SLIVER SOLAR CELL TECHNOLOGY

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Overview

Sliver solar cell technology was invented at the Australian National University in 2000 and developed with financial support from Origin Energy. The technology has startling potential for rapid and dramatic reductions in the costs of solar energy conversion, by up to three quarters. It is a fundamental technical breakthrough with profound implications for the PV industry and energy and climate change policy worldwide.

ANU continues research into Sliver technology. Origin Energy is commercialising Sliver technology at their new factory in Adelaide - first sales occurred in 2005 and mass sales are expected late this year (http://sliver.com.au).

This paper describes the exciting prospects for Sliver solar cell technology.

Solar energy

There are five available energy sources: solar energy in its various forms, fossil energy, nuclear energy, geothermal energy and tidal energy. Of these five, only solar energy can provide very large-scale energy in a long-term sustainable and environmentally acceptable manner. The other four energy sources can supplement solar energy to increase the diversity, and hence the stability and security of energy supply.

Fossil fuel reserves are finite, and these valuable resources will be depleted by large-scale burning. The escalating consumption of fossil fuels produces large quantities of greenhouse gases, causes local and regional pollution, and requires large-scale mining. In addition, the highly non-uniform distribution of fossil fuels gives rise to international tensions. Nuclear energy has problems of waste disposal and devastating accidents, and is inextricably linked to nuclear weapons proliferation and the risk of terrorist strikes. While geothermal and tidal energy can make a useful contribution, they both have limited geographical availability.

Solar energy includes both direct radiation where energy is harnessed directly from sunlight, and indirect forms of energy such as biomass, wind, hydro, ocean thermal, ocean currents and wave energy caused by the effects of the Sun on Earth. Most of these energy forms will be part of the energy resources mix when solar energy becomes the dominant traded-energy form. Some solar energy technologies are more advanced than others, and the eventual solar energy mix will vary from region to region. The key to successful mass-utilisation of solar energy is diversity.

Photovoltaics, solar thermal energy, which is also referred to as solar heat energy, and wind energy are the only solar energy technologies in sight that can provide very large quantities of sustainable energy with sufficiently high efficiency (more than 20%) to limit land requirements. These conversion technologies have small environmental impacts and insignificant military applications. In some countries biomass may also make a substantial contribution to energy supply, despite low solar-to-electricity conversion efficiency of around 0.2% in total.

Photovoltaics (PV) is the science of converting sunlight directly into electricity via solar cells without the use of mechanical conversion or any moving parts. PV has found widespread use in niche markets such as consumer electronics, remote area power supplies and satellites. As costs decline, large numbers of photovoltaic systems are being installed on house roofs in cities in Europe and Japan. The cost of photovoltaic systems is not a strong function of scale, which means that photovoltaic systems are often the most economical energy source for small applications. Presently, over 90% of the world photovoltaic market is serviced by crystalline silicon solar cells. This strong market dominance is likely to continue for many years.

Most solar thermal electricity technologies use mirrors to concentrate sunlight onto a receiver. The resulting heat is ultimately used to generate steam, which passes through a turbine to generate electricity. Solar concentrator methods are equally applicable to concentrating photovoltaic systems. The usual ways of concentrating sunlight are point focus concentrators, in the case of dishes; line focus concentrators in the case of troughs; and central receivers in the case of heliostats and power towers.

Solar thermal electricity is not yet a commercial proposition. The reason for this is that, unlike photovoltaics, there are strong economies of scale. This means that small systems that might be suitable for an individual household are far too expensive. This lack of a niche market, in contrast to photovoltaics, will inhibit the development of solar thermal electricity in the short to medium term. In the longer term, solar thermal electricity will compete with photovoltaics, because the efficiency of specialist solar cells designed to operate at solar intensities above 500 times normal intensity, or "500 suns", is similar to the efficiency of turbines. Solar thermal systems can be used to drive chemical reactions. This constitutes a form of chemical energy storage that can be recovered at will.

Wind energy is now a mainstream energy technology and is the cheapest of the new renewable energy technologies. However, constraints on resource availability will limit the contribution of wind energy to about 20% of worldwide electricity supply.

