RISE-EWT: Simple and Robust High-Efficiency Silicon Solar Cells

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Abstract: Concepts for photovoltaic solar energy conversion that allow efficiencies in excess of the Shockley-Queisser limit (i.e. higher than about 30% without optical concentration) have been labeled as third-generation photovoltaics (3rdG PV). 3rdG PV is an exciting field of research, however, the terminology of a "3rd generation" is potentially misleading. While the concepts of 3rdG PV *theoretically* allow ultra-high efficiencies the "previous generations" have already *in practice* set rather high benchmarks in terms of both efficiency and low cost of production technologies. To illustrate the current status of industrially relevant "first generation PV" we present here the **R**ear **I**nterdigitated **S**ingle **E**vaporation **E**mitter **W**rap-**T**hrough (RISE-EWT) silicon solar cell, which is capable of achieving energy conversion efficiencies above 20 %. The manufacturing process avoids any lithography and masking steps and consists of only non-contacting manufacturing methods. For low process complexity, the RISE-EWT concept includes only one (phosphorus) diffusion and a single processing step for metallization. Laser technology is applied as the key processing tool for achieving such characteristics. We present experimental results of solar cell performances, reaching 20.0% of efficiency. Our experimental results underline the potential for very high efficiencies, while the EWT structure makes it particularly promising for medium and low-quality material. Furthermore, the completely contact less process sequence makes the RISE-EWT well suited for processing thin wafers.

1 Introduction

Concepts for back-contacted solar cells can be classified into: (i) Interdigitated Back-Contact (IBC) solar cells [i], (ii) Emitter Wrap-Through (EWT) solar cells [ii], (iii) Metallisation Wrap-Around (MWA) solar cells [iii], and (iv) Metallisation Wrap-Through (MWT) solar cells [iv]. While MWT and MWA solar cells still have metal fingers on the front side, there is no front metallisation for IBC and EWT solar cells. In the IBC concept the collecting junction is located on the rear side of the absorber and thus requires for efficient operation minority carrier diffusion lengths that exceed the thickness of the absorber. A promising solar cell structure to circumvent the demand for high-quality material is the Emitter-Wrap-Through (EWT) cell structure. Via holes in the EWT cell connect an emitter layer at the front surface to the contacted rear side emitter layer.

In this article we present a simple processing sequence for the manufacturing of high-efficiency EWT solar cells. Using neither selective (phosphorus) emitter diffusion nor boron diffusion nor any kind of lithography we employ laser technology as the key tool for our completely contactless solar cell manufacturing process. We developed a laser ablation process which designs the interdigitated rear junction and simultaneously provides a rear surface topography for a self-aligning reliable separation of the metal contacts after a single metallisation step. This is the key feature of our new **R**ear **I**nterdigitated **S**ingle **E**vaporation **E**mitter **W**rap-**T**hrough (RISE-EWT) solar cell concept. Moreover, compared to most other EWT concepts, RISE-EWT uses only a single diffusion step and is nevertheless showing potential for efficiencies well above 20 %. Our novel RISE-EWT cell combines the advantages of the EWT concept with a simple and contactless processing sequence and high throughput techniques. It is therefore promising for (a) producing low-cost high efficiency solar cells, (b) achieving improved efficiencies for solar cells made of low-quality absorber material and (c) producing solar cells from very thin wafers by contactless processing.

2 Cell Design

A schematic representation of the RISE-EWT silicon solar cell is given in Figure 1. The structure on the rear side consists of interdigitated metal grid fingers like at the IBC solar cell.

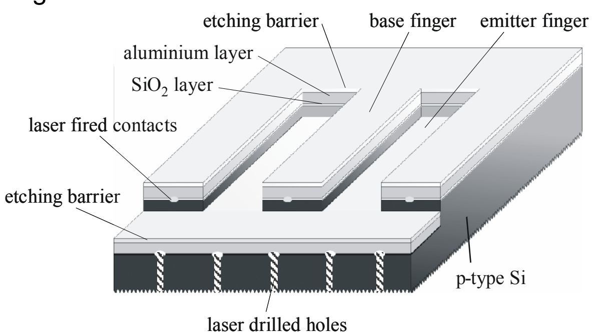

Figure 1: Schematic of the RISE-EWT solar cell structure. The solar cell is drawn upside down in order to provide a clear view onto the layout of the rear side.

Busbars are placed on the rear of the solar cells at opposing edges. A feature of the RISE-EWT structure is the difference in the levels of the emitter and base regions at the rear surface. The different levels are produced by laser ablation of SiO_2-covered Si. The optimised laser process plus additional etching result in very homogeneous and smooth surfaces and steep flanks to the elevations. These steep flanks are used for the self-aligning separation of the rear contacts after a single metallisation step by evaporation. The contact separation can be further assisted by introducing an additional thin etching barrier on top of the metal contact to the silicon and subsequent metal etching [v].

The EWT design is realised by connecting front and rear side emitter by laser drilled holes. In order to maintain a low complexity of the cell process, the vias and the back surface structuring are made in one laser processing step prior to emitter diffusion.

We use a so called tunnel oxide consisting of a thin (~ 1.5 nm) oxide layer to produce a high-quality $Al/SiO_x/n^+$-Si emitter contact. The contacts to the base are produced by laser-firing of aluminium through a SiO_2 layer into the *p*-type silicon, the so called "Laser-Fired Contacts" (LFC) [vi].

