Renewable Energy 34 (2009) 2571–2576

Contents lists available at ScienceDirect

Renewable Energy

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

A new energy efficient, environment friendly and high productive texturization process of industrial multicrystalline silicon solar cells

P.K. Basu [a,*], H. Dhasmana [b], N. Udayakumar [c], D.K. Thakur [a]

[a] *Department of Electronics, Lingaya's Institute of Management and Technology, Nachauli, Faridabad-121003, Haryana, India*
[b] *Department of Applied Science and Humanities, Lingaya's Institute of Management and Technology, Nachauli, Faridabad-121003, Haryana, India*
[c] *Udhaya Energy Photovoltaics Pvt. Ltd, 1/279Z, Mudalpalayam, Arasur post, Coimbatore-641407, Tamil Nadu, India*

ARTICLE INFO

Article history:
Received 1 January 2008
Accepted 19 April 2009
Available online 23 May 2009

Keywords:
Isotropic texture using NaOH–NaOCl
Industrial multicrystalline silicon solar cells
Quality improvement analysis
Cost effectiveness

ABSTRACT

A new texturization process based on a uniform, isotropic and slow removal of silicon, using a composition of sodium hydroxide (NaOH) and sodium hypochlorite (NaOCl) solution at an elevated temperature is developed recently for multicrystalline silicon solar cells. This process is applied in optimized condition in regular industrial production line and it immediately replaces the old popular industrial process of texturization using a combination of NaOH solution, alcoholic NaOH solution and hydrochloric acid solution in different steps at a higher temperature. Also the gain in solar cell efficiency at global AM1.5 spectrum, 1 SUN intensity condition is nearly 10% in final value. In addition, it has become finally an energy efficient and environment friendly texturization process for large area multicrystalline silicon solar cells for commercial use. In this paper the cost effectiveness and environment friendly aspects of the proposed process have been studied in detail along with the surface texture analysis of wafers with SEM and AFM micrographs to substantiate the reasons behind the above facts.

1. Introduction

Multicrystalline silicon surface texturing is a key issue to fabricate low cost and high efficiency solar cell in mass production level. For monocrystalline silicon, the well established texturing method is anisotropic etching with alcoholic solutions of potassium or sodium hydroxide which results in the surface covered with pyramids. This is due to the very different etch rates of the ⟨100⟩ and ⟨111⟩ orientated planes of silicon [1]. But, conventional alkali texturing has little usefulness for the multicrystalline silicon where the grains are randomly oriented and are of different shapes and sizes. Several texturing techniques are under investigation, but none have reached the status of mass production for standard screen printed solar cells [2] of widely spreading photovoltaic industry. Reactive Ion Etching (RIE) and isotropic etching by acidic solution are two main techniques out of many under investigation for texturing multicrystalline silicon surface for solar cell fabrication. RIE is a complicated process [3] and requires expensive system compared to the isotropic texturing process by acidic solution. Wet acidic texturing [4], performed with solutions containing hydrofluoric acid (HF) and nitric acid (HNO_3) that tends to etch isotropically, can result in features with rounded surfaces, as opposed to flat-sided features which arise from anisotropic etching. These rounded features produce scalloped surface that can have good antireflection properties. A new method has been developed recently [5] which uses a combination of sodium hydroxide (NaOH) and sodium hypochlorite (NaOCl) solution at an elevated temperature. Here NaOCl acts as an oxidizing agent and NaOH acts as a silicon etching agent. During this texturization process silicon surface gets oxidized and this oxide weakens the etching speed of NaOH. It ultimately leads to an isotropic texturing (or rather polishing) of multicrystalline silicon surface [6]. The advantage of this texturing is not only in the reflection reduction, but also in the ability to contact shallow emitters [7]. However, they are also having their inherent problems [8]. This paper reports for the first time the optimum use of NaOH–NaOCl solution in large production line of multicrystalline silicon solar cells. This process yields more output power in terms of cell efficiency. It not only saves input power, but also leads to high productivity and reduction in environmental hazards. It ensures less health hazards for operators by minimizing chemical handling. Ultimately it leads to modern day requirement of HES (health, energy and safety) for any successful photovoltaic industry.

* Corresponding author. Tel.: +91 0129 2202296; fax: +91 0129 2202612.
E-mail address: prabir_basu64@rediffmail.com (P.K. Basu).

