22%-EFFICIENCY HIT SOLAR CELL

Yasufumi Tsunomura , Yukihiro Yoshimine, Mikio Taguchi, Toshihiro Kinoshita,
Hiroshi Kanno, Hitoshi Sakata, Eiji Maruyama and Makoto Tanaka
Advanced Energy Research Center, SANYO Electric Co., Ltd.
7-3-2, Ibukidai-higashimachi, Nishi-ku, Kobe City, Hyogo, 651-2242, Japan

ABSTRACT

We have achieved the world's highest solar cell conversion efficiency of 22.3% (Voc: 0.725 V, Isc: 3.909 A, FF: 0.791, total area: 100.5 cm^2, confirmed by AIST) by using a HIT (Heterojunction with Intrinsic Thin-layer) structure. This is the world's first practical-size (>100 cm^2) silicon solar cell that exceeds a conversion efficiency of 22% as a confirmed value. This high efficiency has been achieved mainly due to improvements in a-Si/c-Si hetero-interface properties and optical confinement.

The excellent a-Si/c-Si hetero-interface of the HIT structure enables a high Voc of over 0.720 V and results in better temperature properties. In order to reduce the power-generating cost, we are now investigating numerous technologies to further improve the conversion efficiency, especially the Voc, of HIT solar cells, with the aim of achieving 23% efficiency in the laboratory by 2010.

1. INTRODUCTION

Global needs for solar energy have been increasing rapidly. The world production volume of solar cell modules reached a level of more than 2,500 MW per year in 2006. To fulfill these needs, Sanyo has decided to increase the production capacity of HIT (Heterojunction with Intrinsic Thin-layer) solar cells [1] annually from 165 MW in 2006 to 600 MW in 2010. The HIT solar cell is a unique high-efficiency silicon solar cell, which results from our amorphous silicon (a-Si) and crystalline silicon (c-Si) solar cell technologies.

In order to further expand the use of solar modules, it is necessary to thoroughly reduce the power-generating cost. With this goal, technologies for a higher conversion efficiency and a thinner c-Si wafer are both important. As for the higher conversion efficiency, we have announced a plan to raise cell conversion efficiency to 23% in the laboratory by 2010.

In this paper, we describe our approaches toward developing high-efficiency HIT solar cells and next-generation HIT solar cells with a thinner c-Si wafer, and the current status of this development.

2. HIT SOLAR CELL

In the HIT solar cell structure, an intrinsic a-Si layer followed by a p-type a-Si layer is deposited on a randomly textured n-type CZ c-Si wafer to form a p/n heterojunction. On the other side of the c-Si, intrinsic and n-type a-Si layers are deposited to obtain a Back Surface Field (BSF) structure. On both sides of the doped a-Si layers, Transparent Conducting Oxide (TCO) layers are formed and finally, metal grid electrodes are formed using a screen-printing method. By inserting the high-quality intrinsic a-Si layer, the defects on the c-Si surface can be effectively passivated, and a high Voc can be obtained. This solar cell is based on Sanyo's technologies for forming high-quality a-Si films and a-Si solar cells with low-plasma and low-thermal damage processes.

The HIT structure provides high performance. As we reported in 2006 [2], a very high conversion efficiency of 21.8% (Voc: 0.718 V, Isc: 3.852 A, FF: 0.790, total area: 100.4 cm^2, confirmed by AIST) has been obtained with this structure. In addition, HIT solar cells exhibit a better temperature coefficient compared to conventional p/n homojunction c-Si solar cells. Therefore, one can obtain more power with HIT solar cells in actual use than conventional c-Si solar cells.

3. APPROACH FOR HIGH-EFFICIENCY HIT

To obtain higher efficiency with the HIT structure, we are focusing on three aspects: (3.1) Improving the a-Si/c-Si heterojunction, (3.2) Improving the grid electrode, and (3.3) Reducing absorption in the a-Si and TCO layers.

