

LASER TEXTURING PROCESS ON THE SURFACE PROPERTIES OF SILICON WAFER

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Received: January 15, 2021; Revised: March 29, 2021; Accepted: March 29, 2021

Abstract

A silicon wafer modification induced by laser texturing process was investigated in this paper to understand the influence of laser power and laser scanning speed on its surface characteristics. The morphology and chemical compositions of the wafer were observed and characterized by using the scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS), respectively. The corrosion potential of laser-scanned wafer was assessed by using potentiodynamic polarization. In addition, the obtained surface roughness was measured by using a surface profiler. Ball-on-disk friction test was employed to quantify the friction coefficient of laser-textured surface. The results indicate that with the increasing laser power at scanning speeds of 10 mm/s, corrosion resistance increases. The laser power of 25 W shows the highest corrosion potential value (E_{corr}) of -0.61 V, indicating good corrosion resistance property. Increasing laser power tends to increase surface roughness and the friction coefficient.

Keywords: Laser texturing, surface properties, silicon wafer, surface morphology, chemical composition

Introduction

Laser technology has been used extensively in the field of medicine and the manufacturing industries and it has also been adopted in various applications, including welding, cutting, drilling, milling and treating of workpiece surface (Ghaisas, 1987; Li, 2011; Honda, 2012; Ezura, 2015; Tsai, 2015; Rotella, 2015). Laser surface modification is a promising process to enhance the surface properties of workpiece. This modification is able to improve the tribological properties and corrosion behavior of various materials (Heitkemper, 2001; Pantelis, 2002; Lo, 2004; Dobrzanski, 2005). Chen

et al. (2017) enhance the corrosion resistance and promote the self-cleaning of TiNi alloy surface by using laser texturing process, where the effect of laser power and scan speed rate were experimentally investigated. A similar work can be found in a study of Lima and Almeida, (2017), noting that hydrophobic surface and low surface roughness of titanium alloy can be promoted when a relatively low laser power is employed. Another approach of using lasers for surface modification is to polish the work surface through the laser melting mechanism. Kayahan, (2018) studied the capability of laser for removing

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face milling patterns in aluminum alloy surface. The work surface obtained can either be smoothened or roughened depending on the amount of molten material induced by laser and the way of cellular and dendritic structures formed during its solidification. The laser polishing process is also applicable for additive manufactured CoCr alloys with the attempts to increase the corrosion resistance performance and surface roughness of 3D printed metal components (Wang *et al.*, 2018). However, the use of lasers for surface texturing, polishing or microstructural modifications can adversely introduce thermal effects to the work material. In general, a suitable amount of laser energy must be applied to yield the desired surface features with minimum heat damage. Since silicon wafer is of brittle and thin, the control of heat input during the laser texturing is a vital concern to the obtained surface characteristics and functionality of silicon after processing. Therefore, this study reveals thermal effects to the work material, which contributes to high quality silicon wafer manufacturing.

In this paper, a laser texturing process was used to treat a silicon wafer surface. The aim of this paper is to study the influence of laser power and scanning speed on the corrosion resistance, surface roughness, surface morphology, chemical composition at the laser-irradiated surface and the friction coefficient of a silicon wafer.

Materials and Methods

Silicon <111> wafers with a thickness of 0.5 mm and a resistivity of 3 Ω -cm were used as specimens. All specimens were cut into 15×15 mm, and a laser-treated area of 10×10 mm was given to each specimen. A nanosecond pulsed fiber laser (Ylia M30EG) having a wavelength of 1,064 nm. Pulse duration was set at 120 ns to texture the silicon wafer. Laser pulse repetition rate and laser beam diameters used in this study were constantly set at 30 kHz and 20 μ m, respectively. During the treatment process, the sample was moved by a two-axis CNC motorized stage. A schematic diagram for

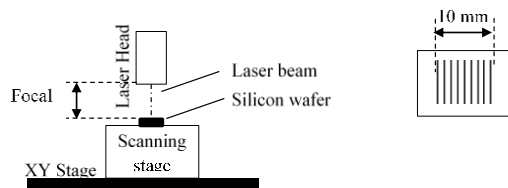


Figure 1. Schematic diagram for laser surface treatment process

the laser treatment process used in this study is shown in Figure 1. The laser parameters are shown in Tables 1 and 2.

