

REALIZATION OF THIN MC-SILICON PERT-TYPE BIFACIAL SOLAR CELLS IN INDUSTRIAL ENVIRONMENTS

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ABSTRACT

We present bifacial solar cells processed with a sequence suitable for industrial production. This method uses the LPCVD silicon nitride deposition based on DCS (dichlorosilane) or BTBAS (bis-(tertiary butyl amino)-silane). The bifacial solar cell process on wafers of 200 μm thickness has the following steps: (1) boron doped BSF of $R_{\text{sheet}} = 60 \text{ ohm/sq}$; (2) POCl_3 emitter (on front side) of $R_{\text{sheet}} = 50 - 55 \text{ ohm/sq}$; (3) thermal oxidation of the wafer surfaces; (4) the deposition of DCS or BTBAS based LPCVD silicon nitride on either sides of the wafer (5); finger grid printing on both sides and firing; (6) edge isolation. The solar cells produced with the DCS based silicon nitride process exhibit fill factor (FF) values of 76% on p-type and 75% on n-type solar cells with a rear to front efficiency ratio $\eta_{\text{rear}}/\eta_{\text{front}}$ of 67% for the p-type solar cells and 43% for the n-type solar cells. The solar cells with the BTBAS silicon nitride show FF values close to 72% and $\eta_{\text{rear}}/\eta_{\text{front}}$ 68% for p-type solar cells.

INTRODUCTION

The present growth rate of the photovoltaic industry shows that the wafer-based crystalline silicon solar cell technology will continue to dominate the industry at least for the next decade. The majority of crystalline silicon solar cells are conventional monofacial cells with an aluminium alloy on the rear side. The full area metallization of thin wafers creates bowing that hinders their use in module fabrication. Moreover the conventional monofacial cell structure is suitable only to a limited extent for the innovative building of integrated photovoltaic applications.

Bifacial solar cells devised in the 1960s are still a topic of interest in solar cell research and development [1]. The advantage of bifacial silicon solar cells on thin multicrystalline substrates are two folds; first, they need less Si per W_p as they use thinner wafers and second, they play an

important role in the building of integrated photovoltaic designs that allow illumination from both sides of the cell.

We present two different types of bifacial solar cells using p-type and n-type material with a n^+pp^+ and p^+nn^+ structure. Most of the bifacial solar cell process steps described in literature include multiple silicon nitride deposition steps or additional masking steps. These steps are either not mainstream in industrial environments or increase the thermal budget. More details of industrially feasible bifacial solar cells on p-type and n-type wafers using PECVD silicon nitride are presented by one of the authors T. Buck (for n-type) [4] and A Kraenzl (for p-type wafers) [5] in this conference. In this work we describe a simple process sequence for passivated emitter rear totally diffused (PERT) type bifacial solar cells. The complete solar cell process has just 8 steps and features a single step nitride deposition using dichloro silane (DCS) or bis-(tertiary butyl amino)-silane (BTBAS) on both sides of the wafer. As the BTBAS based nitride deposition can be done at lower temperatures compared to DCS based nitride deposition, bulk hydrogen passivation is also carried out during the nitride deposition process. We first describe the solar cell process and present the cell results in the second part.

EXPERIMENTAL TECHNIQUES

Solar cell process

The material used in this work is p-type and n-type mc-Si. The p-type multicrystalline silicon substrates have a thickness of 200 μm and a resistivity in the range of 0.5 – 1.5 ohm cm . The bifacial solar cell process starts with the damage etch in NaOH at 80°C followed by IMEC cleaning and an HF dip. The cleaned wafers are loaded into an open tube diffusion furnace for a boron diffusion with a sheet resistance of 60 ohm/sq . The wafers are placed front to front and kept together by special quartz clamps to avoid the diffusion of boron on the front side. Even though the clamps are meant to prevent the diffusion of boron on the rear side of the wafers a small area close to the edges on the protected front side of the wafers can be diffused by boron. This region can be removed either at the end of the

solar cell process by performing mechanical edge isolation or just before the POCl_3 diffusion, if necessary. The boron glass and boron rich layer formed during the BBR_3 diffusion are removed in diluted HF. In the next step the wafers are placed back to back and loaded into the diffusion oven for POCl_3 diffusion of a sheet resistance of 50 ohm/sq. P-glass formed during the POCl_3 diffusion is removed by HF. For the surface passivation of the phosphorous emitter and boron back surface field (BSF), a dry, 15 nm thick SiO_2 is grown on both sides.