3.1 Improving the a-Si/c-Si heterojunction

The high Voc of the HIT solar cell is achieved primarily by the effective passivation of defects on the c-Si surface with high-quality intrinsic a-Si.

In the p-a-Si/n-c-Si heterojunction without intrinsic a-Si layers, tunneling is caused by the many localized states in the doped layer. As a result, a high Voc cannot be achieved [3]. By inserting the high-quality intrinsic layer, tunneling can be suppressed and excellent interface properties can be obtained. Moreover, by

inserting an intrinsic a-Si layer into the backside n+-a-Si/n-c-Si interface, the interface recombination velocity in the BSF structure can be decreased, allowing for a high Voc.

Therefore, in order to attain a higher Voc, it is very important to have high-quality intrinsic a-Si layers and excellent a-Si/c-Si interfaces. We also need to develop a fabrication process with the following technologies:
(1) A clean c-Si surface before a-Si deposition
(2) Deposition of a high-quality intrinsic a-Si layer
(3) Lower plasma and/or thermal damage to the c-Si surface during a-Si, TCO and conductive electrode fabrication

Experimentally, we have achieved an outstandingly high Voc of 0.736 V (Isc: 3.749 A, FF: 0.793, Eff.: 21.6%, total area: 101.3 cm^2, measured by Sanyo).

3.2 Improving the grid electrode

For a higher Isc and FF, the grid electrode requires lower resistance and finer lines for a larger aperture, simultaneously. Since the grid electrode of HIT solar cells is made of resin-bonded silver (Ag) paste, which has high resistivity in itself, the aspect ratio must be as high as possible. Figure 1(a) shows a conventional grid electrode fabricated by the screen-printing method. The conventional grid electrode has a spreading area that causes optical loss. In order to lower the optical loss and the resistance loss, it is necessary to eliminate this spreading area and improve the height, as shown in Figure 1(b).
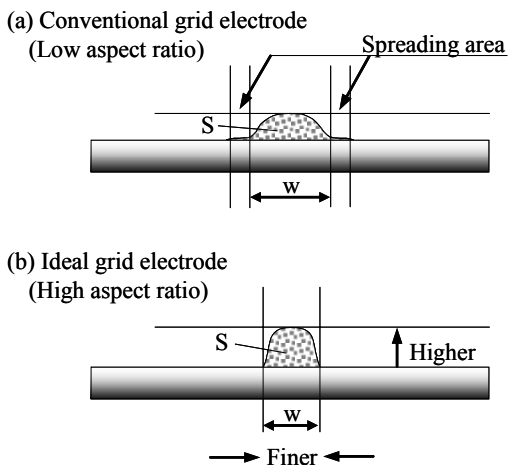

(a) Conventional grid electrode
   (Low aspect ratio)
   Spreading area
   S
   w

(b) Ideal grid electrode
   (High aspect ratio)
   S
   Higher
   w
   Finer

Fig. 1 Schematic diagrams of (a) a conventional grid electrode with a larger spreading area, and (b) an ideal grid electrode without a spreading area.

Figure 2 shows a simulated relationship between an improved aspect ratio for the grid electrode and the normalized conversion efficiency of HIT solar cells relative to a HIT solar cell with 21.8% efficiency. Considering the cross sectional shape of the grid electrode, the aspect ratio was calculated using the following equation: $A=S/w^2$, where S and w denote the cross section and the line's width excluding the spreading area, as shown in Fig. 1. In Fig. 2, the triangle represents the HIT solar cell with 21.8% efficiency using a conventional grid electrode with spreading area. The squares represent HIT solar cells using a grid electrode without a spreading area. The circles show HIT solar cells using a finer (60% width) grid electrode without a spreading area. By improving the aspect ratio of the grid electrode to a level exceeding 1.0 with the finer grid electrode, we can enhance the efficiency by about 1.6% compared with that of the 21.8% HIT solar cell. To achieve this performance, we need to optimize following factors:
(1) The viscosity and rheology of the silver paste
(2) The process parameters in the screen-printing

