# a-Si:H/c-Si Heterojunction Solar Cells on 50 $\mu$m Thick Wafers With Rear Point Contacts

S Amtablian, M Labrune, P Carroy, J. Dupuis, E. Fourmond, A. Kaminski, A. Fave, P. Roca I Cabarrocas, P-J Ribeyron, M. Lemiti

# A-Si:H/c-Si HETEROJUNCTION SOLAR CELLS ON 50 µm THICK WAFERS WITH REAR POINT CONTACTS.

S. Amtablian[1], M. Labrune[2], P. Carroy[1], J. Dupuis[1], E. Fourmond[1], A. Kaminski[1], A. Fave[1], P. Roca i Cabarrocas[2], P-J. Ribeyron[3], M. Lemiti[1]
[1]Institut de Nanotechnologies de Lyon, UMR - CNRS 5270, Université de Lyon
INSA-Lyon, Bât Blaise Pascal, 7 avenue Jean Capelle, F-69621 Villeurbanne Cedex, France.
Tel: (33)472438464, fax: (33)472438531 email: sevak.amtablian@insa-lyon.fr, mustapha.lemiti@insa-lyon.fr
[2]Laboratoire de Physique des Interfaces et Couches Minces, UMR - 7647 CNRS Ecole Polytechnique
Bâtiment 406, 91128 Palaiseau Cedex France email : pere.roca@polytechnique.edu
[3]CEA-INES –, 50 Avenue du lac Léman, BP 332, F-73370 Le Bourget du Lac, France email: pierre-jean.ribeyron@cea.fr

ABSTRACT: Crystalline silicon thin film processes for thicknesses in the 20 - 80 µm range are more and more interesting given the issue of silicon shortage. Layer Transfer Processes (LTP) were widely investigated to obtain thin films because of the unavailability of suitable wire sawing. LTP avoids hazardous handling with fragile layers and silicon waste during sawing. In addition, a-Si:H/c-Si heterojunction solar cells are well suited to reduce the photovoltaic power cost. High efficiency on bulk substrate has been demonstrated by Sanyo Corporation and the low temperature process, less than 250 °C, ensures economical gain. In this paper, we present the fabrication of 26 cm$^2$ solar cells on 50 -70 µm thick CZ wafers. The emitter is obtained either by a-Si:H (n$^+$) deposition or by phosphorus diffusion. A 10 % efficiency solar cell on 52 µm thick silicon substrate has been achieved with a-Si:H/c-Si heterojunction. Further improvement is expected with an optimized ITO deposition and a progress in fill factor. Moreover, we also evaluate the effects of rear point contacts obtained by lithography through a dielectric layer. LBIC measurement has been used and a relative 10 % enhancement of photogenerated current has been observed at wavelength 980 nm on no contacted area compared to point contacts area. Moreover defects at the silicon metallization interface can be revealed. Such characterization has been made on 45 µm thick transferred layer.
Keywords: Layer transfer process, thin film, a-Si:H/c-Si heterojunction, rear point contacts.

## 1 INTRODUCTION

The important growth of photovoltaic market leads to solar grade silicon shortage. Among different ways for increasing the silicon offer, layer transfer process combines crystalline quality and low silicon consumption. Such process [1, 2, 3], based on porous silicon formation and epitaxial growth is under investigation, and allows to carefully handle 20 - 70 µm thick substrates. This kind of thickness is considered as sufficient to allow efficiencies up to 20 %.[4]

In addition, a-Si:H/c-Si heterojunction technology allows low thermal budget with high efficiency as already shown by Sanyo Corporation [5]. So, this technology is particularly well adapted to thin crystalline silicon films, as surface passivation becomes predominant on the efficiency.

In this paper, we report on solar cell processed on 50 – 70 µm thick CZ wafers. On 4 inches p-type wafers, we carried out a-Si:H/c-Si heterojunction and homojunction solar cells with and without rear point contacts. Firstly, we present the solar cells process, highlighting front and back side formation steps. Next section deals with photovoltaic results with electrical and spectral response measurements.

## 2 SOLAR CELL TECHNOLOGY

Substrates are 4” p-type CZ wafers which have been obtained by mechanical and chemical etching. Thicknesses in the range of 50 µm - 70 µm have been measured by SEM. Their resistivity is around 1 Ω.cm. Another 300 µm thick FZ wafer is taken as a reference for the solar cell process and to compare thickness effects. Various solar cell structures are represented on figure 1. They differ by their emitter (either phosphorus diffused or amorphous silicon deposited), by their rear side (locally or fully contacted), and by their thickness. On table 1, available solar cells comparisons are exposed.

