APPLICATION OF BTBAS BASED SILICON NITRIDE IN BURIED CONTACT-SCREEN PRINTED PERT-TYPE BIFACIAL SOLAR CELLS

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ABSTRACT: The high efficiency solar cells, like buried contact solar cells, often require a dense silicon nitride as a diffusion barrier and anti reflection coating. This is normally realized by Low Pressure Chemical Vapour Deposition (LPCVD) using dichloro silane based nitride deposited at temperatures in the range of 700°C-800°C. In this work we present bifacial solar cells with front side buried contact and rear side screen printed, realized using a lower temperature LPCVD process based on bis-(tertiary butyl amino)-silane (BTBAS) precursor. The temperature used for the nitride deposition is in the range of 550°C to 600°C. The solar cells produced show fill factors over 77.6% on the front side and 76.8% on the rear side. This higher fill factor values indicates that this hybrid contact structure works well for the bifacial solar cell structure. In addition the cell structure has better mechanical strength as compared to double side buried contact solar cell.
Keywords: BTBAS, LPCVD, silicon nitride, bifacial solar cells

1 INTRODUCTION

The present growth 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. Up-to-date the majority of crystalline silicon solar cells manufactured in the industry are conventional mono-facial cells with an aluminium alloy on the rear side. In order to achieve the cost reduction in solar cell power, both sides of the wafers must be utilised. i.e., bifacial solar cells.

Bifacial solar cells devised in the 1960s [1] are still a topic of interest in solar cell research and development due to its commercial and technological possibilities. In the commercial point of view the bifacial silicon solar cells find application in building facades, as power producing elements on highways, as sound barriers etc. In the technological point of view, typical boron diffused PERT-type bifacial solar cell has features such as lower surface recombination velocity on the rear side as compared to aluminium back surface field (BSF), boron diffusion allows to produce both deep junctions and high doping which are essential for an effective BSF, avoids bowing effect that hinders the use of the cells in module fabrication etc.

Many research groups around the globe have presented several bifacial solar cell structures either both side screen printed contacts or both side buried contact [2,3,4]. Evolution of bifacial solar cell efficiencies is given in reference [2]. Most of the works on screen printed bifacial solar cells uses PECVD silicon nitride as ARC while the works presented on the double side buried contact solar cells have SiO_2 or DCS based LPCVD silicon nitride as the arc and diffusion barrier. The disadvantage of the DCS bases LPCVD is that it requires higher deposition temperature in the range of 700-800°C. The use of the PECVD silicon nitride as diffusion barrier of buried contact solar cells especially for textured wafer is difficult because of the creation of the pinholes or cracks during the selective emitter diffusion process. These cracks or pinholes are also metallized, along with the groove metallization, during the electroless plated plating of nickel and copper.

In this work we present a bifacial solar cell process with a front side buried contact and rear side screen printed solar cell structure using a low temperature LPCVD process based on bis-(tertiary butyl amino)-silane (BTBAS) precursor. The resulting solar cell structure has hybrid contact scheme of buried contact and a screen printed solar cell. The front side of the solar cell has the features of a buried contact solar cell, such as lower shadowing losses and better blue response and the rear side contact causes 'reasonable' shadowing losses (comparable shadowing losses as in the case of standard screen printed solar cell) and helps to maintain better mechanical strength for the solar cell.

2 EXPERIMENTAL

2.1 Solar cell process

The material used in this work is p-type both mono and mc-Si of 300 µm thickness and resistivity in the range of 0.5 – 1.5 Ωcm. The front side buried contact rear side screen printed PERT-type bifacial solar cell process starts with the damage etch in NaOH at 80°C followed by piranha cleaning and an HF dip. The cleaned wafers are loaded into an open tube diffusion furnace for boron diffusion with a sheet resistance of 60 Ω/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 furnace for shallow $POCl_3$ diffusion achieving a sheet resistance of 100 Ω/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*.