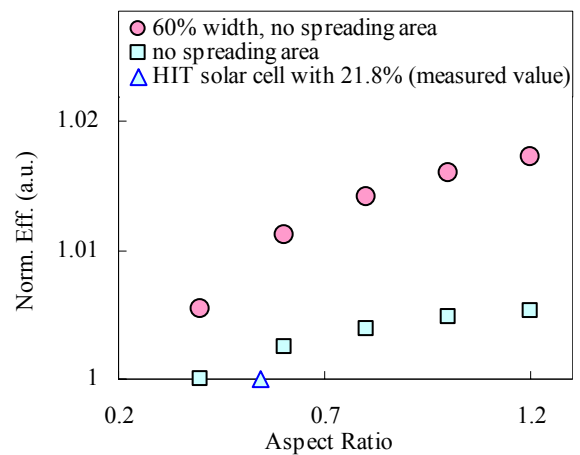**Fig. 2** Simulated relationship between grid electrode improvement and conversion efficiency relative to a 21.8% HIT solar cell.

3.3 Reducing absorption in the a-Si and TCO layers

For a higher Isc, optical losses such as absorption in the a-Si and TCO layers must be reduced. These optical losses are mainly caused by the optical absorption of a-Si and the free carrier absorption of TCO. Therefore, to reduce the optical losses, we need to develop the following layers:
(1) High-quality widegap alloys such as a-SiC
(2) High-quality TCO with high carrier mobility

4. 22.3%-EFFICIENCY HIT SOLAR CELL

As a result of our progressive studies, we have achieved a new record of 22.3% efficiency (Voc: 0.725 V, Isc: 3.909 A, FF: 0.791, total area: 100.5 cm^2, confirmed by AIST) as shown in Figure 3. The Voc, Isc and FF have been simultaneously improved compared to a 21.8% HIT solar cell.

4.1 Improved Voc

We have succeeded in obtaining a high Voc of 725 mV for the best-performing cell by improving the a-Si/c-Si interface property by means of new cleaning process and new deposition conditions for the a-Si layers. Especially, the new deposition conditions allowed us to reduce plasma and thermal damage during a-Si deposition.

Generally, the temperature properties of the conversion efficiency mainly depend on those of the Voc, and a more excellent temperature coefficient is exhibited by a solar cell with a higher Voc. Therefore, the HIT solar cell with its high Voc shows a very excellent temperature coefficient [4]. The temperature coefficient of the HIT solar cell with 0.73 V is comparable to that of an a-Si solar cell, which is generally said to have an excellent temperature coefficient. This excellent temperature property enables high performance in outdoor use and leads directly to user benefits.
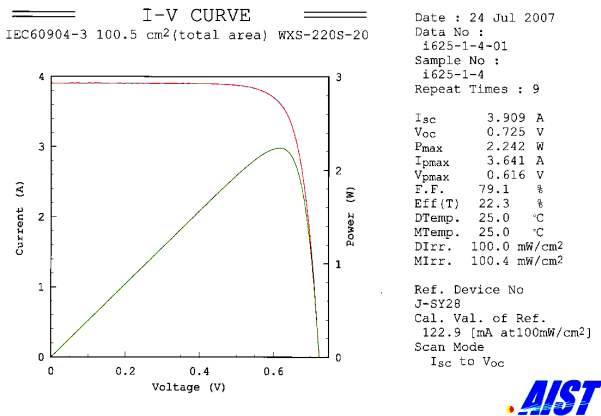

Fig. 3 Illuminated I-V characteristics of the HIT solar cell with the world's highest confirmed conversion efficiency of 22.3%.

4.2 Improved Isc

We have succeeded in developing a lower-light-absorbing TCO in the long wavelength region. Figure 4 shows the IQE spectra of HIT solar cells with the newly developed TCO and with our previous TCO. These TCO films are deposited onto HIT solar cells fabricated under the same conditions. The new TCO shows improved IQE in the long wavelength region (>1,000 nm), and the high FF (0.791) in the HIT solar cell with 22.3% efficiency suggests that the conductivity of higher-transparency TCO maintains a high value.

