FABRICATION OF PERIODIC TEXTURES AT MICRON LEVEL ON SILICONE MEMBRANE USING FEMTOSECOND LASER

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Abstract

Membranes in microfluidics have several uses, including separation / filtration such as particle separation, solute separation, and reverse osmosis. Membranes are increasingly being employed in biomedical applications such as blood partitioning and can be used to extract circulating tumor cells. In the current work, a femtosecond 400 fs laser was used to fabricate periodic structures on silicone membranes, including pCO_2 and pO_2. The goal is to generate periodic forms without cutting through the membranes' thin coated surface. The maintenance of the hydrophobicity of the laser-fabricated samples is another area of interest in the study. To accomplish the study's goal, several parametric parameters were used. From the study, it was observed that Fabrication of different periodic structures on pCO_2 and pO_2 is feasible. From the study it was observed that the depth of penetration can be controlled by scanning speed. The study encourages biomedical and sensor manufacturers to implement femtosecond laser for surface modification of the membranes and biosensor products.

keywords: Membrane; Femtosecond laser; Laser Induced Periodic Surface Texture (LIPSS); Wettability.

1. Introduction

Silicone rubber insulators have recently gained popularity in power system networks due to their greater performance over traditional ceramic and glass-based insulators. Despite its popularity, silicone is not as frequently utilized as certain other materials, which results in poor economies of scale. Siloxanes, commonly known as silicones, are polymers which have large molecules composed of many repeated sub-units. A chain of alternating silicone and oxygen atoms that is commonly coupled with carbon and/or hydrogen is the building block of these polymers. As an elastomer, silicone rubber is non-reactive, stable, and resistant to harsh conditions and temperatures. These qualities make silicone a popular material for use in electronics, HVAC systems, autos, airplanes, and rail transportation. Silicone also has advanced and distinguished properties such as superior hydrophobicity and hydrophobic recovery, lightweight, flexibility, vandal resistance, and other benefits distinguish silicone insulators [1-2]. The hydrophobic silicone rubber (contact angle: 110°) has excellent dielectric properties as well as a high aging resistance. In order to address such issues, a superhydrophobic silicone surface with self-cleaning capabilities is required. This can be accomplished by using low surface energy coatings [2] or by creating a textured silicone surface using laser [3-5].

Laser surface texturing (LST), electrochemical, chemical etching, masked meshing of microtextured coatings, etching-plasma nitriding, and photochemical machining (PCM) are all different approaches for material surface modification [6]. Laser surface texturing (LST) is a promising and rapidly evolving surface modification technology. It encompasses a wide range of processes based on various types of laser material processing, such as heating, melting, sublimation, subtractive, and additive technologies. LST procedures provide for a wide range of variation in the basic features of the treated surface, such as macrostructure, roughness, porosity, and wetting qualities [7-9]. Furthermore, the employment of a focused laser enables surface alteration with set structural parameters without the use of any masks. In the present study, laser surface texturing on pCO_2 and pO_2 membranes has been performed using ultrafast laser processing. The fabrication of different periodic patterns (parallel & crosshatch) on the membranes was carried out using different laser process parameters without thorough cut of the substrate. The study was carried out at different parametric settings so that maximum process related information can be gathered from less experimental trails.

2. Material and Methods

2.1. Materials

The two distinct types of silicone rubber that are coated on PET-foil having thickness of 200 µm were used in the current study to create periodic structures using an ultrafast laser. The two different silicone materials (Figure 1) used for the experimentation are shown below:

1. Cover layer of optical pCO_2-sensor knife coated on PET-sheet (filler: pigment black) (Figure 1a).
2. Cover layer of optical pO_2-sensor knife coated on PET-sheet (filler: carbon black) (Figure 1b).

(a) (b)

