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High Voltage Bifacial Amorphous Si Quintuple-Junction Solar Cells for IoT Devices

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Abstract

A bifacial amorphous Si quintuple-junction solar cell was proposed as a power source for IoT devices. In addition, a-SiO_x:H/ a-SiO_x:H/a-Si:H/a-SiO_x:H/ a-SiO_x:H quintuple-junction solar cells were fabricated by plasma CVD method. As a result, a very high open circuit voltage of 3.4 V was demonstrated under LED light illumination.

1. Introduction

Recently, development of solar cells as a power source for IoT devices such as sensors, has come to attract attention. Interconnected hydrogenated amorphous Si(a-Si:H) solar cells have been widely used for consumer applications in order to increase the operating voltage. On the other hand, with the decrease of the operating voltage of the LSI, it is expected that a high voltage capable of sufficiently driving the sensor can be obtained by using a multi-junction solar cell structure without using interconnection technology such as laser processing. In this paper, we have proposed and developed a high-voltage multi-junction amorphous Si solar cell for LED light illumination which will become mainstream in the future.

2. Proposal of Bifacial Amorphous Si Quintuple -Junction Solar Cells

When a solar cell is used as a power source of a sensor device, operating voltages of 3V or more are required. When an amorphous Si single-junction solar cell is operated under sunlight of 100 mW/cm^2, the open circuit voltage is on the order of 0.85 V. On the other hand, in applications for IoT devices, the irradiation intensity is on the order of 1-3 mW/cm^2 or 1,000 -3,000 lux. When the irradiation intensity becomes 1 / 100th of that of sunlight, the open-circuit voltage of the a-Si solar cell drops by about 150-200 mV. Therefore, to obtain an operating voltage of 3 V or more, an amorphous solar cell with 5 junctions (quintuple-junction) is required.

In the development of amorphous Si-based multi-junction solar cells for power use, quadruple-junctions have been reported up to now[1-3]. However, because it uses sunlight containing a lot of infrared light as a light source, it has a structure such as a-Si:H /a-Si:H/a-SiGe:H/μc–Si:H and as a bottom cell, narrow gap materials such as a-SiGe:H or μc-Si:H are widely used. Therefore, the open-circuit voltage of the bottom cell is lowered, and as a result, the open-circuit voltage is about 2.8 V under sunlight. Even if the conventional quadruple-junction solar cell is operated under room light, the open circuit voltage drops to about 2.3 V.

In this paper, we proposed a quintuple-junction solar cell consisting of amorphous Si(O):H for LED illumination with high short-wavelength component ratio compared with sunlight. The emission spectrum of LED lighting is completely different from the solar irradiation spectrum. In the quintuple-junction solar cell, the bottom cell becomes very thick in order to keep current continuity between cells(1st – 5th cell). Therefore, in this paper, we proposed a bifacial a-Si(O):H multi-junction solar cell that generates high voltage while keeping the thickness of the amorphous layer thin. In bifacial solar cells, the light is illuminated from the front side as well as from the rear side. In the case of indoor use, since light is often irradiated from all directions by reflection from the wall, “bifacial” functions effectively. The bifacial cell has the merit that the bottom cell can be as thin as about 100 nm like the top cell.

Originally the bifacial amorphous Si single-junction solar cell was first reported by M.Konagai in 1982[4], but there were no reports of bifacial a-Si:H solar cells for multi-junction. In this paper, we developed the world's first quintuple-junction amorphous Si solar cell and achieved an open circuit voltage of 3.4 V (3,000 lux).

3. Solar Cell Structure and Preparation Method

Fig. 1 shows the structure of a quintuple -junction solar cell. As the substrate, a UV-type substrate (Glass/SnO_2) manufactured by Asahi Glass Co., Ltd. was used.

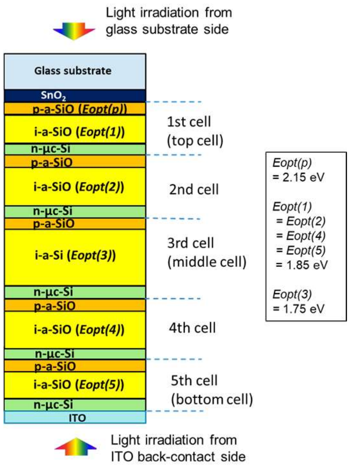

Fig.1 Structure of a quintuple -junction solar cell.

Each layer was deposited by a plasma CVD method. The first cell (top cell) and the second cell consist of wide bandgap a-SiOx:H (*Eopt*=1.85 eV) developed by D.W.Kang et al.[5][6] . For the third cell (middle cell), conventional a-Si:H (*Eopt* =1.75 eV) is used. The fourth cell and the fifth cell (bottom cell) are the same as the second cell and the first cell, respectively. In particular, a-SiO_x (*Eopt* =2.15 eV) which is wider bandgap than the first cell absorber is used as a p-layer material. The thickness of each cell needs to be adjusted according to the light intensity ratio from the front surface and the rear surface. After depositing the amorphous layer, ITO having a thickness of 80 nm was deposited by a sputtering method. The area of the cell is 1 cm^2.

