Cost Boundary in Silicon Solar Panel

V.K.Sethi, Mukesh Pandey, and Priti Shukla

***Abstract*—Photovoltaic is a solar power technology that uses solar cells or solar photovoltaic arrays to convert light directly into electricity with no emission of dangerous gases and with least amount of industrials waste. Solar cells are a key technology in the drive toward cleaner energy production. Unfortunately, solar technology is not yet economically competitive and the cost of solar cells needs to be brought down. Growth of the photovoltaic (PV) market is still constrained by high initial capital costs of PV. One way to overcome this problem is to reduce the amount of expensive semiconductor material used. The materials cost and manufacturing cost of thin-film solar is much lower than wafer based and drops much faster than wafer based in large-scale manufacturing, but thin-film solar cells tend to have lower performance compared with conventional solar cells. Developments in PV technologies may lead to cheaper systems at the likely expense of life expectancy and efficiency. Cost boundaries are required for future PV technologies to compete effectively within the current PV market.[B. Azzopardi, 1].Micro- and nano-enabled thin-film photovoltaics provide an attractive-and increasingly cost-competitive-clean-tech alternative to carbon-based energy solution.**

***Index Term*—Nanodefect, Nanowire, Breakthroughs**

I. Introduction

As more people become aware of the problems associated with greenhouse-gas emissions, the demand for sources of clean energy goes up. As the demand for high-quality solar-cell feedstock exceeds supply and drives prices upwards, cheaper but dirtier alternative feedstock materials are being developed [Tonio Buonassis2]. c-Si has the advantage of maturity, material stability, the highest conversion efficiencies (the percentage of the sun's energy converted into electricity), and an already-established global manufacturing infrastructure. But, thin-film PV has many advantages, too: It is lightweight, requires relatively minuscule amounts of active semiconducting materials, and can be applied on a variety of substrates, including plastics, flexible steel, composites, and building materials. High-relatively minuscule amounts of active semiconducting materials, and can be applied on a variety of substrates, including plastics, flexible steel, composites, and building materials. High-efficiency crystalline silicon cells are well suited for cooler, high-latitude environments. Thin films are more cost effective in warmer, brighter climates, while very high-efficiency, high-output concentrator solar cells work in areas with minimal cloud cover, independent of temperature or latitude

Most solar-cell technology is silicon based. There are three primary types of silicon solar cells, each named after the crystalline structure of the silicon used during fabrication:

- Mono-crystalline silicon has a single and continuous crystal lattice structure with practically zero defects or impurities.
- Poly-crystalline silicon, also called poly-silicon, comprises discrete grains, or crystals, of mono-crystalline silicon that create regions of highly uniform crystal structures separated by grain boundaries.
- Amorphous silicon is an entirely non-crystalline form of silicon that can be thought of as grains the size of the individual atoms.

Crystalline Si's relatively high efficiency has, however, a negative correlation with temperature. The hotter it gets, the less electricity it produces. Most crystalline Si solar cells decline in efficiency by 0.50%/°C. Thus, it is particularly suitable for cooler climates.

Mono crystalline Si wafers, cut from grown cylindrical ingots, make the most productive cells, with efficiencies ranging from 20-24%. The crystal lattice is continuous and there are no grain boundaries. Polycrystalline Si wafers are cut from cast, square ingots. Due to the presence of grain boundaries, they achieve about half the efficiency of single-crystal cells. Many commercialized solar cells incorporate amorphous silicon and poly-silicon, which have acceptable conversion efficiency and cost much less than mono-crystalline silicon.

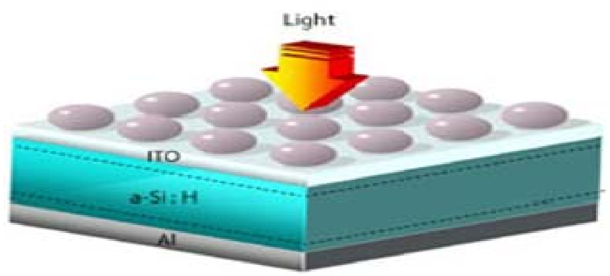

Fig. 1 Schematic illustration of a silicon solar cell (a-Si:H) sandwiched between aluminum (Al) and transparent indium tin oxide (ITO) electrical contacts. Aluminum nanoparticles on the top (gray) enhance the absorption of light.

The process developed by Naseem, known as topdown aluminum-induced crystallization, creates poly-silicon with crystal grains 30 times larger than grains currently produced in the photovoltaic industry. Standard poly-silicon contains grains of 0.5 to 1 micrometer, which is one-100th the diameter of a human hair. Naseem's process yielded a grain size up to 150 micrometers, which is important because the performance of a photovoltaic device is limited primarily by

Manuscript received March 28, 2011, revised September 19, 2011.
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defects at the boundaries of crystal grains. Increasing the size of crystal grains decreases the number of boundaries.

