

# Optimization of Surface Reflectance for Alkaline Textured Monocrystalline Silicon Solar Cell

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**Abstract**—Surface texturization is well known as one of the major paths to improve the conversion efficiency of silicon solar cells by increasing the short-circuit current through the enhancement in antireflection property and effective photon trapping. Compared to the antireflection coating, it is more lasting and effective process. The anisotropic texturing of a (100) n-type monocrystalline silicon surface was performed using alkaline etching solution of potassium hydroxide (KOH) including isopropyl alcohol (IPA) additive. The reflection properties of alkaline-etched wafers were investigated using UV-VIS-NIR spectrophotometer and the images of the surface morphology were obtained using a scanning electron microscope (SEM). The influence of KOH/IPA concentration on etched wafers has been studied i.e. process variables considered were KOH & IPA concentration. An optimum value of surface reflectance has been achieved by exploring the better concentration of alkaline solution (KOH, IPA). Minimal reflectance of textured surface achieved was -0.83 % at wavelength of 800nm in the visible region.

**Keywords**—Monocrystalline silicon; Solar cell; Texturization; Alkaline solution; Surface reflectance.

## I. INTRODUCTION

Renewable resources affect our environment much lesser than conventional energy resources. These resources are clean and green. They are replenished naturally – which means that they will never run out. For example Solar cells obtain the energy from the sun, a free and inexhaustible source of fuel to produce emission-free electricity. The monocrystalline silicon is the most important material in the solar cell today [1] and it will remain foremost and dominant material over the next 10-30 years, owing to its well recognized properties and its established production technology [2].

With the purpose to increase the light collection and the resultant efficiency of silicon solar cells, the reflection of the front surface needs to be minimized [3]-[5]. Surface texturization of monocrystalline structure of silicon (100) by alkaline etchants is called “random pyramid” texture [6], [7]. The pyramidal structures are formed on the surface of silicon because alkaline solutions etch silicon along crystallographic orientation. The etch rate in the <100> direction is much faster than <111> direction as <111> plane shows a very high atomic packing density. So when the slow etching planes, apparently of (111) orientation are exposed, they intersect at the surface to

form square based upright pyramids of random size which are distributed randomly on the surface as shown in Fig. 1 [8]. These pyramidal textures have geometries which allow sunlight to be more easily coupled into the silicon. Thus it allows as much light as possible to be absorbed due to multiple reflections and thus converted to electrical current in the solar cell [9].

In this study, texturization based on alkaline anisotropic etching was investigated by using potassium hydroxide (KOH) as alkaline etchant and isopropyl alcohol (IPA) as surfactant. Etching of silicon in potassium hydroxide solution has the advantages of simplicity, easy handling, its low-cost and its homogeneous etching rate of the (100) crystal plane [10]. The study aims at optimizing the process of surface texturization to obtain as low reflectance as possible. The morphological characteristics of silicon surfaces etched with varying concentration of alkali and alcohol as well as the average reflectance to evaluate the surface texturization effects have been reported.

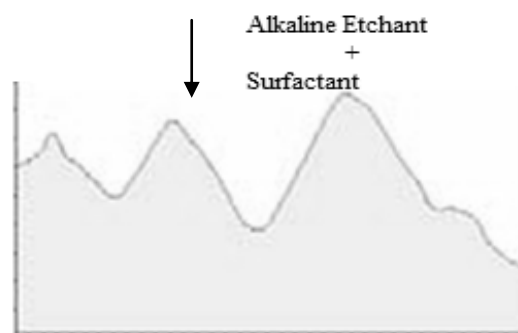


Fig. 1 Formation of pyramids using Alkali/Alcohol solution [8]

## II. EXPERIMENTAL DETAILS

### A. Cleaning of Silicon wafers

Experiments were carried out on n-type silicon (100) substrate pieces of size (2.5cm×2.5cm). Wafers were cleaned by standard piranha solution (H<sub>2</sub>SO<sub>4</sub>:H<sub>2</sub>O<sub>2</sub>=3:1 by volume) for 10 minutes to remove metal and organic contaminants which cause problem on the surface. After

this, the wafers were rinsed thoroughly with de-ionized water. These were then dipped into diluted HF solution (HF: H<sub>2</sub>O=1:20) to remove the native oxide [11] and again rinsed in DI water and dried in an oven. The samples were placed in a holder made up of quartz glass and immersed vertically into etching solution of composition as given in Table I

Table I: The Composition Of Etching Solution Used For Texturization Of Different Samples

Sample No.	KOH (wt. %) at 60°C	IPA (vol. %)	Time (mins)
1.	30	5	10
2.	30	10	10
3.	2	6	10