We have also achieved a 78% finer width in the grid electrode with half of the spreading area compared to a HIT solar cell with 21.8% efficiency. The aspect ratio is almost the same as that of the HIT solar cell with 21.8% efficiency. By incorporating the new TCO, the finer grid electrode, and improvements in the textured structure,

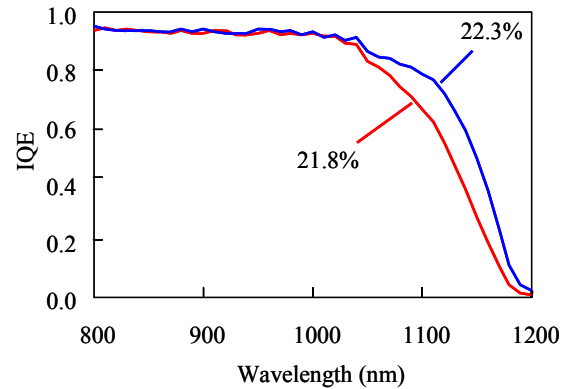we have improved the Isc by about 1.4% relative to a HIT solar cell with 21.8% efficiency.

Fig. 4 Improved TCO transparency in the long wavelength region shown by IQE.

5. PROGRESS IN CONVERSION EFFICIENCY

Figure 5 shows the progress in conversion efficiency of HIT solar cells with a practical size of ~100 cm^2. We have made every effort to achieve higher efficiency both in the laboratory and in the factory. Many new technologies for mass production have been developed and adopted. We have thus succeeded in increasing the conversion efficiency.

Further, in our laboratory, we have been continuously developing technologies to improve efficiency, and achieved a very high conversion efficiency of 22.3% (confirmed by AIST) with a size of 100.5 cm^2 in July 2007.

With the approaches mentioned above, we are now pursuing further improvement in the conversion efficiency of the HIT solar cell, and should be able to attain an efficiency level exceeding even 23% in the laboratory by 2010.
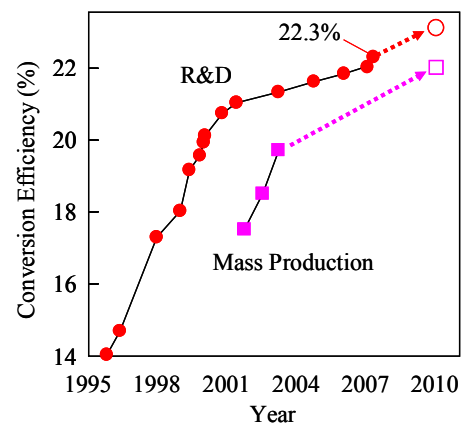

Fig. 5 Progress in the conversion efficiency of HIT solar cells.

6. THINNER HIT SOLAR CELL

In order to reduce the power-generating cost, we have also been developing thinner HIT solar cells. Here, we have evaluated the possibility of thinner HIT solar cells for the first time. Figure 6 shows a picture of a HIT solar cell with a c-Si wafer thickness of ~70μm. We can see no bowing because the effect of thermal stress is suppressed by its symmetrical structure. This shows high potential for HIT solar cells with a thinner c-Si wafer. Figure 7 shows the thickness dependence of I-V parameters normalized by those of a 200-μm-thick HIT solar cell. As the thickness of the c-Si wafer decreases, the I_{sc} decreases as shown in Fig. 7. This decrease in I_{sc} is caused by insufficient light absorption and agrees well with the calculated result using SUNRAYS [5]. On the other hand, the V_{oc} shows no decrease because of the excellent HIT passivation effect on the c-Si surface. However, there seems to be a slight decrease in FF of about 0.5-1%. This result suggests that we still have room for improving the a-Si/c-Si heterojunction performance toward a next-generation, thinner c-Si wafer structure below 100μm.

