

Current Status and Future Trends of Amorphous Silicon Solar Cells

Masahiro Sakurai
Toshiaki Sakai

1. Introduction

The Kyoto Protocol for preventing global warming was adopted at the Conference of Parties III (COP3) of The United Nations Framework Convention on Climate Change held in Kyoto, Japan in December 1997. This Protocol established numerical targets for reducing greenhouse gas emissions in 2010 for each of the participating industrialized countries. In February 2005, the Kyoto Protocol was enacted and full-scale efforts began to reduce carbon dioxide (CO₂) emissions, and subsequent efforts to introduce new energy having a low impact on the environment are expected to become invigorated.

Among the types of new energy, photovoltaic power generation systems emit no CO₂ while generating power, and their widespread use is highly anticipated. The Japanese government is promoting adoption of new energy by adopting:

- (1) measures involving power generation (① expanded adoption by the public sector, and ② technical development to promote lower cost, higher efficiency, etc.)
- (2) measures involving heat (① comprehensive plans for local governments to introduce new forms of energy, ② promotion of the Biomass Nippon Total Strategy, and ③ promotion of the introduction of biomass-derived fuel as transportation fuel, etc.)

and other measures in order to achieve the projected level of adoption of new energy in 2010 as established by the Investigative Committee on Natural Resources and Energy.

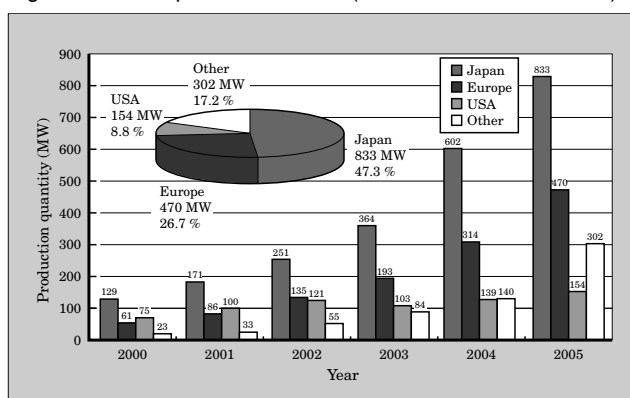
In particular, to achieve the goal of photovoltaic power generation of 4,820 MW by the year 2010, various assisting businesses (such as the Program for Infrastructural Development of Introduction of Residential PV System and Field Test Project on Photovoltaic Power Generation System for Industrial and Other Applications) and preferential governmental policies have accelerated the introduction of photovoltaic power generation. Moreover, the New Energy and Industrial Department Organization (NEDO Technical Development Organization), an independent administrative agency, has developed the “Photovoltaic Power Genera-

tion Roadmap for Year 2030 (PV2030)” which is a long-term strategy for technical development from 2004 through 2030. Here, it is assumed that by the 2030, photovoltaic power generation will provide approximately one-half of the electric power for household-use (approximately 100 GW as a photovoltaic power generating system), and therefore, technical innovation and system use have been studied in order to improve economic efficiency and to expand applicability.

Meanwhile, the production of solar cells has increased dramatically since 1997, and the produced capacity of 288 MW in 2000 has undergone a more than 6.1-fold increase to 1,759 MW by 2005. Japan accounts for 833 MW or approximately 47 % of the total production quantity. Figure 1 shows the share of total solar cell production by country. Of the solar cells produced in 2005, crystalline silicon (Si) solar cells accounted for 84 %, and thin film Si accounted for approximately 14 %, but due to the problem of depletion of Si raw material, the share of amorphous silicon (a-Si) and CIS (copper-indium-selenium) solar cells is expected to increase.

Fuji Electric began research and development on a-Si solar cells in 1978. In 1980, Fuji successfully developed and sold the world's first commercial solar cells for use in calculators. Since 1980, Fuji has been contracted to perform research under the Sunshine Program administrated by the Agency of Industrial Science and Technology that belongs to the Japanese

Fig.1 Solar cell production share (data from 2006 PV News)



Ministry of International Trade and Industry, and has developed a-Si solar cells that provide electric power. In 1993, Fuji Electric was the first in the world to achieve a 9 % conversion efficiency with a large-area a-Si solar cell (30 cm × 40 cm) that uses a glass substrate.

The commercialization of a-Si solar cells, however, would involve the batch processing of solar cells having glass substrates, and problems arise involving the long manufacturing time, substrate conveyance and handling when processing large quantities of large-area substrates (estimated to be approximately 1 m²) with a vacuum apparatus, and therefore these solar cells were poorly suited for mass production. Consequently, based on previously acquired technical expertise, Fuji Electric began developing a manufacturing process capable of simultaneously achieving high productivity and low cost since 1994, and as of October 2004 has been selling a newly developed a-Si solar cell having a plastic film substrate.

