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Production of silicon crystals for application in Solar cells and solar technology

An Abstract

July 2007

A **solar cell**, or photovoltaic cell, is a semiconductor device consisting of a large-area p-n junction diode, which, in the presence of sunlight is capable of generating usable electrical energy. This conversion is called the **photovoltaic effect**. The field of research related to solar cells is known as photovoltaic.

Solar cells have many applications. They are particularly well suited to, and historically used in situations where electrical power from the grid is unavailable, such as in remote area power systems, Earth orbiting satellites, handheld calculators, remote radiotelephones, water pumping applications, etc. Solar cells (in the form of modules or solar panels) are appearing on building roofs where they are connected through an inverter to the electricity grid in a net metering arrangement.

Various materials have been investigated for solar cells. There are two main criteria - efficiency and cost. Efficiency is a ratio of the electric power output to the light power input. Ideally, near the equator at noon on a clear day, the solar radiation is approximately 1000 W/m². So a 10% efficient module of 1 square meter can power a 100 W light bulb. Costs and efficiencies of the materials vary greatly.

By far the most common material for solar cells (and all other semiconductor devices) is crystalline silicon. Crystalline silicon solar cells come in three primary categories:

- **Single crystal or monocrystalline wafers** made using the Czochralski process. See Sunpower and Shell Solar. Most commercial monocrystalline cells have efficiencies on the order of 14%; the SunPower cells have high efficiencies around 20%. Single crystal cells tend to be expensive, and because they are cut from cylindrical ingots, they cannot completely cover a module without a substantial waste of refined silicon. Most monocrystalline panels have uncovered gaps at the corners of four cells.

- **Poly or multi crystalline** made from cast ingots - large crucibles of molten silicon carefully cooled and solidified. See GT Solar HEM Furnace, BP Solar, Sharp Solar and Kyocera Solar. These cells are cheaper than single crystal cells, but also somewhat less efficient. However, they can easily be formed into square shapes that cover a greater fraction of a panel than monocrystalline cells, and this compensates for their lower efficiencies.

- **Ribbon silicon** formed by drawing flat thin films from molten silicon and has a multicrystalline structure. See Evergreen Solar, and RWE Schott Solar. These cells are typically the least efficient, but there is a cost savings since there is very little silicon waste since this approach does not require sawing from ingots.

These technologies are wafer based manufacturing. In other words, in each of the above approaches, self supporting wafers of ~300 micrometres thick are fabricated and then soldered together to form a module.

Thin film approaches are module based. The entire module substrate is coated with the desired layers and a laser scribe is then used to delineate individual cells. Two main thin film approaches are amorphous silicon and CIS:

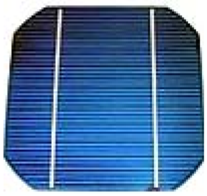
- **Amorphous silicon films** are fabricated using chemical vapor deposition techniques, typically plasma enhanced (PE-CVD). These cells have low efficiencies around 8%.
- **CIS** stands for general chalcogenide films of $Cu(In_xGa_{1-x})(Se_xS_{1-x})_2$. While these films can achieve 11% efficiency, their costs are still too high.

There are additional materials and approaches. For example, Sanyo has pioneered the HIT cell. In this technology, amorphous silicon films are deposited onto crystalline silicon wafers.

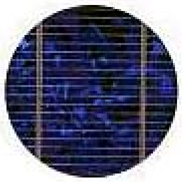
Silicon from Earth to Solar technology

Solar Module

Solar Cells



Wafers



Ingots

silicon

silica

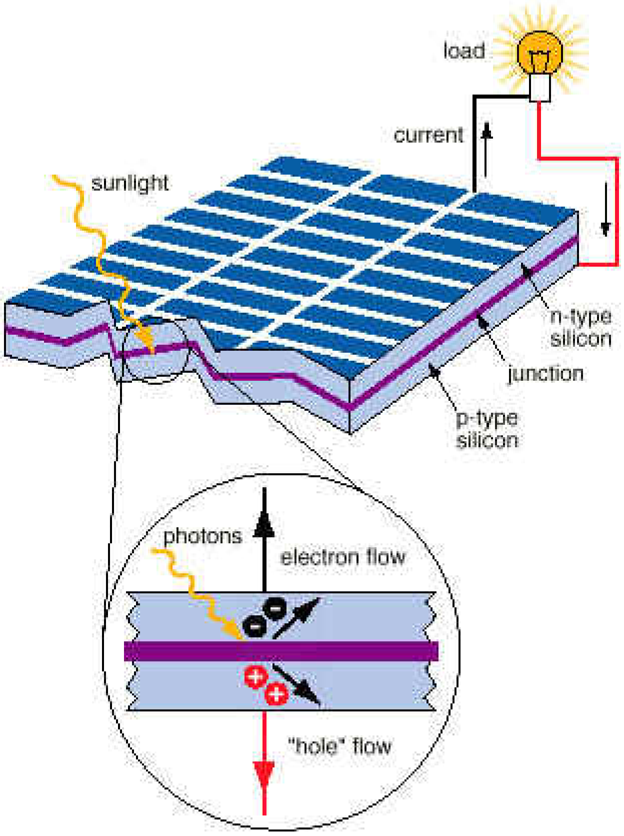
Solar Cells To understand the operation of a PV cell, we need to consider both the nature of the material and the nature of sunlight. Solar cells consist of two types of material, often p-type silicon and n-type silicon. Light of certain wavelengths is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charges ("holes") from the negative charges (electrons) within the photovoltaic device. The holes are swept into the positive or p-layer and the electrons are swept into the negative or n-layer. Although these opposite charges are attracted to each other, most of them can only recombine by passing through an external circuit outside the material because of the internal potential energy barrier.