In most cases, storage of solar electricity is not a serious issue until the proportion of wind and solar in the mix rises above about 10%. This is not likely within 20 years, with some notable exceptions. This lead time will give adequate time to develop solutions. Some options for ensuring continuity of supply include diversity of technology, diversity of geographical location, energy conservation, load shifting from night to day, strong long-distance electrical interconnection, judicious use of natural gas, bio-fuels and coal to meet peak loads, sophisticated wind and solar prediction on every time scale from seconds to months, pumped hydro, compressed air, thermochemical energy storage and advanced batteries.

Photovoltaic energy conversion

Solar cells are made on wafers of pure, crystalline silicon typically 15 cm in diameter and 0.3 mm thick. In conventional solar modules, about 40 solar cells are connected together and packaged behind glass to form a solar power module with an area of about 0.5 m^2. PV modules are highly reliable, with modern modules carrying a 25-year guarantee. PV systems comprise PV modules, support structures, electrical interconnection, and inverters that convert DC electricity to AC electricity.

PV systems have traditionally found widespread use in niche markets such as remote area power supplies. Now, as costs come down, millions of PV systems have been installed in cities around the world. Apart from producing clean electricity, PV systems have many other attractive attributes such as distributed generation and peak load levelling capabilities.

Low cost PV electricity can readily provide much of the world's electricity in a carbon-constrained world. It will not be surprising to those in the photovoltaics industry if half of the world's electricity comes from photovoltaics by 2050. The other half could come from wind energy, solar thermal electricity, waves, biomass and other sources. This goal will be achieved assuming that world electricity consumption triples in line with population growth and rising living standards and that annual average growth rates in the PV industry over the past 15 years (23% per year) continue to prevail.

About 0.2% of the world's land surface would be required, which is approximately equal to the area presently covered by the built environment. The steady-state sales of the PV industry (for replacement of worn-out systems) would be A$0.5-1 trillion per year, which is about the same size as the electronics industry and current global defence spending.

An important interim milestone for the photovoltaic industry is to reach energy costs below peak daytime retail costs. When this occurs explosive growth in sales is likely, since building owners around the world will benefit financially from installation of their own photovoltaic system. On current trends, this is likely to happen around 2015.

A world electricity supply based on photovoltaics would be truly sustainable in the very long-term. Most of the systems would be deployed on the roofs of buildings or in arid regions. The raw materials (mostly silicon and glass) are neither in short supply nor toxic. The operational time required to recover the energy used in the fabrication of advanced PV systems (eg based on Sliver cells) is one year, compared with an expected lifetime of 30-50 years. The environmental and health impacts of solar cell factories are minimal.

Photovoltaics has many social advantages over competing energy technologies. There are few avenues for the diversion of the technology to military and terrorist uses. The PV industry would provide a decentralised, democratising energy source, allowing individuals and groups to control their own energy production and to make the national energy supply less vulnerable to war or terrorist activity. Furthermore, the solar resource is ubiquitous. In fact, poorer regions of the world tend to have good solar resources.

The global PV industry is booming. Not only has growth been sustained since the industry was established, but global annual growth rates in the PV industry are accelerating. Global PV industry exponential growth rates were 24%, 31% and 37% averaged over the last 15, 10 and 5 years respectively.

Crystalline silicon solar cells are used in 95% of PV modules. Silicon, which is the second most abundant element in the Earth’s crust, has many advantages, including the abundance of raw material, non-toxicity, high and stable cell efficiencies, market dominance, and the ability to share infrastructure and development costs with the well-established integrated circuit industry.

For many reasons, wafer-based silicon solar cells cannot be a long-term solution to large-scale energy production. Indeed, a major challenge presently facing the PV industry is a critical shortage of hyperpure silicon at an affordable price. The silicon used to make solar cells must be purified in very expensive facilities. The PV industry used to consume 10% of the world’s hyperpure silicon (off-spec silicon from the integrated circuit industry), but this figure is now 50%.

