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## B-4-4 Improvement of The Open Circuit Voltage of Amorphous Silicon Solar Cells

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Hydrogenated amorphous silicon (a-Si(H)) shows large optical energy gaps. Therefore, it is expected that solar cells with high open circuit voltages ( $V_{oc}$ ) can be obtained by using plasma deposited a-Si(H) films. So far the reported open circuit voltages of high efficiency a-Si(H) solar cells, however, are only about 0.8 V for a Schottky barrier cell<sup>1)</sup> (5.5%) and 0.6 V for a p-i-n cell<sup>2)</sup> (4.5%). For the increase of a-Si(H) solar cell efficiencies, we have been investigating the way to improve the  $V_{oc}$  of p-i-n a-Si(H) solar cells.

To improve the  $V_{oc}$ , it is necessary to prepare high quality a-Si(H) films. The RCA group<sup>3)</sup> had reported that values of  $I_{sc}$  of Schottky barrier cells varied by ~ 30% and this variation was probably due to the influence of the chamber walls on the discharge (chamber diameter  $\simeq 6$  cm). M. Taniguchi<sup>4)</sup> et al had produced a-Si(H) films under magnetic field in a glow discharge of silane, and reported that impurity doping efficiency had been improved because the discharge plasma was accumulated to the center of the reaction chamber. To elminate the influence of the chamber walls on the discharge, we have prepared a-Si(H) films in large diameter reaction chamber of an inductively coupled RF glow discharge system and fabricated p-i-n type a-Si(H) solar cells.

Figure 1 shows the RF glow discharge system for the deposition of a-Si(H) films. The reaction chamber diameters are 16 cm (A) in large and 5.5 cm (B) in small to investigate the influence of the chamber walls on a-Si(H) solar cell characteristics. The discharge plasma is excited with 13.56 MHz radio frequency (15 W) under a gas pressure of 0.6 Torr of SiH<sub>4</sub> diluted with hydrogen to 25 %. Under these conditions, the discharge plasma has a tendency to be accumulated to the center of the chamber. Doping is achieved by adding to SiH<sub>4</sub> the desired amouts of PH<sub>3</sub> and  $B_2H_6$ . Corning 7059 glass coated with ITO is used as substrate material and substrate temperature is about 280 °C ~ 290 °C.

Figure 2 shows the AM 1 (100 mW/cm<sup>2</sup>) photovoltaic I-V characteristics of thus produced p-i-n solar cells (cell area 4 mm<sup>2</sup>) in the chamber A and the chamber B. The layer thicknesses are 100 Å, 5000 Å and 400 Å for p-type, non-doped i- and n-type layers, respectively. The non-doped i-layer shows the dark conductivity  $\delta_{d} \simeq 1 \times 10^{-9} (\Omega - \text{cm})^{-1}$  and the photo-conductivity  $\delta_{L}=4 \sim 6 \times 10^{-4} (\Omega - \text{cm})^{-1}$ . In the case of the chamber A, high  $V_{\text{oc}}$  of 0.845 V is obtained and the AM 1 photovoltaic conversion efficiency is 5.0 %. In the case of the chamber B, however, the  $V_{\text{oc}}$  decreases to 0.78 V and also the conversion efficiency decreases to 3.5 %.

Farther investigations to improve the  $V_{OC}$  of p-i-n solar cells in the case of the chamber A have been performed under various a-Si(H) film deposition conditions. As an example of such deposition condition, effects of p-layer impurity doping ratio  $(B_2H_6/SiH_4)$  on the solar cell performance have been examined, and the result is shown in figure 3. When the doping ratio  $(B_2H_6/SiH_4)$  increases more than 5 x 10<sup>-3</sup>, the  $V_{OC}$  shwos high values more than 0.8 V, and the maximum  $V_{OC}$  of 0.87 V is attained. The short circuit current  $(I_{sc})$  is also shown in figure 3, and exhibits large values between 2 x  $10^{-3}$  and 8 x $10^{-3}$  doping ratio.

The open circuit voltage is  $V_{OC} = \frac{nkT}{q}$  (  $1 + \ln \frac{I_{SC}}{I_O}$  ), where  $I_O$  is the saturation current. Figure 4 shows the dark I-V characteristics of a -Si(H) solar cells representative of the  $V_{OC}$ . The  $V_{OC}$  increases as the  $I_O$  decreases. The minimum value of  $I_O$  obtained in this work is  $3 \times 10^{-11} \text{ A/cm}^2$ . The saturation current  $I_O$  is greatly affected by the i-layer defect state density. It is clear that a-Si(H) film quality of the reduced  $I_O$  value has been more improved than ever.

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Figure 1. RF glow discharge system for the deposition of m-Si(H) films. Chamber A diameter is 16 cm. Chamber B diameter is 5.5 cm.









