

Development of Epitaxial Interdigitated Back Contact Solar Cell by HWCVD Process

Amirjan Nawabjan^{1*}, Antulio Tarazona¹, Darren M Bagnall², Stuart A Boden¹,

¹Nano Group, Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK

²School of Photovoltaic and Renewable Energy Engineering, The University of New South Wales, Sydney, NSW 2052, Australia

*Corresponding author: an1a11@ecs.soton.ac.uk

Abstract

The design of a test platform for novel antireflection and light trapping schemes, based on the interdigitated back contact solar cell concept, is presented. The fabrication process includes POCl_3 diffusion to create n+ regions and the epitaxial deposition of p+ regions using hot wire chemical vapour deposition (HWCVD). To provide a comparison with traditional antireflective methods, a silicon nitride single layer coating and an optional texturing step to form a random pyramid array are included in the process. The optimum thickness of the SiN_x coating deposited by HWCVD is shown to be 110 nm and the optimum KOH etching time for complete texturing of the surface is shown to be 30 minutes.

Introduction

In recent years, interest in new methods of achieving antireflection (AR) and light trapping (LT) for solar cells has been growing as part of the search for ways to increase cell efficiency and hence drive down the cost-per-watt of PV. These include biomimetic 'moth-eye' structures [1], plasmonic metal nanoparticle arrays [2] and Mie resonator arrays [3]. This has led to the requirement of a solar cell test platform to facilitate the comparison of these new AR and LT methods with more traditional thin film and micron-scale texturing approaches. Since the front surface of the cell is free of any contacts, the interdigitated back contact (IBC) monocrystalline silicon solar cell design is well suited to fulfil this need [4].

IBC cells offer potentially higher efficiency compared with conventional solar cells. Complete elimination of the front contacts leads to a higher short circuit current due to the absence of shading losses and lower resistive losses. The front and back of the cell can be fully utilized for optical and electrical improvement, respectively. The cell design offers easier interconnection and increased packing density within a module [5]. Furthermore, the approach also improves aesthetics, increasing the likelihood of large scale adoption in building integrated PV. The

concept has been used to manufacture large-area cells with efficiencies of more than 24 % [6].

Most of the encouraging results in the fields of IBC cell were realized with emitters deposited by plasma enhanced chemical vapour deposition (PECVD). An alternative deposition technique is hot wire chemical vapour deposition (HWCVD), but this has attracted much less attention to date due to inferior electronic properties for the films produced compared to those prepared using PECVD. However, HWCVD possesses some key technological advantages in terms of deposition rate, gas decomposition, uniformity of the final film, and also plasma free deposition [7]. Some groups have already reported encouraging results using this method [8], [9].

In this paper, steps towards the development of a HWCVD based IBC cell for testing novel AR and LT schemes against traditional thin film and micron-scale texturing are described. The fabrication process is described and the cell design is presented. This is followed by the optimizations of two traditional AR/LT schemes for the top surface: A thin film single layer antireflective coating (SLAR) of silicon nitride and a random pyramidal texture.

Cell Design

The IBC cell designs in this study are illustrated in Figure 1 and an outline of the process listing is given in Figure 2. Two designs are shown: Design A has a planar surface and a SiN_x SLAR whilst design B includes an additional etching process to texture the top surface with a random array of pyramids.

The process begins with cleaning of a silicon wafer (n-type, <100>, 1-10 $\Omega\cdot\text{cm}$). For design B, the top surface is then textured using a KOH etch, with the back surface protected by a nitride layer. A photolithography and dry etch stage is then used to define the n-type contact pattern on the rear of the cell, through which the n+ back surface field (BSF) is formed by POCl_3 diffusion at 900°C. This also forms the floating emitter at the front surface. This is followed by

nitride deposition (by PECVD or HWCVD) to form the SLAR. A second photolithography and dry etch stage is then used to define the p-type contacts. The epitaxial p+ contacts are then fabricated by HWCVD deposition and lift-off. Finally, a third lithography process followed by aluminium evaporation and lift-off forms the n and p ohmic contacts. The wafer is then diced to form 1 cm × 1 cm individual devices.

