Solar Energy Materials and Solar Cells xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Solar Energy Materials and Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Printable liquid silicon for local doping of solar cells

Felix Haase[a,*], Bianca Lim[a], Agnes Merkle[a], Thorsten Dullweber[a], Rolf Brendel[a,b], Christian Günther[c], Michael H. Holthausen[c], Christoph Mader[c], Odo Wunnicke[c], Robby Peibst[a,d]

[a] Institut für Solarenergieforschung Hameln (ISFH), Am Ohrberg 1, D-31860 Emmerthal, Germany
[b] Institute for Solid State Physics, Leibniz Universität Hannover, Hannover, Germany
[c] Evonik Creavis GmbH, Marl, Germany
[d] Institute of Electronic Materials and Devices, Leibniz Universität Hannover, Hannover, Germany

ARTICLE INFO

Keywords:
Printable silicon
Out diffused emitters
Local doping
Back-contact solar cell

ABSTRACT

We demonstrate the application of a liquid-processed doped silicon precursor as a doping source for the fabrication of interdigitated back contact solar cells. We integrate phosphorus- as well as boron-doped liquid silicon in our *n*-type interdigitated back contact cell process based on laser-structuring. The cell with the phosphorus back surface field from liquid silicon has an efficiency of 20.9% and the cell with the boron emitter from liquid silicon has an efficiency of 21.9%. We measure saturation current densities of 34 fA cm^{-2} on phosphorus-doped layers with a sheet resistance of 108 Ω/sq and 18 fA cm^{-2} on boron-doped layers with a sheet resistance of 140 Ω/sq using passivated test samples.

1. Introduction

Fast and cost-effective formation of locally doped regions is a key manufacturing step for cost-effective fabrication of highly efficient solar cells. Previous examples for efficiency improvements due to the implementation of locally doped regions are the transition from full area Al-back surface field (BSF) to local BSF contacts, the implementation of selective emitters, and interdigitated back contact (IBC) solar cells [1]. Many technical solutions and various types of dopant sources can achieve local doping. Laser processing such as laser chemical processing (LCP) [2,3] or laser doping using the phosphosilicate glass (PSG) layer from a $POCl_3$ diffusion [4,5], a sputtered boron layer [6], nano particles [7], or dopant-containing amorphous silicon (a-Si) layers [8], are options for forming locally doped regions. Another possibility is in-situ masked ion implantation [9–11]. As a further alternative to laser processing Woehl et al. [12] formed local Al-doped layers by Al-screen printing and Scardera et al. [13] formed B- and P-doped layers by screen printing of B- and P-containing pastes for IBC cells.

In this work, we investigate liquid silicon (LiSi), a Neopentasilane-based ink, as a dopant source. LiSi has a potentially lower capex than most of the abovementioned techniques and can be applied to the wafer by spin coating or inkjet printing under inert atmosphere. The application of LiSi in amorphous silicon solar cells was already shown [14–16]. The amorphous LiSi layers can also be applied to wafer-based solar cells, e.g. heterojunction cells [17] or as a drive-in source for homojunction cells. In the following, we apply doped LiSi to form local BSF or emitter regions in homojunction crystalline IBC solar cells. In the first step, we deposit the LiSi by spin coating onto the wafer. We investigate the sheet resistance and recombination parameters on test samples after annealing in nitrogen and fabricate n-type IBC cells from these layers. In Batch 1 we use the phosphorus-doped LiSi for the BSF formation and in Batch 2 we use the boron-doped LiSi for the emitter formation of IBC cells. The second step is local printing of the LiSi for both polarities, for which we present first results.

2. Sample preparation

Liquid silicon is a Neopentasilane oligomer. It is liquid at room temperature and converts into amorphous silicon above 220 °C, contrary to pure mono-, di-, tri- or Neopentasilanes, which evaporate when exceeding their individual boiling point. LiSi can be *n*- or *p*-type doped with up to 5 at%. Since it is a pyrophoric liquid it has to be processed under inert atmosphere. For our studies we used a nitrogen atmosphere.