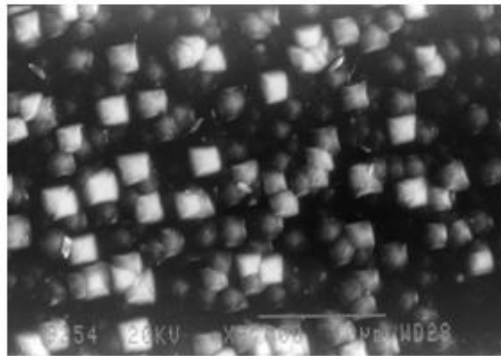


Fig. 2 (a)

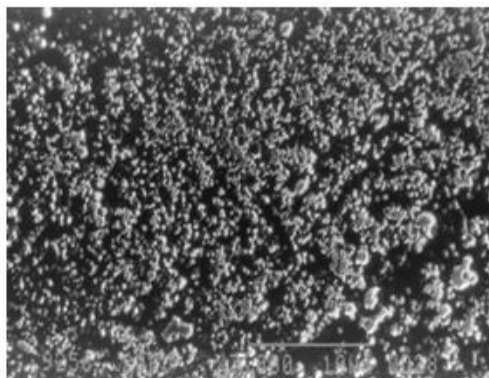


Fig. 2 (b)

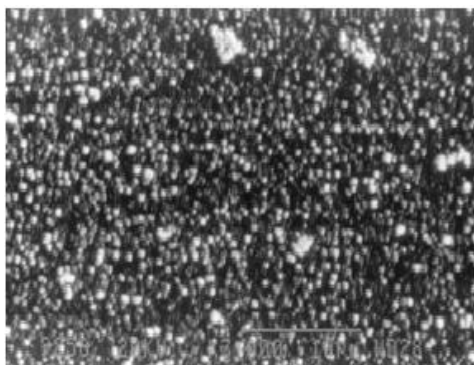


Fig. 2 (c)

Fig. 2 SEM images of textured surfaces using KOH/IPA (a) Sample 1 (b) Sample 2 (c) Sample 3

B. Characterization technique

Morphology of the texturized samples was observed with SEM (Scanning Electron Microscope) and their reflectivity in the wavelength range from 200nm to 1200 nm was measured with a UV-VIS-NIR spectrophotometer (Perkin Elmer Scan-Lambda 750 double-beam) equipped with an integrating sphere accessory at Punjab University, Chandigarh.

III. RESULTS AND DISCUSSIONS

A. SEM Results

Fig. 2 presents a perspective view of SEM images of surfaces etched in alkaline solution (KOH/IPA). As a result, random pyramidal structures are formed [12]. The pyramid size for different samples as evaluated from the SEM images is also shown in Table II.

Table II: Comparison Of Pyramid Size For Different Samples Varying In Concentration Of Koh&Ipa

Sample No.	Pyramid size
1.	2.2 μm
2.	0.58 μm
3.	0.8 μm

Morphology of Fig. 2 suggests uniform etching, dense distribution of pyramids and reasonable pyramid size for sample 1. It shows cracks and non-uniform textures because of different and very small sizes of pyramids in case of sample 2 and exhibits non-uniform etching and small pyramid size for sample 3. Small pyramids, due to their increasing density of pyramid valleys, are not suitable for solar cells. Main problem arising from these valleys are local epitaxial growth and possible capture of wet processes contaminants [13].

Thus shape and coverage of pyramids depend on concentrations of KOH and IPA in the solution. With the concentration of KOH increased, the shape is large and coverage of these pyramids is more uniform. Also low IPA concentration yields less number of pyramids but of bigger size [17]. In general, isopropyl alcohol (IPA) acts as a wetting agent when added to alkaline etchant, resulting in higher uniformity of the pyramid structure. IPA also promotes the formation of pyramids by removing the hydrogen bubbles sticking on the silicon surface. Their masking effect results in a lateral etching action of the solution, which is essential for the formation of the pyramid [14], [15]. Thus concentration of KOH & IPA solution has prominent role in texturing.

**B. Spectrophotometer Results**

Fig. 3 uses two-dimensional groove textures to demonstrate how geometrical texturization can reduce the amount of light lost by front surface reflectance for silicon in air, without the use of an antireflection coating. Light, which is

reflected away from a groove facet at its first point of incidence may be redirected toward the silicon via a neighboring texture facet, for a second chance of transmission into the silicon thereby lowering reflectance at the front surface. The probability with which light will receive such double-bounce incidence or still higher orders of multiple incidences depends upon the facet tilt angles of the geometrical textures with respect to the surface of the wafer as in Fig. 3.