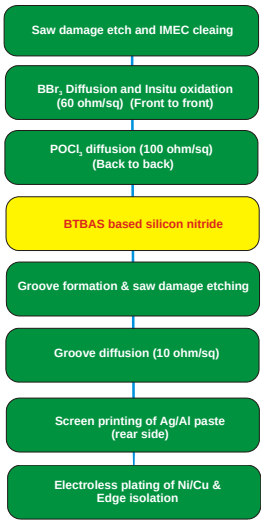

Figure 1: Process sequence of a PERT-type front side buried contact rear side screen printed bifacial solar solar cell with bis-(tertiary butyl amino)-silane BTBAS based nitride.

In the next step Low Pressure Chemical Vapour deposition (LPCVD) silicon nitride of thickness 110 nm is deposited using a BTBAS precursor on both sides of the wafer. Grooves of width 15µm and depth 50 µm are created on the phosphorous diffused side of the wafer using a laser or mechanical dicing saw. The saw damage created during the groove formation is removed by alkaline etching and cleaning followed by a selective emitter diffusion reaching a sheet resistance of 10 Ohm/sq.

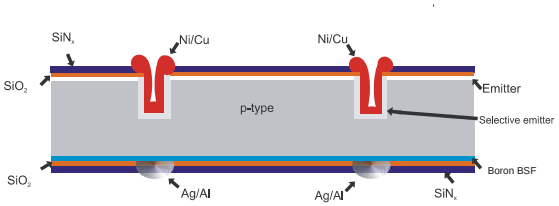

Figure 2: The front side buried contact rear side screen printed solar cell with BTBAS based nitride.

Just like the DCS based LPCVD silicon nitride, about 20-30 nm BTBAS based silicon nitride is consumed from the surface of the wafer during the selective emitter diffusion. After the removal of phosphorous glass formed during the phosphorous diffusion, screen printed Ag/Al open rear contacts are formed on the boron diffused side of the wafer. The metal contacts are fired through the BTBAS silicon nitride at temperatures above 830°C. After performing a short HF dip an electroless deposited nickel and copper is plated inside the grooves.

**In this work the solar cells without SiO_2 overlaying the boron BSF or phosphorous emitter are presented. More investigations on passivation effect of BTBAS nitride in BC/SP structure are in progress at the University of Konstanz.*

The HF dip before the plating is compulsory as a thin oxide layer is expected to form inside the grooves during firing.

Unless removed, this oxide is enough to hinder the electroless plating of nickel and copper inside the grooves. The resulting solar cell structure is given in figure 2. The main features of the present design are the BTBAS based nitride as an Anti Reflection Coating (ARC) and diffusion barrier and front side buried contact and rear side screen printed open grid

2.2 BTBAS Based silicon nitride deposition

The highlighted feature of the present BC/SP bifacial solar cell design described in this paper is a low temperature LPCVD process using a BTBAS precursor. A small note on BTBAS based nitride deposition is given in the following section.

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 inceased 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.

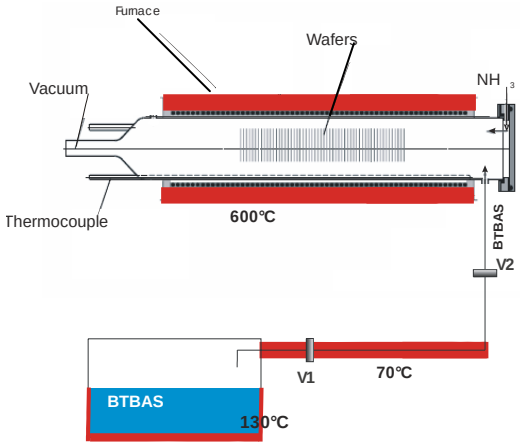

Figure 3: Schematic view of the LPCVD reactor used for the silicon nitride deposition using a BTBAS precursor.

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 depassivation can occur, if no atomic hydrogen is provided [5]. Unfortunately, LPCVD using BTBAS does not allow a parallel use of activated hydrogen so far, as the microwave activation interferes with the LPCVD reaction.

