第1章

论太阳能光伏近期发展趋势

Ⅰ 选摘专业文献(Quoted article)

Recent developments in photovoltaics[1]

Abstract

The photovoltaic market is booming with over 30% per annum compounded growth over the last five years. The government-subsidised urban residential use of photovoltaics, particularly in Germany and Japan, is driving this sustained growth. Most of the solar cells being supplied to this market are "first generation" devices based on crystalline or multi-crystalline silicon wafers. "Second generation" thin-film solar cells based on amorphous silicon/hydrogen alloys or polycrystalline compound semiconductors are starting to appear on the market in increasing volume. Australian contributions in this area are the thin-film polycrystalline silicon-on-glass technology developed by Pacific Solar and the dye sensitised nanocrystalline titanium cells developed by Sustainable Technologies International. In these thin-film approaches, the major material cost component is usually the glass sheet onto which the film is deposited. After reviewing the present state of development of both cell and application technologies, the likely future development of photovoltaics is outlined.

1 Introduction

Although photovoltaics cells have been used since the 1950s in space craft, the interest in their terrestrial use was heightened by the oil embargoes of the early 1970s. 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 (Green, 2000). However, the industry is now in an explosive period of growth where the subsidised urban residential use of photovoltaics is providing the main market. The industry has grown at a compounded rate of 30% per annum over the last five years, corresponding to a quadrupling of annual production over this period (Fig. 1).

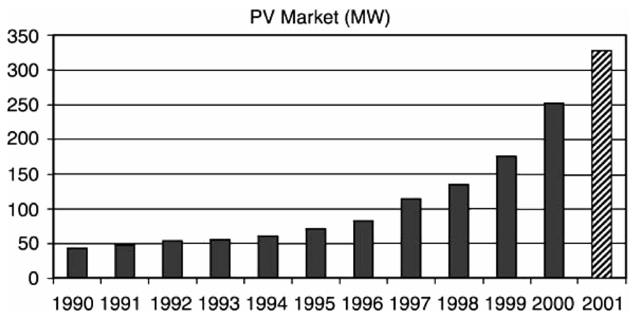

Fig. 1 Growth in PV module shipments (1999—2001).

The present healthy state of the industry is stimulating the fabrication of several large new manufacturing facilities and the commercialisation of new cell technologies. Although most of the product over the coming decade will be "first generation" silicon wafer based, it is thought likely that a "second generation" thin-film technology will make its mark during this period.

2 First generation 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 Fig. 2. 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 (Green, 1995). 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. The laser grooved, buried contact solar cell shown in Fig. 3 was developed at the University of New South Wales (UNSW) in the early 1980s as a way of transferring some of the groups laboratory improvements into commercial practice. The distinctive feature of this technology is the use of lasers to form deep grooves in the silicon cell surface.

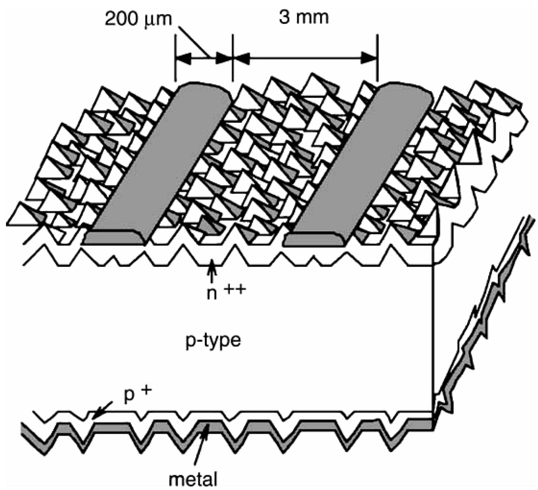

Fig. 2　Standard screen printed solar cell (Green, 1995).

