Photovoltaic Solar Energy Conversion:Recent Progress

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ABSTRACT

Along with fusion energy, photovoltaic solar energy conversion has long been considered as one of the few sustainable options for large scale energy supply in the future. In the past, commercial use has been restricted largely to remote area applications where conventional electricity is expensive. However, 1998 marked a year of transition where the major application of the cells changed to become generation of residential electricity in urban areas already supplied by the conventional grid.

The current state of the technology is discussed as are major overseas programs to accelerate the urban residential use of photovoltaics, particularly in Japan, Europe and the United States, including the "million roof" program in the latter. Finally, the planned use of photovoltaics in the Sydney 2000 Olympics is described, where the technology will be used to provide most of the electricity requirements of the 665 residences which will be a legacy of the Olympic Village.

INTRODUCTION

Photovoltaics involves the direct conversion into electricity of sunlight using a sheet of semiconductor material, usually silicon. Although photovoltaics cells have been used since the 1950's in spacecraft, the interest in their terrestrial use was heightened by the oil embargoes of the early 1970's. Since then, a steadily growing terrestrial industry has developed which, in the past, has supplied cells mainly for remote area applications where conventional electricity is expensive. However, the industry is now at a turning point where the urban use of photovoltaics is beginning to surpass these remote area uses. Improving cell economics and the accelerating interest in sustainable energy generation is driving this transformation.

OPERATING PRINCIPLES

A schematic of a conventional "screen printed" solar cell is shown in Figure 1 [1]. Sunlight entering the cell is converted to an electrical current which flows through any electrical load connected between the cell terminals on the front and rear of the cell. Albert Einstein's Nobel prize winning work on the photoelectric effect provides the basis for understanding the quantum particulate behaviour of the incoming light. Each

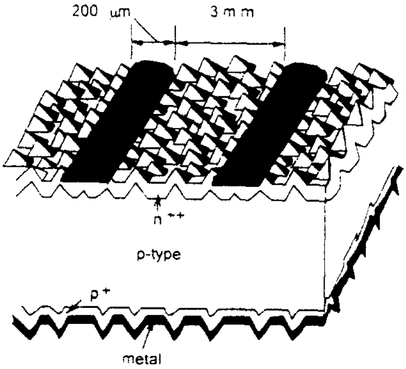

Figure 1: Standard screen printed solar cell [1].

photon in the sunlight is ideally converted into an electron within the semiconductor material forming the cell. The positive-negative (p-n) junction within the cell ensures that these light generated electrons flowing unidirectionally to the cell terminals and hence through the electrical load connected between them [2].

PRESENT CELL TECHNOLOGY

In the past, the overwhelming majority of cells have been fabricated using silicon wafers, as used in microelectronics, as the starting material and a screen printing technology for depositing the metal contact, giving the final cell structure shown in Figure 1. The main attributes of this technology are the simplicity of applying the metal contact, which uses a process similar to printing patterns on T-shirts, as well as the availability of equipment for this purpose from the hybrid microelectronics industry [1]. The price for this simplicity is substantially lower cell performance than would otherwise be possible. This sacrifice is not particularly sensible given the material intensiveness of current solar cell manufacturing, with over 40% of the cost of the final product being attributable to the cost of the starting silicon wafer used in cell fabrication.

During the early 1980's a research team at the University of New South Wales (UNSW) dramatically improved the performance of silicon laboratory cells. Highlights included the demonstration of the first ever 20% efficient silicon cell in 1985, a target long considered the "4 minute mile" of the photovoltaics area. While demonstrating those record efficiencies, the group also considered ways that these improvements could be incorporated into low cost commercial production sequences.

The result was the development of the laser grooved, buried contact solar cell shown in Figure 2. The distinctive feature of this technology is the use of lasers to form deep grooves in the silicon cell surface. Since these grooves are formed through an insulating layer on the cell surface, subsequently they can be used to define where *the metal contact is deposited by electroless* plating. This gives numerous performance advantages compared to the standard screen printing approach, by allowing the elegant incorporation of many of the performance enhancing features previously developed at UNSW [1].

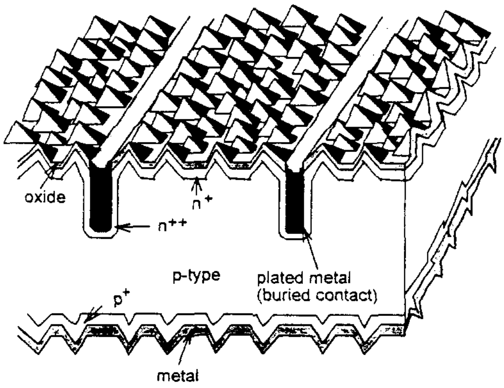

Figure 2: UNSW buried contact solar cell [Green, 1995].