Traditional processing of silicon-based cells requires a heating temperature of 1,000 degrees Celsius to cause the silicon to reach a crystalline state. Naseem's method of converting amorphous silicon into poly-silicon can be done at temperatures between 100 and 300 degrees Celsius, which saves time, materials and energy

II. Manufacturing Cost Of Solar Cell

A. Monocrystalline Cells

Monocrystalline cells are the most costly from a manufacturing standpoint. The raw material is expensive and there are a limited number of manufacturers. With rectangular wafers cut from cylindrical ingots, there is a substantial waste of refined Si. Improved manufacturing techniques are making wafers thinner and larger, and optimized gridlines are obscuring less surface area, improving efficiencies. Techniques for roughening the surface area, including building pyramidal structures, increase the effective surface area as well. Si ink technologies can also incrementally improve cell efficiency.

B. Polycrystalline Cells

Polycrystalline Si is much less expensive to produce; wafers are cut from large, rectangular blocks produced by carefully cooling and solidifying molten Si. In the market, there is a definite trend towards polycrystalline products as technological advances lessen the effects of grain boundaries. Sun Power, the world's largest producer of Si solar cells, has set records with its monocrystalline technology, recently achieving 24.2% efficiency. However, Sun Power is increasingly investing in its polycrystalline product lines, anticipating the need to meet skyrocketing demands with lower-cost manufacturing solutions.

C. Thin Films

Thin-film photovoltaic solutions are gaining ground quickly and are expected to capture up to 30% of solar panel market share by 2013 . Production costs are significantly less than with crystalline products for a variety of reasons: deposition processes use a fraction of the raw material as wafers, the raw material need not be grown or cast, and there is no sawing or waste from unused portions.

The average price for a PV module, excluding installation and other system costs, has dropped from almost $100 per watt in 1975 to less than $4 per watt at the end of 2006. With expanding polycrystalline cell , average PV prices are projected to drop to $2 per watt in 2010. For thin-film PV alone, production costs are expected to reach $1 per watt in 2010, at which point solar PV will become competitive with coal-fired electricity. With concerns about rising oil prices and climate change spawning political momentum for renewable energy, solar electricity is poised to take a prominent position in the global energy economy

III. Engineering Metal-Impurity Nanodefects for Low-cost Solar Cells

To eliminate dependence on high-quality silicon feedstock, the development of low-cost 'solar-grade silicon' (SoG-Si) has been proposed, which contains much higher concentrations of deleterious transition metal impurities. Many studies have shown that transition metals can decrease the minority carrier diffusion length—a key parameter for determining the efficiency of solar-cell devices. An entirely new approach is needed to make cost-effective solar cells from low-cost, abundant, but impurity-rich feedstock.

The concept proposed in this study opens a new and exciting opportunity to recover low quality silicon for commercially viable solar-cell material. This concept is not necessarily limited to annealing, it could also be extended to appropriate engineering during crystal growth. As material performance is vary on the distribution of the interstitial metals, metal clusters and metal precipitates, and not only by total metal concentrations, even heavily contaminated materials can show dramatic enhancements through nanodefect engineering. The defect engineering could be complemented by the existing solar-cell processing techniques such as gettering or hydrogen passivation, which can be expected to improve the material performance. Even further metal-rich SoG-Si, which would be much cheaper and far more abundant than current silicon feedstock material, has the real potential to produce cost-effective solar cells, provided metal nanodefects are engineered correctly.[Tonio Buonassisi 2].

IV. Solar Cells Can Be Made Thinner and Lighter With The Help of Aluminum Particles

Metallic nanoparticles can direct light better into the solar cell and prevent light from escaping. In conventional 'thick-film' solar cells, the nanoparticles would have little effect because all the light is absorbed by the film due to its thickness. For thin films, however, the nanoparticles can make a big difference. Their scattering increases the duration the light stays in the film, bringing the total absorption of light up to a level comparable with that for conventional solar cells. The strategy allows us to reduce the production costs of solar cells by several times and makes photovoltaics more competitive with respect to other forms of power generation.[Akimov3,4].

The researchers modeled the light absorption efficiency of solar cells for various nanoparticle materials and sizes, specially they compared the properties of silver versus aluminum nanoparticles. In most studies on the subject, silver particles have been preferred. These have optical resonances in the visible part of the spectrum that are even better at focusing the light into the solar cell. Unfortunately, there is a trade off: the optical resonances also cause the absorption of light by the nanoparticles, which means the solar cell is less efficient.

In the case of silver, this resonance is right in the key part of the solar spectrum, so that light absorption is considerable. But not so for aluminum nanoparticles, where these resonances are outside the important part of the solar spectrum. Furthermore, the aluminum particles handle oxidation well and their properties change little with variations in shape and size. And more importantly, their scattering properties are robust in comparison with silver nanoparticle. Researchers found that nanoparticles made of aluminum perform better than those made of other metals in enhancing light trapping in thin-film solar cells.[Akimov.4] So Aluminum particles can help make thin-film solar cells commercially viable."

