Some Key Issues In the Processing and Fabrication of Higher Efficiencies Silicon Solar Cells

CHEOW SIU LEONG[1], NOWSHAD AMIN[1], M.Y. SULAIMAN[1], AZAMI ZAHARIM[2], K. SOPIAN[3] AND SALEEM H. ZAIDI[4]
[1]Solar Energy Research Institute
[2]Head for Renewable Energy Resources and Social Impact Research Group
Solar Energy Research Institute, and
Head Centre for Engineering Education Research
Faculty of Engineering and Built Environment,
[3]Director of Solar Energy Research Institute,
Universiti Kabangsaan Malaysia
43600, Bangi, Selangor
MALAYSIA
[4]Gratings Inc.
2700 Broadbent Pkwy NE, Suite B.
Albuquerque,
New Mexico 87107
U.S.A.
siuleong1983@yahoo.com, azaminelli@gmail.com

Abstract: - This paper reviews recent progress in the development of solar cell processing and fabrication. Standard of solar cell fabrication process has been summarised and used as baseline. The strengths of the advanced silicon cell technologies and steps that can lead to cost savings or as well as reducing silicon usage are briefly reviewed. Next, the issues and challenges in (i) light trapping and the nature of textured interface, (ii) front contacts and emitter, (iii) the quality of the active-layer material, (iv) surface passivation and (v) anti-reflection coatings were presented.

Keywords: Crystalline Silicon; Solar Cell Technology; Solar Cell Processing

1 Introduction

There is a wide range of research activities worldwide that has demonstrated the efficiency potential of crystalline silicon cells. Most of the research has been shown both theoretically and practically that thin crystalline silicon cells can have low manufacturing costs and reasonable efficiencies. Several researchers have attempted to study the effect of wafer thickness on the performance of crystalline silicon cells, and the best efficiencies on wafers with thickness less than 200µm are typically in the range of 14-15.5% [1]. There are three types of solar cells namely (a) silicon based solar cells, (b) thin films such as CIGS, CdTe and (c) organic based solar cells. However silicon based solar cells occupied 90% of the total market. The keys issues in making high efficiency solar cell are light trapping, surface passivation, anti-reflection coatings, and metallization [2][3]. This paper presents a review of the baseline process on the fabrication of solar cells and elaborates the various steps that can lead to improving cell efficiencies hence reducing manufacturing costs. The objective is aim to investigate the development of low cost, higher conversion efficiencies, and large-scale production line for solar cells manufacturing process.

2 Basic Solar Cell Process

In table 1 we see the simplest process of crystalline silicon solar cell applied by many manufacturers. A single crystalline Si solar cell started with the preparation of chemically stable and contamination free epitaxial surfaces for the subsequent fabrication process. In order to prepare the excellent surface, we need special combination of wet-chemical treatments. This process is a conventional standard process involving removal of organic contaminants, thin oxide layer, and metallic contamination and carried out under clean room conditions using different procedures. After that, textured front surface with KOH solution will create random structures to enhance light absorption.

Table 1:The Basic solar cell process with an energy conversion efficiencies range between 10 – 18%

Step	Purpose	Description
1) Wafer Cleaning.	Removal of the organic contaminants, thin oxide layer, and metal particles.	A sequence of: H_2SO_4:H_20_2, HF, SC2, HF, H_2S0_4:H_2O_2, (With DI Rinses)
2) Wafer Texturing	To prolong the diffusion length and increase light absorption.	Wet etching – KOH solution
3) Diffuse junction (Doping)	To create a junction which separate emitter layer and p-type silicon layer (base)	1 to 2 hours of furnace time with liquid POCl3 dopant source
4) Strip dopant	Removal of the phosphorous glass	Using dilute HF (with DI Rinse)
5) Metallisation	To form a front metal contact and back surface field	Use screen printing method, Al paste for back surface field and silver paste for front contact
6) Rapid Thermal Annealing	To change substrates interfaces, activate dopant and enhance electrical properties	1 to 2 hours of furnace time, Forming gas used
7) Anti Reflective Coating (ARC)	To fabricate passivation and antireflective layer	PECVD SiNx film, TiO2 or Spin-on dopant