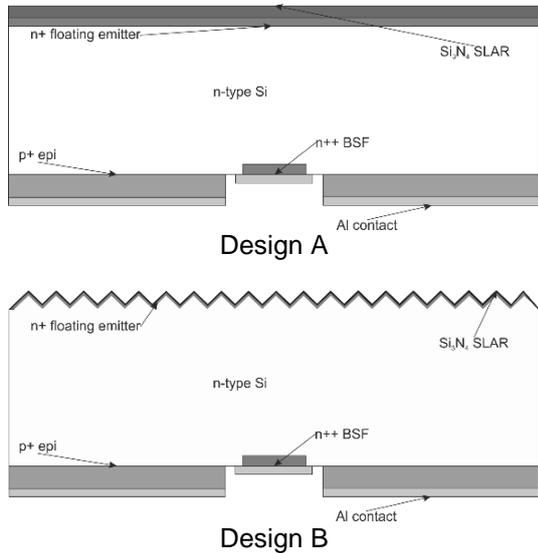


Figure 1: Schematic of the IBC cell designs for this study. Design A has a planar surface and Design B has a textured surface.

In this paper, optimizations for two steps of the fabrication process are presented. Firstly, the optimization of the thickness of the nitride SLAR using a transfer matrix approach, with input from experimentally-determined film properties, is presented. This is followed by an experimental optimization of the KOH texturing process.

Optimization of SLAR

Two methods were investigated for the deposition of a SiN_x SLAR in this work, with standard recipes being used in each case. PECVD nitride was deposited using a SiH₄/NH₃/N₂ gaseous mixture with the flow rates of 12.5/20/500 sccm. HWCVD nitride was deposited with a 30/450 sccm SiH₄/NH₃ mixture. Both processes were performed at a temperature of 300°C. Film thicknesses and complex refractive index data (*n* and *k*) were determined by variable angle spectroscopic ellipsometry (VASE, J.A Wollam). The *n* and *k* values for nitride films deposited by PECVD and HWCVD, using the standard recipes, are shown in figure 3.

The complex refractive index data was used in a model employing the transfer matrix method

[10] to calculate the normal incidence reflectance spectra of the PECVD and HWCVD deposited thin films.

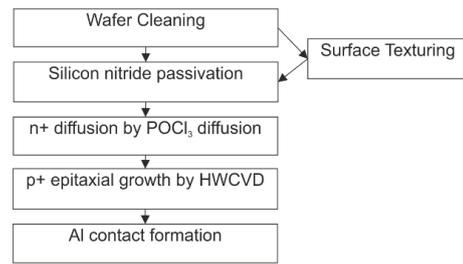


Figure 2: Simplified outline of fabrication process.

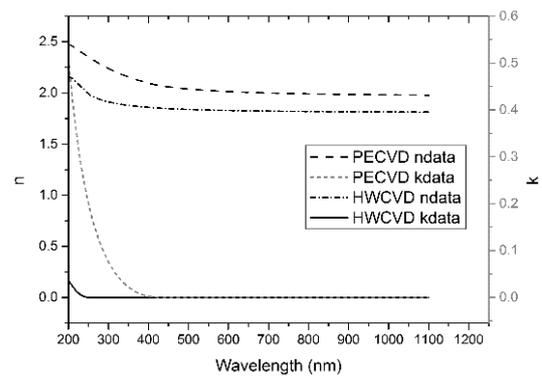


Figure 3: Complex refractive index (*n* and *k*) data for silicon nitride AR layers deposited by PECVD and HWCVD.

These simulated spectra match well with measured reflectance spectra (see figure 4), obtained using an integrating sphere spectrophotometer (Bentham Instruments). This verifies that the simulation method can accurately predict the reflectance behaviour of the SiN_x thin films on silicon and therefore can be used to optimize the film thickness.

