SUMMARY OF THE BMWI – UKN PROJECT ON INNOVATIVE AND COST-EFFECTIVE CRYSTALLINE SILICON SOLAR CELLS WITH NEW APPLICATIONS

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ABSTRACT: The primary focus of the project 'Innovative, kostengünstige kristalline Siliziumsolarzellen mit neuen Anwendungen' (innovative, cost-effective crystalline silicon solar cells with new applications) was on the development of technologies feasible in industrial production.
Within the project, three back contact solar cell concepts were improved to reach readiness for start of industrial production: The Metal-Wrap-Around (MWA) concept, the Metal-Wrap-Through (MWT) design and the Emitter-Wrap-Trough (EWT) idea. All three cell concepts have both n- and p-type current draining busbars on the rear side. This reduces series resistance losses and simplifies cell interconnection.
To show the efficiency potential of these cell designs, solar cells sized 10*10 cm² based on CZ monocrystalline material were manufactured. MWT solar cells, which are currently the most feasible solar cells for industrial production, showed efficiencies of up to 17.3 %.
Based on the lessons learned from the EWT solar cell design, bifacial solar cells were produced with typical efficiencies of 11.5% for frontside illumination and 5.5 % for backside illumination.
In parallel to solar cell fabrication, technical studies on advanced solar cell processing were carried out, e.g. the application of modern, ultra-fast cutting/scribing lasers for laser ablation, drilling contact holes and cutting contact grooves and alternative LPCVD SiN_x deposition precursors.
Keywords:- back contact solar cell – 1, bifacial solar cell – 2, crystalline silicon solar cell - 3

1 INTRODUCTION

From 2000-2003, the solar cell research group at the University of Konstanz (UKN) ran a project on improvement of back contact and bifacial solar cells funded by the German Ministry of Economics (BMWi) under the contract number 0329897A. All research done has been documented in the final report which is written in German, accessible via [1]. This contribution is meant to inform the international public about the most relevant results of the project.

2 WORKPACKAGES

Laser technology
- Development of machine software
- Investigations on laser machining: drilling holes, laser ablation, laser damage, laser gettering

Abrasive technologies
- Drilling holes
- Mechanical ablation

Metallisation
- Screen printing and plating in small holes
- Screen printing of local Al-BSF

p/n Definition
- Investigations on diffusion barrier pastes
- locally confined ablation of emitter regions
- directional plasma etching

Emitter optimisation
- experimental
- computer simulation

further aspects:
- LPCVD-SiN_x and combination with hydrogen passivation
- development, analysis and optimisation of monofacial and bifacial back contact solar cells
- fabrication and tests of mini modules
- adaption of machinery for fabrication of back contact solar cells

3 PROGRESS REPORT

The expected solar cell efficiencies at the beginning of the project were 16 % on large-area mc Si solar cells and 17.5 % on large area monocrystalline solar cells. The latter has been reached, whereas optimisation on multicrystalline material was postponed due to lack of time.
The project focused mainly on the adaption and optimisation of existing equipment and technologies to the manufacturing of back contact solar cells. Therefore the results achieved were less academic in nature, but a number of patents have been granted:
- DE000010047556A1 / EP000001319256A2, WO002002025743A3 and WO002002025743A2, already licensed.
- DE000010021440A1 / EP000001279196A1, JP002003533029T2, US020030102022A1, WO002001084639A1, already licensed
- DE000010020541A1 / EP000001277239A1, JP002003532297T2, US020030089393A1, WO002001082383A1, already licensed.

Together with our partner company centrotherm, a production line for back contact solar cells has been developed. The planned production facility can be built up within one year and reach rated production capacity two years after the beginning of construction.
As already mentioned, licenses for back contact solar cell concepts were granted and staff of the licensees has been trained.

4 TECHNOLOGIES IMPROVED WITHIN THE PROJECT

4.1 Laser technology

Silicon machining with lasers has many advantages as compared to conventional mechanic cutting or drilling. Contactless laser cutting is contamination-free and as

the mechanical stress is low there is no need for a mechanical fixation of the wafer. Within the project, a 1064 nm Nd:YAG laser was used for drilling holes and cutting contact grooves of back contact solar cells. The machine software and optical system have been adapted to the peculiarities of back contact solar cell processing. The laser damage introduced by the 1064 nm laser (average depth 15 µm) has always been removed by a hot sodium hydrochloride solution etch.
For many types of back contact solar cells, laser ablation of thin layers (doped regions or dielectrics) is useful. However, the introduced laser damage is comparable to conventional saw damage when using excessively long laser wavelengths or pulses. Therefore tests were performed with frequency-doubled Nd:YAG at 532 nm and with short laser pulses (< 100 ns). The latter were used to remove dielectrics from silicon with only little thermal damage to the substrate.

