Silicon surface texturing by forming sub-micron bumps with a CW fiber laser

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Abstract

Laser surface texturing based on ablation has been well reported in literature. However, few reports can be found in the public domain on non-ablative laser forming of uniform micro-bumps on silicon surface. Despite silicon is transparent to the infrared wavelength of fiber laser (λ= 1090nm), we succeeded in forming submicron bumps on Si surface using a CW fiber laser. Laser-induced thermal oxidation is believed to be the reason for the formation of micro-bumps.

1 Introduction

Surface texturing is an important research area with a broad range of applications in electronics, solar cells, and precision engineering. Surface texturing of silicon by laser ablation [1-4] has obtained great interest due to its wide use in microelectronics and photovoltaic. Many research groups have also reported the application of pulsed lasers to produce grooves and pits on surfaces of many other materials such as Ge [5], metals [6] and thin films [7] under diverse experimental conditions. Material ablation and redistribution of melt materials are the main mechanisms of surface texturing. Few reports can be found on non-ablative surface texturing of silicon. In this paper, we report on a method of texturing Si by forming arrays of sub-micron bumps with a CW fiber laser. The non-ablative texturing method can be potentially used for functionalising surfaces and debris-free marking of silicon wafers.

2 Material and experimental procedures

A single crystal (100) n-type (phosphorous doped) Si wafer in the size of 10 mm × 10 mm was used in the study. Ultrasonic cleaning of the samples was carried out. A CW fibre laser with wavelength λ = 1090 nm was used to irradiate the sample in an area of 2 mm × 2 mm with a point scanning pitch of 20 µm, as shown in Figure 1. The laser beam was focused to the size of ≈ 20 µm with a focusing lens of 50 mm in focal length. In order to create micro-bumps, the laser experiments were conducted at the fixed laser power of 19 W with dwell time of 40 ms in either ambient, oxygen or argon gas atmospheres. Oxygen and argon were delivered onto the Si surface in three different pressures (0.25, 0.5, or 0.75 bar) through a coaxial nozzle, as shown in Figure 1. The laser-irradiated surfaces were characterized using confocal microscope and dispersive X-ray spectroscopy (EDX).

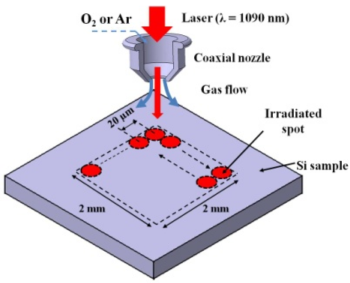

Figure 1: Schematic experimental set-up

3 Results and discussion

The laser-irradiated surfaces in ambient are seen to have rough and irregular patterns as shown in Figures 2(a). It is interesting to note that the irradiated surfaces raised few microns above the original surface as shown in Figure 3(a). In Ar, the laser-irradiated surfaces also have irregular patterns but no protruding patterns observed as shown in Figure 2(b) and 3(a). The laser-irradiated surfaces in oxygen at various oxygen pressures (0.25, 0.5, 0.75 bar) are seen to have uniformly patterned submicron bumps, as shown in Figures 2(c), 2(d), 2(e), 3(b), 3(c), and 3(d). The formation of the micro-bumps indicates the swelling of the material during the laser irradiation. We attribute the swelling to the laser-induced thermal oxidation. EDX results shown in Figure 4(a), indicates the absence of oxides on the surface irradiated in Ar, whereas Figure 4(b) indicates the existence of oxides on the surface irradiated in oxygen. The laser-induced thermal oxidation process is described in Figures 5(a) and (b). For photon energies near the Si bandgap (1.12 eV), the enhancement in oxidation rate is mainly due to the laser surface heating and the increased electron population in the Si-SiO_2 interface. Considering that Si bandgap decreases with increasing temperature [9], laser radiation with the 1090 nm wavelength (E_{photon} =1.138 eV) causes the electron emission from Si into the Si-

SiO_2 interface and O_2 diffusion. The electrons are also transferred from Si to adsorbed O_2 and enhance the diffusion of O_2 through the oxide layer, as shown in Figure 5(b). Introducing O_2 flux into the locally heated region provides more diffusive and oxidizing atmosphere and therefore helps the thermal oxidation process.

