Introduction to Silicon Solar Photovoltaic

by
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Part 2  Science of Solar PV Cells

Part 3  Application of Silicon Solar PV

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Part 1

Overview of Silicon Solar Photovoltaic Technology
Viability of Silicon Solar PV

By Socio- Economic- Political Causes:

- Growing demands for energy by rising economic powers like China and India → Significant increase of petroleum price → Makes the cost of alternative energy, e.g. solar energy competitive.

- Energy supply becomes a national security issue by not just USA and Japan, but also by countries like China. Alternative energies are viewed to reduce nation’s dependence on foreign oil supplies.

- Rapidly worsening environmental and ecological situations – global warming and alarming air-quality related deaths of human lives → The needs for clean energy is immediate and urgent. According to World Health Organization: 2 million premature death due to air pollution every year (October 5, 2006)

- Governments’ incentives for investments and subsidies to corporal and private citizens in alternative energy usage.
Solar PV Has Become a Viable Clean and Sustainable Power Source

It is a Maturing Technology:

Continuous improving conversion efficiency:
- Commercial/Lab: 7%/14% in 1977 to 18%/20% in 2003
- SunPower Corp: 21% (commercial) in 2003, shooting for 25%

Thin wafer (< 200 μm) technology → less materials used

Improving throughout: 750 – 2400 wafer/hr towards 3000 wafer/hr → Mass production for lower production cost

Fully integrated manufacturing plants → Shorter production cycles

Global manufacturing – The China factor: Low-cost, vast market, etc.
An Explosive PV Market Growth

Electric power generated by silicon solar PV:

Projected power generating capacity in 2050: 85,000 GW

World major solar PV power generators: Germany (the leader), Japan, USA, Spain, China (started in 2002)
The Largest Solar PV Power Generation Station in US

Nellis Airforce Base, in southern Nevada
• Built in April 2007 by SunPower Corporation in San Jose
• Cost $100 million

Capacity: 14 MW or 30 GWh/yr
• 72,000 solar panels on 140 acres land
• Supplies 30% of power requirement by the Base with 12,000 workers and 7,215 residents.

• The Airforce pays 2c/kWh instead of 9c/kWh to Nevada Power (cost for coal-fired electricity = 4c/kWh)
• Net saving to Airforce: $1 million/year

• Reduce 24,000 ton/year CO₂ emission
Revenue Growth of Solar PV

Year

Generated Revenue ($billion)

2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
**Reduction in Cost and Price**

**Significant drop in average cost**

**Projected Cost Reduction of Solar PV**

Projected further drop in price with high-efficiency solar PV cells
Price of PV Module (SunPower Corp)

- Price of $21.83 per Watt
- The price has decreased over the years: 1.44 in 2020
Part 2
Science of Silicon PV Cells

- Scientific base for solar PV electric power generation is solid-state physics of semiconductors

- Silicon is a popular candidate material for solar PV cells because:
  - It is a semiconductor material.
  - Technology is well developed to make silicon to be positive (+ve) or negative (-ve) charge-carriers – essential elements for an electric cell or battery
  - Silicon is abundant in supply and relatively inexpensive in production

- Micro- and nano-technologies have enhanced the opto-electricity conversion efficiency of silicon solar PV cells
Working Principle of Silicon Solar PV Cells

Photovoltaic material of device converts:

- **Light (photon) Energy** ➔ **Electric Energy**

**Silicon solar photovoltaic cells** = a device made of semiconductor materials that produce electricity under light

- A **p-n junction** is created in silicon by a **doping process**.

- The **photons** from the exposed light prompted electrons flowing from n-junction to the p-junction ➔ **Electric current flow**.
Doping of Semiconductors

- Doping for common semiconductor, e.g. silicon (Si) involves adding atoms with different number of electrons to create unbalanced number of electrons in the base material (e.g. Si).

- The base material, after doping, with excessive electrons will carry –ve charge.
- The base material, after doping, with deficit in electron will carry +ve charge.

- Doping of silicon can be achieved by “ion implantation” or “diffusion” of Boron (B) atom for +ve charge or of Arsenide (As) or Phosphorus (P) for –ve charge.