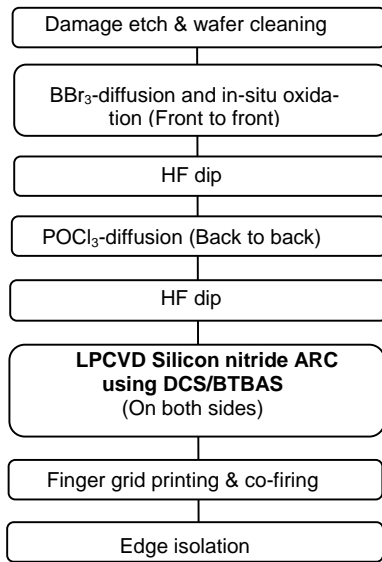


Figure 1. Process sequence of a PERT-type bifacial solar cell.

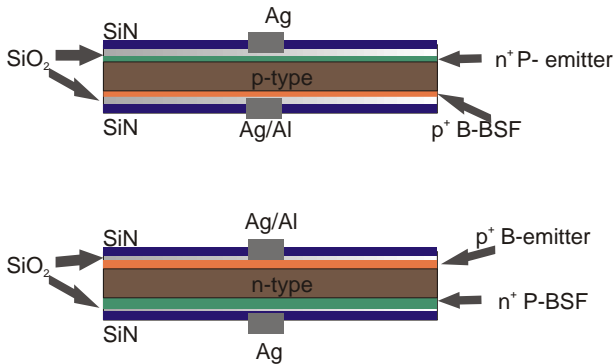


Figure 2. Cross sections of PERT-type bifacial solar cells.

Figure 2 shows the boron back surface field cell on p-type substrates and the bottom figure shows the n-type solar cells with front boron emitter on n-type substrates.

The next step is the low pressure chemical vapour deposition (LPCVD) of silicon nitride using an integrated hydrogen passivation step. Two different types of LPCVD silicon nitride based on DCS and BTBAS are tested and compared in this work. Details for BTBAS based LPCVD

nitride deposition is discussed in the next section while the technique of DCS based LPCVD nitride deposition can be found in literature [2]. The silicon nitride deposition and an in-situ hydrogen passivation are carried out in the same step. Then the wafers are metallised using a standard screen printing and firing technique. For p-type substrates silver is printed on the front side and Ag/Al paste is used on the rear side to contact boron BSF. In the case of n-type wafers the boron doped layer is not a back surface field but forms the emitter at the front surface of the wafer. See figure 2 for details.

In this work, both DCS and BTBAS based LPCVD silicon nitride processes are applied in the bifacial solar cell fabrication.

LPCVD Silicon nitride deposition using BTBAS

Figure 3 shows the schematic diagram of the LPCVD reactor set up used in our experiments. The microwave induced hydrogen enters the tube through the inlet on the right side of the reactor. For details of standard LPCVD processing see reference [2].

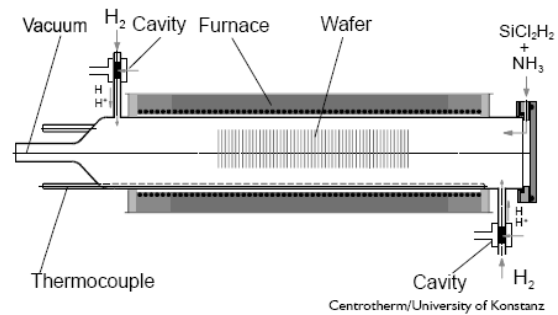


Figure 3. Schematic view of the LPCVD reactor.