3 RESULTS AND DISCUSSION

3.1 ECV profiles

The Electrochemical Capacitance Voltage (ECV) measurements of the boron and phosphorous diffusion profiles are given in the following figure 4. For comparison emitter profile of a 50 ohm/sq emitter is also provided.

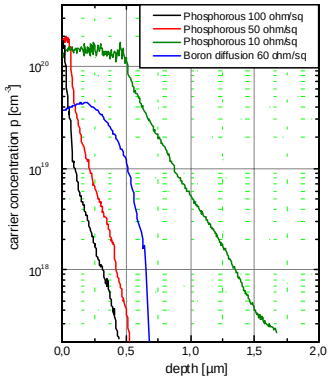

Figure 4: Diffusion profile of phosphorous and boron in silicon wafer at different temperatures (see text for details)

As the buried contact solar cell structure involves two high temperature steps and one nitride deposition step at 550°C - 600°C, the initial boron concentration on the surface of the wafer is expected to change. For this reason a higher temperature (+20°C) is applied as compared to the standard firing nitride to establish a good contact with screen printed Ag/Al and boron BSF. Even though the shallow emitter profile changes during the subsequent high temperature steps, it can be well contacted with the selective emitter of 10 ohm/sq sheet resistance.

One more problem which occurred during the solar cell process is the different thickness of oxide on the phosphorous and boron diffused surfaces. The growth of the oxide is found to be lower on the boron BSF (of sheet resistance 60 ohm/sq) side as compared to the phosphorous diffused emitter (of sheet resistance 100 ohm/sq). The ECV diagram in figure 4 further reveals that the different concentrations of the charge carriers in emitter and BSF play a vital role on the growth of oxide during the thermal oxidation process. The surface carrier concentration of the phosphorous doped layer is higher 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 uniform nitride films on both wafer surfaces. 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. But, for a standardised BC/SP process, the boron diffusion profile must be tailored.

3.2 IV characteristics

The solar cell parameters of the BC-SP bifacial cells are given in table I. The solar cells are made on wafers of thickness 300 µm and size 100x100 mm² on mono crystalline wafers. For comparison the solar cell parameters of a screen printed solar cell are given in the same table. It should be noted that the boron BSF in the BC/SP bifacial solar cell is not passivated by SiO_2. The solar cell parameters of a reference cell are given in the same table. Unlike the screen printed bifacial solar cell, the BC/SP structure has higher fill factor values. This indicates that the boron BSF could be contacted effectively in the BC/SP hybrid bifacial solar cells without any shunting. The lower fill factor values in the reference cells were due to higher series resistance. The lack of passivation on the boron BSF results in lower open circuit voltage during the rear illumination.

Table I: Solar cell parameters of bifacial solar cells

Cell type	Illu.	FF [%]	J_{sc} [mA/cm²]	V_{oc} [mV]	η [%]
BC/SP	front	77.6	32.7	601	15.2
	rear	76.8	9.1	566	4.0
Bifacial SP cell (Ref.)	front	71.8	30.0	589	12.7
	rear	71.0	21.0	580	8.6

Even though the nitride thickness on either side was not uniform for the reference cell still exhibit higher short circuit current that are comparable to the short circuit current produced on the front side. But in the case of BC/SP structure the silicon nitride thickness was quite uniform yet exhibit lower short circuit current. A life time monitoring of the BC/SP solar cell structure is necessary to keep an eye on the life time changes in each process step. A comparison of screen printed bifacial solar cells prepared using BTBAS based nitride and DCS based nitride is given in the reference [6].