2.1. Test samples

Fig. 1 shows the test samples for investigating the electrical properties of the doped LiSi layers. We test various LiSi compositions in which we vary the doping concentration and solvent.

a) The *n*- or *p*-type LiSi layers are deposited by spin coating with thicknesses from 20 nm to 150 nm onto one side of an *n*-type Cz-Si

* Corresponding author.
E-mail address: f.haase@isfh.de (F. Haase).

https://doi.org/10.1016/j.solmat.2017.11.003
Received 12 June 2017; Received in revised form 1 November 2017; Accepted 2 November 2017
0927-0248/ © 2017 Elsevier B.V. All rights reserved.

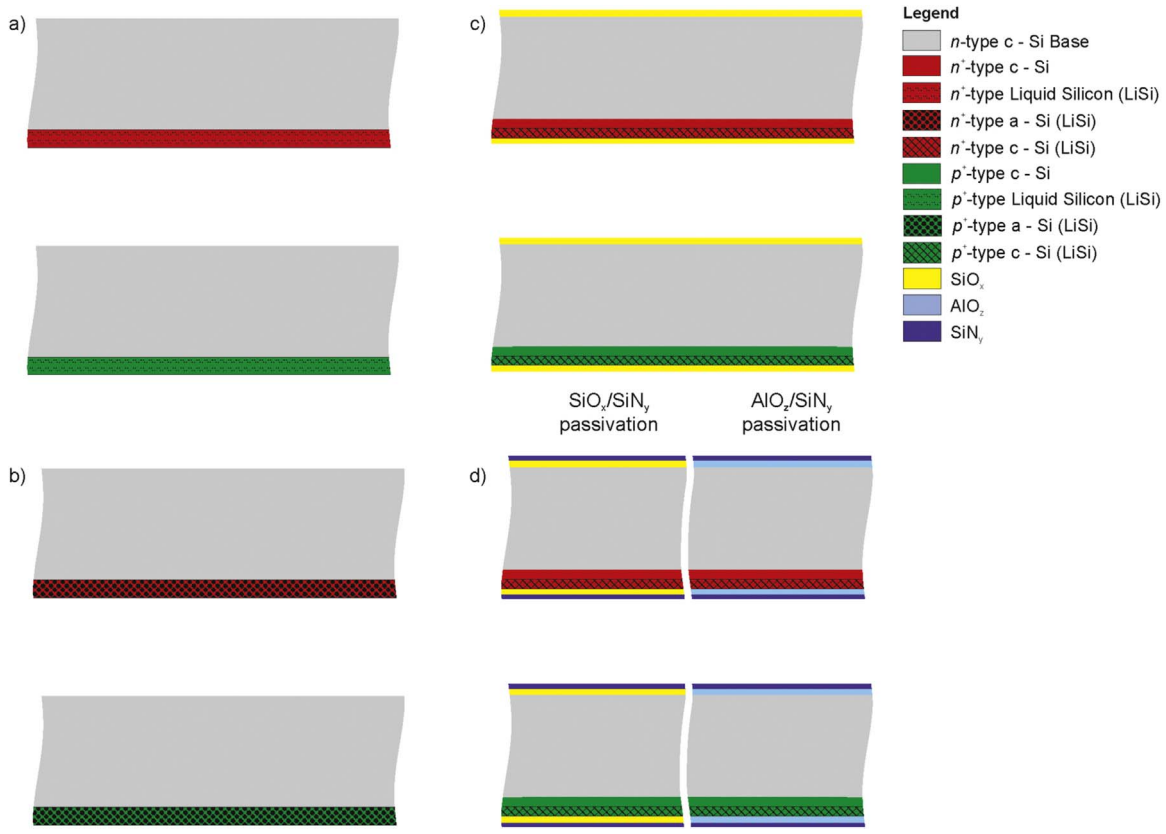

Fig. 1. Process sequence of test samples. a) Spin coating of Liquid silicon, b) transformation to amorphous silicon, c) drive-in and oxidation, and d) passivation.

