

THIN SILICON CELLS USING NOVEL LASE PROCESS

K.J. Weber¹, A.W. Blakers¹, M.J. Stocks¹ and P.J. Verlinden²

1. Centre for Sustainable Energy Systems, corner North Rd and University Ave, ANU, Canberra 0200, Australia

2. Generation Group, Origin Energy Pty. Ltd., Level 13, 1 King William Street, Adelaide SA 5000, Australia

ABSTRACT

We present a new concept for thin silicon solar cells. In the LASE process (Lateral Anisotropic Silicon Etching) shallow grooves are cut into a (111) oriented silicon wafer at regular intervals. Using alkaline etching, lateral channels are formed which extend underneath the silicon wafer and eventually meet to detach the silicon layer on top. Unlike other liftoff techniques, no silicon deposition is required. The technique can be used to produce silicon strips as well as continuous sheets. Silicon strips can be used to fabricate monolithically connected solar cells and high voltage, low current modules.

1. INTRODUCTION

The great majority of solar (photovoltaic) modules currently being installed worldwide are made from wafer-based silicon solar cells. Wafer – based c-Si cells have the advantage of relatively high efficiency and good stability. However, since high quality, high purity silicon is an expensive material, a substantial cost reduction can only be achieved by reducing the cell thickness beyond what the current generation of wire saws can achieve.

Despite the obvious benefits of thin film silicon photovoltaics, there are many challenges, such as the need to find or develop a suitable combination of deposition technique and substrate that allow high quality silicon films, and high efficiency solar cells, to be made at low cost. There are currently many substantial research efforts in this field [1,2]. However, the challenge of developing a thin film silicon technology, with comparable efficiencies to current wafer based cells but at a much reduced cost, remains.

A recent approach to the challenge has been to deposit the thin silicon film on a silicon wafer, and then somehow detach the film later. These approaches have been termed lift-off approaches. The silicon wafer acts as a crystal template, which ensures that the silicon film is single crystalline and of high quality. Apart from the obvious benefit of allowing the production of a high quality silicon film, this approach also has the advantage of decoupling the conflicting demands made on the substrate during film deposition and during module assembly: during film deposition, the substrate may need to withstand high temperatures and should be expansion matched to silicon, while in the final module the substrate must be, above all, cheap. Several methods have been developed to implement

the general concept of the growth and detachment of a silicon film from a silicon substrate [3-6]. Excellent results have been achieved with the various lift-off techniques, with efficiencies up to 16.6% having been reported [7]. However, the lift-off approaches still suffer from the fact that they require the development of a suitable deposition technique. In this paper, we present an alternative approach which does not require any silicon deposition [8].

2. THE LASE PROCESS

The steps involved in the fabrication thin silicon films by the LASE process are as follows:

- A standard, commercially available silicon wafer of (111) crystal orientation is used. The wafer is initially several mm thick.
- Using a dicing saw, grooves approximately 50 microns deep, 100 microns wide and with a pitch of 1mm are produced in the wafer. These grooves extend parallel to the wafer flat.
- A thin layer of a suitable masking material such as silicon nitride is conformally deposited over the entire surface.
- A second, narrower groove is now made inside the first groove, so that the masking material as well as a small amount of silicon is removed from the bottom of the grooves (fig. 1(a)).
- The wafer is immersed in a potassium hydroxide (KOH) solution. The silicon {111} planes etch much more slowly in KOH than any other crystal orientation, by a factor of more than 100. As a consequence of the wafer preparation described above, these conditions will result in the etching of narrow channels in the silicon wafer, with the channels extending parallel to the surface.
- Eventually, the channels meet to detach a thin silicon film, or 'strip' (fig. 1(b)).
- The silicon strips can be used for the fabrication of solar cells, while the substrate can be re-used for the production of another set of silicon strips. If the second set of grooves does not extend to the edge of the wafer, the silicon strips will remain attached to the wafer at the wafer edges, thus allowing easier processing. At the end of the process, the strips are detached from the

substrate by cutting through the attachments using a laser or dicing saw. The substrate is re-used.