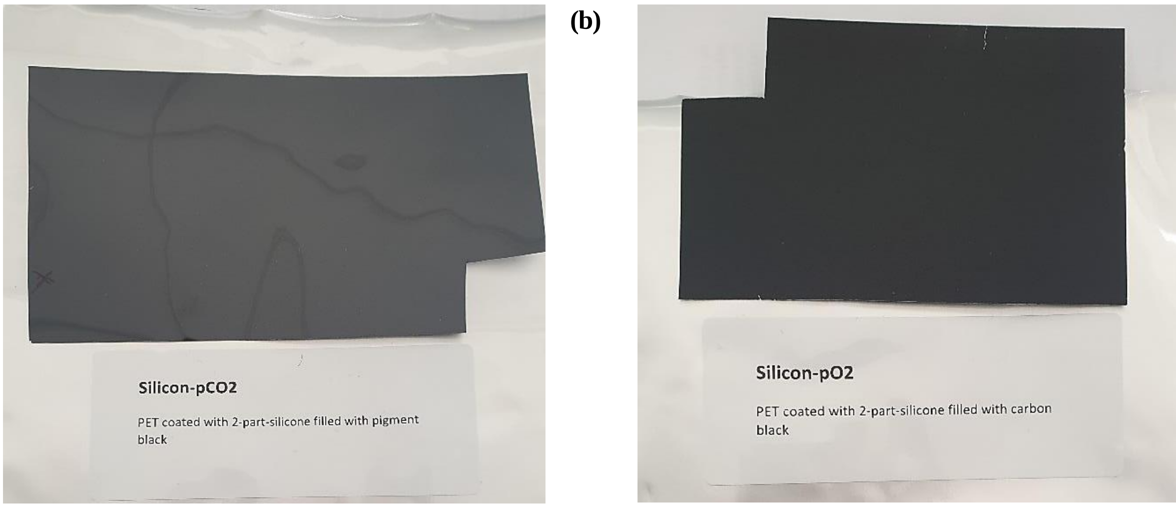


Figure 1: Pictures of the two different silicone materials before laser processing (a) pCO_2 and (b) pO_2.

2.2. Experimentation

The ultrafast laser having an average wavelength of 1030 nm, a pulse duration <400 fs and 4W laser power. The laser beam surface scanning with different speeds can be conducted with a galvo scanner (Focusshifter-15, Raylase GmbH) and the beam was focused on the sample using an f-theta lens with a 136 mm focal length. The laser parameters used for the process were reported in Table 1. The schematic of the laser processing and periodic structures used for fabricating the silicone substrate are shown in Figure 2.

Table 1. Laser process parameters for the fabrication of periodic structures.

Process parameters	Parametric values
Laser power	0.2 W – 2 W
Scan speed	10 mm/s – 100 mm/s
Pulse frequency	100 kHz – 600 kHz
Hatch distance	0.1 mm – 0.3 mm
Pattern type	Parallel, Square

(a)

(b)

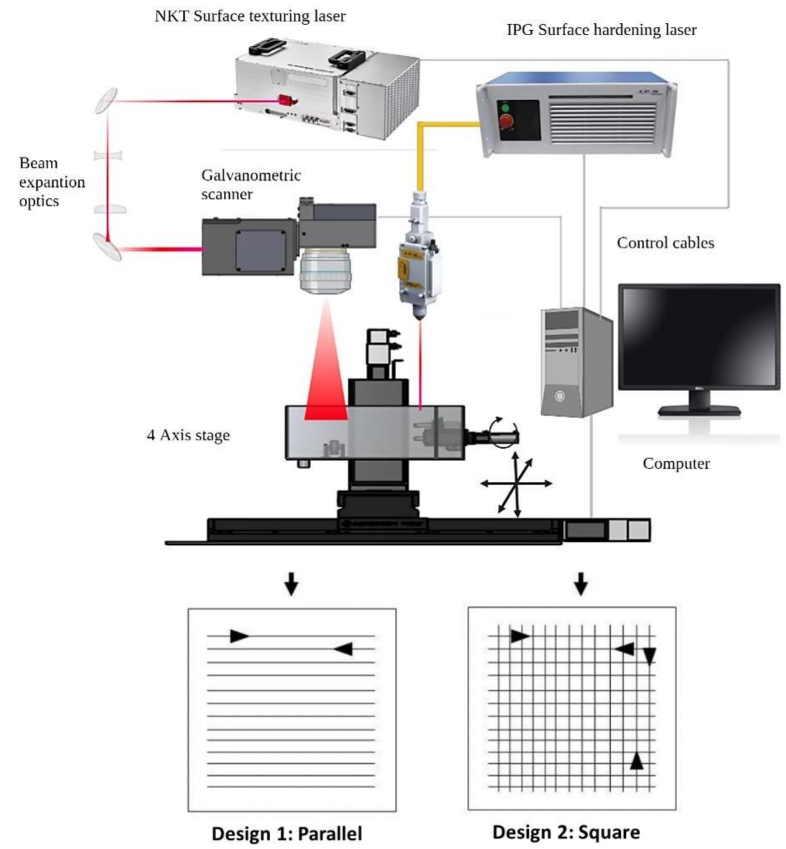


Figure 2: (a) Schematic layout of femtosecond laser, (b) different periodic structure.