2. a-Si Solar Cell with Film Substrate

2.1 Structure of cell having plastic film substrate

The greatest advantage in using a flexible substrate such as plastic film is that a roll-to-roll process can be utilized. By placing an entire roll of the substrate in the vacuum apparatus, problems relating to substrate conveyance can be avoided and automation simplified, thereby enabling the configuration of processes suitable for large-scale mass-production.

Plastic film is electrically non-conductive and therefore can be used to fabricate integrated series-connected structures, however, because it has a low heat resistance characteristic, there are problems such as significant expansion and shrinkage of the substrate, and connective structures and processes require innovative designs. Fuji Electric manufactures solar cells using a special film having a high heat resistance characteristic as the plastic substrate material, and then forms metal electrodes, an a-Si layer and front ITO electrodes on top of the plastic film substrate.

Fuji Electric has developed a novel solar cell

structure known as SCAF (series-connection through apertures formed on film). In order to connect adjacent cells in series, holes for series connections are formed on the edges of a module, and metal electrodes formed on both surfaces of the plastic film substrate are connected via these holes to enable series connections. Figure 2 shows the series-connection structure of Fuji Electric's a-Si solar cell.

A SCAF-structure film-substrate cell is subdivided into several rectangular solar cells known as unit cells. So that the module output voltage is at a practical voltage level, it necessary to connect these unit cells in series, and a series-connection structure was realized by connecting metal electrodes of adjacent unit cells via the series connection holes provided in the film substrate. With the SCAF structure, due to the formation of several current collector holes having high resistance, the electric current generated by the unit cells avoids generating a voltage loss at the front ITO electrodes and instead flows to the metal electrodes having low resistance, and this current flow is also connected via series connection holes formed at the cell edge to the metal electrodes of adjacent unit cells. This structure enables the number of series connections to be changed by modifying the pattern, and enables a single solar cell to be capable of providing a voltage level suitable for the particular application.

2.2 Manufacturing process technology

The SCAF structure solar cell manufacturing process is based on a roll-to-roll processing method. The process consists of the steps of: ① using a substrate pre-processing apparatus to form holes in a roll-shaped film substrate by a mechanical punching method, ② using a sputtering method and an electrode forming apparatus to form metal electrodes on the film, and ③ using a stepping-roll method with a layer forming apparatus to fabricate sequentially an a-Si layer (plasma CVD: chemical vapor deposition method), front ITO electrodes (sputtering method), and backside electrodes (sputtering method). Multiple layer formation chambers are contained within a single vacuum container, and step ③ is devised such that, by stepping the substrate and then stopping the substrate inside a layer formation chamber, each layer formation cham-

Fig.2 SCAF series-connection structure

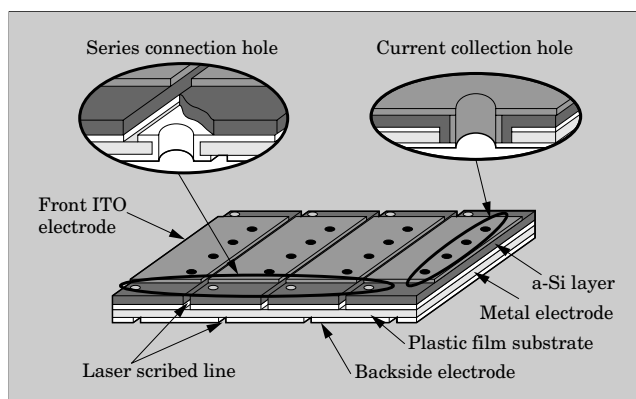
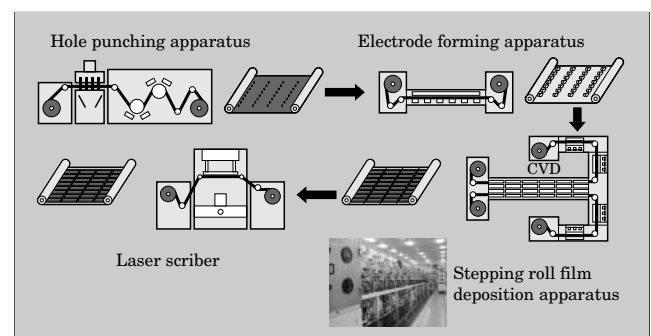


Fig.3 SCAF-structure a-Si solar cell manufacturing process



ber can operate as an independent chamber.

Figure 3 shows the process for manufacturing a SCAF-structure a-Si solar cell and the appearance of a stepping roll layer forming apparatus.

3. Application to a Photovoltaic Generation System

3.1 Advantages of film-type solar cell modules

Solar cell modules that use a SCAF-structure cell with a plastic film substrate have the following advantages.

