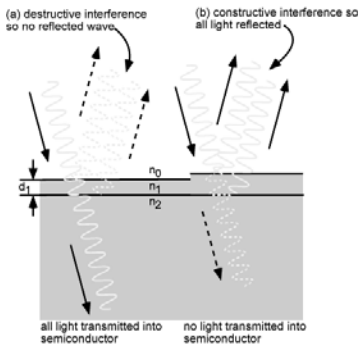
Ways to Reduce Optical Losses

- Minimize top contact coverage area of the cell (although this may result in increased series resistance).
- Use anti-reflection (AR) coatings on the top of the cell.
- Texturing the surface of the
- Thicker solar cell to increase optical absorption (also need matching diffusion length)
- The optical path length in the solar cell may be increased by a combination of surface texturing and light trapping.

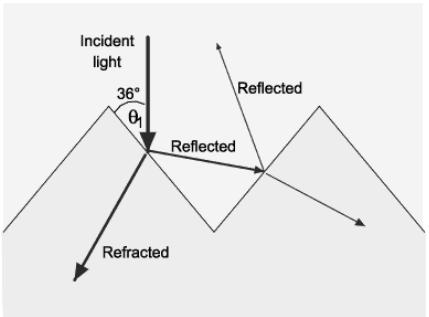
Different Front Metal Patterns



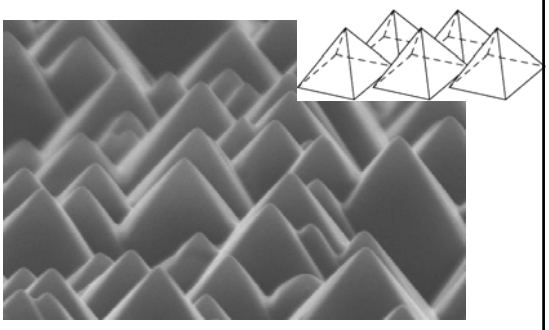
Anti-Reflection Coatings



Textured Surface to Decrease Reflection loss on the Top

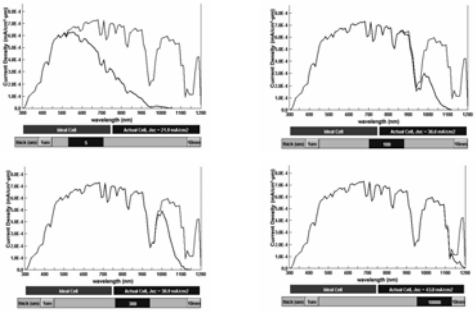


Surface Texturing

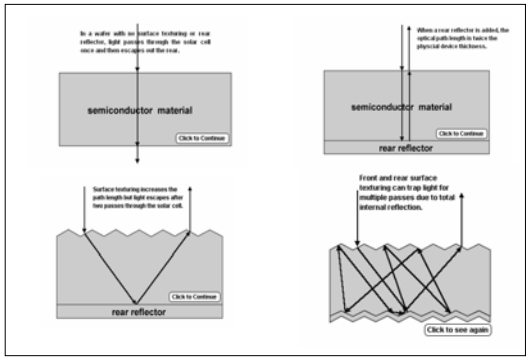


Scanning electron microscope photograph of a textured silicon surface

Photocurrent vs Cell thickness

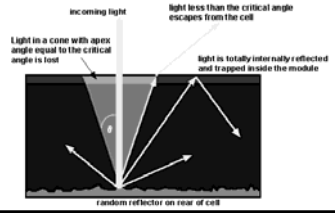


Light Trapping in Solar Cell by Total Internal Reflection

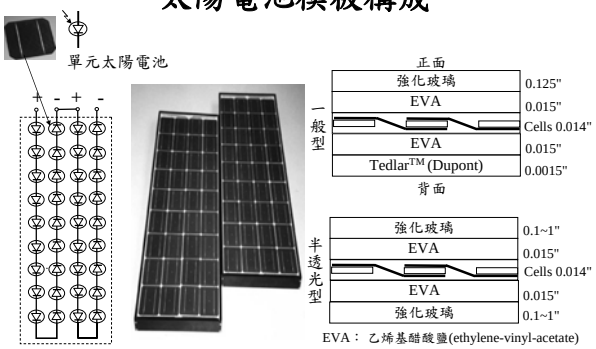


Lambertian Back Reflector (Back Surface Texturing)