3. Results and Discussion

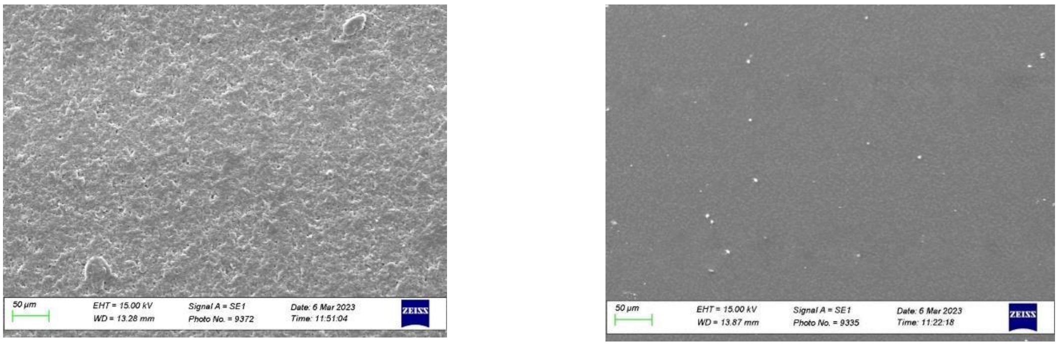
In the present study, the goal is to obtain periodic shapes without slicing through the thin coated surface. It is crucial that the ion barrier is still maintained, hence laser material removal should be quite minimal. The periodic structures were fabricated using different laser parametric setting as discussed in Table 1. Trail experimental tests were carried out to determine the ideal parametric setting for the laser processing of silicone samples. In order to check the thorough cut of the samples, the initial visual examination of the laser-processed samples was done in the presence of light. The parametric selected for the study was shown in Table 2.

Table 2: Selected process parameters for the fabrication of periodic structures on pCO_2 and pO_2.

Process parameters	Parametric values
Laser power	0.36 W – 0.48 W
Scan speed	80 mm/s – 100 mm/s
Pulse frequency	500 kHz
Hatch distance	0.1 mm
Pattern type	Parallel, Square

3.1. SEM analysis

To observe the surface morphology of the silicone samples scanning electron microscopy (SEM) was performed on non-textured and laser processed samples as shown in Figures 3-7. The SEM images shows the different periodic structures fabricated on the surface by femtosecond laser.



(a) **(b)**

Figure 3: Plan views of (a) untextured pCO_2 and (b) untextured pO_2.

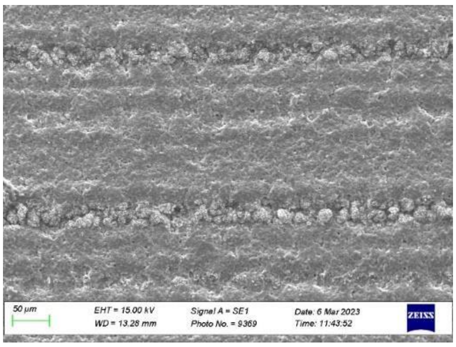


Figure 4: Plan views at different magnifications of pCO2 silicone membrane, which was laser processed at 0.36 W laser power, 60 mm/s scanning speed, 500 kHz pulse repetition rate, and 0.1 mm hatch distance.

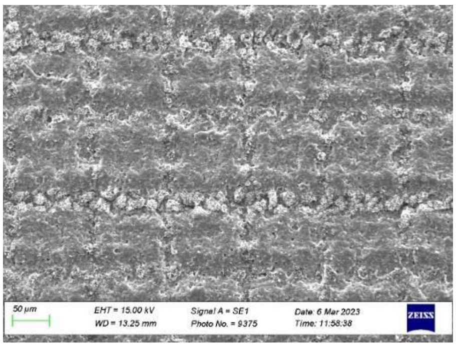


Figure 5: Plan views at different magnifications of pCO2 silicone membrane, which was laser processed at 0.36 W laser power, 80 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatch distance.

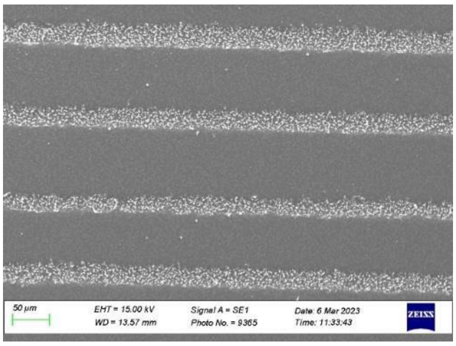


Figure 6: Plan views at different magnifications of pO2 silicone membrane, which was laser processed at 0.4 W laser power, 80 mm/s scanning speed, 500 kHz pulse repetition rate, and 0.1 mm hatch distance.