- (1) **Lightweight:** A film-type solar cell weighs 1 kg/m², which is less than 1/10th the weight of a conventional solar cell.
- (2) **Flexibility:** The structure, which does not use glass, can be installed even on curved surfaces, and has excellent designability.
- (3) **High output voltage:** The use of an original series-connection structure makes it possible to obtain easily a high output voltage to which an inverter may be connected directly.

Consequently, all external connections between solar cells can be implemented as parallel connections, and there is no risk of incorrect wiring occurring during the fabrication of an array with series and parallel connections when using a crystalline module, and thus, system reliability is improved.

The solar cells developed by Fuji Electric are a-Si/a-SiGe tandem-type solar cells, based on a-Si technology, and have the following advantages compared to crystalline Si solar cells.

- (1) **Large annual power generation:** a-Si solar cells have a small temperature coefficient and therefore the decrease in their summertime efficiency is also small. At the same rated capacity, the annual power generation is approximately 10 % larger than a crystalline Si solar cell (according to Fuji Electric's in-house comparative data).
- (2) **Low consumption of energy during manufacture:** Compared to conventional crystalline Si solar cells, a-Si solar cells consume only a small amount of energy during manufacture, and are environ-

mentally friendly.

Figure 4 shows the results of a field test of Fuji Electric's a-Si/a-SiGe tandem solar cells in the Yokosuka area of Japan. In the figure, efficiency is shown as the ratio of power generation in the case where it is assumed that the solar cell operates with the energy conversion efficiency of standard conditions, compared

Fig.5 Metal-integrated PV module and its specifications



Fig.6 Flexible a-Si solar cell module and its specifications

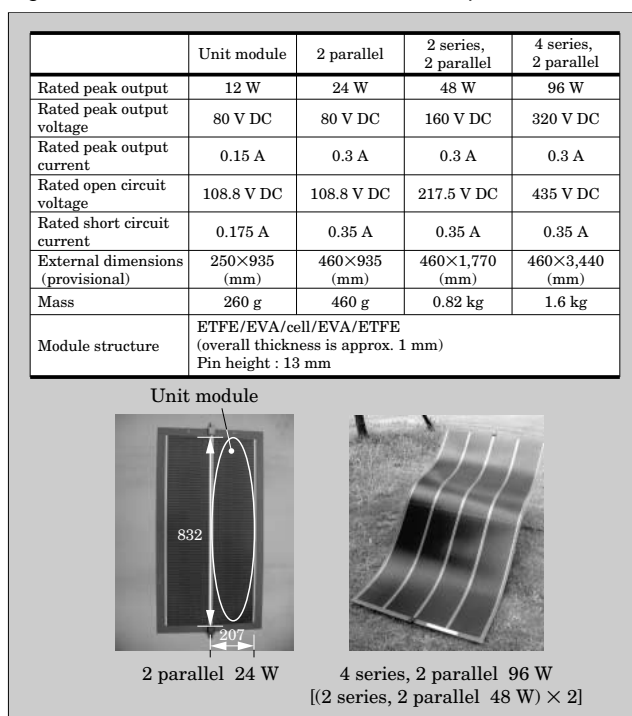


Fig.4 a-Si solar cell field test results

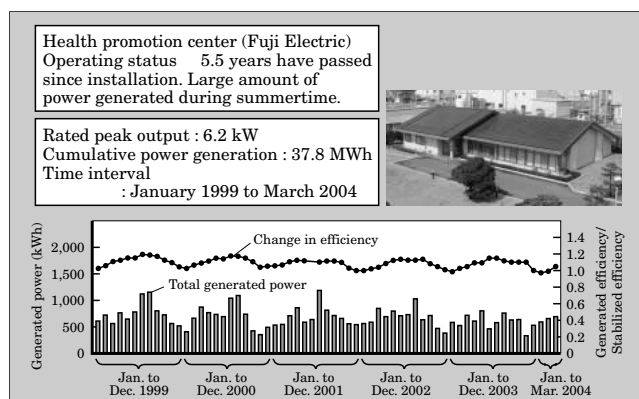
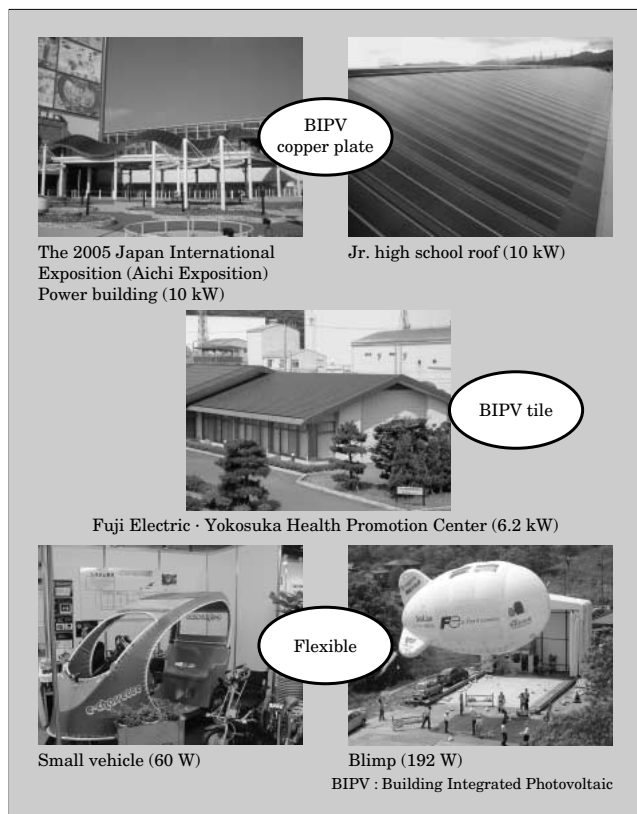


