Photovoltaic Module as Source of Infinite Energy for the Earth

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1. Introduction

Photovoltaic (PV) modules generate energy without emitting appreciable CO_2 or other pollutants after their installation. Prospects for PV modules are growing as countermeasure against global warming and exhaustion of oil resources. The PV module market has been expanding rapidly in recent years. To expedite the spread of PV modules, it is necessary to offer products that are not only environmentally-friendly but also capable of convincing customers that the introduction of such products will bring a high return on their investment.

Mitsubishi Heavy Industries, Ltd. (MHI) has been engaged in the development of such products, always paying strong attention to customers' needs and giving top priority to technologies that will create high added-value for the products. This paper introduces the innovative technologies for the amorphous Si/microcrystalline Si tandem PV module[1] developed as a next-generation version of the amorphous Si PV module, whose industrial production started in 2002.

2. New technologies that enable high performance and cost reduction

The key technologies that enable high performance and cost reduction of the amorphous Si/microcrystalline Si tandem PV module (**Fig. 1**) include a technique for light entrapment for efficient utilization of solar light and a technique for high-rate and high-quality microcrystalline silicon thin-film deposition aiming at higher productivity.

The thickness of the microcrystalline silicon film is approximately 1/100 that of the crystalline Si PV module. Therefore, there is a requirement for a light entrapment technique to elongate the substantial light path length within the thin film. A texture structure to allow light diffusion is provided in a transparent electrode film on the solar light incidence side.

In order to optimize the texture structure, the diffusion of longer wavelength light is accelerated by using the analytical result of the finite difference time domain (FDTD) method[2] shown in **Fig. 2**.

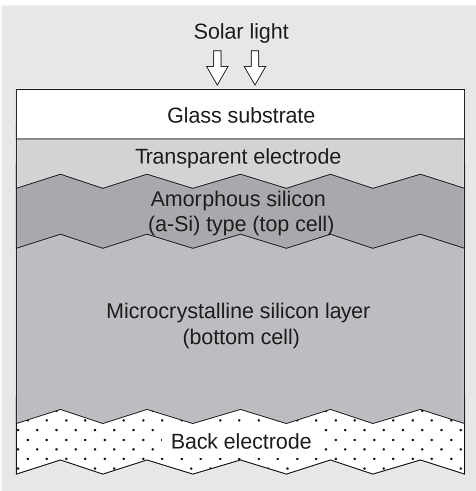

Fig. 1 Amorphous Si/microcrystalline Si tandem PV module structure
The a-Si top cell and the microcrystalline Si bottom cell are deposited to broaden the usable wavelength range of the solar light, thereby increasing the energy generation efficiency.

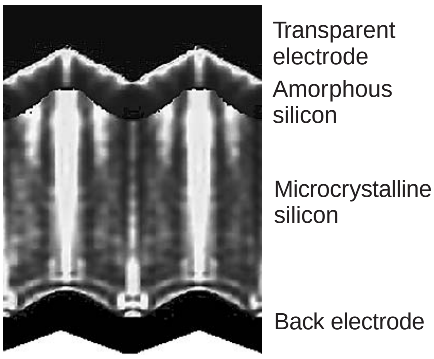

Fig. 2 An example of light entrapment analysis by FDTD method (wavelength range: 300-1200 nm)
Light diffusion, absorption and reflection by micro-structure whose size compares to the light wavelengths are calculated and used in designing the cell structure.
The brightness expresses the degree of light absorption in each layer.

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The reflectivity of the back electrode for the incident light was also improved by using the back electrode materials and optimizing process conditions, resulting in improving the light trapping between the transparent electrode of the incidence side and the back electrode. As a result, initial cell efficiency of 13.5% was achieved.

In order to obtain a high-quality microcrystalline silicon film, it has conventionally been necessary to restrict a deposition rate of approximately 0.5 nm/s or less. MHI has developed technology of high-density VHF (very high frequency) plasma CVD (chemical vapor deposition) method with low ion damage by using a modified ladder-shaped electrode .

MHI has developed a high-quality microcrystalline silicon film at a deposition rate of 2.5 nm/s, which is five times higher than the usual deposition rate as shown in **Fig. 3**[3].

3. Advanced technology that supports next-generation PV module production

In order to lower the cost of PV modules, it is necessary to raise their performance and simultaneously to develop an outstanding mass-production technique. It is important to improve the production line capability and continue its stable operation.

As long as the plasma CVD mass-production technique (the core technology of the production process) depends on the conventional technique available commercially, the production capacity will be severely limited and the production cost reduction will not be realized. MHI has independently developed plasma CVD facilities using the world's top technology in the possession relating to heat, fluid and plasma. MHI has significantly promoted (1) fabricating large area PV modules, (2) processing time reduction and (3) improvement of the operation rate using these plasma CVD facilities.

Regarding the mass-production of amorphous PV modules, MHI has already realized extremely high productivity[4]. MHI has developed the film deposition technology of the amorphous Si/microcrystalline Si tandem PV module based on the above-mentioned amorphous Si PV module production technique.

(1) Fabrication of large area PV modules

A microcrystalline silicon production facilities were produced by improving the world's largest 1.54 m^2 (1.4 m × 1.1 m) amorphous PV module film deposition facilities (**Fig. 4**). Surface area enlargement of the deposition and effective generation was realized by uniform film deposition based on the phase modulation method as shown in **Fig. 5**.