P-type doping
(“holes” for electrons)

N-type doping
(with extra electrons)
Doping by Ion Implantation and Diffusion

- Doping of Si can be done by either **ion implantation** at room temperature, or **diffusion** at high temperature.

- Ion implantation requires energy to ionize the dopant. It is a faster doping process.

- Diffusion is a **chemical process**. It is a slower process but at lower cost and easy to control.

- The **profile of the spread of dopant** in silicon by diffusion is different from that by ion implantation:

  ![Dopant profile by Diffusion](image1)

  ![Dopant profile by ion implantation](image2)
Silicon Solar Photovoltaic – solar battery cell

- **n-silicon** (excessive electrons)
- **p-silicon** (atoms with “holes” by unbalanced electrons)

Electric field with +ve and -ve electrodes (like a battery):

- Extra electrons:
- Positive ions:

[Diagram showing the electric field with +ve and -ve electrodes]
Silicon Solar Photovoltaic – Cont’d

Bombardment of photons from solar rays energize electrons → Junction.

Break the junction into the p-layer → Electricity

Photons from the Sun

Extra electrons: ...

Flow of electrons

POWER
Solar Radiation Energy

Spectrum of sun light

Density on Earth surface: 1.4 kW/m²

- Solar energy is associated with photons in the rays.

Global distribution of solar energy
Silicon Solar PV Product –

Silicon Solar PV Panels

- 150 mm dia. Wafers
- 150 cm²
- 12.25 cm x 12.25 cm

For power generation

SunPower Corp. Model SPR-215-BLK modules:
- 798 mm wide x 1559 mm long x 46 mm thick (with 72 cells)
- Weight: 15 kg
- Output: 40 V, 5.4 A (216 W)
- Conversion efficiency: 17.3% (21.5% for all-black-contact cells)
# Common Solar Cell Materials

<table>
<thead>
<tr>
<th>Single Crystalline</th>
<th>Polycrystalline (Thin films)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Silicon (Si):</strong></td>
<td><strong>Cadmium telluride (CdTe)</strong></td>
</tr>
<tr>
<td>Single crystalline</td>
<td>Copper indium diselenide (CIS)</td>
</tr>
<tr>
<td>Polycrystalline silicon</td>
<td></td>
</tr>
<tr>
<td>Amorphous silicon (non-crystalline Si for higher light absorption)</td>
<td></td>
</tr>
<tr>
<td><strong>Gallium arsenide (GaAs)</strong></td>
<td></td>
</tr>
</tbody>
</table>

## Approximate Achievable Conversion Efficiencies

<table>
<thead>
<tr>
<th>Material</th>
<th>Efficiency</th>
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<tbody>
<tr>
<td>Single Si</td>
<td>15 – 25%</td>
</tr>
<tr>
<td>Poly Si</td>
<td>10 – 15%</td>
</tr>
<tr>
<td>A-Si</td>
<td>5 - 10</td>
</tr>
<tr>
<td>GaAs</td>
<td>25 – 30%</td>
</tr>
<tr>
<td>CdTe</td>
<td>7%</td>
</tr>
<tr>
<td>CIS</td>
<td>10</td>
</tr>
</tbody>
</table>
Conducting Grids – a necessary evil

Grids:
- Opaque metal strips - called conductive “fingers”
- Necessary to guide and regulate electron flows induced input by solar energy
- Grids reduce the exposure area → reduce conversion efficiency
- Also cause electric resistance losses
- Transparent conducting oxide (TCD) layers are used to mitigate these negative effects
- DRIE and plasma etching are often used to create these grids
Types of Solar PV Cells

A. Flat plate systems:
- On rigid flat surface
- Usually from single wafers from 300 to 250 to 200 μm tk
- Area: 170 cm² approx.
- Output power: 1 - 2 W approx.
- Output Voltage: 0.5 v approx.