This technology was licensed to Tideland Energy, a local manufacturer, in 1985. The company was almost immediately acquired by BP Solar who developed a production version of the technology at their Brookvale plant in Sydney. A pilot production plant was commissioned in Spain and operated side by side with the company's standard screen printing line, allowing a direct comparison of the relative performance and economics of the two technologies. Comparison of the output characteristics of the two technologies shows a 20-30% performance advantage for the buried contact approach [3].

Published manufacturing cost analyses by BP Solar also show that the product is no more expensive to produce per unit area, giving rise to a similar 20-30% economic advantage based on the price per Watt of the final product. A recent major European Union study showed that the UNSW buried contact cell approach was the most economic silicon cell processing method yet *suggested [4].*

Operating experience with the technology has shown an additional advantage in the field. The better quality of the product allows about 15% more energy to be generated per rated Watt under changing conditions of weather and light intensity than with standard product [5]. Not surprisingly, given these advantages and the overwhelming market acceptance of this product, BP Solar is reported to be scaling up production of the buried contact approach at the expense of its screen printed technology, reportedly targeting 10 Megawatts per year production in 1998 [6] (total world production of solar cells was 122 MW in 1997). In May, 1997, in a presentation at Stanford University, John Browne, Group Chief Executive of British Petroleum, announced the company's plan to expand its solar business to a billion dollar per year activity within the decade using its "distinctive technologies" [7]. Given the relatively immature state of its other solar technologies fitting this description, this would suggest that the Australian developed buried contact cell technology will form the basis for this billion dollar business.

THIN FILM TECHNOLOGY

Although the place of the UNSW buried contact technology as the premium industrial photovoltaic technology seems unassailable over the next 5-10 years, the long term future of photovoltaics is likely to be based on what is known as a "thin film" technology. In the thin film approach, a thin layer of the photovoltaically active material is deposited onto a supporting substrate or superstrate. This not only greatly reduces the semiconductor material content of the finished product (over 100 times less material), it also allows for higher throughput commercial production since the module, instead of the individual cell, becomes the standard unit of production (a unit some 100 times larger unit).

Since the thickness of the semiconductor material required may only be of the order of 1 micron, almost any semiconductor is inexpensive enough to be a candidate for use in the cell (silicon is one of the few that is cheap enough to be used as a self-supporting wafer based cell. Many semiconductors have been investigated with five thin film technologies now the focus of commercial development.

One type of thin film cell is based on a hydrogenated alloy of amorphous silicon, as successfully commercialized by Japanese companies, in particular, for consumer products such as pocket calculators and digital watches. The second is based on the use of the compound semiconductor, copper indium diselenide. This approach has produced the highest laboratory performance for thin film cells, with small area devices giving efficiencies above 17% but has presented manufacturing difficulties [8]. The third is technology based on cadmium telluride, which has proved to be very robust from the manufacturing point of view, but its toxicity generates serious doubts about the market acceptability. The fourth is a unique technology based on a nanocrystalline titanium dioxide in combination with organic dyes as initially developed in Switzerland but also being explored further in Australia by Sustainable Technology Australia. The fifth, and I think the most promising, is that based on thin films of polycrystalline silicon, very similar material to that already dominating the commercial market.

The UNSW research group has combined its now successfully commercialized buried contact work with a new approach to the design of thin film cells. This new approach involves parallel junctions within the cell material to produce the parallel multijunction thin film solar cell as shown in Figure 3.

This technology attracted enormous international attention on the announcement of the filing of patent applications in 1994. Since then, a new Australian company, Pacific Solar, has been established to commercialize this approach. Pacific Solar is a joint venture between leading utility, Pacific Power, and Unisearch Ltd., the commercial arm of UNSW. Pacific Solar will begin pilot line production of the thin film silicon parallel multijunction cell in 1998, with full scale production planned by the year 2001. The approach offers the potential for high cell performance at much lower manufacturing costs than present silicon cell approaches. The company's targets are to demonstrate 15% cell efficiency using this approach by 1999, while also demonstrating a manufacturing cost of less than US$1/peak Watt [9].

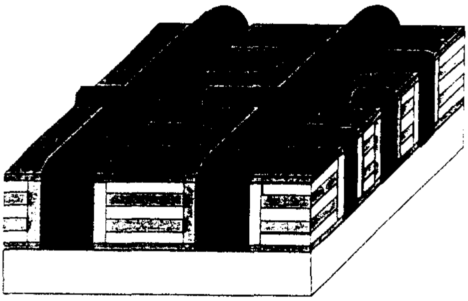

Figure 3: Parallel multijunction thin film silicon solar cell.

Given this initiative and parallel initiatives with the other cell technologies mentioned, it seems highly likely that photovoltaic cells will continue to be available at costs that steadily decrease over the company two decades. As discussed below, even at present cell costs, large new areas of applications for the cells are rapidly emerging.