TABLE 1 MODULE MANUFACTURING COSTS & PROFITABLE PRICE FORECOST (US$)

Cell Technology	2005		2010		2015	
	Cost	Profitable Price	Cost	Profitable Price	Cost	Profitable Price
Crystalline Silicon						
Monocrystalline Silicon	2.50	3.75	2.00	2.50	1.40	2.20
Multicrystalline Silicon Cast Ingot	2.40	3.55	1.75	2.20	1.20	2.00
Crystalline -Based Silicon						
Ribbon/ Sheet Silicon	2.00	3.35	1.60	2.2	1.00	1.70
Concentrator silicon Cell	3.00	5	1.5	2.5	1.00	1.70
Non-Crystalline cell						
Amorphus Silicon (a-Si)	1.5	2.50	1.25	2.00	0.90	1.60
Non Silicon						
Copper Indinum (G) Diselenide (CIS / CIGS)	1.50	2.50	1.20	2.00	0.80	1.33
Cadmium Telluride (CdTe)	1.50	2.50	1.20	2.00	0.80	1.33
Profitable price includes 40% gross product margin						

V. NEW SILICON NANOWIRES MAKE PHOTOVOLTAIC DEVICES MORE EFFICIENT

More than 90% of PV is currently made of Si modules assembled from small 4-12 inch crystalline or multi crystalline wafers. However, the newer thin-film technologies are monolithically integrated devices approximately 1 m^2 in size which cannot have even occasional shunts or weak diodes without ruining the manufacturing yield. Thus, these devices require the deposition of many thin semiconducting layers on glass, stainless steel or polymer and all layers must function well a square meter at a time. This is the challenge of PV technology-high efficiency, high uniformity, and high yield over large areas to form devices that can operate with repeated temperature cycles from —40 C to 100 C with a provable twenty- year lifetime and a cost of less than a penny per cm^2.

Polycrystalline and amorphous thin-film cells use inexpensive glass, metal foil or polymer substrates to reduce cost (Chu 5) The polycrystalline thin film structures utilize direct-gap semiconductors for high absorption while amorphous Si capitalizes on the disorder to enhance absorption and hydrogen to passivate dangling bonds. The very defective thin-film materials can yield high carrier collection efficiencies due to field-assisted collection and clever passivation of defects and manipulation of grain boundaries.. It is now commonly accepted that, not only are grain boundaries effectively passivated during the thin-film growth process or by post-growth treatments, but also that grain boundaries can actually serve as collection channels for carriers. In fact it is not uncommon to find that the polycrystalline thin-film devices outperform their single-crystal counterpart.

Silicon nanowires oriented along [100] plane, in a square array with equilibrium lattice relaxed to a unit cell with Si-Si bond spacing to be 2.324A and Si-H spacing to be 1.5A. Since the nanowires are direct band gap semiconductors which make them excellent for optical absorptions. The lowest excitonic peaks for each of the nanowires occur at 5.25 eV, (232 nm), 3.7 eV (335 nm), and 2.3 eV (539 nm) in the increasing order of size. Absorption is tunable from the visible region to the near UV portion of the solar spectrum. No doubt, such silicon nano wires are excellent and could decrease solar cell costs efficiently

VI. BREAKTHROUGH TECHNOLOGY MAKE PHOTOVOLTAIC DEVICES MORE EFFICIENT

The UNSW researchers have devised a way to deposit a thin film of silver (about 10 nanometres thick) onto a solar cell surface and then heat it to 200° Celsius. This breaks the film into tiny 100-nanometre "islands" of silver that boost the cell's light trapping ability, thereby boosting its efficiency.

A typical solar cell generates only one electron per photon of incoming sunlight. Some exotic materials are thought to produce multiple electrons per photon, but for the first time, the same effect has been seen in silicon. Researchers at the National Renewable Energy Laboratory (NREL), showed that silicon nanocrystals can produce two or three electrons per photon of high-energy sunlight. The effect, could lead to a new type of solar cell that is both cheap and more than twice as efficient as today's typical photovoltaics.

As in earlier work with other materials, the extra electrons come from photons of blue and ultraviolet light, which have much more energy than those from the rest of the solar spectrum, especially red and infrared light. In most solar cells, the extra energy in blue and ultraviolet light is wasted as heat. But the small size of nanoscale crystals, also called quantum dots, leads to novel quantum-mechanical effects that convert this energy into electrons instead.(Vidur 6)

By generating multiple electrons from high-energy photons, solar cells made of silicon nanocrystals could theoretically convert more than 40 percent of the energy in light into electrical power, Concentrating sunlight with mirrors or lenses could raise that figure to about 40 %, but the same approach could boost the efficiency of a silicon-nanocrystal solar cell to well over 60 %.

VII. CONCLUSION

These developments suggest an exciting runway. Thin-film advocates also point to production advantages such as inherent process scalability and lower cost, claiming potentially exponential savings compared to the capital outlay required for crystalline manufacturing facilities. Within the next decade, we will see the development of cost-effective thin-film solar panels that will reach efficiencies up to 30% — a factor 2-3x that of current thin-film panels. The effectiveness and cost of these new panels will enable the use of the same basic panel designs over all climactic environments, eliminating the need for different technologies for different light levels. The global ubiquity of these panels will drive costs even lower by enabling the highest-volume manufacturing rates. Recent analyses of the energy payback time for solar systems show that today's systems pay back the energy used in manufacturing in about 3.5 years for silicon and 2.5 years for thin films.

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