We are now focusing on developing optical confinement technologies to improve the I_{sc} and enhanced passivation technologies to improve the FF toward the next generation.
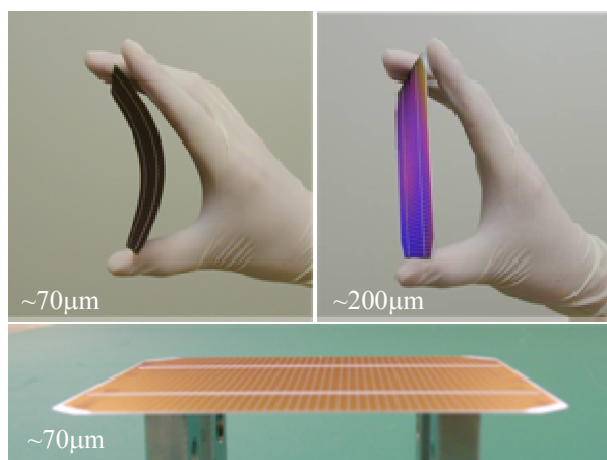

Fig. 6 A picture of a HIT solar cell with a c-Si wafer thickness of ~70μm. 70μm cell does not show any bowing after whole process (lower).

7. SUMMARY

We have described the near-future target performance for HIT solar cells and the possibility of further improving conversion efficiency (over 23%) by studying technologies for improving V_{oc}, I_{sc} and FF, and have also presented guidelines to obtain better temperature properties.

Based on our studies, we have developed a cleaning process that achieves a clean c-Si surface and an improved textured structure, a lower-damage-deposition process, a lower-light-absorbing TCO, and a finer grid electrode with reduced spreading area. By applying these technologies, we have achieved the world's highest confirmed conversion efficiency of 22.3%. We have also shown a high potential for thinner HIT solar cells.

We are aggressively pursuing further improvement in power generating cost in order to respond to growing world demand for solar cell modules.
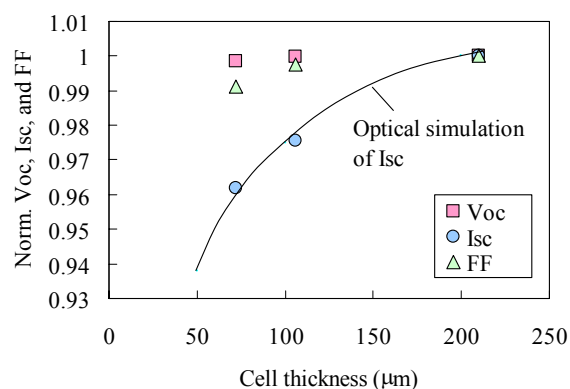

Fig. 7 Thickness dependence of I-V parameters normalized by those of a 200μm-thick HIT solar cell. The solid line shows the simulation result (I_{sc}) by using SUNRAYS.

REFERENCES

[1] M. Taguchi et al., "Improvement of the Conversion Efficiency of Polycrystalline Silicon Thin Film Solar Cell", Proc. Fifth PVSEC, 1990, pp. 689-692.

[2] E. Maruyama et al., "Sanyo's Challenges to the Development of High-efficiency HIT Solar Cells and the Expansion of HIT Business", WCPEC-4 (Hawaii, 2006) pp. 1455-1460.

[3] M. Tanaka et al., "Development of New a-Si/c-Si Heterojunction Solar Cells: ACJ-HIT (Artificially Constructed Junction-Heterojunction with Intrinsic Thin-Layer)", Jpn. J. Appl. Phys. **31**, 1992, pp. 3518-3522.

[4] S. Taira et al., "Temperature Properties of High-Voc HIT Solar Cells", RENEWABLE ENERGY 2006 Proceedings, 2006, pp. 115-118.

[5] R. Brendel, "SUNRAYS: A versatile solar cell ray tracing program for the photovoltaic community" Proc. 12th EC Photovoltaic and Solar Energy Conf., 1994, p. 1339