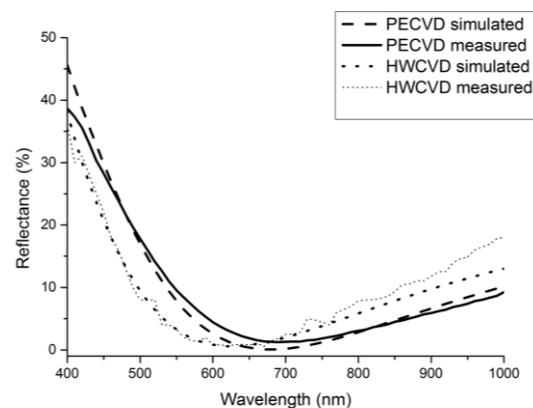


Figure 4: Simulated and measured reflectance spectra for SLAR layers on silicon.

The optimization was carried using the transfer matrix method to calculate reflectance spectra for a range of film thicknesses. Each reflectance spectra was then weighted to the AM1.5 solar spectrum (ASTM173G, global tilt) expressed as a photon flux density (*PFD*), and averaged to give a single figure of merit called the weighted average reflectance, R_w , using equation 1.

$$R_w = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} R(\lambda) PFD(\lambda) d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} PFD(\lambda) d\lambda} \quad (1)$$

Values of R_w versus film thickness for the PECVD and HWCVD nitrides are plotted in Figure 5. The optimum film thickness, read from the plots in Figure 5, is 100 nm for the PECVD nitride and 110 nm for the HWCVD nitride. These give R_w values of 6.7% and 5.2% for the PECVD and HWCVD nitride films, respectively, demonstrating that HWCVD compares well with PECVD as a deposition method for SiN_x SLARs.

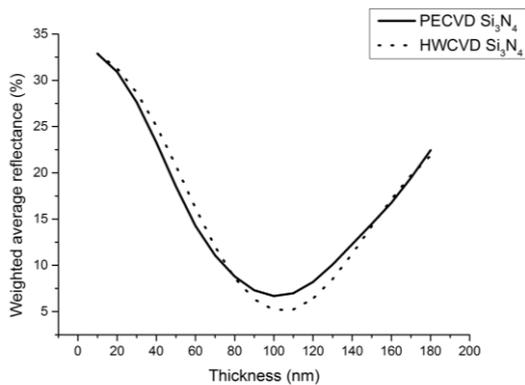


Figure 5: Optimum thickness calculation for SiN_x SLAR deposited by PECVD and HWCVD.

Texturing Process Development

Etching in an alkaline solution is a commonly used texturing method to confer an

antireflective effect. Light reflected from one facet of the texture is incident on an adjacent facet and so has multiple chances of being coupled into the cell. The method also enhances light trapping within the cell by changing the propagation direction of light through refraction and thereby increasing the optical path length. In this study, a simple maskless technique based on a recipe from King *et al.* is used to form random arrays of upright pyramids [11]. The aim is to develop a good quality AR scheme based on the widely-used traditional approach of micron-scale texturing that can act as a comparison to more novel AR and LT schemes.

After cleaning, monocrystalline silicon wafers (n-type, <100>, 1-10 Ωcm) were etched in a 1.5% KOH, 3.8% IPA solution at 70°C [11] for various lengths of time. The wafers were rinsed, dried and the inspected by scanning electron microscopy (SEM). The spectral hemispherical reflectance of the surfaces was then measured using an integrating sphere spectrophotometer (Bentham Instruments).