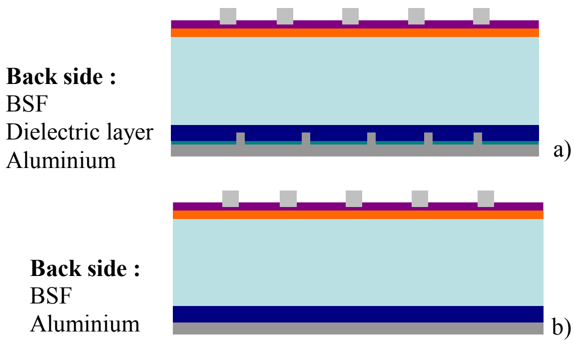


**Figure 1**: Solar cell structures with diffused or a-Si:H emitter and a) rear point contacts or b) whole rear side contact.

**Table 1**: Solar cell particularities and available comparisons

| Cell | Thickness | | Emitter | | Rear contact | |
|---|---|---|---|---|---|---|
| | 50-70 µm | 300 µm | P diffused | a-Si:H | Full area contacted | Locally contacted |
| 1 | o | | o | | o | |
| 2 | o | | | o | o | |
| 3 | o | | | o | | o |
| 5 | o | | | o | | o |
| 7 | | o | o | | o | |

### 2.1 Front side process

In case of homojunction emitter was carried out by phosphorus diffusion at 850°C resulting in a 40 Ohms square doping level and 0.3 µm deep junction. Emitter formation is followed by 75 nm thick SiN:H deposition as antireflective and passivating coating. Deposition occurred in a low frequency PECVD reactor at 370°C. Metallizations are obtained after lithography by 1 µm thick evaporated silver.

Concerning a-Si:H/c-Si heterojunction solar cells, emitter consist in a 3 nm thick intrinsic hydrogenated amorphous silicon layer and a 8 nm $n^+$ a-Si:H deposited in a PECVD reactor at a temperature below 250°C [6]. To improve the electric contact and surface reflectivity, 84 nm of ITO are deposited on top of the a-Si:H in a sputtering system. Finally front contacts are made of 1 µm thick evaporated silver using a mask.

All solar cells are without texturization and surfaces are 4 $cm^2$ and 26 $cm^2$ for respectively homojunction and heterojunction structures.

2.2 Rear side process

On the rear side of all solar cells, back surface field (BSF) is performed using bore implantation. Implanted dose is $10^{16}$ $at.cm^{-2}$ resulting in a doping level of $5.10^{20}$ $at.cm^{-3}$. For rear points contact, a dielectric layer composed of a stack of 20 nm oxide / 50 nm SiN:H / 100 nm oxide [7], is deposited in a PECVD reactor. Openings corresponding to 10% metallization are made by lithography following the pattern shown in figure 2.

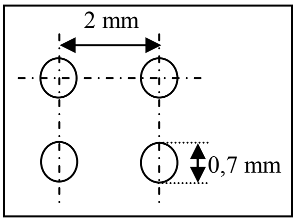


**Figure 2:** Locally contacted rear side pattern resulting in 10 % metallization.

Then, 1 µm thick aluminum is evaporated. For full area contact the same process is applied without dielectric deposition. Cleavage is used for junction openings.

3 SOLAR CELLS RESULTS AND DISCUSSION

3.1 I-V curves under illumination

Under 1 sun illumination thin film solar cells show open circuit voltage, $V_{oc}$, in the vicinity of 590 mV, except for the 300 µm thick wafer that has a higher $V_{oc}$ at 611 mV. Such difference is attributed to material quality difference between CZ and FZ wafers. Short circuit current densities achieve 25 $mA.cm^{-2}$ for heterojunction solar cells and increase to 29.5 $mA.cm^{-2}$ for diffused emitter on a 50-70 µm CZ wafer. Cell efficiency is limited by fill factor which doesn't exceed 70 %. 10 % efficiency has been achieved on thin wafer for a-Si:H/c-Si heterojunction and 11.9 % for homojunction solar cells. Solar cells results are summarized in table 2.

**Table 2:** Solar cell results

| | **Cell 1** | **Cell 2** | **Cell 3** | **Cell 5** | **Cell 7** |
|---|---|---|---|---|---|
| Thickness (µm) | 50-70 | 68 | 64 | 52 | 300 |
| $V_{oc}$ (mV) | 595 | 590 | 590 | 583 | 611 |
| $I_{cc}$ ($mA.cm^{-2}$) | 29.5 | 23.8 | 24.3 | 25.1 | 31.5 |
| FF (%) | 67.6 | 62.3 | 58.8 | 69.2 | 67.5 |
| η | 11.9 | 8.4 | 8.7 | 10.2 | 12.6 |
| | SunsVoc measurement | | | | |
| Pseudo FF | 81.7 | 81.8 | 81.8 | 81.4 | 81.7 |
| Pseudo η | 14.4 | 11.7 | 12.3 | 12.2 | 15.3 |

SunsVoc measurements, which allow to estimate efficiency without the influence of the series resistance, predict potential efficiency as high as 11.7 % or 14.4 % for respectively heterojunction and homojunction thin film solar cells. $I_{cc}$ value appears to be the main factor that explain gap efficiency between homojunction and heterojunction structures. To address this point we performed spectral response measurements.