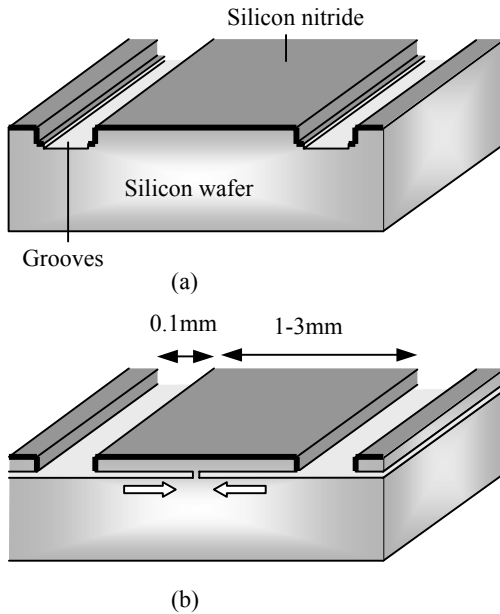


Figure 1: Illustration of the LASE process. (a) grooves are cut at regular intervals into a silicon wafer, and the wafer is coated with silicon nitride. The nitride is removed from the bottom of the grooves. (b) Anisotropic etching is used to create channels which undercut the silicon and lead to the detachment of silicon strips.

It is also possible to produce continuous sheets of thin silicon using the technique. In order to do this, it is necessary to use a pattern of grooves as shown in fig. 2. Each groove etches out diamond-shaped area underneath the silicon surface. With proper line spacings, the etched areas of adjacent lines overlap, leading to the detachment of the overlying silicon film.

3. A POSSIBLE CELL FABRICATION SEQUENCE

A possible cell process sequence, which would lead to the cell structure shown in fig. 3, is as follows:

- Thin silicon strips are created using the LASE process. They remain attached to the substrate at the wafer periphery. The strips are textured using a suitable method, such as reactive ion etching (RIE).
- A phosphorus diffusion is made. Experiments have confirmed that phosphorus is able to creep into the gap between the wafer and the bottom surfaces of the silicon strips, so that all surfaces end up phosphorus diffused.
- A layer of thermal silicon dioxide is grown. The oxide is removed from a portion of the top surface of each

silicon strip, and a boron diffusion is made. The oxide is now stripped.

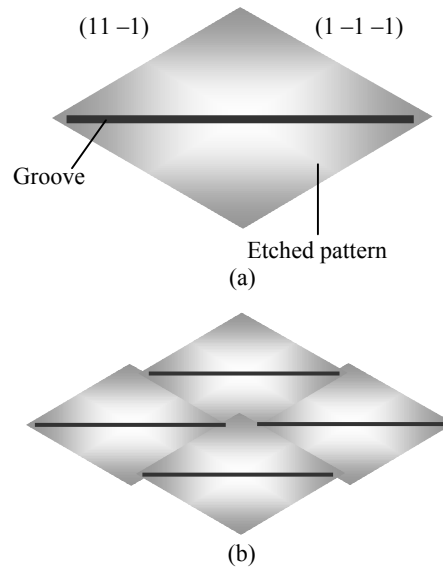


Figure 2: Production of thin silicon sheets by the LASE process. (a) a groove of limited dimensions results in the etching of a diamond shape, (b) by staggering grooves, a continuous layer can be lifted off.

- An antireflection coating is applied. This could be silicon nitride, deposited by low pressure chemical vapour deposition (LPCVD). LPCVD nitride has the property that it will uniformly coat all surfaces, even surfaces hidden within narrow channels.
- Contact regions are opened by selectively removing the oxide/nitride stack in the appropriate regions. Metal contacts are formed, for example, by electroless plating.

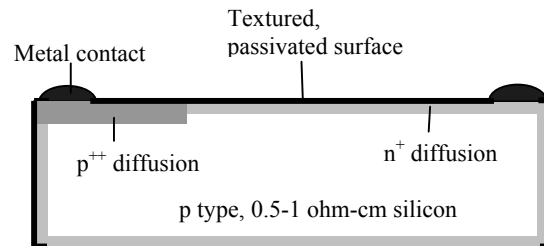


Figure 3: A possible structure for cells fabricated by the LASE process.