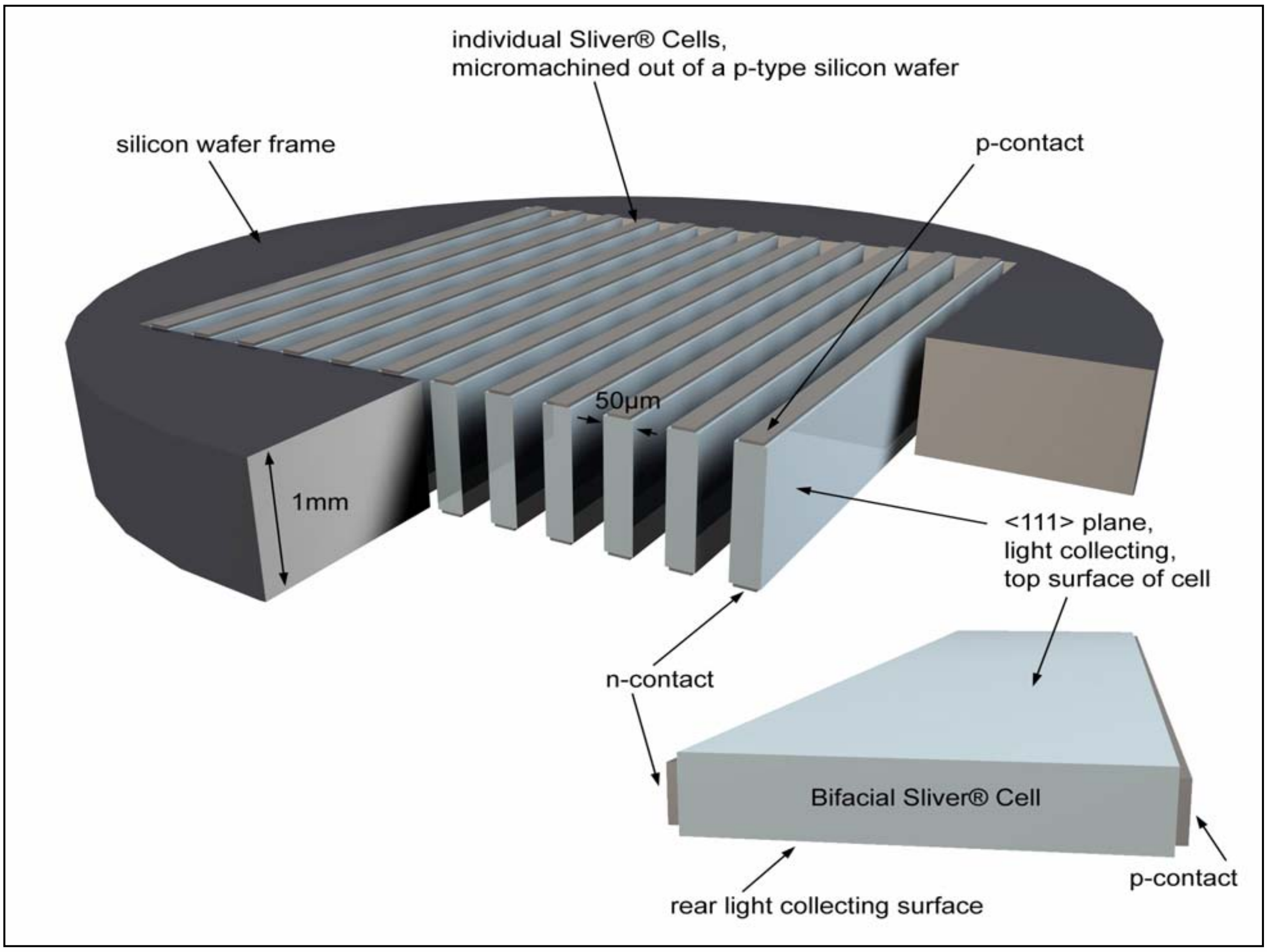
Possible solutions to this problem are thin crystalline silicon solar cells such as Sliver technology, non-silicon thin film cells such as CdTe, CuInGaSe, dye-sensitised and organics, and hypothetical advanced high efficiency cells based on quantum wells or engineered materials. The high efficiency potential and low cost potential of Sliver technology confers a major advantage over alternatives.