3.2 Spectral analysis

On figure 3 and 4, internal quantum efficiency (IQE) and reflectivity of cell 3 and cell 1 give some indications.

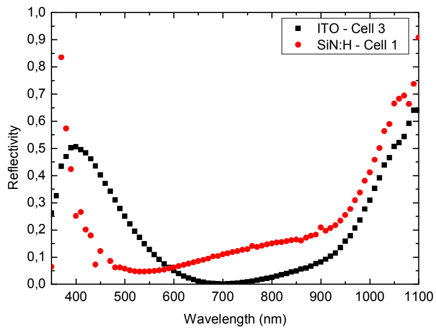


**Figure 3:** Reflectivity comparison of ITO (cell 3) and SiN:H (cell 1).

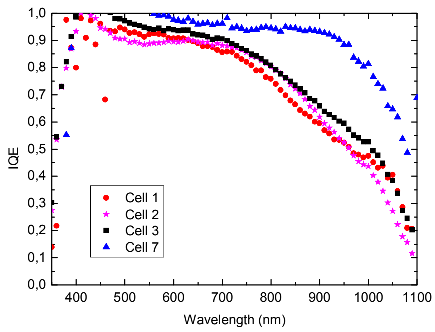


**Figure 4:** Internal quantum efficiency of solar cells.

IQE are quite similar but reflectivity shows strong difference. ITO thickness is not optimized with a minimum reflectivity at 700 nm instead of 590 nm. It explains the observed $I_{cc}$ decrease using ITO.

Comparison between cell 1 (50-60 µm thick) and cell 7 (300 µm thick) outlines the thickness effect on the IQE as shown on figure 4. In spite of rear point contacts, IQE at long wavelength remains smaller for the thin wafer. Nevertheless cell 3 shows IQE improvement over 900 nm compared to cell 2 with full area rear contact. Such enhancement is confirmed by LBIC measurement at 980 nm.

3.3 LBIC measurement

Light beam induced current (LBIC) measurement consists in scanning the solar cell front surface with a laser diode and collecting photogenerated carriers. Laser beam at wavelength of 980 nm is focused down to a 20 µm spot size diameter perpendicular to the sample surface. At this wavelength, two thirds of light intensity are absorbed in 100 µm thick silicon layer. In the case of a 70 µm thick wafer, photogenerated current is strongly dependent on the solar cell back side. That is why we are able to characterize rear points contact as shown on figure 5. On this figure, blue lines correspond to front surface metallization and blue circles represent rear aluminum contacts. It appears that generated current is 10 % higher above dielectric area than above rear point contacts at a wavelength 980 nm. Because of the whole surface BSF, such enhancement is expected coming from reflectivity rather than passivation improvement. Analogous measurement on 300 µm thick cell 7 shows lighter improvement with 5 % more generated current.

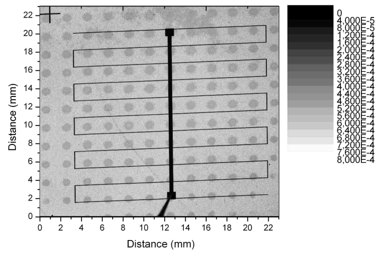


**Figure 5:** LBIC cartography of cell 1. Photogenerated current appears 10 % higher on non contacted area.

## 4 SOLAR CELL ON TRANSFERRED EPILAYER

In a previous work [8], we introduced the fabrication of solar cells on thin epilayers transferred on a foreign substrate. Transfer occurred by aluminum welding after using the layer transfer process ELIT, based on porous silicon. 45 µm thick silicon film has been processed into solar cells thanks to amorphous silicon deposition. IQE of this solar cell is compared to cell 2 and cell 3 on figure 6. It appears that aluminum welding behaves like evaporated aluminum. At long wavelength IQE curve is superimposed to the one of cell 2.

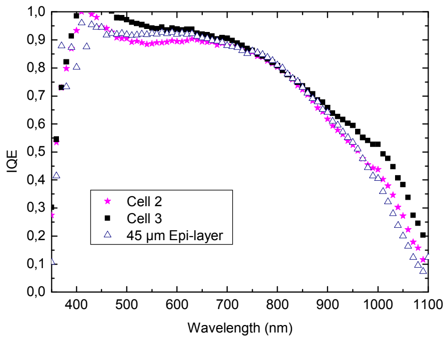


Figure 6: IQE comparison of Cell 2 (full area rear contact), Cell 3 (rear points contact) and a 45 µm thick cell transferred from ELIT process (full area rear contact)

In the same way than previous paragraph, LBIC measurements have been made (see figure 7). One can see concentric circles and small white lines like cracks. Circles came probably from porous silicon process and remained after epitaxial growth. But small cracks are most likely due to aluminum-silicon interface stress on the rear face. Temperature profile during aluminium welding has probably to be optimized. In these conditions, rear point contacts, not only improves rear side reflectivity and passivation but also could decrease stress damage introduced by metallization.

