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World's largest amorphous silicon photovoltaic module

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Abstract

In order to reduce costs for thin film Si photovoltaic solar, large area VHF plasma CVD technology was developed. Two VHF voltages which had the phase difference controlled by the phase-shifter are supplied to the both ends of an electrode, which is successful in getting time-averaged uniformity of VHF voltage on the electrode. Using the frequency of 60 MHz, the a-Si film with the deposition rate of 1.7 nm/s $\pm$18% was prepared on a 1.4 m $\times$ 1.1 m glass substrate. A plasma CVD apparatus with 5 deposition chambers configured in a star shape was fabricated for the production of a-Si solar modules. 728 modules of 1.4 m $\times$ 1.1 m were manufactured during the long-run producing test in which deposition and plasma-cleaning were repeated. 93% of total modules manufactured in this test had electric outputs that were included within $\pm$2% of the deviation of the average module output.

Keywords: PECVD; VHF plasma; a-Si; Solar cell; Ladder-shaped electrode

1. Introduction

Photovoltaics solar cell is establishing the status as power generation technology that provides electricity demand in the near future. Thin film Si solar cell is considered to be the solar cell of the next generation following the present mainstream crystal Si solar cell, and the early introduction is strongly desired. For this reason, the reduction in cost is important as well as improvement of conversion efficiency. It is required to improve the productivity of the plasma CVD equipment which is the main equipment on manufacture of thin film Si solar cell, and the development of the plasma CVD method having the ability to fabricate quality Si film uniformly on a large area substrate at high deposition rate is very important.

The VHF plasma CVD is one of the methods that have actual results most in respect of highly quality deposition at high speed, and many researches have been done from the second half of the 1980s [1–5]. However, since the standing wave generated on an electrode made the voltage distribution on an electrode non-uniform, large-area uniform film was impossible [6,7]. As a result, VHF plasma was not used in practical production.

We have developed a so-called ladder shaped electrode for large area plasma CVD to replace the conventional parallel plate type electrode, and have pursued larger area VHF plasma using this new electrode [8]. Accordingly, as reported in our previous research [9], we have proposed the method of reducing the influence of the standing wave by applying multiple power feeding technology to the ladder-shaped electrode. By using this method, we produced a 60-MHz VHF-excited SiH_4 plasma and succeeded in preparing a high-speed and high-quality a-Si:H film of the deposition rate of 1.5 nm/s and 10^6 in ratio of photoconductivity/dark conductivity, over a glass substrate of 50 cm $\times$ 40 cm, with a distribution of $\pm$10%. However, this method could not be applied for deposition on the substrate exceeding 1 m $\times$ 1 m in size, which is deemed necessary for cost reduction to

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facilitate actual production of thin film silicon solar cells. This reason was because the voltage distribution on the electrode exceeding a length of 1 m was fully uncontrollable only by the multiple power feeding method described above. That is, when the size of the substrate exceeds 1/4 of the wavelength, nodes of standing wave are generated, and the deposition rate in those locations becomes slower.

Given these circumstances, we developed a new VHF power supply technology so as to enable uniform deposition onto large area substrate greater than 1 m^2 in size. Based on this method, we then developed large area VHF plasma CVD equipment applicable for the production of amorphous silicon solar cells. Plasma cleaning technology using NF_3 was also developed and applied in this equipment for improving productivity, specifically with respect to a-Si solar cells. Extremely stable production was confirmed for prototype a-Si cells thus manufactured, and the corresponding research results are reported below.

2. Experimental

A schematic diagram of the experimental apparatus is shown in Fig. 1. The system consists of a vacuum chamber, a ladder-shaped electrode and a RF power source. A VHF plasma was produced using a ladder-shaped electrode, which was positioned within a stainless steel vacuum chamber. The vacuum chamber was electrically grounded. SiH_4 and H_2 gas were used and were introduced through many small holes on the ladder-shaped electrode.