- **Lambertian back reflector randomizes the direction of the reflected light. Light absorption can be dramatically increased by a factor up to $4n^2$**
- **This allows an optical path length of approximately 50 times the physical devices thickness**

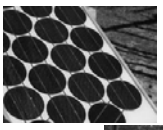


太陽電池模板構成

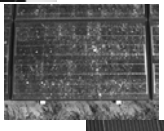


太陽電池模板接線例 太陽電池模板外觀例 太陽電池模板結構例

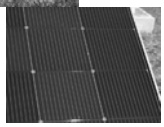
太陽電池模板外觀



單晶矽模板

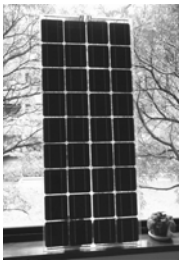


複晶矽模板



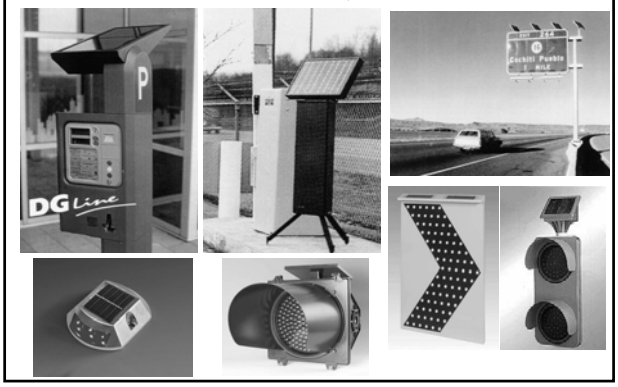
非晶矽模板

(薄膜太陽電池本身就是模板的一部份)



半透光型模板

交通號誌及顯示看板上之應用

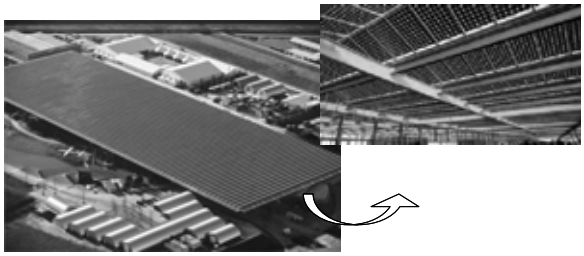


二高東山休息站太陽能路燈

Building-Integrated Photovoltaic (BIPV) System

- 可有效利用建築物的外表大面積
- 可替代建築物的外表包覆材料
  - ◆代替屋頂、牆面、窗戶之建材
- 可遮陽，降低建築物外表溫度
- 兼具建材及發電之功能
- 與生活、用電緊密結合
- 高可見度、高宣傳效果

荷蘭Floriade Exhibition Hall BIPV系統



- PV系統容量：2.3 MWp
- 佔地：長 278、寬100 公尺(3個足球場)

德國 DB Lehrter Station, Berlin BIPV系統

- PV系統容量：325 kWp (2003)，面積 3,311 m^2
- 太陽電池模板：Flabeg Solar 透光型模板 1,440 片
- 太陽電池：144,000 片 BP LGBG ，123x123 mm，η =17%

（資料來源： http://www.cler.org/predac/article.php3?id_article=511, http://www.jxj.com/magsandj/rew/2003_05/lehrter.html）

NASA Helios

- **飛行高度：5-7 萬英呎(最高記錄 96,000 英呎) 遙控**
- **時速：60 mph (起飛 25 mph)**
- **翼展：247 英呎(比波音747客機的翼展要長，甚至比波音747的機身長)**
- **重量：2,000 磅**
- **太陽電池效率要求：>22%**