wafer with a thickness of 150 µm and a resistivity of 5 Ω cm. We use the spin coating technique, since a spin coating process for LiSi formulations is well established [14–16].

b) Annealing at a temperature of 400 °C to 600 °C for less than a minute transforms the LiSi into solid *n*- or *p*-type a-Si. The amorphous silicon crystallizes and the dopants diffuse into the *n*-type bulk of the wafer in a subsequent drive-in step at temperatures ≥ 900 °C in nitrogen atmosphere.

c) A thermal oxide grows to consume a part of the LiSi and drive-in more dopants into the bulk of the wafer. The silicon oxide is subsequently etched. The best carrier lifetimes are obtained if all of the spin-coated silicon is oxidized and removed, as we do for the best results of the *p*-type LiSi samples. This etching step is optional, but it optimizes the recombination properties.

d) Both surfaces are passivated by a double layer of 50 nm-thick thermal SiO_2 and 100 nm-thick plasma enhanced chemical vapour deposition (PECVD) SiN_y with an refractive index of 1.9 at 630 nm wavelength (left column) or a double layer of 10 nm-thick atomic layer deposition (ALD) AlO_z and 100 nm-thick PECVD SiN_y (right column).

We also print the LiSi with an inkjet printer as an interdigitated finger structure on a crystalline silicon wafer to test whether the printing process is precise enough for an interdigitated back contact (IBC) cell. Fig. 2 shows an interdigitated finger structure of LiSi printed via inkjet. Finger widths of 220 µm and 300 µm are easily achieved. The maximum deviation of the inkjet-printed line from a laser-scribed line for contact opening or separation is 45 µm. This is sufficient for the alignment of our laser system to the printed structure. The different colours originate from thickness deviations in the printed ink. The process was not yet optimized in terms of homogeneity.

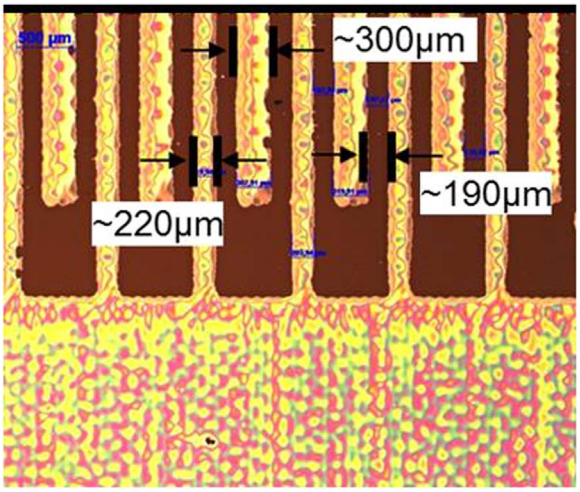

Fig. 2. Top view optical microscope image of an interdigitated finger structure of LiSi printed with an inkjet.

2.2. Back-contact solar cells

Fig. 3 shows the process sequence for IBC solar cells using the spin-coated samples described above. The upper row of each figure shows Batch 1, where we use phosphorus-doped LiSi for the BSF formation and the bottom row shows Batch 2, where we use boron-doped LiSi for the emitter formation of IBC cells. In parallel to the cells with the LiSi junctions (shown in the left column), we fabricate reference solar cells with the BSF and the emitter regions formed by standard $POCl_3$- and BBr_3- tube furnace diffusions (shown in the right column).

a) We have to structure the homogenous LiSi layer to form an IBC

Download English Version:

https://daneshyari.com/en/article/6534274

Download Persian Version:

https://daneshyari.com/article/6534274

Daneshyari.com