Fig.7 Example installations



to the power generation in the actual roof environment. Additionally, the stabilized efficiency shown in Fig. 4 is the value when the solar cell is exposed to light several times every 48 hours and the range of fluctuation of efficiency at that time is within 2 %.

3.2 Product form

Fuji Electric has been selling metal-integrated PV (photovoltaic) modules and film-type solar cells since October 2004.

(1) Metal-integrated PV module

Previously, most of the commercially available building-integrated PV modules had been covered with glass. Glass covered building-integrated modules have a heavy weight per unit area, and when installed at high elevations as roofing material, their size has been restricted due to safety considerations. Targeting application to buildings, and especially the rooftops of public and industrial buildings, for which large demand is anticipated, Fuji Electric has developed a lightweight metal-integrated PV module constructed from a film-type PV module laminated directly to a steel plate.

The metal-integrated PV module has a weight, not including the steel plate, of approximately 1 kg/m², and has a total weight, including the steel plate, of approximately 4 to 8 kg/m², which is approximately half that of the conventional stationary-type PV module. Therefore, when solar cells are to be installed, there is no need to drastically redesign the load

resistance of the structure, and further, since construction can be carried out in the same manner as a usual metal roof, a well-designed metal roof with attached solar cells can be realized at low cost. Figure 5 shows the appearance of metal-integrated PV modules and lists the specifications.

(2) Flexible film solar cell

Modules suitable for curved surfaces because they use a flexible plastic film as the substrate and do not use constraining members such as a glass cover or a frame can also be installed. Application and development is being advanced in fields such as buildings where the visual design is important, or power supplies for electronic devices where lightweight is desired. Additionally, as a PV module suitable for many applications, including power supplies for energy-saving devices, independent power supplies, emergency power supplies, etc., Fuji Electric has also developed a film-type PV module capable of parallel and series connections and consisting of unit sub-modules of 12 W each. Figure 6 shows the appearance of a flexible a-Si Solar Cell module and lists its specifications.

3.3 Example installations

Figure 7 shows example installations that leverage the advantages of metal-integrated a-Si PV modules and flexible a-Si PV modules.

4. Conclusion

The production of solar cells continues to grow at an annual rate of greater than 50 %, and the cumulative produced capacity is predicted to reach 4.82 GW by 2010 and 34 GW by 2020. The market size is expected to reach 1 trillion yen by 2020. In the future, a large gain in market share is forecast for thin film solar cells, and under these favorable market conditions, Fuji Electric has begun selling two types of PV modules that use flexible a-Si solar cells having a thin film substrate. Fuji Electric intends to continue its R&D efforts in order to reduce cost and boost efficiency, and to advance the development of new applications that leverage the lightweight, flexibility and other advantages of flexible a-Si solar cells.

References

- (1) Ichikawa, Y. et al. Large-Area Amorphous Silicon Solar Cells with High Stabilized Efficiency and their Fabrication Technology. Proc. of 23rd PV Specialist Conf. USA. 1993, p.27.
- (2) Ichikawa, Y. et al. Production Technology for Amorphous Silicon Based Flexible Solar Cells. 11th Int'l Photovoltaic Science and Engineering Conference. Sapporo, Japan, 1999, p.49.
- (3) Ichikawa, Y. et al. Large-Area Amorphous Silicon Solar Cells with High Stabilized Efficiency and their Fabrication Technology. Proc. of 23rd PV Specialist Conf. USA. 1993, p.27.



* All brand names and product names in this journal might be trademarks or registered trademarks of their respective companies.