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Surface Engineering towards Self-Cleaning Applications: Laser Textured Silicon Surface

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Abstract

Surface finishing of parts plays a critical role in engineering applications. Although the efforts towards improving surface finish have been made over the past decades, the recent developments in science and technology accelerate the progresses made towards superior surface characteristics. Tailoring the physical and chemical characteristics of the surfaces enable to extend the surface engineering studies in many new fields including medical, biological, environmental engineering, and architecture. The current interest in self-cleaning of surfaces for energy applications, such as solar thermal and solar photovoltaic energy harvesting, makes the surface finish as one of the hot topics of the research. In the present study, laser texturing of silicon surface is presented in line with the self-cleaning characteristics. It is found that laser texturing gives rise to hydrophobicity characteristics at the surface because of: i) micro/nano size pillars, and ii) nitride phase formed at the surface.

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Keywords: Laser texturing; silicon wafer; hydrophobicity

1. Introduction

In photovoltaic applications, the protection of surface from particle accumulations, such as dusts, in harsh environments is necessary for maintain the device performance in terms of device efficiency. This is because of the fact that the accumulated particles partially block and scatter the incoming solar radiation while reducing harvested

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solar radiation on the active surface of the solar photovoltaic collector. To reduce the particle accumulations on device active surfaces, regular cleaning becomes essential. The external efforts such as cleaning by air and water jets are expensive and require additional cleaning equipment and skilled personal. However, the self-cleaning of surface offers considerable advantages over the conventional cleaning techniques, which involve water and air jet cleaning. In order to establish the fundamental understandings of the self-cleaning, natural cleaning techniques need to be explored. Some of these natural self-cleaning surfaces include rose petals, rice leafs, and lotus leaves. Therefore, mimicking the nature for self-cleaning is the key concern to minimize the particle accumulation on selective surfaces. The close examination of natural surfaces of self-cleaning characteristics reveals that such surfaces has textures composing of micro/nano pillars and low surface energies. Consequently, artificial resembling of such surfaces can make it possible to generate self-cleaning surfaces. On the other hand, silicon wafers are widely used in photovoltaic industry because of its high energy conversion efficiency. However, silicon has high surface energy giving rise to the hydrophilic surface characteristics. In order to reduce the surface energy of silicon, chemical compounding of the surface towards achieving low surface energy becomes essential. One of the techniques to achieve such compounding is to generate nitride compounds at the surface via chemical and/or physical processes. Although several techniques are available to improve hydrophobicity of surfaces, some of these techniques are expensive and involves with harsh environmental conditions [1-6]. However, laser texturing and creating nitrogen compound at the silicon surface offers significant advantages over the other techniques [7]. Some of these include high speed processing, precise of operation, and low cost. Laser texturing involves with high power processing at the substrate surface, which generates combination of evaporation and melting of the substrate material in the surface vicinity. The use of assisting gas such as high pressure nitrogen provides nitride reactions at the surface while modifying the surface chemistry of the silicon wafer. Because of the high temperature processing at the surface, the temperature gradients remain high while causing thermal strain and stresses in the textured surface. The formation of the high stress fields at the treated surface may cause cracks and crack networks in the treated layer. Consequently, investigation of laser nitrogen gas assisted texturing of silicon surfaces in relation to surface hydrophobicity and texture characteristic, in terms of surface cracks, becomes essential.

The oxygen concentration and microstructure of laser-irradiated silicon was examined by Zhu et al. [8]. They demonstrated that the initial ablation played crucial role for the generation of the cross-patterned periodic surface structures. The laser-chemical doping process towards achieving electrically active ions on the silicon surface was investigated by Linaschke et al. [9]. They showed that infrared wavelength laser texturing reduced the sheet resistance considerably. Laser treatment of silicon wafer and the assessment of the microstructural characteristics were carried out by Ma et al. [10]. They explored the morphology surface texture incorporating the analytical tools. The texturing of a silicon surface using a pulsed laser irradiation was realized by Wang et al. [11]. They demonstrated that increasing of laser output power resulted in combination of melting and surface evaporation, which gave rise to micro/nano poles at the surface. The laser treatment of silicon surface using the short-pulses was studied by Toth et al. [12]. They showed that thickening of the oxide layer took place for the nanosecond laser pulse irradiations, which suppressed the formation of crystalline silicon layer thickness at the surface. The laser irradiation of silicon surfaces via multi-pulses was carried out by Lugomer et al. [13]. They indicated that the laser pulse repetition resulted in damped membrane-like oscillations at the silicon surface.

Although laser texturing of silicon surface towards surface hydrophobicity was examined previously [14], the main emphases was to use the laser beam while rotating the silicon wafer around the laser beam axis. This in turn resulted in hierarchical surface texture along the radial direction. Consequently, in the present study laser texturing of silicon surface along the regular laser scanning tracks without angular rotation. The surface characteristics towards the surface hydrophobicity are examined in the light of the previous study [7]. The residual stress formed due to thermal effect of the laser treatment is also determined.

2. Experimental

The CO_2 laser (LC-ALPHAIII) delivering nominal output power of 2 kW was used to irradiate the workpiece surface. The nominal focal length of the focusing lens was 127 mm while resulting in 200 μm of the irradiated spot