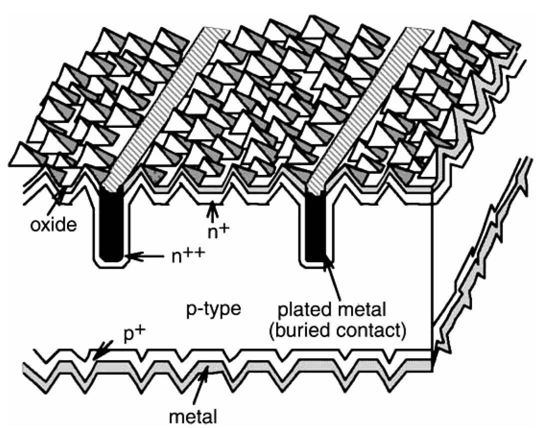

Fig. 3　UNSW buried contact solar cell.

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 (Green, 1995). Comparison of the output characteristics of the two technologies shows a 20%-30% performance advantage for the buried contact approach (BP Solar, 1991). 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 (Bruton et al., 1997). Over recent years, this technology is the one used in highest volume in Europe, with the $1 billion in accumulated sales expected well before the end of the decade.

Another recently introduced technology has been the HIT cell (Fig. 4) introduced by Sanyo which is a successful merger of that company's thin-film amorphous silicon technology and wafer-based technology.

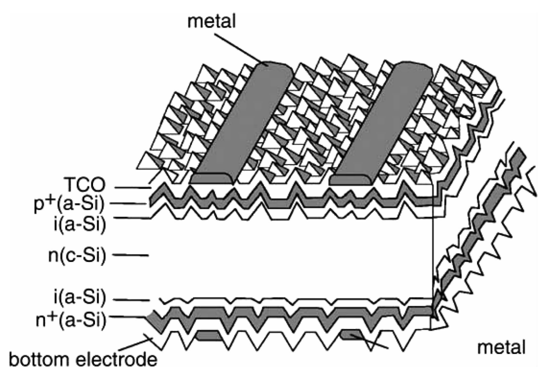

Fig. 4 Heterojunction with intrinsic thin-layer (HIT) cell.

Cell efficiencies are similar to the production values of buried contact cells, although module efficiency is higher due to denser packing in the module.

A survey of the manufacturer's nominal efficiency of a range of first generation commercial modules is shown in Fig. 5. Typical efficiency is in the 10%-15% range. Modules at the low end of this range are based on lower cost substrates such as silicon-on-ceramic ribbon or multicrystalline silicon, while those at the high end use the buried contact or HIT cell structure on single-crystalline wafers.

3 Second generation

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 lm, 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.

Thin-film cells based on a hydrogenated alloy of amorphous silicon has been successfully commercialised by Japanese companies, in particular, for consumerproducts such as pocket calculators and digital watches. Over recent years, several manufacturers, notably Solarex (now BP Solar), United Solar and Kaneka have begun marketing larger modules for outdoor use. A second approach 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 18% but has presented manufacturing difficulties (Delahoy and Myers, 1997). These arise from difficulties in maintaining the required stoichiometric composition over large areas and the complexity of the active junction regions of these devices. A third technology is based on cadmium telluride, which has proved to be relatively robust from the manufacturing point of view, but its toxicity generates serious doubts about 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 International. 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.

In 1995, a new Australian company, Pacific Solar, was established to commercialise an approach to thinfilm cells, based on combining the UNSW's group now successfully commercialised buried contact work with a new approach to the design of thin-film cells Pacific Solar is a joint venture between leading utility, Pacific Power, Unisearch Ltd. and the commercial arm of UNSW.

Pacific Solar began pilot line production of the new thin-film polycrystalline silicon of glass solar cell in 1998, with full scale production planned by the year

2005. The approach offers the potential for high cell performance at much lower manufacturing costs than present silicon cell approaches. The company reports the demonstration of energy efficiency above 8% in the previous financial year, with exceptionally high yield and repeatability. It is felt this technology overcomes difficulties with cost, stability, manufacturability, durability, and/or toxicity experienced by the other thin-film candidates.

Given this initiative and parallel initiatives with the other cell technologies mentioned, it seems highly likely that a second generation technology will make a more significant market impact than to date over this decade. This would make it likely that photovoltaic cells will continue to be available at costs that steadily decrease over the coming two decades. As discussed below, even at present cell costs, new applications are rapidly emerging.

