

A simple and cost-effective approach for fabricating pyramids on crystalline silicon wafers

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ARTICLE INFO

Article history:

Received 9 September 2008
Received in revised form
19 January 2009
Accepted 28 January 2009
Available online 9 March 2009

Keywords:

Silicon
Texture
Pyramid
Pseudo-mask

ABSTRACT

A simple and cost-effective approach for texturing crystalline silicon wafers is proposed. The advantage over conventional texturization processes is the fact that no surfactant is added in alkaline etchants. Hydrogen bubbles, regarded as residuals in conventional texturization processes, are utilized in this approach as etch masks on a silicon surface. This is accomplished by placing a metal grid with suitable openings on silicon wafers to confine the hydrogen bubbles created during etching. Pyramids with a size ranging from 6 to 9 μm are uniformly fabricated using this method. Without antireflection coating, an average weighted reflectance of 15.1% is achieved.

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1. Introduction

Surface texturization of (100)-oriented crystalline silicon wafers is a frequently used technique in modern solar cell processing to reduce optical reflections. Many successful approaches based on texturing silicon surface utilizing alkaline solutions [1,2] have been reported. Alkaline etchants such as sodium hydroxide (NaOH) [3] or potassium hydroxide (KOH) [4] at low concentration in water expose Si {111} faces resulting in square-based pyramids randomly distributed over the cell surface. This texture will enhance light trapping capability by increasing both coupling of lights into the cell and reflectivity [5,6] of lights trying to escape from the cell [7,8]. In general, isopropyl alcohol (IPA) is added to the alkaline etchants to improve the uniformity of the random pyramid texture. Though IPA is expensive, it is essential for the process because it removes hydrogen bubbles sticking on the silicon wafer by improving the wettability of the wafer surface. In a typical texturing condition, high concentration of IPA is required [9] to obtain uniform pyramid textures. However, the etching rate of silicon decreases drastically with IPA concentration [10]. In addition, IPA is volatile in a heated etching bath. To maintain a sufficient wettability of the silicon surface, IPA must be constantly added to the solution to compensate the amount lost due to evaporation. In current commercial texturing technique based on alkaline anisotropic

etching, the cost of IPA can be the key factor of overall texturization cost reduction approach.

Recent research on low-cost silicon texturization centers on investigating alternative solutions [11,12] for surface texturing and reducing amount of IPA in the solutions [13]. Several novel processing techniques were reported using different chemicals, such as tetramethyl ammonium hydroxide (TMAH) and sodium phosphate (Na_3PO_4). Moreover, Nishimoto and Namba [14] successfully textured the silicon surface with sodium carbonate (Na_2CO_3) solution and claimed that no IPA was needed for the process. In this paper, we propose a different approach based on KOH texturization without adding any surface-active additive in the solution. In a conventional alkaline etching process, KOH reacts with silicon in water producing hydrogen bubbles. These hydrogen bubbles with 2–3 mm diameter can stick on the silicon surface and suppress chemical reaction between the silicon surface and the KOH solution. This will lead to insufficient pyramid nucleation and result in poor texture uniformity and reproducibility. However, these bubbles can also be used as a “pseudo-mask” [15] as long as they can be constantly trapped on the silicon surface during the etching process. This is accomplished by placing a metal grid with periodic opening at close proximity to the silicon wafers. The hydrogen bubbles created due to KOH-Si reaction can be confined by the openings of the metal grid because of surface tension of the bubbles. Thus the hydrogen bubbles, which are regarded as residuals in the conventional texturization processes, are utilized in this approach as the etch-mask on the silicon surface. Pyramids with a size ranging from 6 to 9 μm are uniformly fabricated using this method.

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2. Pyramid fabrication

The etching experiments were carried out using 3", *p*-type, <100>; oriented, crystalline silicon wafers with resistivity 1–3 Ωcm . Before texturization, the wafers were etched in 10% hydrofluoric acid (HF) to remove native oxide and rinsed in deionized water. The wafers were then etched in KOH (1 wt%) solutions at different temperatures for 10, 15, and 20 min. The etching solution was heated with a temperature-controlled hot plate. No surfactant was added in the etchants during the processes. The hydrogen bubbles produced during etching were trapped on the wafer surfaces utilizing the stainless steel metal grids with different square openings. To optimize the size and uniformity of the pyramid, we tested four metal grids with 1, 1.5, 2, and 3 mm square opening for texturing at 1 and 2 mm wafer-to-grid separations. After the etching process, the surface morphology of the silicon wafers was examined by a surface scanning electron microscope (SEM). To characterize the optical performance, hemispherical surface reflectance of the textured surfaces was measured. An integrating sphere/spectroradiometer was used with light in the wavelength range from 400 to 1100 nm at near-normal incidence. Finally, the weighted reflectance was calculated by normalizing the reflectance using AM1.5 solar spectrum.