A small note on BTBAS based nitride deposition is given in the following paragraphs. BTBAS is a liquid precursor for low temperature LPCVD starting at 550°C . To achieve a reasonable deposition speed of 2.5 nm/min we increased the deposition temperature to 600°C . In the same reactor, a standard LPCVD deposition using dichlorosilane (DCS) would require a temperature of 770°C . Similar to the standard LPCVD with DCS, we used an ammonia (NH_3) to BTBAS ratio of 4:1 at a pressure of 300 mTorr. To provide gaseous BTBAS for the process, the BTBAS container is heated to 130°C . Leaving that container through valve V1, BTBAS immediately condensates due to the expansion, no matter what temperature is set in the expansion tube between V1 and V2. See figure 4 for details. The same happens in any heated or non heated mass flow controller and may clog that device within a few minutes. A reasonably constant gas flow (+/- 10%) is maintained by controlled heating of the expansion tube between V1 and V2 and by intermittent opening of V1 to refill the expansion tube. The BTBAS flow is measured by the pressure rise of the process chamber

at a fixed pumping speed. For the silicon nitride reaction, NH_3 is provided by a second, independent tube. Both BTBAS and NH_3 tube meet at a gas mixing plate right at the process tube door. The low temperature BTBAS process can be combined with a microwave induced remote plasma hydrogen passivation during heating up and cooling down. However, other experiments showed that at 600°C a non-neglectable de-passivation can occur, if no atomic hydrogen is provided [3]. Unfortunately, LPCVD using BTBAS does not allow a parallel use of activated hydrogen so far, as the microwave activation interferes with the LPCVD reaction.

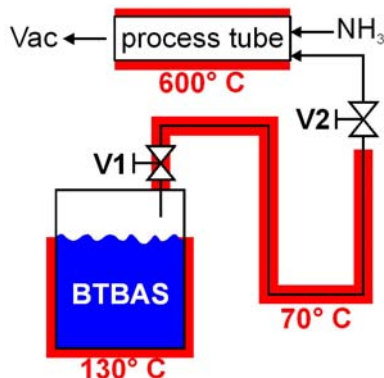


Figure 4: Schematic diagram of BTBAS based nitride deposition process. The details of process tube is given in figure 3.

A redesign of the LPCVD reactor will be necessary to allow additional hydrogen passivation during the LPCVD process.

RESULTS AND DISCUSSION

ECV profiles and optical properties

The first results of bifacial solar cells fabricated with the process sequence mentioned in figure 1 showed an optical inhomogeneity. Eye-catching was an apparent disagreement in the silicon nitride thickness of the front and rear side of the wafer that seems to be thicker on the n^+ doped side. The effect is caused by a faster oxide growth on n^+ than on p^+ and leads to a different thickness for the $\text{SiO}_2/\text{SiN}_x$ stack on the different doped surfaces of the wafer.

The electrochemical capacitance voltage (ECV) diagram in figure 5 reveals the different concentrations of the charge carriers in emitter and BSF that plays a vital role on the growth of oxide during the thermal oxidation process. The surface carrier concentration of the phosphorous doped layer is greater than that of the boron doped one and thus results in a thicker SiO_2 film growth on the phosphorous side. This inequality in SiO_2 growth has to be optimised by tailoring the boron diffusion profile. A similar surface charge density of boron and phosphorous diffusion would lead to uniform deposition of SiO_2 and hence uni-

form nitride films on the wafer surface. The optical inhomogeneity is partially solved by allowing the oxide to grow only on the boron diffused side. This was achieved by keeping the wafers back to back during the thermal oxidation process. More studies to tailor the diffusion profile has not yet completed while writing this manuscript.

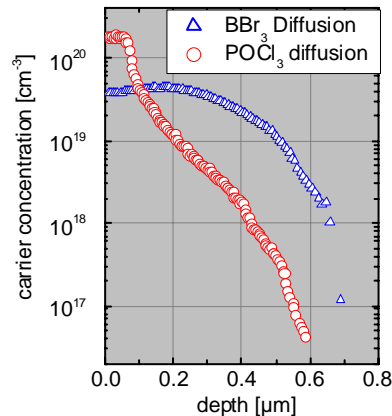


Figure 5. ECV profiles of boron doped (60 ohm/sq) and phosphorous doped (50 ohm/sq) layer.

IV measurements

The solar cell parameters of bifacial solar cells made with the DCS based nitride and BTBAS based nitride are given in the following tables. Table 1 shows the solar cell parameters of bifacial solar cells made by using DCS based LPCVD nitride.

