

Title	Cat-CVD a-Si:H膜へのFLAによるpoly-Si:Hの形成と薄膜シリコン太陽電池への応用
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# Abstract

The use of solar energy has always been a priority in order to solve environmental issues. Of a wide variety of solar cells, crystalline silicon (c-Si) solar cells have been utilized most widely. Thin-film polycrystalline Si (poly-Si) solar cells, expected to be one of the future low-cost solar cells, require only a few  $\mu\text{m}$  of Si material. We use flash lamp annealing (FLA) to crystallize amorphous Si (a-Si) in a millisecond range duration using pulsed light from a xenon lamp. We have thus far demonstrated the formation of phosphorus doped n-type polycrystalline Si (n-poly-Si) films by crystallizing precursor hydrogenated P-doped a-Si (n-a-Si:H) films by FLA on Silicon nitride ( $\text{SiN}_x$ )-coated textured glass substrates. The doping concentration can be controlled and consistent before and after crystallization. We have also confirmed that explosive crystallization (EC) occurs during FLA. The potential of the absorption layer is estimated by fabricating a test cell with a simple back-contact structure. This test cell can estimate the  $J_{\text{SC}}$  and the  $V_{\text{OC}}$ . To investigate the potential of poly-Si formed by FLA, I fabricate and characterize the test cells. I used Corning Eagle XG glass substrates. Texture patterns were formed by reactive ion etching. Silicon nitride ( $\text{SiN}_x$ ) and several  $\mu\text{m}$ -thick n-a-Si:H with a P concentration  $\sim 2 \times 10^{17} \text{ cm}^{-3}$  were deposited on the textured glass substrates by Cat-CVD. After crystallizing by FLA, I performed Cat-CVD hydrogen treatment (Cat-HT) and electric furnace heat treatment for 30 min for defect reduction. I deposited Cat-CVD i-a-Si:H bilayer films and  $\text{p}^+$ -a-Si:H emitter layer to create a  $\text{p}/\text{i}_1/\text{i}_2$ -a-Si:H stacked structure for solar cells. Minority carrier lifetime ( $\tau_p$ ) of crystallized Si films was characterized by  $\mu$ -PCD method. ITO film was deposited by sputtering. A Kapton tape with a diameter of 8 mm was stuck on the ITO film, and then the sample was immersed in  $\text{HNO}_3/\text{H}_3\text{PO}_4/\text{HF}/\text{H}_2\text{O}$  solution to etch ITO and a-Si:H layers. An Al electrode was deposited thereon by vacuum evaporation. Suns- $V_{\text{OC}}$  measurement was also performed to extract  $V_{\text{OC}}$  and pseudo fill factor (pFF).

The i-bilayer structure significantly improved the  $\tau_p$  compared to the sample with  $\text{p}/\text{i}_1$  film. This is attributed to be due to the annealing of the  $\text{i}_1$  film by increasing the substrate temperature ( $T_{\text{sub}}$ ) in the second layer, which causes the termination of dangling bonds on the n-poly-Si surface by migrated hydrogen in the first layer. This result suggests that stacked a-Si:H passivation on n-poly-Si films is useful for improving solar cell characteristics. However, excessively thick a-Si:H increases parasitic absorption and series resistance, leading to the degradation of solar cell characteristics. Further improvement of carrier lifetime is expected by selecting appropriate film thickness and depositing low-defect passivation films. An increase in  $V_{\text{OC}}$  by using the i-bilayer structure can also be confirmed in the Suns- $V_{\text{OC}}$  curves. The low pFF value of 0.60 also indicates the poor surface passivation effect of the single i-layer. By using the i-bilayer, the pFF improves to 0.70, which is 0.10 higher than that obtained for the single i-layer. The  $V_{\text{OC}}$  of the cell with a single i-layer passivation film was 0.2 V, whereas the  $V_{\text{OC}}$  of the cell with i-bilayer improved to 0.44 V. This result adequately suggests that stacked a-Si:H passivation of n-poly-Si films is useful for improving solar cell properties.

In the heat treatment results. The  $\tau_p$  increases gradually with increasing annealing temperature, improving significantly at 450 °C and decreasing at higher temperatures.  $\tau_p$  increase is due to the increased diffusion length of H atoms at higher treatment temperatures, as well as the dissociation of  $\text{H}_2$  molecules and the number of H atoms to bond DB in the Si film increases. On the other hand, when the annealing temperature exceeds 450 °C, the Si-H bonds are broken and the effect of H termination is lost, resulting in a significant decrease in  $\tau_p$ . It is considered that low temperature and short annealing time are insufficient to terminate DB, while high temperature and long annealing time result in a large amount of H loss in the film due to Si-H bond break. Therefore, I confirmed that heat treatment is effective in reducing defects in n-poly-Si. Using the hydrogen present in the n-poly-Si film, a passivation performance equivalent to that of the i-a-Si:H stacked structure was obtained after heat treatment. A  $V_{\text{OC}}$  value of about 0.40 V was achieved with heat treatment. In Cat-HT, the effects of  $T_{\text{sub}}$ , pressure, hydrogen flow rate, and processing time of Cat-HT on  $\tau_p$  of n-poly-Si thin films were investigated, and it was found that HT by Cat-CVD system is effective for defect termination. Cat-HT improved test cell characteristics.  $J_{\text{SC}}$  improved from 0.005  $\text{mA}/\text{cm}^2$  to 0.06  $\text{mA}/\text{cm}^2$  due to the termination of DB at grain boundary defects. In addition,  $V_{\text{OC}}$  due to defects in the cell grains and grain boundaries before Cat-HT improved from 0.30 V to 0.44 V.

**Keywords:** Cat-CVD (Catalytic Chemical Vapor Deposition), FLA (Flash Lamp Annealing), Simple back contact solar cell, Passivation, Defect reduction.