B. Concentrator systems:
- With optical components, e.g. lenses to direct and concentrate sunlight on the PV cells of small areas
- Involving tracking mechanisms for directing the sunlight
- Can increase power flux of sunlight hundreds of times
- Heat dissipation required
Flexible Silicon Solar PV Panels

- Typically operate at lower conversion efficiencies at around 6%
- Solar cells in most of these panels can have photoelectric effect even in cloudy days.
- Most of these panels are portable for outdoor activities or military applications.
- They can fit to curved surfaces:

A Global Solar Sunling
12 W panel:

- Power output: 12 Watts
- Deployed dimensions: 749 mm long x 457 mm wide x 0.762 mm thick
- Weight: 0.9 lb or 0.4 kg
- Max. power/weight: 13.3 W/ib or 30 W/kg

A candidate solar panel for curved chassis exterior of vehicles.
Rollable Silicon Solar PV Panels

- Power output: 5-20 W
- Model SKU 06-1003 for 20 W output.
- Panel size: 11.5” x 73”
- Weight: 1.1 lb
Spectrum of Silicon Solar PV Cells

Spectral Properties

Exceptionally broad spectral response efficiently converts the full range of available sunlight

![Graph showing the spectral response of SunPower and conventional cells compared to the AM 1.5 global spectrum.](image)
Current-Voltage Performance of SunPower Corp. Cells

Stable supply of current

1000 Watts/m²; 25°C; AM 1.5g
Part 3

Applications of Silicon Solar PV
Electric Power Generation by Silicon Solar PV:

(1) Use solar PV for supplementary electric power supply to conserve power generation by fossil fuels in developed countries (up to 100 kW units)

(2) Regions where electric power supply by utility is not sufficient and not reliable.

(3) Remote villages with no electric power supply.
Solar PV – Major Contributor to US Electricity Supply

US Electric Power Generation by Solar PV

- Capacity
- Share

Significant amount
## Major Components in Solar PV Power Station

- The **“Balance of System”** (BoS) components is responsible for **controlling** and **managing** the power output of the PV arrays.
- It is a significant part of the **cost** of a PV system.

<table>
<thead>
<tr>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batteries</strong></td>
<td>They are used to store the electricity produced by the PV modules. They also serve as the back-ups in the case of grid connected systems.</td>
</tr>
<tr>
<td><strong>Blocking Diode</strong></td>
<td>Prevents discharging of electricity from batteries to the PV cells.</td>
</tr>
<tr>
<td><strong>Charge Controller</strong></td>
<td>Regulates the flow of electricity to and from batteries. Prevents over-charging the batteries.</td>
</tr>
<tr>
<td><strong>Circuit Breaker</strong></td>
<td>To protect the electronic circuitry.</td>
</tr>
<tr>
<td><strong>Inverter</strong></td>
<td>Converts dc produced by PV cells to ac electricity for household appliances.</td>
</tr>
<tr>
<td><strong>Meter</strong></td>
<td>It is used in grid connected systems to track the amount of energy produced by the PV system.</td>
</tr>
<tr>
<td><strong>Switch Gear</strong></td>
<td>To open and close the route of electricity flow.</td>
</tr>
<tr>
<td><strong>Wiring</strong></td>
<td>Connects the PV system to utility grid or batteries and load and control the movement of electricity</td>
</tr>
</tbody>
</table>
For cost saving and conservation of fossil fuel electric power generation:

100 MW solar power
**Recent development of solar PV power generations:**

**Solar PV Power Generation by Two Silicon Valley Companies**

<table>
<thead>
<tr>
<th></th>
<th>Google Inc.</th>
<th>Applied Materials Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Mountain View, CA</td>
<td>Santa Clara, CA</td>
</tr>
<tr>
<td><strong>Business line</strong></td>
<td>Internet servers</td>
<td>Semiconductor and solar PV manufacturing equipment</td>
</tr>
<tr>
<td><strong>Date of solar power installation</strong></td>
<td>October 2006</td>
<td>September 2008</td>
</tr>
<tr>
<td><strong>Generating capacity</strong></td>
<td>1.6 MW</td>
<td>2.1 MW</td>
</tr>
<tr>
<td><strong>Installer</strong></td>
<td>Sharp Electronics</td>
<td>SunPower Corporation</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>Up to 30% power requirement</td>
<td>Up to 10% of power requirement</td>
</tr>
</tbody>
</table>