Fig.s 2 and 3 show the SIMS analysis and the cross sectional SEM image of the quintuple-junction solar cell with the total thickness of 2.5-3.0 μm. In order to analyze the O, B and P concentrations, each layer is deposited somewhat thicker than the optimum value. The third cell has a smaller thickness than that of the 2nd and 4th cell, because the *Eopt(3)* is smaller than the other layers. The oxygen concentration in the p layer is as high as 8×10^{22} / cm^3. On the other hand, the oxygen concentration in the i-layer of the first, second, fourth and fifth cell is 2×10^{22}/ cm^3, and since the film is formed at a low substrate temperature of 120°C, the *Eopt* is 1.85 eV due to an increase in hydrogen concentration in the film.

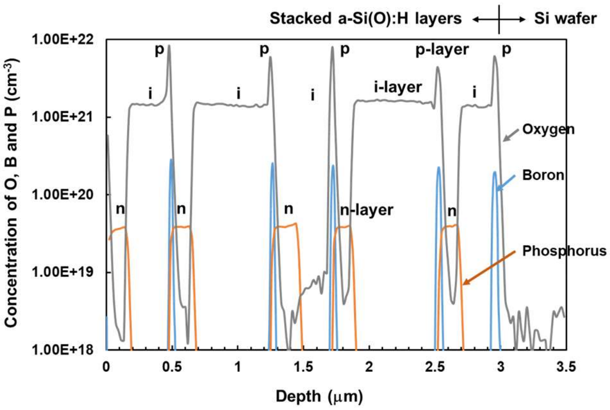

Fig.2 SIMS analysis of a quintuple -junction solar cell.

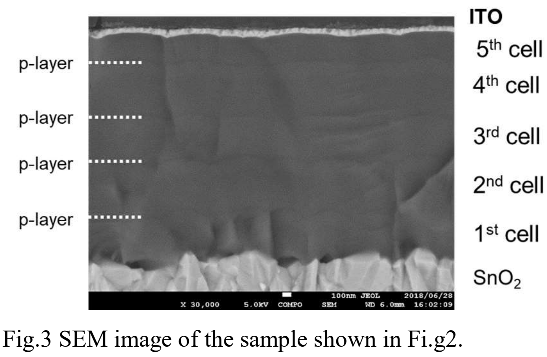

Fig.3 SEM image of the sample shown in Fi.g2.

In the SEM image in Fig. 3, it is possible to distinguish the p-a-SiO_x:H layer with a high oxygen concentration as a slightly dark line.

4. Current-Voltage Characteristics under LED Light

Fig. 4 shows the characteristics of the bifacial quintuple-junction solar cell under LED light illumination. When 3000 lux LED light was irradiated from both sides, an open circuit voltage of 3.4 V could be obtained. In the sample, since the grid electrode is not formed on the ITO electrode on the back surface, the series resistance is high. Furthermore, the-i layer and n-layer are deposited thicker than the optimum value in order to avoid shunting due to pinhole and to obtain the highest operating voltage as much as possible. Therefore, although the fill factor is low (FF = 0.35) at present, the fill factor could be significantly improved by adjustment of each layer thickness.

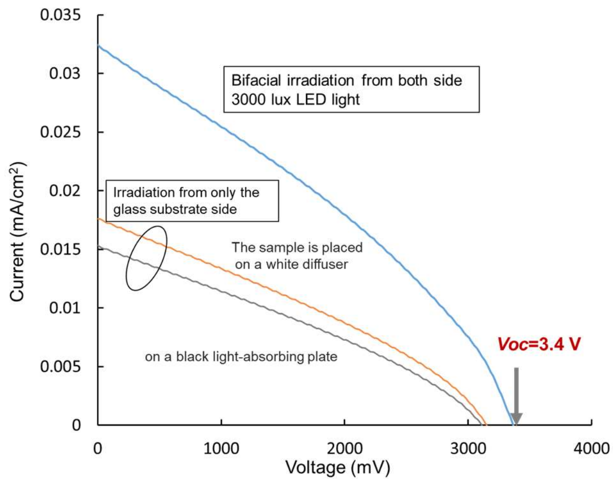

Fig. 4 I-V characteristics under LED light.

5. Conclusions

We proposed a bifacial amorphous Si quintuple-junction solar cell as a power source for IoT devices. a-Si(O):H based quintuple-junction cell was fabricated by plasma CVD method. As a result, an extremely high open circuit voltage of 3.4 V was achieved under irradiation with 3,000 lux of LED light. In addition, it was demonstrated that a-Si quintuple-junction structure consisting of 15-layers can be stacked with high accuracy by using the plasma CVD method.

References

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