4.2 Metallisation by screen printing

Screen printing of metallic pastes is an established way of contacting industrial type solar cells. Therefore this technique has been adapted and optimised for use with back contact solar cells. A screen printer with optical adjustment was used to achieve a position accuracy below 100 µm and a tilt accuracy below 0.1°. This is the precondition to fabricate MWT and EWT solar cells (see sections 5.2 and 5.3). For those cell types, it is necessary that the screen printing paste penetrates into holes of 100 µm in diameter. This was achieved by an optimisation of paste viscosity and screen printing parameters. One major issue was shrinking of the screen printing pastes during thermal treatment. A volume reduction of up to 50% was observed. The achieved contact resistivity was 5-10 mΩcm², which is comparable to conventional solar cells.
For the MWA solar cells (see section 5.1), it would be favourable to apply the metallisation around the edges in one step together with front/rear side contact printing. Though it is possible to design and adjust a printing screen in an appropriate way, it was not successful to print a series of wafers with that configuration due to spilled paste. A possible technical solution would be a screen printing machine with automatic chuck cleaning after each wafer.

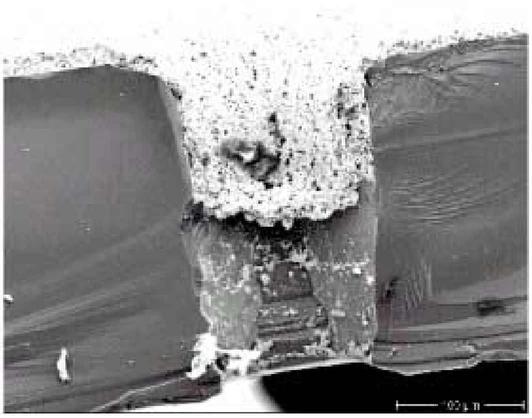

Fig. 1: Cross-sectional SEM-picture of a hole (100 µm dia.) metallised by a screen printing paste. The paste was applied from the top. The designated front side of the solar cell is at the bottom of the image. The hole was initially completely filled, but during firing the screen printing paste shrunk by about 50%.

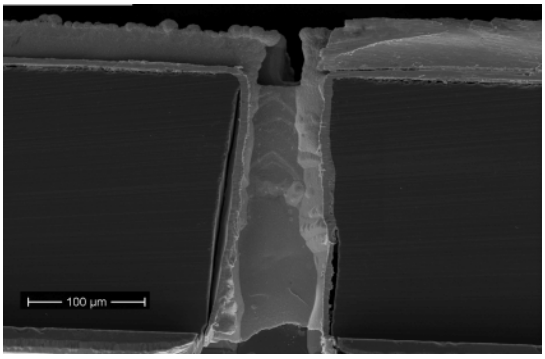

Fig. 2: Cross-sectional SEM picture of a hole (< 100 µm dia.) metallised by electroless plating. The hole is perfectly covered with highly conductive copper.

4.3 Metallisation by electroless plating

An alternative to screen printing is the electroless plating technique used for industrial production of buried contact solar cells. The plating reaction is selective, preferably conducting surfaces (e.g. blank silicon) is covered by metal. This technique is a great benefit for all back contact solar cells, as metallisation through holes or around edges can be realised easily. The contacts made by electroless plating are narrow (down to 20 µm) and deep (up to 40 µm), produce less shadowing and are highly conductive. This is advantageous for the typically longer contact fingers of back contact solar cells.

4.4 definition of p/n regions

For most back contact solar cells, a selective emitter consisting of at least two different doping levels is favourable to pool high conductivity beneath the contacts and low emitter recombination at the cell's surface. Those two-step selective emitters (typically 10/100 Ω/sq.) are usually produced by a slight uniform diffusion followed by a strong masked diffusion. LPCVD silicon nitride (SiN_x) proved to be a reliable diffusion barrier. Experiments were performed to replace the medium temperature LPCVD process by a low temperature PECVD deposition. Direct plasma PECVD silicon nitride deposited at rather high pressures (> 1.5 torr) turned out to be equal or better as compared to LPCVD SiN_x, esp. if single sided or partly directional coating is required. PECVD SiN_x can create problems in combination with electroless plating if the SiN_x surface is not smooth enough. The result is unwanted metal deposition on SiN_x covered areas.
A SiN_x diffusion barrier for a selective emitter usually needs further treatment to achieve a designated mask shape. Besides cutting (buried contact method) laser ablation, masked plasma etching and removal by a HF-containing paste is possible.
An interesting way to define p/n regions is the Al/P codiffusion[2]. The results achieved using evaporated contacts were very promising, but could not be maintained or improved using screen printing techniques. A prerequisite for substantial improvements are Ag pastes that can be sintered at much lower temperatures as compared to the products currently available.