- World’s largest solar-powered generating station: Arnstern, Germany (near Frankfurt) @ 12 MW
- Top US solar power generating facility in Arizona desert near Tucson @ 4.6 MW
**Needs for Electricity in Remote Villages**

**For Essential Living:**

<table>
<thead>
<tr>
<th>Device</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling fan</td>
<td>60</td>
</tr>
<tr>
<td>Clock</td>
<td>5</td>
</tr>
<tr>
<td>Portable fan</td>
<td>115</td>
</tr>
<tr>
<td>Lighting (Single lamp)</td>
<td>3x60</td>
</tr>
<tr>
<td>Equivalent compact fluorescent</td>
<td>18</td>
</tr>
<tr>
<td>Table lamp</td>
<td>100</td>
</tr>
<tr>
<td>Fluorescent (2 tube 4 ft)</td>
<td>100</td>
</tr>
<tr>
<td>Radio</td>
<td>1</td>
</tr>
</tbody>
</table>

**Total: 579 W**

**For More Comfortable Living:**

<table>
<thead>
<tr>
<th>Device</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer (monitor + printer)</td>
<td>200</td>
</tr>
<tr>
<td>Electric heater (portable)</td>
<td>1200</td>
</tr>
<tr>
<td>Range</td>
<td>3200</td>
</tr>
<tr>
<td>Refrigerator (13 cu.ft)</td>
<td>300</td>
</tr>
<tr>
<td>Sewing machine</td>
<td>75</td>
</tr>
<tr>
<td>Microwave oven</td>
<td>1300</td>
</tr>
<tr>
<td>Television</td>
<td>180</td>
</tr>
<tr>
<td>Water heater for 4</td>
<td>3800</td>
</tr>
</tbody>
</table>

**Total: 10.25 kW**
Solar PV in remote villages
For Special Purposes

- Mars vehicle
- Satellite
- Lighting for bus stops
- Street lights
- Telecommunication
For bazaars at night

Pumping water

Mobile portable power generator
Part 4

Selected Student Projects Involving Silicon Solar PV

- by undergraduate students at SJSU-MAE Department
  In course ME 195 Senior Design Projects
Project Goal:
- To design and construct an affordable vehicle that is:
  - Low in operating and maintenance costs,
  - Energy efficient,
  - Emission free, non-gasoline powered, and
  - Environmentally and ecologically sustainable vehicle
  for urban transportation.
- Urban commuting typically involve:
  - Low speed,
  - Low occupancy per vehicle,
  - Frequent stops,
  - Short traveling distance,
  - Narrow streets and congested traffics in noisy and polluted air environments.

Unique Characteristic of ZEM Vehicle
- Energy conservation for longer cruising range
  - Human pedaling for low speed up to 5-10 mph in congested inner cities
  - Electric motor drive at higher speed in light traffic up to 35 mph
  - Continuous charging batteries by solar PV while driving the vehicle in sunny days, and parking in open lot
### A Multi-Year Student Design Project

<table>
<thead>
<tr>
<th>Year</th>
<th>Objectives</th>
<th>Teams</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 - 2006</td>
<td>Hybrid human pedaling/electric powered vehicle</td>
<td>12 ME students</td>
<td>P-1 Prototype</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty supervisors: Drs. T.R. Hsu and R.K.Yee</td>
<td></td>
</tr>
<tr>
<td>2006 - 2007</td>
<td>Hybrid human pedaling/Electric/solar powered vehicle (HPV-ZEM)</td>
<td>16 ME + 3 EE students</td>
<td>Design of P-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty supervisors: Drs. T.R. Hsu, R.K. Yee (ME) and T. Le (EE)</td>
<td></td>
</tr>
<tr>
<td>2007 - 2008</td>
<td>Hybrid human pedaling/Electric/solar/(wind) power vehicle (HPV-ZEM)</td>
<td>26 ME + 7 EE + 7 (Bus) students</td>
<td>Construction &amp; Business plans for P-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faculty supervisors: Prof. T.R. Hsu (ME)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. R.K. Yee (ME)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. T. Le (EE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prof. D. Rummler (Business)</td>
<td></td>
</tr>
</tbody>
</table>
Portable Water Purification System
(2006-2007)