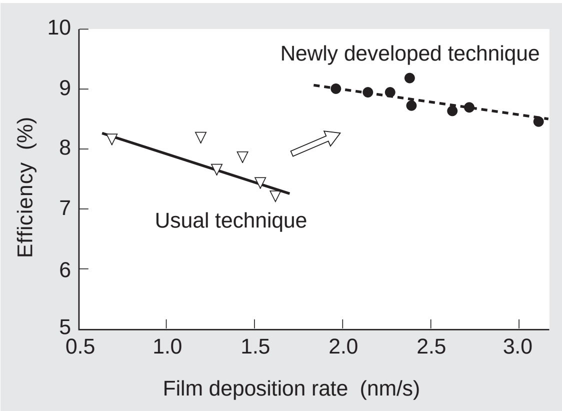

Fig. 3 Microcrystalline silicon film high-quality and high-rate formation
A film deposition technique has been developed that prevents efficiency loss even when the film deposition rate is increased by five times.

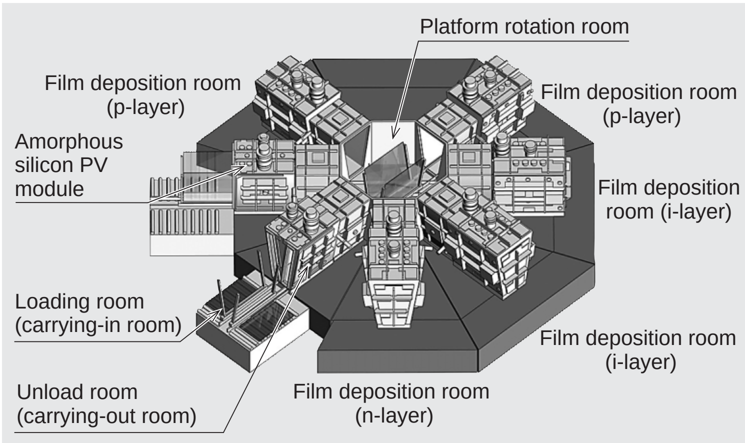

Fig. 4 Five-room star layout large-area high-rate plasma CVD facilities
Developed by "NEDO 2000 - 2001 PV module system for promoting technical development project."

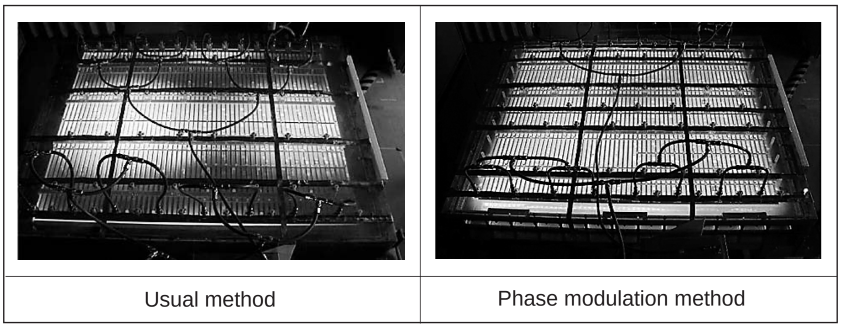

Fig. 5 Large-area uniform plasma generation
By the usual method, plasma emission distribution cannot be uniform under the influence of the standing wave, but the phase modulation method enables uniform plasma generation.

(2) Processing time reduction

The processing time was shortened by increasing the film deposition rate and the substrate temperature raising/droping speed. Since the microcrystalline silicon film is five times thicker than that of the amorphous film, new type large-area electrodes which do not degrade the film quality in high-rate film deposition were developed to complete all of the processes in the same processing time as in the case of the amorphous type.

In the high-rate film deposition, a high-power VHF is supplied to generate high-density plasma. Substrate deformation in the plasma was restricted by introducing VHF power to the substrate uniformly so as to uniformalize the substrate temperature distribution and by designing the facilities using the nonstationary thermal analysis technique. As a result, the processing time was significantly shortened without any troubles.

(3) Self-cleaning for upgrading of the rate operation

Within the film deposition facilities, the Si film is deposited not only on the substrate surface but also on interior structures such as the ladder electrode. If the excess film on the interior structures separates and adheres to the product, the product will be defective, degrading the product yield rate. In order to prevent this, it was necessary to remove the excess film deposit periodically.

MHI has developed a self-cleaning technique which completely removes the excess Si film deposited inside without opening the film deposition facilities. This technique enables continuous production without suspending the operation of the facilities except for the air-exposed inspection that is performed a few times every year.

4. Conclusions

MHI is engaged constantly in the development of thin-film Si PV modules that can be used as a clean and trouble-free power source. A new product with a power generation efficiency of 12% has thus been developed incorporating MHI's own advanced techniques in various parts of the product. MHI believes that the products will offer the customers value that is superior to that of the conventional crystalline Si PV module, and also solve the energy problem of our resources-impoverished country.

It is also our pleasure to mention that development of the amorphous Si/microcrystalline Si tandem PV module is in progress by MHI under the consignment of New Energy and Industrial Technology Development Organization (NEDO) and under the guidance of the National Institute of Advanced Industrial Science and Technology (AIST). MHI is also highly proud of expressing its appreciation for the assistance of these organizations.

References

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