Over the last few years, thin-film modules from production and pilot-production lines have become available on the commercial market. Fig. 6 surveys the efficiency of such present product offerings. Efficiencies tend to range from about 4% up to close to the lower end of the range of first-generation modules (Fig. 5).

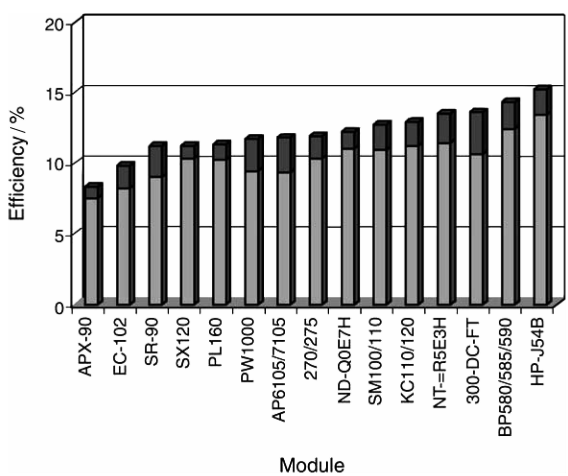

Fig. 5 Survey of first generation module efficiencies (from manufacturer's data at standard test conditions).

4 Applications

Fig. 7 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

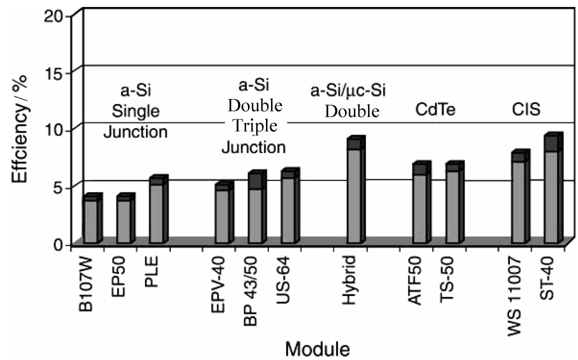

Fig. 6　Survey of efficiency of second generation thin-film solar modules (from manufacturer's data at standard test conditions).

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, surpassing all others.

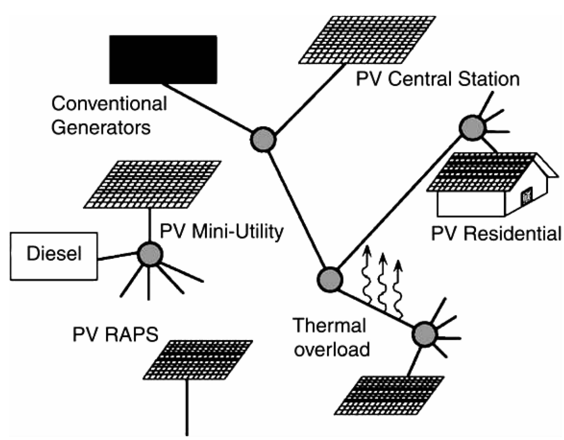

Fig. 7　Range of photovoltaic applications.

5　Residential use of photovoltaics

The residential use of photovoltaics was first systematically explored in the USA during the Carter administration (Green, 1982). 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 "1000 roof" program in the early 1990s. This program was intended to subsidise the installation of 1000 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%-70%). 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 2250 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 centralised 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 kW rating, the installation of systems in 1995 and 1866 systems in 1996 were encouraged by a 50% government subsidy (Hamakawa, 1997). In the 1997 financial year, the program changed gears with a massive increase in the number of systems with a concurrent decrease in the level of government subsidy to 33.3%.

Under this program, 70,000 roofs have been equipped with photovoltaics (Fig. 8) with a massive 4.6 GW of photovoltaic systems to be installed by the year 2010, corresponding to about 1.5 million roofs. Japanese installations reported elsewhere are shown.