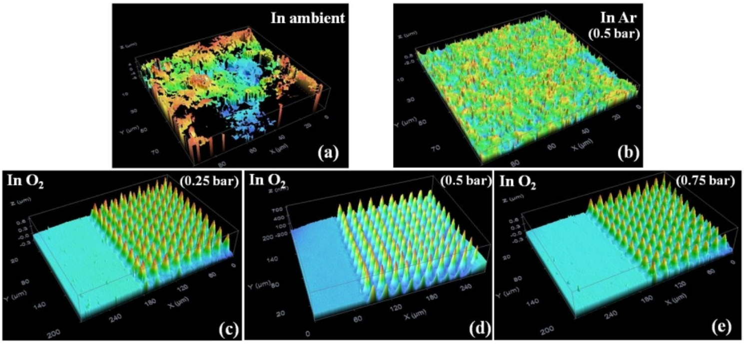

Figure 2: Confocal microscope images of the Si surface irradiated at laser power of 19 W and dwell time 40 ms (a) in ambient, (b) in Ar (0.5 bar), (c) in O_2 (0.25 bar), (d) in O_2 (0.5 bar) and (e) in O_2 (0.75 bar).

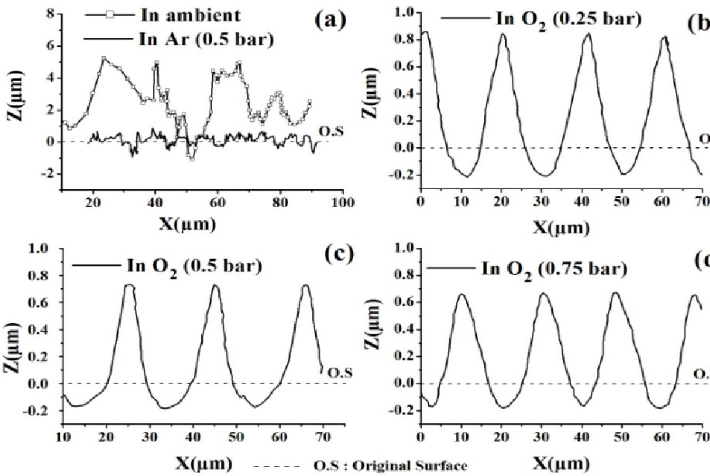

Figure 3: Profile of the Si surface irradiated at laser power of 19 W and dwell time 40 ms (a) in ambient and Ar, (b) in O_2 (0.25 bar), (c) in O_2 (0.5 bar) and (d) in O_2 (0.75 bar) [8].

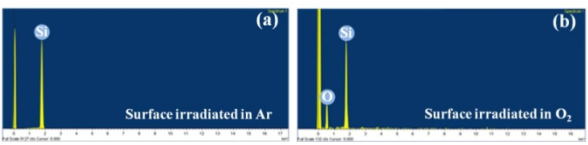

Figure 4: EDX spectrum of (a) Si surface irradiated in Ar and (b) Si surface irradiated in oxygen [8].

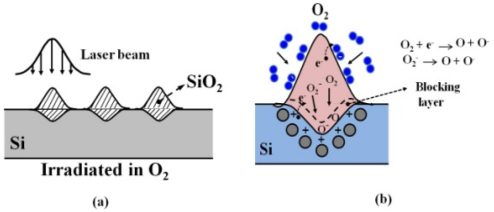

Figure 5: (a) laser-induced SiO_2 bumps by localised Gaussian heating source, (b) microscopic model for the laser-induced surface oxidation.

4 Conclusion

A regular array of micro-bumps was produced on Si surface based on laser produced non-ablative texturing. The bumps were found to be SiO_2 based on EDX analyses. Laser-induced thermal oxidation is explained as the possible reason for the formation of the micro-bumps. The non-ablative laser processing is debris-free and can be potentially used for altering surface functionalities.

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