Conventional process steps such as phosphorous tri-chloride (POCl3) diffusion, strip dopant, screen printed metallisation, rapid thermal annealing were followed for the fabrication of silicon solar cells [4] [5]. Here, emitter layer was formed by POCl3 diffusion into the p-type silicon substrates. The phosphorous gas was then removed using dilute HF. Metallisation was presented by screen printing of a metal paste to form a front contact and back surface field with appreciable thickness and minimum resistance. Wafers were then annealed in forming gas to change substrates interfaces, activate dopant and enhance electrical properties by using rapid thermal annealing method. It can be accomplished in a relatively short time and has a lower budget. The cells were finished with anti-reflection coating which was deposited by spin-on or plasma enhance chemical vapor deposition (PECVD). The deposition technique which has been and is still most widely used in the context of epitaxial solar cells is based on thermally assisted heterogeneous decomposition of Si precursor and doping gases at a heated Si-surface [6].

3 Issues in making Higher Efficiency C-Silicon Solar cells

The following are issues and challenge in fabrication and process in attaining higher efficiency solar cells.

3.1 Light trapping and texturing

A major disadvantage thin c-Si cells is weak absorption in near Infrared (IR) spectral region (800-1100nm), particularly near the band edge. This weak absorption fundamentally limits the efficiency of solar cells, due to the incomplete optical absorption for thin films and bulk recombination loses for thick films. Efficiency can be improved further by adding a texture to the front surface and/or a mirror at the back surface to trap any unabsorbed light. To maximise the amount of light that can be returned to the active layers the substrate needs to be significantly thinned prior to deposition of the rear mirror. Current technology at the Fraunhofer ISE limits this to approximately 50µm total structure thickness [7]. Saleem et al. [8] have developed large area (~ 200 cm^2) random Reactive Ion Etched (RIE) and wet-chemical nanoscale texturing techniques aimed at low-cost, reflection reduction and enhanced near-IR absorption for single and multicrystalline Si solar cells.

3.2 Front contacts and emitter surface

The quality of the emitter is very closely related to the front contact type. For instance using screen printed contacts, the phosphorus surface concentration has to be very high to allow for a sufficiently low contact resistance. Unfortunately, this leads to a high recombination activity (Auger) in the emitter and additionally cannot be improved significantly by surface passivation. Thus, the blue response is strongly reduced and the open-circuit voltage is limited to a quite low value. High efficiency cells tackle this problem by using two-step emitters or metallisation schemes which allow contact of lowly doped emitter profiles. A prominent example for an advanced contact scheme is certainly the laser-buried contact cell produced by BP solar. Rajiv et al. [9] have designed and built an extremely simple plasma immersion implantation system using low-cost, easily available components. Ion implantation methods to form front surface emitters in Si solar cells were first introduced in eighties on account of their inherent ability to independent control dopant profile, junction depth, and carrier concentration.

3.3 Active-layer material

Most of the crystalline solar cell manufacturers are using boron-doped Czochrolski silicon as starting material. This material type shows a severe degradation of minority carrier lifetime induced by illumination or carrier injection. For a reduction of this degradation two options are promising: (i) the use of thinner wafers to improve the ratio diffusion length/cell thickness or (ii) decreasing the boron concentration to reduce the light-induced degradation. By using layer transfer technology, a single wafer can be used to fabricate several thin-film solar cells. Furthermore, the concept of thin solar cell will only become economically viable for PV applications if the frequent reuse of the substrate is possible.

3.4 Surface passivation

Even an excellent material quality would be useless if the surface recombination velocity is too high. The fabrication process in industrial production for the reduction of surface recombination is the implementation of aluminium BSF by firing the Al/Ag screen-printing back contact. However, the electrical and optical properties of such an Al-BSF are only moderate. In fact, the highest potential can be attributed to a surface passivation using a dielectric layer e.g. SiO_2 or SiN_x. Beside that, removing the void region by etching and passivating also further improve the cell voltage. A promising technique has been presented in Fosca et al. [10] is double layer (a-Si:H/SiNx:H) deposited by plasma at relatively low temperature (<400°C). This low temperature passivation technique also important for decreasing the solar cell production costs.