3. Results and discussion

The pyramids fabricated using the proposed approach are dependent not only on the conditions of the KOH etchants but also on the structures of the metal grids to the silicon wafers. Both must be considered to obtain pyramid structures with satisfactory optical performance. The etching was performed by placing the metal grid on top of the silicon wafer and submerged them into the KOH solution. At the beginning of the etching process, hydrogen bubbles were observed to emerge from the wafer surface and captured by the openings of the metal grid. Shortly after the etching started, hydrogen bubbles were found to fill most of the grid openings if suitable size of the openings was used. As the etching process continued, the bubbles in the openings grew in size until a pressure balance on the bubbles was reached. The hydrogen bubbles released from the wafer surface in the subsequent etching could be pushed away from the openings and were observed to escape from the edges of the grid. However, the bubbles within the openings were found to stay within the openings throughout the etching process. They can now function as the pseudo-mask for pyramids fabrication. It is generally believed that the formation of pyramids on monocrystalline silicon wafers makes use of anisotropic etching with alkaline solutions. So there is no basic difference in the etching mechanism between the proposed method and other texturization techniques.

Fig. 1 shows the SEM photos of the surface morphology of the silicon wafers textured in 1 wt% KOH solution at 70 °C for 10, 15, and 20 min without ultra-sonic agitation. The size of the opening of the metal grid is 2 mm \times 2 mm, and the separation between the grid and the wafers is 1 mm. Fig. 1a depicts the pyramids formed with the metal grid during the initial stages of texturization. Random upright pyramids were observed but were distributed sparsely on the wafer surface. Poor surface coverage was obtained. Fig. 1b shows that the pyramid structures had grown in size after an etching time of 15 min. The size of the pyramids increased with increase in etching time, which indicated that the nucleation and growth of the pyramids took place simultaneously. In addition, the surface coverage of the sample improved substantially. The average pyramid base size was between 3 and 6 μm . As shown in Fig. 1c, however, some of the pyramid structures were found to

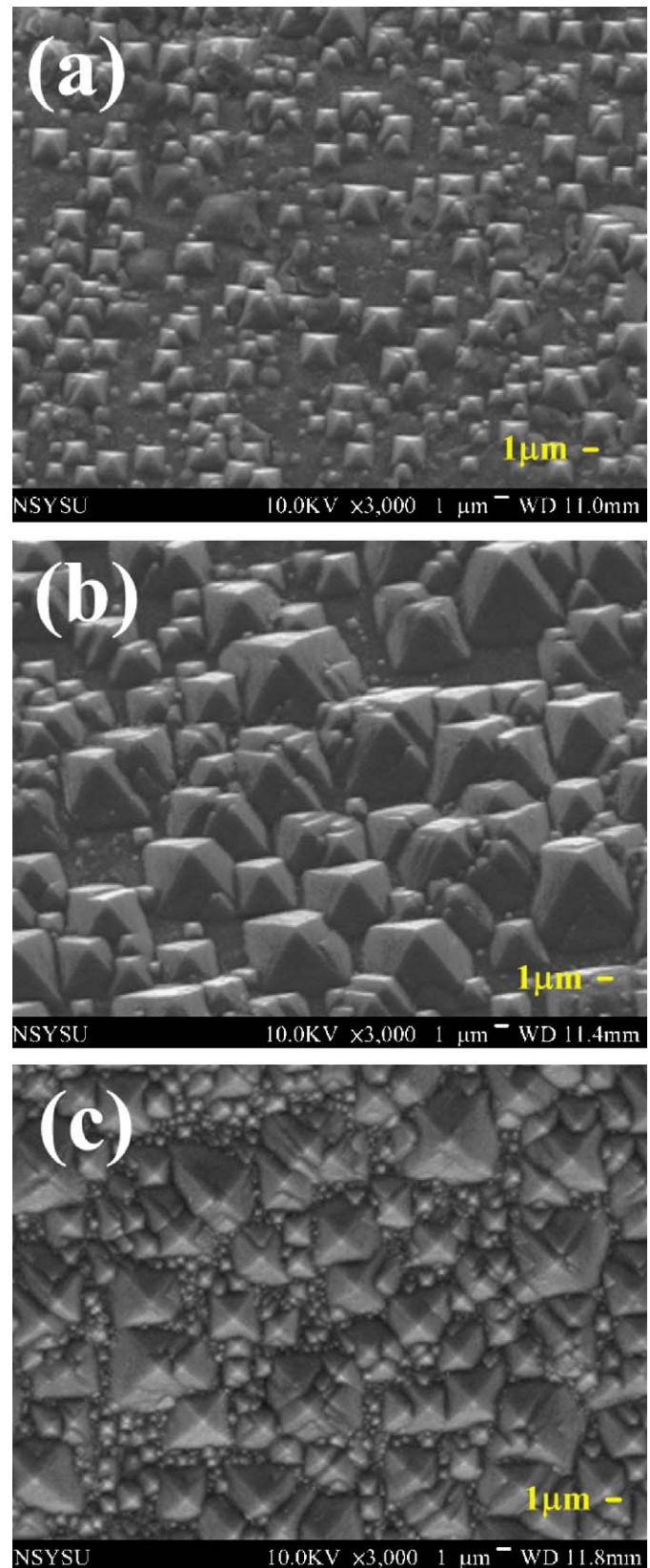


Fig. 1. The SEM photos of the surface morphology of the silicon wafers textured in 1 wt% KOH solution at 70 °C for (a) 10, (b) 15, and (c) 20 min.

collapse. For a 20 min duration of texturization, some pyramids can grow at the expense of others, resulting in a decrease of uniformity in size. Nevertheless, the surface coverage of the

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