The morphology of the silicon wafer was analyzed by scanning electron microscope (SEM) (JEOL; JSM 5610LV). The chemical composition of the silicon wafer was measured by using an energy dispersive X-ray spectroscopy (EDS) on the top surface with the acceleration voltage of 15 kV. The corrosion behavior of the silicon wafer was obtained by using the potentiodynamic polarization test in an aqueous with 0.05 M NaCl solution. A Pt sheet and Ag/AgCl were used as counters and reference electrodes, respectively. The potential voltage varied from -3 V to +3 V at a scanning rate of 10 mV/s. The average surface roughness (R_a) of silicon wafer was measured by using a surface profilers (Taylor Hobson; TalySurf Series 2) with the measuring length of 4 mm. The friction coefficient of all specimens was determined by using a ball-on-disk tribometer (CSEM; Tribometer). A dry sliding test was carried out using a ball indenter; AISI440C (SUS440C, diameter of 6.0 mm) under a normal applied load of 1N, rotation radius of 4 mm, linear speed of 15 mm/s, and 10,000 number of cycles.

Table 1. Laser surface texturing parameters and relative atomic content

Scanning Speed (mm/s)	Laser power (W)	Relative atomic content (wt%)		
		C	O	Si
10	7	3.15	52.28	44.31
	11	2.79	49.27	47.94
	25	2.19	43.28	54.99
20	7	4.20	33.83	61.97
	11	3.83	32.66	63.51
	15	3.28	36.14	60.58

Table 2. Corrosion potential and average surface roughness

Scanning Speed (mm/s)	Laser power (W)	Corrosion potential (E_{corr} (V))	Average surface roughness (μ m)
Untreated	-	-0.16	-
10	7	-0.85	2.44
	11	-0.67	3.42
	25	-0.61	3.51
15	7	-0.75	2.69
	11	-0.78	3.44
	25	-0.97	3.90
20	7	-0.67	2.36
	11	-0.73	3.40
	15	-0.93	3.40

Results and Discussion

Surface Morphology

The surface characteristic of specimens is presented in Figures 2 and 3, indicating that the increase in laser power increases the porosity and number of melted particles, which are shown as white particles on the sample surface. These particles were ejected from the molten region during the laser melting process. Recoil pressure induced by the vaporization of work material is responsible for this feature as resulting pressure is high enough to mechanically drive the liquid material away from the laser-irradiated area. The liquid droplets splashed outwardly from the molten zone before being solidified and adhering to the workpiece surface. The surface morphology presented in Figure 3 is

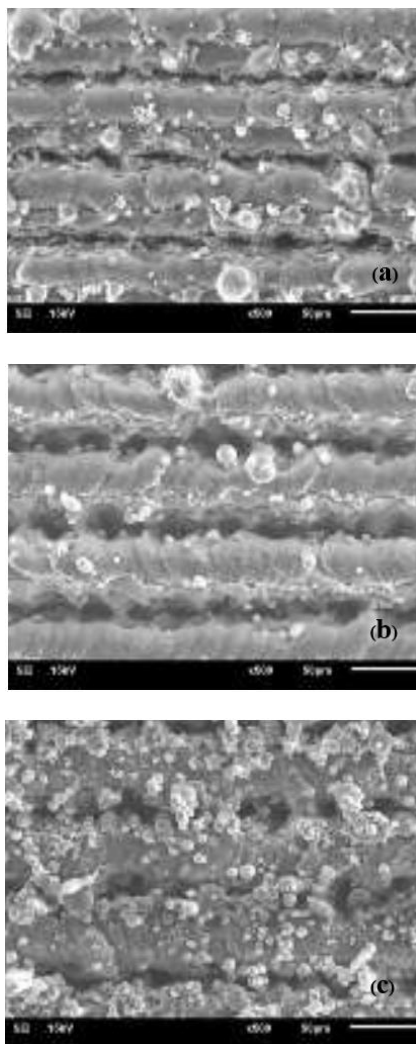


Figure 2. SEM images of laser treated silicon surface (x500) (a) $P = 7\text{ W}$, $S = 10\text{ mm/s}$ (b) $P = 11\text{ W}$, $S = 10\text{ mm/s}$ (c) $P = 15\text{ W}$, $S = 10\text{ mm/s}$

also similar to the findings of Charee *et al.* (2015). In addition to the laser power, an increase in scanning speed was found to reduce the porosity of the samples particularly at low laser power (Figure 2(c)). This is due to the reduction of heat input that cause the weakening of recoil pressure during the process. Thus, the molten silicon cannot completely be ejected away from the surface and it is rather unmoved and solidified as a recast layer. This condition is highly preferred for reducing the roughness of workpiece surface as the dynamics of molten material can be kept at minimum with the limited amount or even no material vaporization during the process, thus decreasing the formations of porosity and particles on and around the laser-irradiated area.