Fig. 2 shows a schematic diagram of the ladder electrode, and the new VHF power supply method, so-called the phase modulation method. The ladder-shaped electrode consists of metallic rods structured in ladder-like arrangement, and with external dimensions of 1.5 m × 1.2 m. VHF power at a frequency of 60 MHz was used for plasma formation. The VHF signal generated from an oscillator is divided into two using a splitter, and is supplied to the upper and lower sides

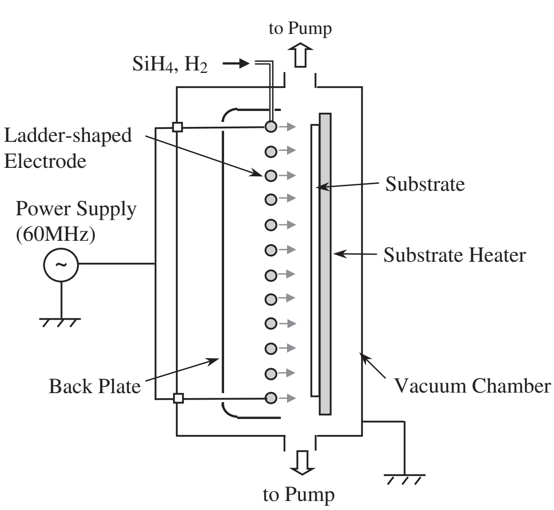

Fig. 1. A schematic of the experimental setup.

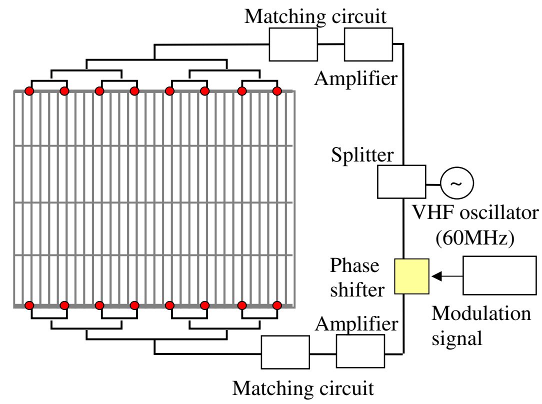

Fig. 2. Aschematic diagram of the ladder electrode, and the supply method of phase modulation method.

of the ladder-shaped electrode through a matching circuit and a power amplifier, respectively. The phase differential between two VHF signals is modulated using a phase shifter. The positions of the standing wave nodes could thus be changed, and the time-averaged voltage on the electrode could be made uniform.

The VHF plasma technology indicated above was applied to the i-layer deposition chamber of the plasma CVD equipment developed by Mitsubishi Heavy Industries, Ltd. (MHI), and prototype solar cells were manufactured. This plasma CVD equipment features a cluster configuration consisting of five deposition chambers, a load lock chamber and an unloading chamber arranged around a substrate transport chamber. Of the five deposition chambers, two are for p-layer deposition, two are for i-layer deposition, and one is for n-layer deposition. The size of the substrate is 1.4 m × 1.1 m, the largest size substrate class in the world. In order to improve the operating rate of the plasma CVD equipment, a plasma cleaning system using NF_3 gas has been installed so as to eliminate the need for overhaul to remove Si film accumulates on the electrode.

In order to evaluate the quality of the film on the glass substrate, Si–H_2/Si–H bonding ratio in a-Si films was measured using the out-situ ATR method. Prototype a-Si solar cells were of the ordinary p-i-n single type, with a construction consisting of glass/SnO_2/B-doped a-SiC:H/buffer layer(a-SiC:H)/a-Si:H /P-doped a-Si:H/back contact electrode. Solar cell performance was measured by means of a solar simulator.

3. Results and discussion

Fig. 3 indicates the deposition rate distribution for a-Si film on 1.4 m × 1.1 m substrate, using the new VHF power supply technology. Deposition gas conditions were 2 SLM for SiH_4, 10 SLM for H_2, and pressure of 45 Pa. The deposition rate distribution was ±18%. As can be confirmed from the figure, the film distribution deteriorates at the edges of the substrate, but this is due to interference with the