Therefore if a circuit is made power can be produced from the cells under illumination, since the free electrons have to pass through the load to recombine with the positive holes. The amount of power available from a PV device is determined by:

The type and area of the material

The intensity of the sunlight

The wavelength of the sunlight

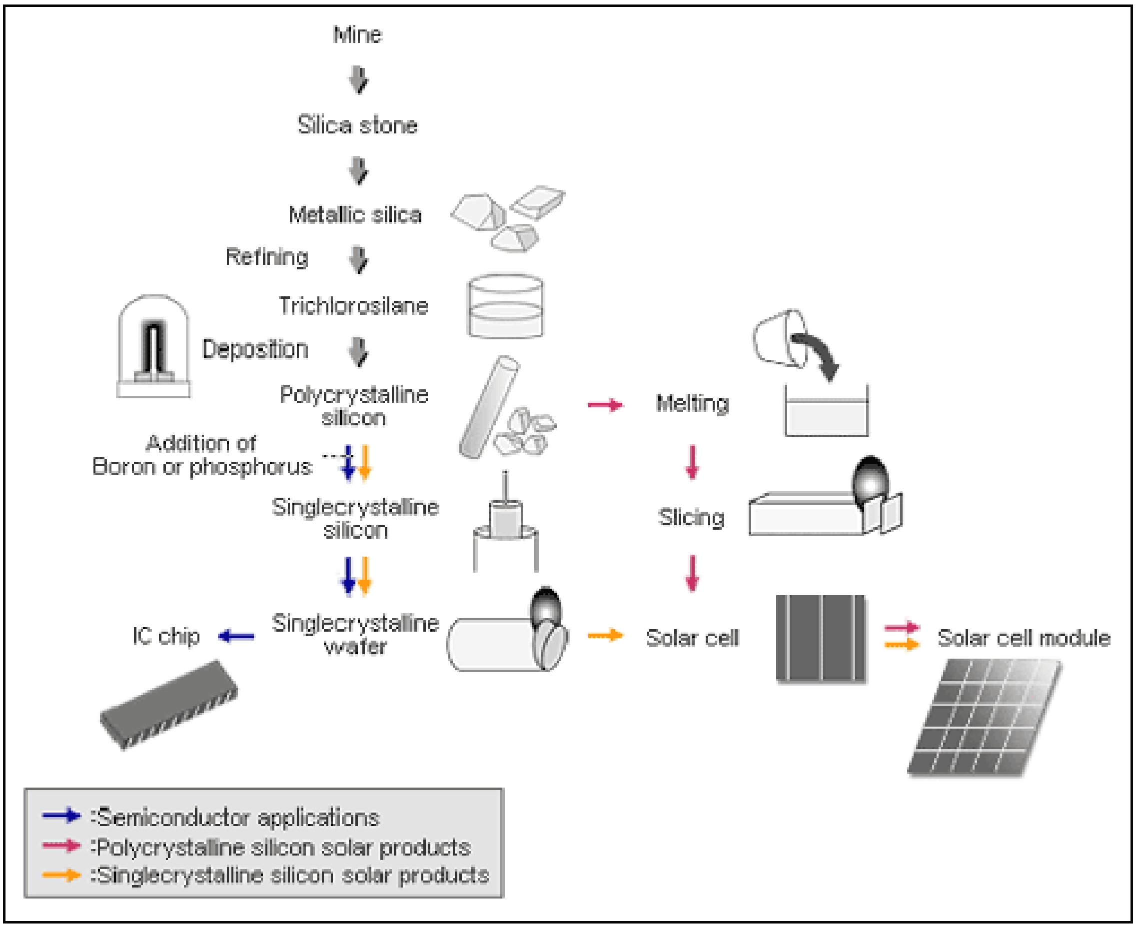


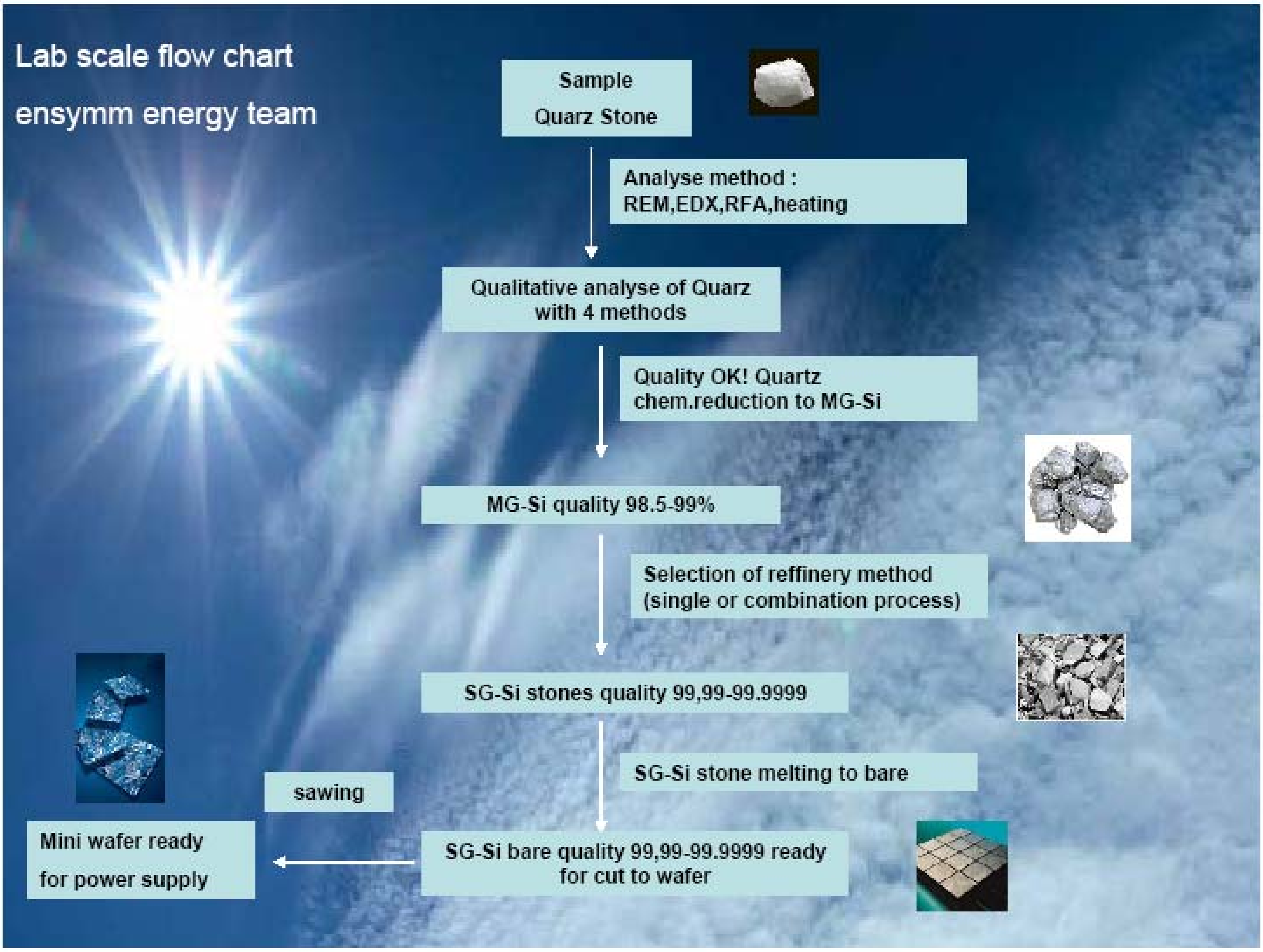
Single crystal silicon solar cells, for example cannot currently convert more than 25% of the solar energy into electricity, because the radiation in the infrared region of the electromagnetic spectrum does not have enough energy to separate the positive and negative charges in the material. Polycrystalline silicon solar cells have an efficiency of less than 20% at this time and amorphous silicon cells, are presently about 10% efficient, due to higher internal energy losses than single crystal silicon.

A typical single crystal silicon PV cell of 100 cm^2 will produce about 1.5 watts of power at 0.5 volts DC and 3 amps under full summer sunlight ($1000 Wm^{-2}$). The power output of the cell is almost directly proportional to the intensity of the sunlight. (For example, if the intensity of the sunlight is halved the power will also be halved). An important feature of PV cells is that the voltage of the cell does not depend on its size, and remains fairly constant with changing light intensity. However, the current in a device is almost directly proportional to light intensity and size. When people want to compare different sized cells, they record the current density, or amps per square centimeter of cell area.

The power output of a solar cell can be increased quite effectively by using a tracking mechanism to keep the PV device directly facing the sun, or by concentrating the sunlight using lenses or mirrors. However, there are limits to this process, due to the complexity of the mechanisms, and the need to cool the cells. The current output is relatively stable at higher temperatures, but the voltage is reduced, leading to a drop in power as the cell temperature is increased. More information on PV concentrators can be found later in this information file.

Production Pathway of solar cells from silica through silicon crystal





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Technology transfer and know how

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Sources:

Wikipedia
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