The boron diffusion and metal contact regions can be defined by screen printing etch pastes [9]. Such pastes have recently been developed by Merck Chemicals. Cells can be series connected to build voltage, as shown in fig. 4

4. EXPERIMENTAL RESULTS

To date, we have proven the LASE concept by producing detached silicon strips from a wafer, with the strips remaining attached only at the wafer periphery. The wafers used for these experiments were 0.8mm thick, (111) oriented Cz wafers, B doped to 5-11 Ω -cm. A dicing saw with a 150 μ m wide blade was used to produce the wide trenches. A layer of silicon nitride, approximately 100nm thick, was deposited by low pressure chemical vapor deposition (LPCVD) at 750 $^{\circ}$ C. LPCVD deposited nitride is particularly resistant to attack by alkaline etchants and is therefore well suited to applications where long etch times are required. A Q-switched Nd:YLF laser operating at 523nm was then used to produce the narrower trenches. The narrow trenches were approximately 10 μ m deep and 50 μ m wide. The width of the strips was 0.8mm, the length was up to 70mm and the thickness was approximately 50 μ m. The channel width at the end of the process was approximately 35 μ m. The wafers had been etched in 44wt% KOH solution at room temperature.

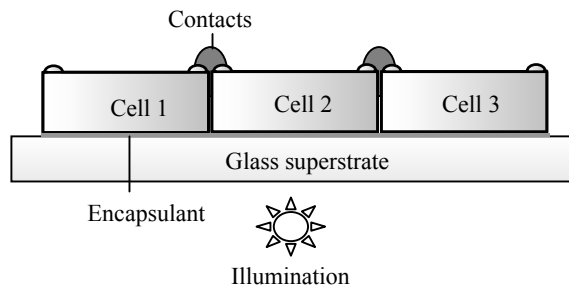


Figure 4: A possible cell mounting and interconnection scheme.

5. CONCLUSIONS

We have presented the LASE process as a method for the fabrication of thin silicon solar cells without the need for silicon epitaxy. By utilizing the highly anisotropic etching of silicon in alkaline solutions, it is possible to detach thin silicon strips or even continuous sheets from a silicon wafer. Experiments to date proven the concept with the detachment of 0.8mm wide and up to 70mm long silicon strips.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge support for this work by the Australian Research Council and Origin Energy Pty Ltd.

REFERENCES

[1] M.McCann, K.R. Catchpole, K.J. Weber and A.W. Blakers, "A Review of Thin Film Crystalline Silicon for

- Solar Cell Applications: Part 1 - Native Substrates", *Solar Energy Materials and Solar Cells* 68, 135 (2001)
- [2] K.R. Catchpole, M.McCann, K.J. Weber and A.W. Blakers, "A Review of Thin Film Crystalline Silicon for Solar Cell Applications: Part 2 - Foreign Substrates", *Solar Energy Materials and Solar Cells* 68, 173 (2001)
- [3] K.J. Weber, A.W. Blakers and K.R. Catchpole, "The Epilift Technique for Si Solar Cells", *Applied Physics A (Materials Science Processing)*. 69,195 (1999)
- [4] R. Brendel, H. Artmann, S. Oelting, W. Frey, J.H. Werner, and J.H. Queisser, *Appl. Phys. A* 67, 151 (1998)
- [5] S. Nishida, K. Nakagawa, M. Iwane, Y. Iwasaki, N. Ukijo, M. Mitzutani and T. Shoji, *Technical Digest 11th International Photovoltaic Science and Engineering Conf.*, Kyoto, p.537 (1999)
- [6] R.B. Bergmann, T.J. Rinke, R.M. Hausner, M. Grauvogl, M. Vetter, and J.H. Werner, *Internat. Journal of Photoenergy* 1, 83 (1999)
- [7] R.B. Bergmann, C. Berge, T.J. Rinke, J. Schmidt and J.H. Werner, "Advances in Monocrystalline Si Thin Film Solar Cells by Layer Transfer, *Solar Energy Materials & Solar Cells* 74, 213 (2002)
- [8] K.J. Weber and A.W. Blakers, PCT application, "Semiconductor Processing", PCT/AU02/01640 (Nov. 2002)
- [9] S. Klein, A. Kuebelbeck and M. Fluegge, "Advanced Materials for High Efficiency Silicon Solar Cell Mass Production", proceedings of the 17th EC Photovoltaic Solar Energy Conference, Munich, Germany, Oct. 2001