3.3 Spectral response

The internal quantum efficiency (IQE) and reflectance of the BC/SP cells are measured using a spectral response set-up and the IQE is compared to the both side screen printed bifacial solar cells. The blue response of BC/SP structure is higher than that of the both side screen printed solar cells. This is due to shallow emitter of the BC/SP bifacial cells. The blue response further indicates that the emitter passivation using BTBAS based nitride is much better than that of the boron BSF. The response of the both side screen printed bifacial solar cell is higher in the range of 650 nm to 1050 nm, indicating that the bulk life time of the reference cell is higher than that of the BC/SP structure. It is well known that solar cell efficiency is highly depend upon the kind of the solar cell process applied (cell technology) and the material used. Same type of material from different wafer manufacturers gives different life time and hence different cell efficiencies.

More details on life time monitoring of different solar cell process (screen printed and buried contact solar cell process) is given in the reference [7].

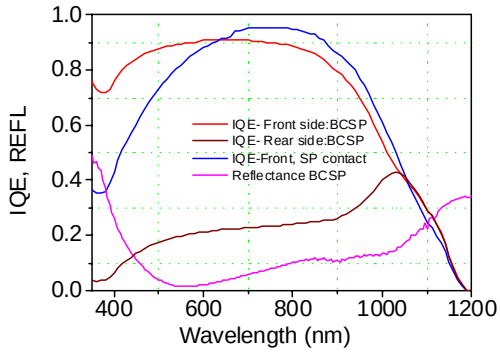

Figure 5. Spectral response of front side buried contact and rear side screen printed solar cells and its comparison with a double side screen printed solar cells. Both cell types are fabricated using the BTBAS based nitride.

The rear side spectral response of the BC/SP solar cell indicates that from 500 nm to 900 nm the response increases quite slowly and after 900 nm the responses increases. This indicates that the photons with higher wavelength penetrate deeper into the wafer and therefore higher spectral response. The IQE is still relatively low as compared to the front side of the BC/SP cell. This indicates the necessity of improving the bulk life time.

4. SUMMARY AND CONCLUSION

A bifacial solar cell process with hybrid buried contact and screen printed is realized using a lower temperature LPCVD process with a BTBAS precursor. The nitride deposition temperature was in the range of 550°C to 600°C. The front side fill factor of the BC/SP structure is 77.6% and the rear side fill factor is 76.8%. Even though the front side efficiency is 15.2 %, the rear side efficiency has to be improved by applying the passivation of boron BSF and standardising the process. The screen printed rear side helps to maintain a higher mechanical strength as compared to double side grooved bifacial buried contact solar cells. The passivation effect of BTBAS nitride on boron BSF and phosphorous emitter has to be studied in detail. 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.

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REFERENCES

[1] Andreas Cuevas 'The early history of bifacial solr cells'. Proceedings of 20th European Photovoltaic Solar Energy Conference, Barcelona 2005.

[2] A. Kränzl, R. Kopecek, P.Fath, K. Peter 'Bifacial solar cells on mc-Si with boron BSF and open rear contact' Proceedings of 4th WCPEC Hawaii 2006.

[3] B. Lenkeit, S. Steckemetz, A. Mücklich, A. Metz and R. Hezel ' High quality screen printed and fired through silicon nitride rear contacts for bifacial silicon solar cells'. Proceedings of 16th European Photovoltaic Solar Energy Conference, Glasgow 2000.

[4] A. U. Ebong, S.H. Lee, W. Warta, C. B. Honsberg, S. R. Wenham 'Characterisation of high-open circuit voltage double sided buried contact solar cells', Solar energy materials and solar cells 45 (1997) 283-299.

[5] T. Pernau, G. Hahn, M. Spiegel, G. Dietsche 'Bulk hydrogenation of mc-Si materials and solar cells: from research lab to PV –industry' 17th European Photovoltaic Solar Energy Conference, Munich 2001.

[6] J. Arumughan, R. Kopecek, T. Pernau, T. Buck, P.Fath, K. Peter 'Realization thin mc-Si PERT- type bifacial solar cells in industrial environment' Proceedings of 4th WCPEC Hawaii 2006.

[7] B. Raabe, J. Arumughan, B. Clark-Phelps, G. Hahn 'Lifetime monitoring and hydrogen passivation in a buried contact solar cell processing using string ribbon' This conference.