3 Processing Sequence

For the manufacturing of the RISE-EWT solar cells presented in this article, we used *p*-type, boron doped, monocrystalline Si as starting material. After a standard RCA cleaning, a wet oxidation is performed at a temperature of 1,000°C. The SiO_2 is removed from the front for texturing with random pyramids.

In order to define the emitter regions on the rear side and to produce a suitable surface topography for the self-aligning contact separation, the SiO_2 layer and additional approx. 20 µm of Si are ablated locally by a Q-switched Nd:YAG laser, operating at a wavelength of λ = 355nm. During the same laser processing step vias are drilled through the wafer to prepare for the EWT structure formation during phosphorus diffusion. The laser-induced damage is removed by a wet chemical etching step in a KOH solution. A conventional phosphorus diffusion with $POCl_3$ is performed, resulting in a sheet resistance of around 40 Ω/square. On the elevated areas of the rear surface the SiO_2 layer is still intact and acts as a diffusion barrier, defining the base region. Anti-reflection properties and an excellent front surface passivation are achieved by depositing a double layer of SiN_x by means of remote plasma-enhanced chemical vapour deposition (PECVD) at 400°C. In a short annealing step at 500°C the very thin (~ 1.5 nm) tunnel oxide layer is grown on the phosphorous diffused silicon surface on the rear. The entire back of RISE-EWT is metallised in a single aluminium evaporation process. On top of the Al layer a thin SiO_x layer, acting as etching barrier later, is evaporated within the same vacuum process. We developed a wet chemical Al etching step which – in combination with the steep flanks between emitter and base region realised by the laser ablation process– produce a reliable separation of contacts. The thin SiO_x layer withstands the Al etching solution and thus protects the underlying Al on planar areas. The vertical flanks of the grooves produce a local disruption or at least perforation of the evaporated SiO_x layer so that the Al is removed from the flanks. Figure 2 shows a SEM image of a clearly separated metal finger on the elevated base region. Finally, the contacts to the *p*-type base are performed by laser-firing of Al through the thermally grown SiO_2 layer into Si.

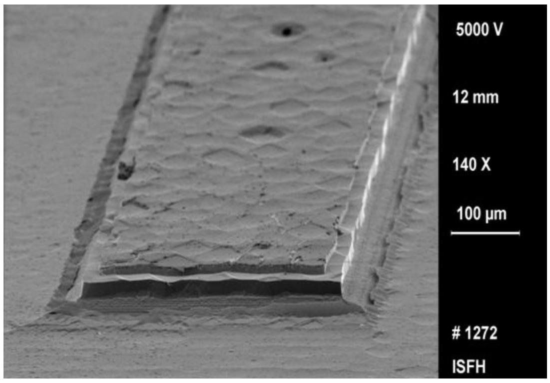

Figure 2 Scanning electron microscope picture of separated metallisation fingers after Al etching. It is clearly visible that contact separation occurs at the steep flanks resulting from laser ablation.

4 Results and Discussion

Using *p*-type, boron doped FZ Si with a specific resistance of 0.5 Ωcm we manufactured RISE-EWT solar cells with a total area of 10x10 cm^2. For measuring the *I-V* curves the 10x10 cm^2 solar cells were illuminated on an area of only 93 cm^2 due to technical reasons concerning the measurement equipment. The 10x10 cm^2 solar cells have an efficiency of 20.0% (inhouse measurement) and thereby demonstrate that RISE-EWT is well suitable for high efficiency on large-sized solar cells. The short circuit current density J_{sc} is 40.0 mA/cm^2. This is a rather high value when considering that only a single diffusion step has been applied with a sheet resistance of 40 Ω/square. For the sake of simplicity the RISE-EWT solar cell does not have a rear side passivation or localised contacting scheme at the rear side emitter, resulting in a rather modest open circuit voltage V_{oc} of about 637 mV. The fill factor of 78.4 % is currently limited by a combination of series resistance and a recombination current with an ideality factor of approximately 2. For all processed solar cells the shunt resistance is in the range of 5-20 $k\Omega cm^2$, showing the effective and reliable contact separation of RISE-EWT.

5 Conclusions

A new concept for the fabrication of simple high-efficiency back-contacted silicon solar cell is presented, the **R**ear **I**nterdigitated **S**ingle **E**vaporation **E**mitter **W**rap-**T**hrough (RISE-EWT) solar cell. The fabrication sequence includes only contactless processing and is therefore suitable for thin wafers. Owing to the EWT concept, the RISE-EWT is very promising for producing high efficient solar cells even from medium- and low-quality material. The simplicity of production is warranted by using only a single diffusion step, only one vacuum metallisation process, and a reliable self-aligning rear contact separation with shunt resistances of several kΩcm^2. We applied laser technology as a key tool in cell processing for defining emitter and base regions on the rear side as well as for separation of contacts. With the inherent feature of working locally, laser processing replaces any lithography and masking steps. The RISE-EWT solar cell combines the advantages of back contacted solar cells with a simple and contactless cell fabrication process. On FZ Si, efficiencies of 20.0 % for 93 cm^2 aperture area have already been obtained in first experiments. Significant increase of cell results can be expected upon optimization of the single phosphorus diffusion and the cell geometry produced by laser processing.

6 Acknowledgements

The authors are grateful to S. Kirstein, B. Terheiden, Mihail Manole, and thank all members of the PV department at ISFH for their valuable contributions to this work. The financial support by the State of Lower Saxony and the German Federal Government is gratefully acknowledged. The ISFH is a member of *Forschungsverbund Sonnenenergie e.V*.

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