SEM images of silicon surfaces etched for 15 minutes, 30 minutes, and 60 minutes are presented in Figure 6. At 15 minutes, the pyramids are just starting to form and do not yet cover the whole surface. At 30 minutes, the pyramids completely cover the wafer surface and have base sizes in the 6-8 μm range. Further etching for 60 minutes results in smaller pyramids with base sizes of 4-6 μm . Reflectance spectra of the samples are presented in Figure 7. After a 15 minute etch, the reflectance spectrum is similar to that of bare silicon. However, for an etch time of 30 minutes, the reflectance is reduced significantly. The reflectance spectrum for the sample etched for 60 minutes is similar to the 30 minute sample, therefore a 30 minute etch is considered to be optimum.

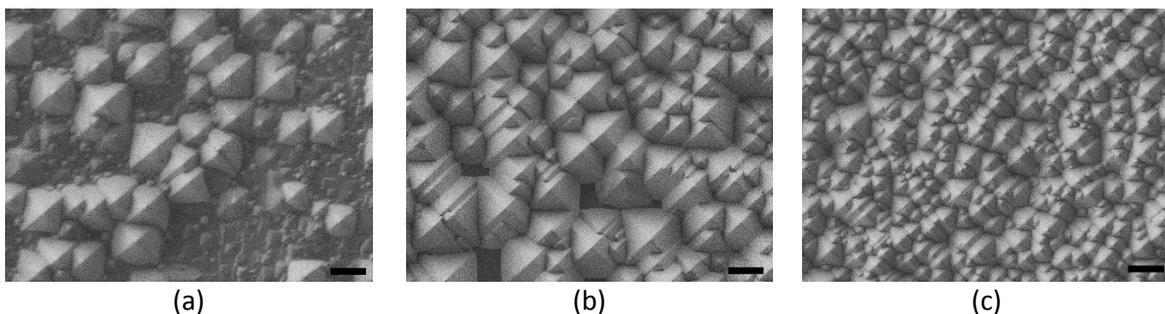


Figure 6: SEM image of random pyramids after etching for (a) 15, (b) 30, and (c) 60 minutes. The scale bar is 4 μm

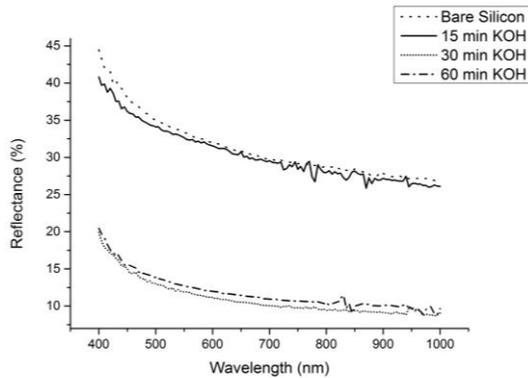


Figure 7: Reflectance spectra for KOH textured silicon surfaces, etched for various times.

Discussion

Besides AR, another important task of the top surface coating is to provide passivation and thereby reduce the front surface recombination. PECVD nitride films have can provide excellent surface passivation with surface recombination velocities down to 4 cm/s being reported [12]. Further investigation is required to determine if the HWCVD process used here can also provide adequate surface passivation. A thin layer of SiO₂ may need to be included in the coating design, with the thicknesses of the layers then re-optimized to provide both antireflection and effective surface passivation.

Conventional solar cells employ a combination of pyramidal texturing and an SLAR to provide AR and LT. In this report, the two schemes have been optimized separately and so further optimization should be possible by considering a combination of the two.

Conclusions

A HWCVD-based epitaxial IBC solar cell for use as a test platform for novel antireflection and light trapping schemes has been designed. For comparison purposes, two common antireflective schemes have been optimized for inclusion in the fabrication process for the full cells. Firstly, the optimum thickness for a HWCVD deposited SiN_x film was shown to be 110 nm, giving an average reflectance, weighted to the AM1.5 solar spectrum, of only 5.2%. Secondly, a KOH texturing process was tested and found to produce a suitably dense random pyramidal array after 30 minutes of etching. The task now is to complete the fabrication and testing of the full cell design with these traditional AR schemes before

implementing novel plasmonic or biomimetic schemes.

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