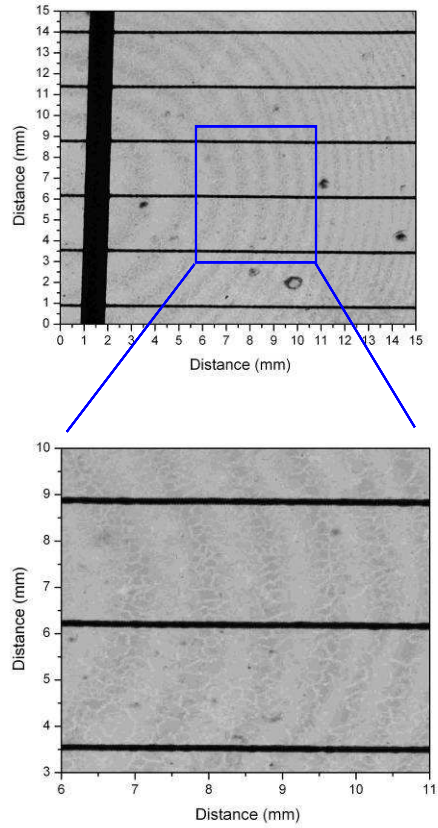


Figure 7: LBIC cartography at 980 nm of 45 µm thick transferred epi-layer.

## 5 CONCLUSION

We achieved a 10 % efficiency solar cell on 52 µm thick silicon substrate with a-Si:H/c-Si heterojunction. Further improvement is expected with an optimized ITO deposition and a lower series resistance, resulting in a higher fill factor. Considering rear point contacts, we showed that it is useful especially for thin layers. The integration into a layer transfer process is desirable for at least two reasons: increasing photogenerated current and decreasing interface stress between metallization and silicon. From this point of view, LBIC measurements seem to be a suitable characterization tool for thin solar cell back side.

## 6 ACKNOWLEDGMENTS

Our work has been made using the equipments of the technological platform NANOLYON and thanks to its members: A. Sabac, P. Girard, J. Grégoire, R. Perrin, and E. Thomas.

This work has been supported by ANR, the French national research agency and by ADEME, the French Agency for Environment and Energy Management.

## 7 REFERENCES

[1] J. Kraiem, S. Amtablian, O. Nichiporuk, P. Papet, J-F. Lelievre, S. Quoizola, A. Fave, A. Kaminski, P-J. Ribeyron, M. Lemiti**,** ELIT process: epitaxial layer for interdigitated back contact on transferred solar cells. 21th European Photovoltaic Solar Energy Conference, Dresden, Germany. 2006. pp 1268 - 1271.

[2] C. Berge, M. Zhu, W. Brendle, M.B. Schubert, J.H. Werner. 150-mm layer transfer for monocrystalline silicon solar cells. Solar Energy Materials & Solar Cells 90, 2006, pp 3102–3107.

[3] A. Wolf, B. Terheiden and R. Brendel. Autodiffusion: A Novel Method for Emitter Formation in Crystalline Silicon Thin-Film Solar Cells. Prog. Photovolt: Res. Appl.

[4] J. Zhao, A. Wang, S. Wenham, M.A. Green. 21,5 % efficient thin-layer silicon solar cell. In proc. 13th European Photovoltaic Solar Energy Conference, 1995, p. 1566

[5] Taira S. Y. Yoshimine, T. Baba, M. Taguchi, H.Kanno, T. Kinoshita, H. Sakata, E. Maruyama and M. Tanaka - Our Approaches for Achieving HIT Solar Cells With More Than 23% Efficiency. 22th European Photovoltaic Solar Energy Conference, Milan, Italy. 2007. pp 932 - 936.

[6] P. Roca i Cabarrocas, J. B. Chévrier, J. Huc, A. Lloret, J. Y. Parey, and J. P. M. Schmitt J. Vac. Sci. Tech. A**9** (1991) 2331.

[7] J. Dupuis, E. Fourmond, O. Nichiporuk, F. Gibaja, M. Lemiti , PECVD rear passivation schemes for industrial silicon solar cells, this conference.

[8] S. Amtablian, D. Eon, A. Kaminski, A. Fave, P. Roca i Cabarrocas, P-J. Ribeyron, M. Lemiti. a-Si:H/c-Si heterojunction solar cells on transferred silicon thin film epitaxially grown on porous silicon. 22th European Photovoltaic Solar Energy Conference, Milan, 2007, p1990-1992.