Sliver solar cell technology

The invention of Sliver solar cell technology in 2000 by Dr Klaus Weber and Professor Andrew Blakers of the Australian National University is a fundamental breakthrough. Sliver cell technology uses standard materials and conventional techniques in novel ways to create thin single crystalline solar cells with superior performance at significantly reduced cost.

Sliver cells are fabricated on single crystal silicon – the gold standard of the PV industry. Sliver modules are manufactured using techniques adapted from conventional module manufacture. Mature Sliver modules will use only conventional materials. Sliver modules can be efficient, low cost, bifacial, transparent, flexible, shadow-tolerant and light-weight. Sliver technology has the potential to be a comprehensive long-term solution for PV.

Standard single crystal silicon wafers around 1 mm thick are used as the starting material for the Sliver cell process. Low cost micromachining methods are used to create many narrow parallel grooves that extend vertically through the wafer but do not extend to the wafer edge. The grooves lead to the creation of an array of thin, parallel, silicon strips, referred to as “Slivers”, confined in the wafer, and held in place at their ends by the un-grooved part of the wafer, referred to as the wafer frame. The entire wafer, containing up to several thousand Slivers, is then processed using standard techniques to turn each of the Slivers into a solar cell.



At the end of the process, the Slivers are cut out of the wafer frame, laid flat, and electrically connected. The rotation of each Sliver through 90 degrees generates a large gain in the active surface area – "area multiplication" – compared with the starting wafer.

Area multiplication is a valuable attribute of Sliver technology, allowing a single wafer containing the equivalent solar cell surface area of around thirty conventional wafers to be processed at not much greater handling cost than a single conventional wafer.

The key to understanding the significance of Sliver technology from the cell processing perspective is to recognise the fundamental difference between conventional cell processing and Sliver cell processing. In the conventional cell process, cells are formed on the wafer surface – essentially a 2-dimensional process. In the Sliver cell process, cells are formed in the wafer volume – essentially a 3-dimensional process, which produces a dramatic increase in the active surface area of solar cells per unit volume of silicon consumed and per wafer that is processed.

By using the Sliver process a large increase is obtained in the active surface area of solar cells, compared to the surface area of the starting wafer, of the order of 10-30 times. Thus the cost of cell processing is greatly reduced by the dramatic reduction in the number of wafer starts required for an equivalent energy output compared with conventional cell processing.

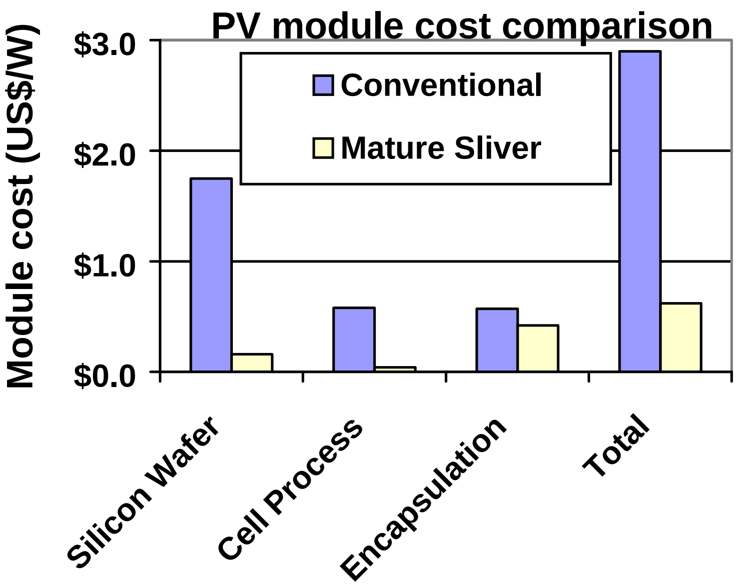
Sliver technology allows for large reductions in the consumption of expensive hyperpure silicon, by 90-95%, compared with conventional silicon solar cells. This solves the hyperpure silicon supply problem.