Chemical Composition

The result of the chemical composition analysis performed in this study is shown in Table 1. Carbon, oxygen and silicon concentrations at the melt particles were measured and normalized into a weight percentage (wt%). According to the results, there is an observable peak of oxide on the substrate. As the laser texturing process was performed in ambient air, oxygen can substantially diffuse into the molten silicon and subsequently form silicon dioxide (SiO_2) as a result. The amount of oxygen content was found to increase with the decreased scanning speed. This is on account of the irradiating time of laser to the substrate that is longer under a slower speed, thus causing a larger recast structure and more of SiO_2 formed into the work surface. This oxide compound is a passive film that importantly changes the surface properties of silicon substrate. Besides the presence of oxygen in the substrate surface, the atomic content of carbon was also detected by EDS, indicating that the content of carbon decreased with the increased laser power. It is anticipated that carbon might be burned out under the use of high laser power. However, the difference in carbon content measured from the tested conditions was not as remarkable as oxygen.

Corrosion Resistance

Generally, the higher potential and low current density indicate the improved corrosion resistance (Sui *et al.*, 2009). In this experiment, the corrosion potential (E_{corr}) is used to indicate the degree of corrosion resistance for laser-treated silicon surface. Potentiodynamic polarization curves of the specimens and the results corresponding to the polarization curve are shown in Table 2 and Figure 4, respectively.

Potentiodynamic polarization curves of the laser-treated specimens at the scanning speed of 10 mm/s are presented in Figure 4(a), correspond

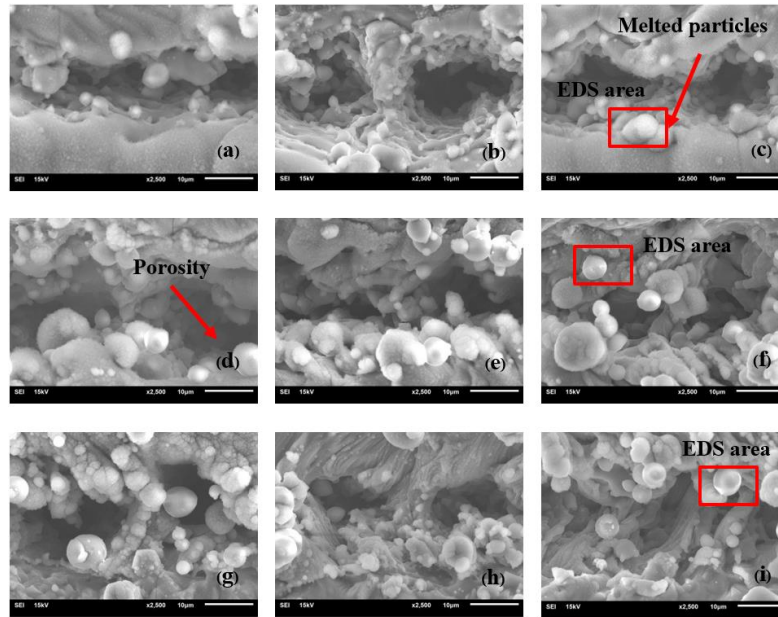


Figure 3. SEM images of laser treated silicon surface (x2,500) (a) $P = 7$ W, $S = 10$ mm/s (b) $P = 7$ W, $S = 15$ mm/s (c) $P = 7$ W, $S = 20$ mm/s (d) $P = 11$ W, $S = 10$ mm/s (e) $P = 11$ W, $S = 15$ mm/s (f) $P = 11$ W, $S = 20$ mm/s (g) $P = 15$ W, $S = 10$ mm/s (h) $P = 15$ W, $S = 15$ mm/s (i) $P = 15$ W, $S = 20$ mm/s