In 1999, the German government implemented its own program to encourage the installation of 100,000 roofs by 2004. So far, 55,000 roofs have been approved under this program (Fig. 9). Not to be outdone, President Clinton, in June, 1997, announced a US target of installing photovoltaic.

On the roofs of 1 million buildings by 2010. The European Union has generated a 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

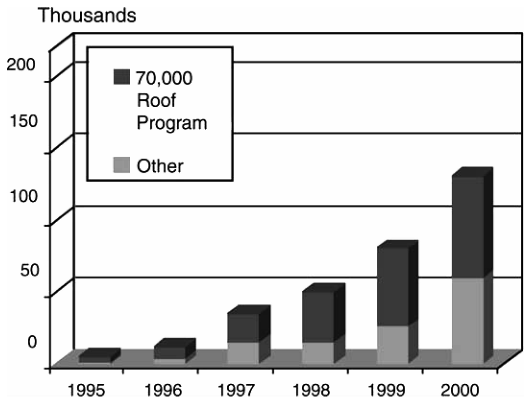

Fig. 8　Grid-connected photovoltaic systems in Japan (Hoffman,2001).

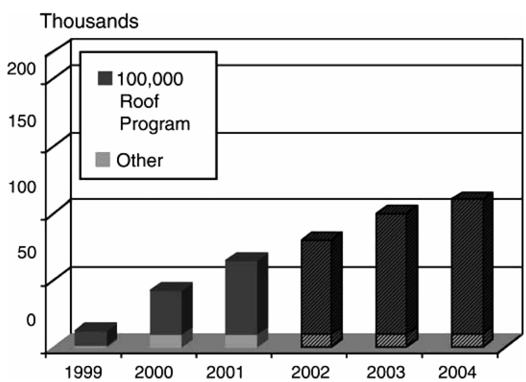

Fig. 9　Grid-connected photovoltaic systems in Germany(Hoffman,2001).

Switzerland have already committed to their own programs which involve of the order of hundreds of thousands of roofs in each case.

In Australia, there are relatively few grid-connected residential systems of this type. The first large-scale installation formed as part of the Sydney Olympics where over 650 private residences, a legacy of the Olympic Village, are each equipped with a 1 kW solar array (Green, 2000). With other energy efficiency features, this array was sized to provide the majority of the electricity requirements of each of these homes. The Federal government has announced an allocation of $32 million over the next four years, specifically to promote the residential use of photovoltaics in Australia. A subsidy of up to 50% is possible with the scheme possibly encouraging the installation of 10 000 systems over this period.

6 Conclusion

Photovoltaic technology has entered 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 important the present health of the industry, although based on a relatively fragile system of government subsidy, is helping to stimulate the introduction of improved manufacturing techniques and technology. This should see the successful introduction of a second generation thin-film technology over the coming decade. Although earlier thin-film technologies have had problems with cost, stability, manufacturability, durability and/or toxicity, the thin-film polycrystalline-silicon-on-glass technology developed in Australia by Pacific Solar would appear to offer new prospects in this area.

The cost of photovoltaic product has been following a learning curve for more than two decades whereby, for every doubling of accumulated production, costs reduce to 80% of their initial value (Green, 2000). If the current market expansion rate can be maintained over the coming decade, this means it is likely that photovoltaics will enter a period where costs are low enough to sustain this growth rate, unsubsidised. We would then be well on the way to seeing photovoltaics fulfilling its potential as one of the most benign ways of large-scale electricity production yet suggested.

Ⅱ 词汇与解析（Words and expressions）

1. solar cell　　太阳能电池
2. silicon solar cell　　硅太阳电池
3. single crystalline silicon solar cell　　单晶硅太阳电池
4. amorphous silicon solar cell　　非晶硅太阳电池
5. polycrystalline silicon solar cell　　多晶硅太阳电池
6. photovoltaic system　　光伏系统
7. photovoltaic material　　光伏材料
8. polycrystalline [pɒlɪˈkrɪstəlaɪn]　　*adj.*　　多晶的
9. semiconductor material　　半导体材料