4.5 LPCVD SiN_x deposition

LPCVD silicon nitride is known for superior surface smoothness and conformal deposition, but contains nearly no hydrogen. Additionally, the rather high temperature (750-800 °C) for conventional LPCVD SiN_x deposition from dichlorosilane (DCS) is not compatible with microwave induced remote plasma hydrogen passivation (MIRHP)[3]. An alternative precursor is bis-tertiary butylaminosilane[4] (BTBAS), which allows deposition temperatures as low as 600 °C. The UKN LPCVD reactor has been modified to use BTBAS, but there was only little success during the project time. However, in spring 2005, after a further modification, first experiments were successful. The surface passivation and smoothness achieved with BTBAS was comparable to conventional DCS, whereas the conformity was slightly lower. The compatibility with MIRHP has not been tested yet, but prospects are promising.

5 BACK CONTACT SOLAR CELL CONCEPTS

Within the project, three back contact solar cell types have been developed for industrial application. The concepts differ in how the front side current collecting emitter is connected to the rear side contacts.

5.1 The MWA concept

The Metallisation Wrap Around (MWA) solar cells use metallised edges to connect front side grid fingers to the rear side emitter contact. MWA solar cells based on the buried contact method have been proposed in [5]. MWA solar cells without selective emitter can be produced like conventional screen printed solar cells, with two minor modifications:

1. Move front side current collecting busbars to the cell edges and screen print Ag paste around those edges
2. Apply two isolating cuts on the rear side between p- and n-region metallisation. Establish an isolation (rectifying junction) between the n- and p-type region on the rear side

The concept is illustrated in Fig. 3. In spring 2004 when the German final report was compiled, this solar cell concept still seemed to be a technical challenge to industrial processing equipment. However, improvements in optical image processing (for wafer recognition / screen printing inspection) in combination with cutting lasers used for edge isolation of screen printed solar cells have can cope with the new solar cell concept. Screen printed MWA solar cells reached 15.5% efficiency on 10*10 cm² CZ wafers.

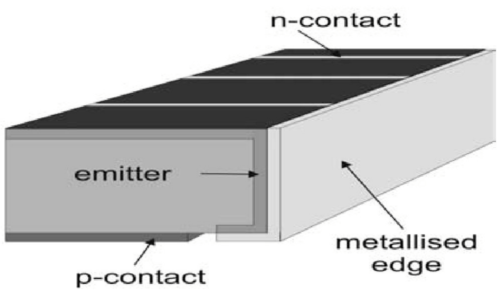

Fig. 3: Partial view of a MWA solar cell. The sketch shows the cell edge, where frontside current collecting grid fingers and rear side emitter busbars are connected by a metal strip around the edge.

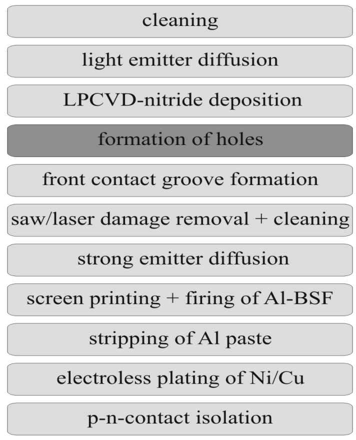

Fig. 4: Processing scheme for MWT solar cells based on the buried contact method. The only additional processing step is the formation of a rather small number of holes.

5.2 The MWT concept

The Metallisation Wrap Through (MWT) solar cells use an number of small laser-drilled an metallised holes to connect front side emitter and rear side emitter contacts. This is a very promising solar cell concept, as the only difference to conventional buried contact solar cells is a rather small number of additional holes that have to be drilled into the wafers, as can be seen from the processing scheme in Fig. 4. This is not necessarily an extra step if using an appropriate laser. The rest of the MWT solar cell process follows the standard buried contact solar cell process. Metallisation of the MWT cells was found to be more challenging than with conventional cells, since the adhesion in the untextured n-type busbar region on the rear side of the cell was poor in many cases. Some problems arose from the use of Ni as a diffusion barrier. Thermography images revealed shunts at the rear side busbars that were caused by improper Ni sintering. The solar cells affected by these problems reached efficiencies of 16.1 % on 10*10 cm² CZ material. The Ni problem was partly overcome in 2004, with an increase in efficiency to 17.3%.