Cell ID	Illu-mination	FF [%]	Jsc [mA/cm ²]	Voc [mV]	η [%]	$\frac{\eta_{rear}}{\eta_{front}}$
Lpb1	front	74.1	28.6	590	12.5	0.64
	rear	73.2	18.9	580	8.0	
Lpb2	front	75.9	26.8	589	12.0	0.67
	rear	74.7	18.5	579	8.0	
Ln1	front	72.5	30.0	579	12.6	0.43
	rear	74.6	13.2	552	5.4	

Table 1. IV parameters of bifacial solar cells fabricated using DCS based nitride. Note that Ln1 is an n-type cell.

All the cells are of $100 \times 100 \text{ mm}^2$ size. In the case of $\text{Eta}_{(rear)}/\text{Eta}_{(front)}$ ratio, the cells made on p-type substrates exhibit better performance than the cells made on n-type substrates. $\text{Eta}_{(rear)}/\text{Eta}_{(front)}$ ratio is just above 60% for p-type solar cells and it is just above 40% for n-type solar cells. The relatively lower performance of cells under rear side illumination is due to non optimised deposition of silicon nitride which has described in detail in the previous section. The performance of the cells could be improved by including isotexture to the solar cell process. Due to the

lower bulk life time of the mc-Si wafers used in this work, the performance of the boron BSF (boron emitter in the case of n-type material) could be decreased under illumination.

Table 2 shows the IV parameters of bifacial solar cells made using the BTBAS based nitride. The cells have undergone no surface texturing step.

Cell ID	Illumi-nation	FF [%]	Jsc [mA/cm ²]	Voc [mV]	η [%]	$\frac{\eta_{rear}}{\eta_{front}}$
btmc1	front	71.8	30.0	589	12.7	0.68
	rear	71.0	21.0	580	8.6	
btmc2	front	71.1	29.7	586	12.4	0.68
	rear	70.3	20.6	579	8.4	

Table2. The IV parameters of bifacial solar cells fabricated with BTBAS based nitride. Both cells are p-type devices.

Even though the cells with BTBAS based nitride shows efficiency digits higher than the cells with DCS based nitride, the performance of both cell types are similar under the rear side illumination condition. To take the full advantage of the lower temperature deposition of BTBAS based silicon nitride bifacial solar cells, more studies have to be carried out. As an attempt to improve the fill factor values the rear side nitride was opened using a laser but there was no noticeable difference. Experiments are undergoing with different paste combination and grid spacing.

CONCLUSION AND OUTLOOK

We demonstrated a simple and cost effective way to produce thin mc-Si PERT-type bifacial solar cells. Two types of both sided nitride deposition based on DCS and BTBAS are applied done in one deposition step. The bifacial cells made by using the DCS based nitride show fill-factor values close to 76% for p-type and 74.6% for n-type silicon solar cells. The efficiencies for all devices are between 12 and 13% so far. The ratio of rear side efficiency to front side efficiency is 67% for p-type and 43% for n-type solar cells. For bifacial solar cells made by using BTBAS based nitride fill-factor values close to 72% and back to front efficiency ratio 68% were achieved. The results strongly suggest the potential for further improvement in solar cell performance for both processes. e.g. by application of isotexture and further process optimisation. The lower temperature deposition of silicon nitride based on BTBAS helps to reduce the thermal budget. Integrated silicon nitride deposition and hydrogen passivation in industrial scale is possible using BTBAS based nitride deposition.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] A.Cuevas 'The early history of bifacial solar cells' 20th EPSEC, Barcelona 2005
- [2] T. Pernau, M. Spiegel, G. Kragler, P. Fath, E. Bucher 'Hydrogen passivation and silicon nitride deposition using an integrated lpcvd process' 16th EPVSEC, Glasgow, May 2000.
- [3] T. Pernau, G. Hahn, M. Spiegel, G. Dietsche 'Bulk hydrogenation of mcSi materials and solar cells: from research lab to PV -industry' 17th ECPVSEC, Munich 2001.
- [4] T. Buck, R. Kopecek, J. Libal, K. Peter, R. Petres, E. Wefringhaus, I. Röver, K. Wambach, L.J. Geerligs, P. Fath 'Large area screen printed n-type mc-Si solar cells with B_emitter efficiencies close to 15% and innovative module inter connection' in this conference
- [5] A. Kraenzl, R. Kopecek, P.Fath, K. Peter 'Bifacial solar cells on mc-Si with boron BSF and open rear contact' in this conference.