- Intended users: Residents in remote villages in developing countries such as Mali, Africa
- For single families of 4
- Designed capacity: 40 gallons/day
- Bacteria to be filtered and eliminated by the system include:
  - Diarrhea
  - Cholera
  - Typhoid fever
  - Onchocerciasis
  - Schistosomiasis
  - Hepatitis A
  - E. coli
  - Blind eye infection trachoma
- Filtering by:
  - Sediment filter
  - Carbon block
- Purification by ultraviolet
- Solar power drives water pump and for the UV light source.
### System Design

- **Raw Water** → **Inlet Particle Screen** → **5 micron Sediment Filter** → **12V Pump** → **0.5 micron Carbon Block Filter** → **UV Gemicidal Lamp** → **Drinkable Water**

### Market Survey

<table>
<thead>
<tr>
<th></th>
<th>LITEWATER</th>
<th>RESPONDER</th>
<th>TREKKER</th>
</tr>
</thead>
<tbody>
<tr>
<td>made by</td>
<td>SJSU MAE students</td>
<td>First Water System, Inc</td>
<td>Noah Water System, Inc</td>
</tr>
<tr>
<td>cost (USD)</td>
<td>995</td>
<td>3000</td>
<td>1200</td>
</tr>
<tr>
<td>weight (lbs)</td>
<td>23*</td>
<td>32</td>
<td>26.5</td>
</tr>
<tr>
<td>flow rate (gal/min)</td>
<td>0.69</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>UV light</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>sediment filter</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>carbon filter</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>pre-filter</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>pump</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>dimension (in)</td>
<td>18.5x15x7.5</td>
<td>17x20x9</td>
<td>17x21x9</td>
</tr>
<tr>
<td>solar energy</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>power source</td>
<td>12VDC (included)</td>
<td>12VDC (extra charge)</td>
<td>12VDC (extra charge)</td>
</tr>
<tr>
<td>hard case</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Backpack</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Components in SJSU Solar Powered Water Purification System

**Backpack**
- Light weight packaging option (23 lbs)
- Durable
- Frees-up hands while carrying

**Water Pump**
- Self-priming start-up
- Runs dry without damage
- Auto shutoff in case of blockage
- Low noise
- 12 Vdc

**Photovoltaic Solar Panel**
- 10 W folding solar module
- Weather resistant
- Light weight (3 lbs)
- Compact

**Charge Controller**
- Solid-state
- Compact, light weight design

**Battery**
- Rechargeable sealed lead-acid battery which is recyclable
- Absorbent Glass Mat (AGM) technology
- Rugged spill proof ABS plastic construction allows safe operation in any position
- 12Vdc 12Amp Hours

**Transformer**

**Feed Water**
- From ponds or lakes
- From streams
- From collected rain water

**Inlet Mesh Filter**
- Prevents large debris, such as leaves and small rocks, from entering the system
- Preserves the life of the sediment filter
- Cleanable

**Sediment Filter**
- 5 micron nominal filtration
- Pleated cellulose/polyester filter
- Easy replacement

**Carbon Block Filter**
- 0.5 micron nominal filtration
- 99.95% reduction of cryptosporidium, giardia, entamoeba, toxoplasma
- Reduces chlorine taste & odor
- Easy replacement

**UV Germicidal Lamp**
- Unlike UVA or UVB, UVC lamps can disrupt the reproduction process of microorganisms, bacteria, and viruses, providing 99.99% efficiency in eliminating these threats.
- Does not introduce any chemicals to the water, produces no byproducts, and does not alter the taste, pH, or other properties of the water.
- Low maintenance, has no moving parts, and has an easily replaceable UVD lamp which is effective for 1 year of continuous use.
- 12 Vdc

**Hard Case**
- Durable packaging option for transport
- Water tight

**Power Switch**

**Filtered Water**
- Clean – bacteria free
- Clear – particulate free
- Fresh tasting
Portable Solar Power Generation Station for Remote Villages
(2006-2007)

Objectives
● To provide residents in rural India with a portable electric power generation station using solar power.

● To provide urban residents with a stand-by electric power supply in case of power black-out in failed grid-power supply.

