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Formation of a periodically distributed inverted pyramid structure on silicon using direct laser interference ablation and surface etching processes

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Abstract

In this paper, we present a new method of structuring a crystalline silicon surface using laser ablation and wet anisotropic etching processes that produce periodic inverted pyramid surface structure. The direct laser interference patterning technique was used as a first process instead of the single focused laser beam. That resulted in the idea-periodicity structure produced on a large area with just a single laser pulse. The morphology investigation of the formed structure depending on the laser processing and etching parameters was performed using SEM and AFM microscopy.

KeyWords: laser Ablation, silicon, inverted pyramid, periodic structure, etching

1. Introduction

Because of low price, abundance in nature and well-established technologies, silicon remains as the main material used in microelectronics and solar cell industry. Thus, it is a tremendous demand for silicon machining technologies. The main and well-established method used for it is photolithography. However, this method requires many processing steps to be done before the final product is fabricated that sometimes, especially for small and versatile production, it is inefficient in terms of time and money. Hopefully, the one-step direct laser ablation (DLA) process can be used as an alternative method. Most of the DLA studies on such Si structuring deal with the formation of self-organized surface structures like sub-wavelength laser-induced periodic structures [1] created by irradiating silicon with multiple

femtosecond laser pulses of the near-IR radiation. This technique was used to control silicon wettability [2], [3] and optical properties [4].

In this work, we present the novel crystalline silicon surface structuring technology that produces periodic inverted pyramid structure. Such structures have been already made using the lithography technique by M. Anastassios et al. for light harvesting application in photovoltaics industry [5]. Our suggested method requires only two fabrication processes to produce the final structure. It is the laser ablation and wet anisotropic etching in KOH solution. The direct laser interference patterning technique was used as a first process instead of the single focused laser beam. This technique uses the interference of several beams to directly pattern the material surface [6]. That results in the ideal periodicity structure produced over a large area with just a single laser pulse. After the ablation of the silicon surface, the etching of the sample was performed and periodically distributed pyramids were formed. The period of the pyramid was the same as the period of the laser ablated structures.

2. Results

Picosecond laser "EKSPLA" 532 nm with the maximum pulse energy of 1.5 mJ and the 2-axes positioning system "Aerotech" were used to ablate the crystalline silicon <100> surface. The ablation of the sample was made using the laser beam interference. The laser interference setup was based on the diffractive optical element (DOE) that splits the incoming collimated laser beam into four or six beams (±1 order maxima). The split beams were made parallel by the lens L1 and gathered by the lens L2 on the sample surface (more detail can be found in [6]. The resulted interference patterns are showed in Fig.1.

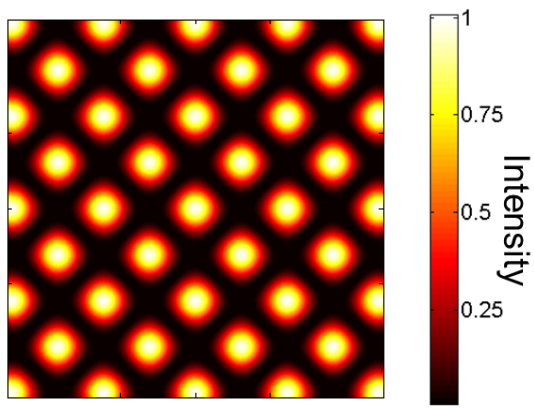

Fig. 1. The interference intensity patterns produce by four.

Ablation using the direct laser interference patterning resulted in the periodic grooves formation on the silicon surface (Fig. 2a.). After etching in 10% KOH solution for 3 hours, the laser ablated round grooves were transformed into square shaped grooves (Fig. 2a). The AFM measurements revealed that morphology of the etched grooves had the pyramid shape (Fig. 3a). The experiments using various laser ablation and etching process parameters were performed to investigate how they affect the final morphology of the pyramid structure.

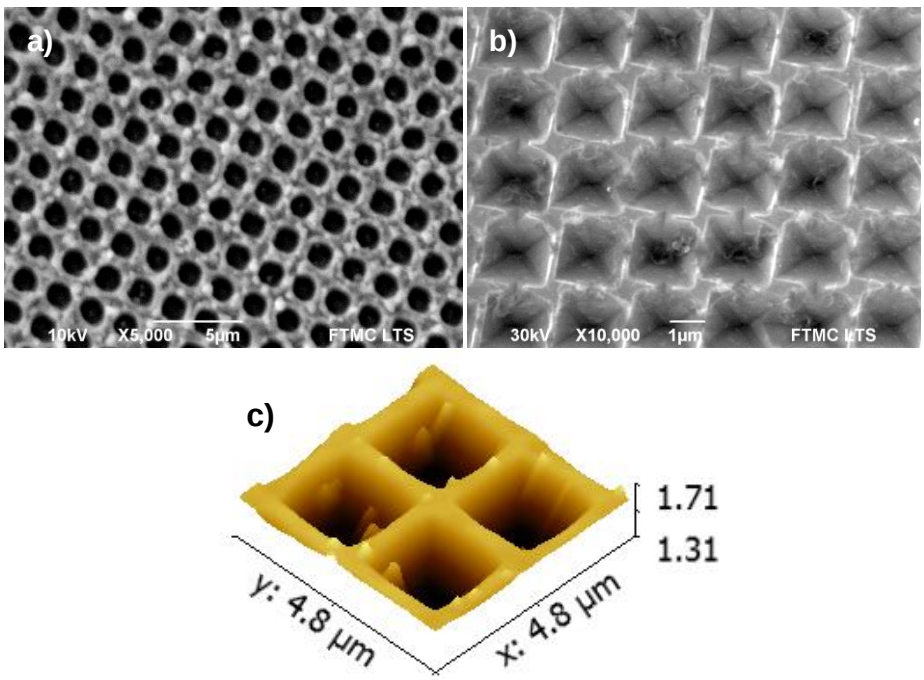

Fig. 1. SEM images of silicon surface after using the four-beam laser interference ablation technique (a) and the same silicon surface etched in KOH solution (b). AFM image of the textured silicon surface etched in KOH solution.

3. Summary

It was showed that laser ablation process performed before a wet anisotropic etching can be used instead of many processes used in photolithography technique. The morphology of the ablated pyramids can be controlled not only by the etching process but also by the laser ablation process. Consequently, the period and distribution of the pyramids can be controlled simply by changing the intensity profile of the laser beam interference. Also, even more complex and non-periodic pyramid distributions can be achieved using laser ablation with only one focused laser beam that can be scanned in desired manner on the sample surface.

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