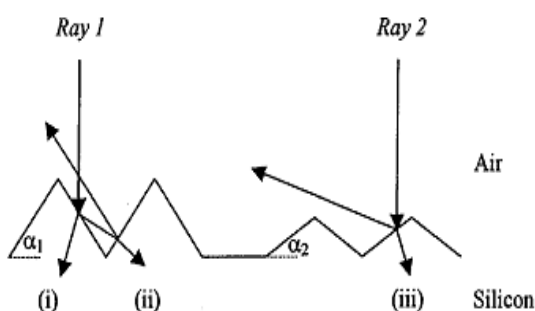


Fig. 3 Possible paths for light incident upon geometrically textured silicon in air [16]

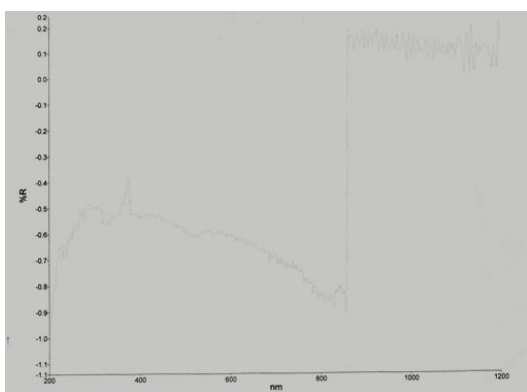


Fig. 4 (a)

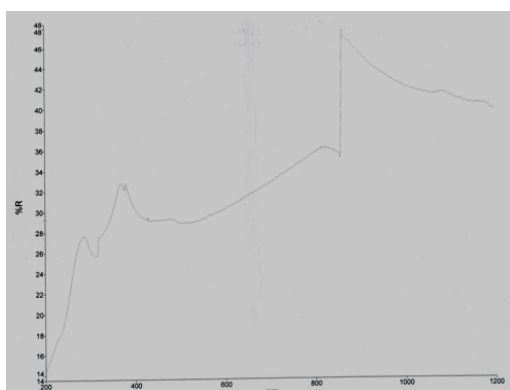


Fig. 4 (b)

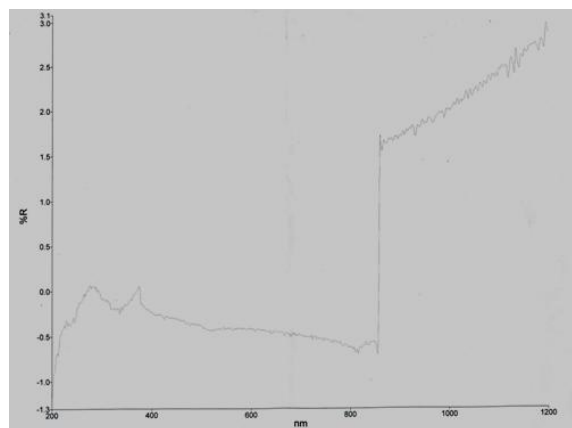


Fig. 4 (c)

Fig. 4 Spectral Reflectance of the texturized silicon (100) surface (a) Sample 1 (b) Sample 2 (c) Sample 3

For normal incident light falling upon periodic textures, ray 1 experiences double bounce incidence for  $\alpha_1 > 30^\circ$ , whereas for  $\alpha_2 < 30^\circ$ , ray 2 is reflected directly away without a second chance of incidence. The multiple incidences of light are more possible if angle of pyramid to the surface lies in the range  $30^\circ < \alpha < 45^\circ$  (in air). The range  $45^\circ < \alpha < 54.7^\circ$  guarantees double bounce incidences of light & the range  $\alpha > 60^\circ$  ensures yielding of at least

Table III: Comparison of Reflectance Values for Different Samples

Sample No.	Average Reflectance (%) (400-800 nm)	Minimum Reflectance (%) (400-800 nm)	Difference of min. & max. Reflectance (%) (400-800 nm)
1	-0.638	-0.83 at 800 nm	0.3
2	31.2	28.8 at 500 nm	6.9
3	-0.414	-0.6 at 800 nm	0.35

triple bounce reflectances. As a result, texturing of the silicon (100) leads to an absolute reflection reduction of approximately 20% compared to a flat polished wafer in air [16].

Spectral reflectance measurements obtained from textured silicon wafers (using different solutions) are shown in Fig. 4. The reflectance spectra have been studied in the wavelength range from 200 nm to 1200 nm. Their analysis (Table III) shows that for sample 1, the average reflectance and the minimum reflectance are -0.638% and -0.83% respectively which are least amongst all samples for visible range. Average reflectance value achieved for sample 1 from Fig. 4(a) is lower than that as obtained in [17]. Also difference between minimum and maximum value of reflectance is about 0.3% showing not much variation in reflectance for visible range in sample 1.

Compared to it, the sample 2 has maximum reflectance amongst all samples in visible range. In infrared region, sample 1 has comparatively constant reflectance (0.2%), sample 3 has increasing reflectance and sample 2 also has high reflectance. This shows that the etchant concentration used for sample 1 is most appropriate for fabrication of silicon solar cells.

#### IV. CONCLUSION

Differently composed alkaline texturing solutions have been investigated by varying the concentration of KOH/IPA at 60°C for 10 minutes. By studying the SEM results and the reflectivity of the textured surface, process variables have been identified that give optimized value for both surface reflectance as well as pyramid size. These values can be further utilized for the fabrication of the silicon solar cell.

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