APPLICATIONS

Figure 4 shows possible applications for photovoltaics. These range from small scale remote area applications which have been economical for the past 25 years, to large scale "central station" generation of power using photovoltaics which may not be fully economic until a similar time in the future. At the present point in time, an important stage in the development has been reached where the technology is making a transition from applications in remote areas to those in urban areas where reticulated electricity supply is already available. In particular, the residential application of photovoltaics has been the focus of international attention over the past few years. Quite substantial quantities of photovoltaics are being installed in this application, internationally, making it likely to surpass all others in 1998.

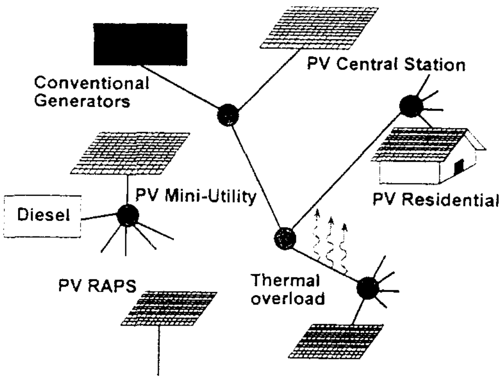

Figure 4. Range of photovoltaic applications.

RESIDENTIAL USE OF PHOTOVOLTAICS

The residential use of photovoltaics was first systematically explored in the USA during the Carter administration [2]. This work was effectively terminated during the following Reagan administration on the grounds that the industry was sufficiently mature to look after its own research needs (which, in hindsight, it clearly was not). Germany took the lead in the residential use of photovoltaics with the initiation of the "1,000 roof" program in the early 1990's. This program was intended to subsidize the installation of 1,000 photovoltaic systems, each of a few kilowatts rating, on the roofs of private residences with the systems being owned by private individuals, but with appreciable government subsidies (50-60%). These subsidies gave special rights in relation to access to the systems and use of the information being generated on system performance. The scheme was hugely over subscribed with 2,250 systems finally installed.

The Japanese had long regarded residential use as the most appropriate way of using photovoltaics for electricity production in their country, due to the limited availability of land for large centralized stations. A test bed involving 200 simulated residences each with its own simulated residential load was installed over the

1986-1991 timeframe at Rokko Island and has provided an enormous amount of information for international researchers on the interaction of these systems with the electricity network.

This steady and methodical Japanese exploration of the technical issues relevant to residential use has been followed by a similarly steady market development exercise. Beginning in 1994, with 577 private residential systems each of 3 kilowatts rating, the installation of systems in 1995 and 1866 systems in 1996 were encouraged by a 50% government subsidy [10].

In the 1997 financial year, the program changed gears with a massive increase in the number of systems to over 8,000 with a concurrent decrease in the level of government subsidy to 33-1/3%.For 1998, a 20% budget increase is expected, suggesting an additional 15,000 residential installations.

The Japanese program is part of the larger New Sunshine Project [10] calling for 80,000 roofs to be equipped with photovoltaics by the year 2000 and a massive 4.6 Gigawatts of photovoltaic systems to be installed by the year 2010.

Not to be outdone, President Clinton, in June, 1997, announced a US target of installing photovoltaics of the roofs of 1 million buildings by 2010. The European Union has generated white paper calling for the installation of 500,000 homes in Europe over a similar timeframe. Individual European countries such as the Netherlands, Austria and Switzerland have already committed to their own programs which involves of the order of hundreds of thousands of roofs in each case.

In Australia, there are very few grid connected residential systems of this type. The first large scale installation has commenced as part of the Sydney Olympics where over 650 private residences which will be a legacy of the Olympic Village will each be equipped with a 1 kW solar array [11]. With other energy efficiency features, this array has been sized to provide the majority of the electricity requirements of each of these homes. Pacific Solar, the company commercializing the UNSW thin film multilayer cell technology, has specifically targeted such residential use of photovoltaics as its market area in the post-2000 timeframe. It is important that there exist a sympathetic local environment for this new method of electricity generation if Pacific Solar's ambitious plans for maintaining Australian leadership in photovoltaic technology are to be realized. "Green Power" schemes of local utilities being co-ordinated by the Sustainable Energy Development Authority (SEDA) are helping to provide such an environment.

CONCLUSION

Photovoltaic technology is entering a new era where the urban residential generation of electricity is becoming the dominant application area. Australia is in a good position to maintain a strong presence in this industry as it grows to become a multi-billion dollar industry over the coming decade. A sympathetic environment for the introduction of grid connected residential photovoltaic systems, considered important for this continued local growth, is being established. Government programs, particularly in the demonstration area, to help identify and remove local barriers to the implementation of this technology would also seem appropriate. This would help to stimulate the growth of local industry which, by all accounts, could provide high levels of employment and plenty of export potential for the future.

ACKNOWLEDGEMENTS

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