0960-1481/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2009.04.017

2. Experimental

The starting material for the experiment is boron doped p-type multicrystalline silicon wafers of base resistivity 0.5 ∼ 3.0 Ω-cm of brand SOLSIX from Deutsche Solar of size 125 mm × 125 mm square. A series of experiments on multicrystalline silicon texturing is carried out with different texturization solutions of NaOH and NaOCl. In the first part of the experiment, it is tried with alkali solution containing NaOH/De-ionized (DI) water and isopropyl alcohol (IPA) of fixed composition and process time. The normally used texturization process steps for monocrystalline silicon wafers are shown in Fig. 1. In the second part, some other raw wafers are treated with new texture solution containing NaOH and NaOCl in optimized condition as shown in Fig. 2. The samples are then phosphorus doped using an optimized diffusion condition with phosphorus oxychloride ($POCl_3$) as the source. During phosphorus diffusion, ultra high pure nitrogen gas bubbles through the bubbler containing $POCl_3$ maintained at 25 °C. After the removal of the layer of phosphosilicate glass (PSG) from the sample surface with diluted HF, thermal silicon dioxide of thickness ∼150–180 Å is then grown on the sample surface at 800 °C. It serves as a passivation layer and also brings sheet resistance to a uniform and expected range for solar cell fabrication. Sheet resistance of these sample wafers is measured by four point probe method. During cell fabrication the minority carrier lifetime is maintained [9] and optimization of emitter dopant impurity profile [10] is ascertained. Using the same batch of raw wafers, solar cells are fabricated by taking textured wafers from both alcoholic NaOH and NaOH–NaOCl processes. Each batch contains 160 numbers of multicrystalline wafers. The process flow chart is given in Fig. 3.

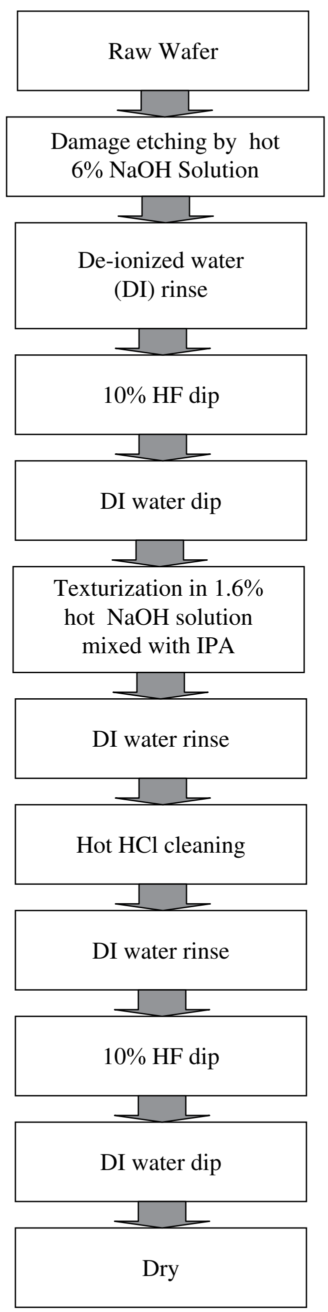

Fig. 1. Alcoholic NaOH texturization process.

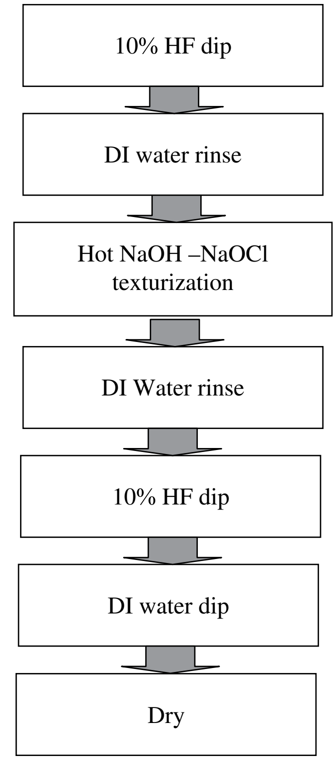

Fig. 2. NaOH–NaOCl texturization process.

Diffuse reflectance of all the textured samples is measured in spectrophotometer in the wavelength range of 400–1100 nm in some representative samples (any two wafers each from alcoholic NaOH and NaOH–NaOCl textured processes). The surfaces of the samples are also studied by Scanning Electron Microscope (SEM) and Atomic Force Microscopy (AFM). In the case of alcoholic NaOH textured samples, non-uniform structures at the different regions of the wafers are found during the SEM and AFM observation. However, the surface that has been treated with NaOH–NaOCl solution shows better uniformity.

3. Results and discussion

After texturization of raw wafers using both the above texturization processes, SEM micrographs of the representative wafers are taken. The SEM micrographs of silicon wafers textured with alcoholic NaOH and NaOH–NaOCl solution are shown in Fig. 4(a) and (b), respectively. The photographs clearly suggest the improved