3.5 Anti-reflection coatings

A good anti-reflection coating (ARC) is important for making higher efficiency solar cell as it ensures a high photocurrent by minimising reflectance. As we know, most of the solar cells operate at a wide range of wavelengths, from 300 – 1200nm. Although single layer ARC reduces reflection compared to a bare silicon surface, but it still not competent to minimise reflectance over a wide range of wavelengths. In term of that, studies on double layer ARCs or even multi-layer ARCs have been reported by many researchers. One of the interesting approaches is to implement a SiO_2/SiN_2 stack deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD), which indicated a low cost and effective way [11]. This technique can be applied to deposit a good anti-reflection coating and also widely used for reducing the recombination losses on a surface. Wright et al. [12] have been conducted single and double layer anti-reflection coatings (ARCs) on polished crystalline silicon wafers, based on the refractive index of PECVD SiN and SiO_2. The result show that an increase in short circuit current density of 6.4% was possible by replacing an optimised single SiN layer with double layer anti-reflection coatings.

4 Conclusions

Thin film crystalline solar cell modules are moving incredibly from laboratory into the market, giving the opportunity for these potentially low-cost approaches to establish their base. Many of these modules are finding application into industrial production. In order to achieve the target, we always need to review the standard baseline solar cell fabrication process and then identify the advanced properties of high-efficiency solar cells. This paper briefly discussed some of the most important methods used for standard solar cell fabrication process.

References:

[1] A. Upadhyaya et al. 2006. "Greater than 16% efficient screen printed solar cells on 115-170µm thick cast multicrystalline silicon", 4th World Conference on Photovoltaic Energy Conversion.

[2] S. W. Glunz. 2006. “New concepts for high-efficiency silicon solar cells”, Solar Energy Materials & Solar Cells 90, 3276-3284.

[3] M. J. McCann et al. 2000. “A review of thin-film crystalline silicon for solar cell applications. Part 1: Native Substrates”, Solar Energy Materials & Solar Cells 68, 135-171.

[4] K. Kim et al. 2008. “Texturing of large area multi-crystalline silicon wafers through different chemical approaches for solar cell fabrication”, Solar Energy Materials & Solar Cells 92, 960-968.

[5] J. Lee et al. 2009. “Optimization of fabrication process of high-efficiency and low-cost crystalline silicon solar cell for industrial applications”, Solar Energy Materials & Solar Cells 93, 256-261.

[6] G. Beaucarne, F. Duerinckx, I. Kuzma, K. Van Nieuwenhuysen, H. J. Kim, & J. Poortmans. 2006. “Epitaxial thin-film Si solar cells”, ThinSolid Films 511 – 512.

[7] I. M. Ballard et al. 2004. “Development of a thin film silicon benchmark cell”, Proceedings 19th European photovoltaic solar energy conference, Paris, Pages: 1229 – 1232.

[8] Saleem H. Zaidi et al. 2002. “Enhanced near IR absorption in random, RIE textured silicon solar cells: the role of surface profiles”, **29th** IEEE PVSC, 142.

[9] Rajiv Prinja, David Modisette, Rich Winder, Saleem H. Zaidi, and K. Sopian, May 11-16, 2008. “Plasma Implantation of silicon cells for emitter and Localized BSF formation”, 33rd IEEE Photovoltaic Specialists Conference (PVSC), San diego.

[10] A. Fosca et al. 2009. “Surface passivation oat low temperature of p- and n-type silicon wafers using a double layer a-Si:H/SiNx:H”, Materials Science and Engineering B, MSB-12008, pages 6.

[11] Z. Chen, P. Sana, J. Salami, A. Rohatgi. 1993. “A Novel and Effective PECVD SiO2/SIN Antireflection Coating for Si Solar Cells”, IEEE Transactions on Electron Devices, 40(6), pp. 1161-1165.

[12] Daniel N. Wright, Erik S. Marstein & Arve Holt. 2005. “Double layer anti-reflective coatings for silicon solar cells”, IEEE, 0-7803-8707-4.