Mature Sliver solar cell technology

Sliver technology has the potential, over the next few years, to reach very low costs per square metre for the crystalline silicon energy-converting material. This will happen as the technology matures. Costs may become so low that the cost of encapsulation, which is much the same for any PV technology, dominates the finished module price. Sliver technology has a decisive advantage over competing low cost technologies because it is likely to be 50-100% more efficient in commercial production than alternatives.

There are three distinct phases in PV module manufacturing: (i) the production of silicon wafers (ii) the processing of the wafers to form solar cells and (iii) the electrical interconnection and packaging of the solar cells to form PV modules. The ratio of costs for each of the above manufacturing phases using conventional solar cell technology is roughly 50%, 25% and 25% respectively. Essentially a mature Sliver technology reduces the 50% cost of the silicon wafers and the 25% cost of the wafer processing to very small values. This leaves only the 25% cost of interconnection and packaging, which is roughly comparable to conventional solar cell technology cost.

In the long term, as cost structures for various technologies converge to the packaging cost, PV choices will ultimately be made on the basis of efficiency alone. Efficiency MUST be high for a PV technology to be competitive in the future. Sliver technology already has demonstrated a clear lead in the efficiency stakes, holding the world record for thin film efficiency. The efficiency of mature Sliver cells in commercial production is likely to be around 20%.



The chart shows our estimates of the cost of mature Sliver technology in the medium term. Heroic assumptions are not required to reach low electricity generation costs. There is no fundamentally new technology required for mature Sliver technology. What is required is careful silicon processing, micromachining and packaging engineering to transfer laboratory-based mature Sliver technology into methods and processes for the commercial manufacture of Sliver cell PV modules. The high efficiency and low cost expected of mature Sliver solar cell technology means that Sliver technology has an excellent chance of dominating the worldwide PV industry.

Applications for Sliver technology span the PV industry, as shown in the Table below.

Application	Salient features of Sliver technology
Power modules	Low cost, efficient
Architectural applications	Bifacial, low-cost flexible, efficient, shadow-tolerant, semi-transparent
Small power supplies (eg toys, phones)	Flexible, efficient, high voltage from small area module
Parabolic trough concentrators	Low cost, efficient, shadow-tolerant
Line-focus microconcentrators	Bifacial, low cost, efficient, shadow-tolerant, suitable cell shape
Transportable panels	Flexible, efficient, light weight, shadow-tolerant
Aerospace	Bifacial, lightweight, radiation tolerant, shadow-tolerant

Applications for Sliver cells span the PV industry

It appears that energy costs in the range of 10 c/kWh will be possible with Sliver technology. This would put solar electricity technology in the same price range as wind energy and projections for “zero emission” coal electricity.

Future value of Sliver technology

Recent market growth and share market events suggest the value of Sliver technology is enormous.

The growth rate of the worldwide PV market in 2005 was 45%. Worldwide sales are estimated at 1.8 Gigawatts (Photon International, March 2006 issue). Over the past decade, the size of the worldwide PV market has been doubling every 2 years.

In December 2005 a Chinese photovoltaic company called Suntech Power floated on the NY Stock Exchange (http://www.suntech-power.com/en/index_en.html). The CEO, Dr Zhengrong Shi, undertook a PhD at the University of NSW and then worked for Pacific Solar for several years before returning to China in 2001 to found Suntech Power. The current share market valuation of Suntech is US$5.4 billion. The company is the world's 5th largest PV producer. On the basis of his shareholding, Dr Shi's fortune of A$3 billion made him Australia's 5th richest person. Sliver technology has large potential advantages over the conventional PV technology implemented by Suntech Power.

Sliver technology could be the subject of a national effort, facilitated by the Federal Government, as a way of capturing a large slice of the worldwide photovoltaic industry for Australia. Such a focus could include the ANU, Origin Energy and other public and private partners that can add value to a dynamic team.