Six (6) hours of battery charged by 3-33 W Solar panels under the sun can supply four (4) hours operations of:

● 3-30 W lights
● An electric fan
● A radio
● A black/white TV

Material/part cost: US$350
Part 5
Thin Film Solar Photovoltaic Cells
- A New Development
WHY THIN FILM SOLAR PV CELLS?

Traditional silicon solar PV cells:
Wafer thickness: 200 µm → 100 µm
Opaque and inflexible

Thin film solar PV cells:
Polymer wafer thickness: a few µm
Some can be made transparent, and flexible

Candidate materials for thin film solar PV cells:

- Cadmium telluride (CdTe)
- Copper indium gallium selenide (CIGS)
- Amorphous silicon/crystalline silicon
### Common Solar Cell Materials

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</tr>
<tr>
<td>Amorphous silicon (non-</td>
<td></td>
</tr>
<tr>
<td>crystalline Si for higher</td>
<td></td>
</tr>
<tr>
<td>light absorption)</td>
<td></td>
</tr>
<tr>
<td><strong>Gallium arsenide</strong> (GaAs)</td>
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</tr>
</tbody>
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### Approximate Conversion Efficiencies

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<tr>
<td>GaAs</td>
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</tr>
<tr>
<td>CdTe</td>
<td>7%</td>
</tr>
<tr>
<td>CIGS</td>
<td>20</td>
</tr>
</tbody>
</table>
Prospects of Thin Film Solar PV Cells

- Can be made potentially much more efficient than silicon PV cells
- Significant saving in materials (can absorb 98% of solar energy with only 1 or 2 µm thick wafers)
- More durable because of higher resistance to solar heating
- Most parts can be recycled → more eco-friendly than traditional silicon PV cells
- Can be made transparent or semitransparent → potential solar power generating “windows”
- Being flexible and durable → potential solar shingle and roofing materials for additional power generation
Part 6

Some R&D in
Efficiency Enhancement,
Packaging and Reliability Testing
Why packaging?

Basic structure of PV cells involves different materials with different properties
Packaging of Silicon Solar PV

Schematic of Flat Plate PV Module Components:

<table>
<thead>
<tr>
<th>Top Cover</th>
<th>Glass or transparent plastic, allows light to enter the cells, while protecting the delicate cells from damage. Coated with anti reflecting polymer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encapsulant</td>
<td>Protects the cells and holds together the top cover, PV cells and back surface (not shown). Ethyl vinyl (EVA) is common material.</td>
</tr>
<tr>
<td>Rear Layer</td>
<td>Protect the back surface of the module, and prevents water, gas and dusts from entering the module.</td>
</tr>
<tr>
<td>Substrate CMOS</td>
<td>Metal conductors carry electrons out of the cells and connect cells in the module in series or parallel, and carry electricity out of the module.</td>
</tr>
<tr>
<td>Frame</td>
<td>To hold all components in place. Usually made of aluminum alloy.</td>
</tr>
</tbody>
</table>
Packaging and Reliability of Silicon Solar PV

- **Major tasks in packaging:**
  - Wiring
  - Bonding
  - Sealing
  - Encapsulation

- **Major tasks in reliability:**
  - Temperature induced thermal stresses and thermal strain
  - Moisture effect
  - Dust contamination
  - Solder joints failure
  - Deterioration of performance due to environmental effects
On photo/electric conversion efficiency

- Application of micro- and nanoscale engineering design of embedded structure in silicon PV to maximize the collection of freed electrons by impinging photons from sun light
- Microcircuitry for freer flow of electrons
- Composite Si/GaAs Nano material particles for enhanced electron mobility

Packaging of solar panels for stationary and mobile systems

- Special bonding of cells to chassis materials
- Protection of robust cell wiring
- Robust sealing of cells
- Thermal-fatigue failure of solder joints
- Structure failure due to dynamic and vibrations of the vehicle
- thermal stress/deformation due to mismatch of coefficient of thermal expansion of materials
- Deterioration of energy conversion due to required strong encapsulation
- Reliability of cell performances in extreme environmental conditions
- Unexpected mechanical and thermal forces to the panels.