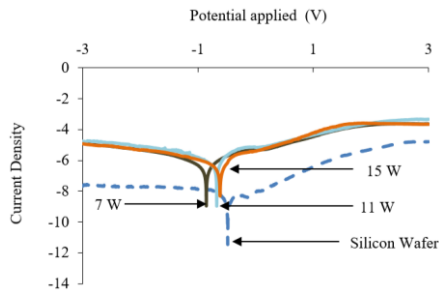


Figure 4. Polarization curve of laser treated on silicon surface with the scanning speed of 10 mm/s

with the results shown in Table 2. It is shown that, increasing laser power increases the corrosion potential of the specimens, which represents an improvement in corrosion resistance. This result is likely caused by the formation of passive films (SiO_2) on the specimen's surfaces due to the increased laser power. According to the previous analysis, corrosion resistance of a material increases with the number of passive films (Chuan and Zhen, 2015). Thus, with this scanning speed, increasing laser power can increase the corrosion resistance of a silicon wafer by increasing the number of passive films on the wafer's surface.

The potentiodynamic polarization results at scanning speeds of 15 mm/s and 20 mm/s are presented in Table 2. In this experiment, decreasing

porosity on the laser-treated surface is shown as laser power increases; this is stable with a previous analysis that showed that the corrosion rate decreases as porosity decreases. It is thus shown that with these scanning speeds, increasing laser power can decrease the corrosion resistance of a silicon wafer by decreasing its surface porosity. The results also show that, increasing laser power produces lower corrosion potential, indicating lower corrosion resistance.

Surface Roughness

The average surface roughness of the laser-treated silicon surface is shown in Table 2, noting that the average surface roughness of the treated surface linearly increases with the laser power. This finding is in line with the surface morphology discussed above. The roughness value was found to increase with the number of particles adhering to the workpiece surface. Furthermore, the morphology of recast layer became uneven as per the Marangoni effect during the laser heating process at high laser power. This feature is also responsible for the increase in surface roughness. According to the results, the average surface roughness of silicon after the texturing process ranged from 2 to 4 μm .

Friction Coefficient

Figure 5 compares the friction coefficient of a laser-treated silicon surface at different scanning speeds. It is shown that at the scanning speed of

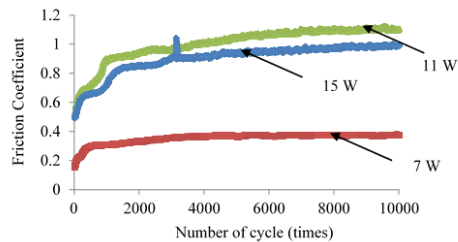


Figure 5. Friction coefficient of samples (Scanning speed of 10 mm/s)

10 mm/s with 7-W laser power, the friction coefficient is lowest (approximately 0.35). This is due to the lower the surface. A larger roughness of surface leads to a higher friction coefficient (Moolsradoo and Watanabe, 2010). The friction coefficient significantly increases when the scanning speed increases. Additionally, the friction coefficient of the laser-treated surface with 15-W laser power was shown to be slightly higher than that of 7-W condition. However, the cause of the change in the friction coefficient at a laser power of 11 W is still not clearly understood and seems to produce the highest friction coefficient (approximately 1.06 at a scanning speed of 15 mm/s).

Conclusions

Laser treatment process was used to treat the surface of silicon wafer. Specimens were investigated in terms of their corrosion resistance, surface roughness, surface morphology, chemical composition at the surface and friction coefficient. The following results can be concluded:

1. Laser power affects the surface characteristics of the wafer; increasing laser power at scanning speeds of 10 mm/s increase corrosion resistance, while at scanning speeds of 15 mm/s and 20 mm/s decrease corrosion resistance. Increasing laser power tends to increase surface roughness and the friction coefficient.

2. Scanning speed affects the surface characteristics of the wafer; increasing the scanning speed from 15 mm/s to 20 mm/s decrease corrosion resistance and surface roughness.

These results are likely produced by the thermal effect on the surface of the silicon wafers. Increasing laser power and scanning speed can increase the number of melted particles and decrease the porosity on the silicon surface.

Acknowledgments

This research project is supported by Thailand Science Research and Innovation (TSRI) Basic Research Fund: Fiscal year 2021 under project number FRB640008

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