5.3 The EWT concept

The Emitter Wrap Through (EWT) solar cell design [6] features no frontside grid fingers at all, the frontside emitter is connected to the rear side emitter, grid fingers and busbars by a larger number of holes (about fifty times as much as with MWT).

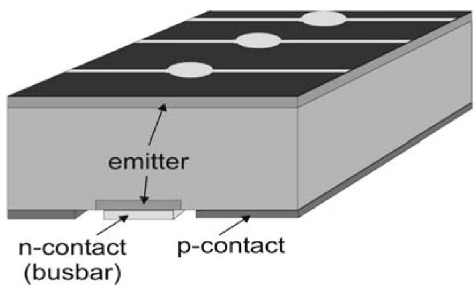

Fig. 5: Section of a MWT solar cell. The emitter grid fingers are connected to the rear side busbars via metallised holes.

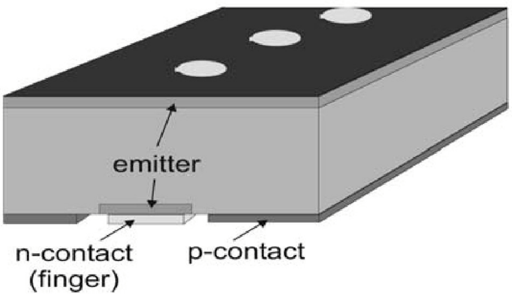

Fig. 6: Section of an EWT solar cell. The frontside emitter is connected to the rear side grid fingers and busbars via a number of holes.

Using the EWT design, both grid fingers and busbars can be 'oversized' without shading losses and without limits to the wafer size. The manufacturing procedure is a little more challenging, as in addition a diffusion barrier paste has to be screen-printed:

1. shallow emitter diffusion (100Ω/sq)
2. one-sided SiN_x coating
3. drilling of holes using cutting laser
4. Laser damage etching
5. screen-printing of diffusion barrier
6. strong emitter diffusion (10 Ω/sq)
7. screen-printing and firing of contacts

Both screen printing process on 10*10 cm² CZ wafers and (more complex) buried contact process on 5*5 cm² reached efficiencies of 16.6 %

6 BIFACIAL SOLAR CELLS

A bifacial solar cell has to drain photogenerated carriers from the front- and backside, therefore a double-sided emitter would be beneficial. Many existing bifacial solar cell concepts do not feature that and thus need to be manufactured from thin, high quality FZ material. If contacting the backside emitter with an extra grid and busbars, additional backside shading losses are introduced. These can be avoided using an EWT design, see Fig. 7. The emitter contact located on the front side is connected to the rear side emitter through a number of laser-drilled holes. The use of electroless plating for frontside metallisation assures good metal coverage inside both contact grooves and holes. The processing was based on the EWT process, but without p- and n-region busbars on the same side. As an antireflection coating LPCVD SiN_x was used, which is applied uniformly on both sides in one step.
The first prototypes of this concept reached a frontside efficiency of 11.5 % and a rear side efficiency of 5.3 % on 10*10 cm² CZ material. Some problems arose from incompatibilities of Al/Ag screen printing paste and electroless plating. Further experiments on this concept are planned by one of the authors.

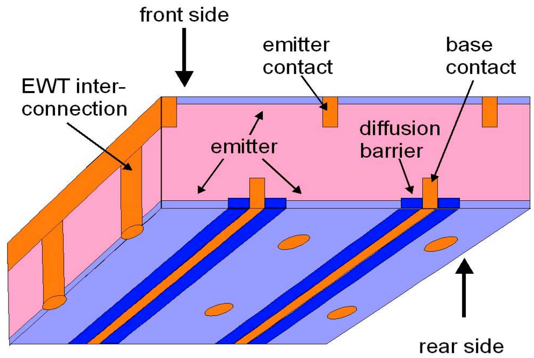

Fig. 7: Schematic view of the bifacial EWT design. The plated metal contacts are orange, the double-sided antireflection coating is light blue and the diffusion barrier is dark blue.

7 ACKNOWLEDGEMENTS

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Within this project, four dissertations have been completed in 2003:

- Barbara Terheiden, PhD thesis [7]
- Thomas Pernau, PhD thesis [8]
- Katrin Faika, PhD thesis [9]
- Wolfgang Neu, PhD thesis

We would also like to thank all our colleagues and technicians for many fruitful discussions, ideas and technical assistance.

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