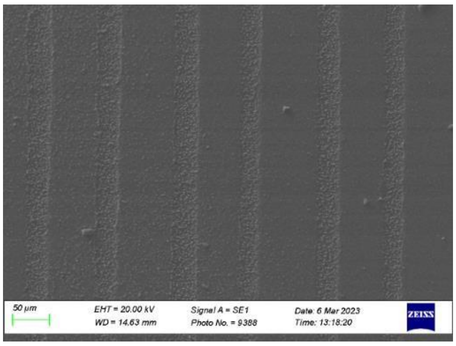
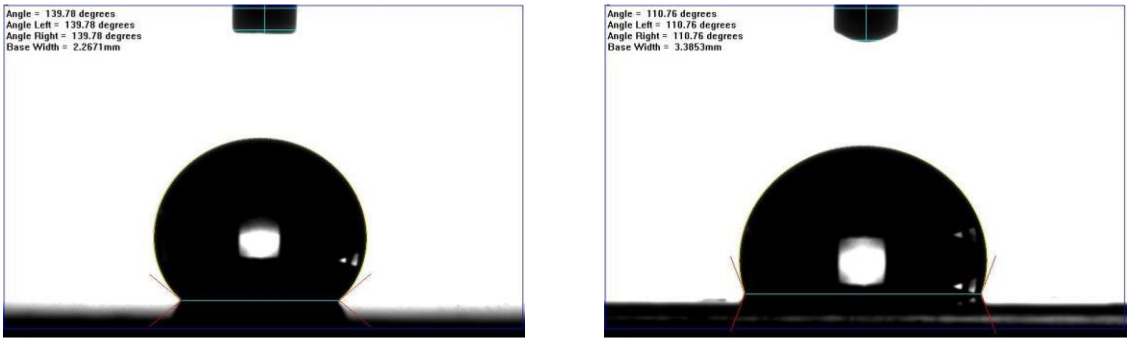


Figure 7: Plan views at different magnifications of pO2 silicone membrane, which was laser processed at 0.48 W laser power, 80 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatch distance.

3.2. Water contact angle (WCA)

Maintaining the hydrophobicity of the laser-textured materials for the plasma and gas flow over the surface is one of the study's primary objectives of the study. To observe the hydrophobicity of the silicone samples the water contact angle (WCA) was measured before and after laser processing as shown in Figures 8-10. The maximum and minimum WCA observed for pCO2 silicone samples were 138.94^{O} and 132.22^{O} respectively. The maximum and minimum WCA observed for pO2 silicone samples were 135.05^{O} and 104.26^{O} respectively.



(a) **(b)**

Figure 8: WCA of (a) untextured pCO_2, and (b) untextured pO_2.

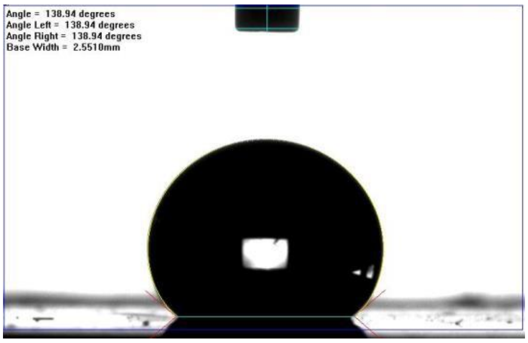


Figure 9: WCA of pCO_2 silicone membrane which was laser processed at 0.36 W laser power, 60 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatching distance.

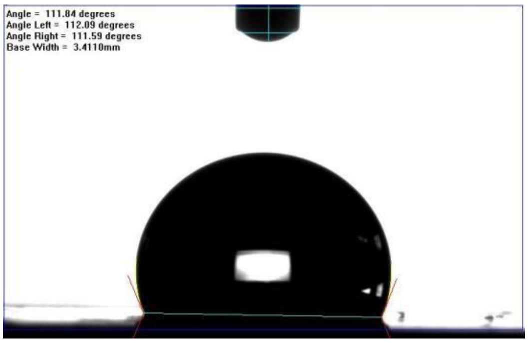
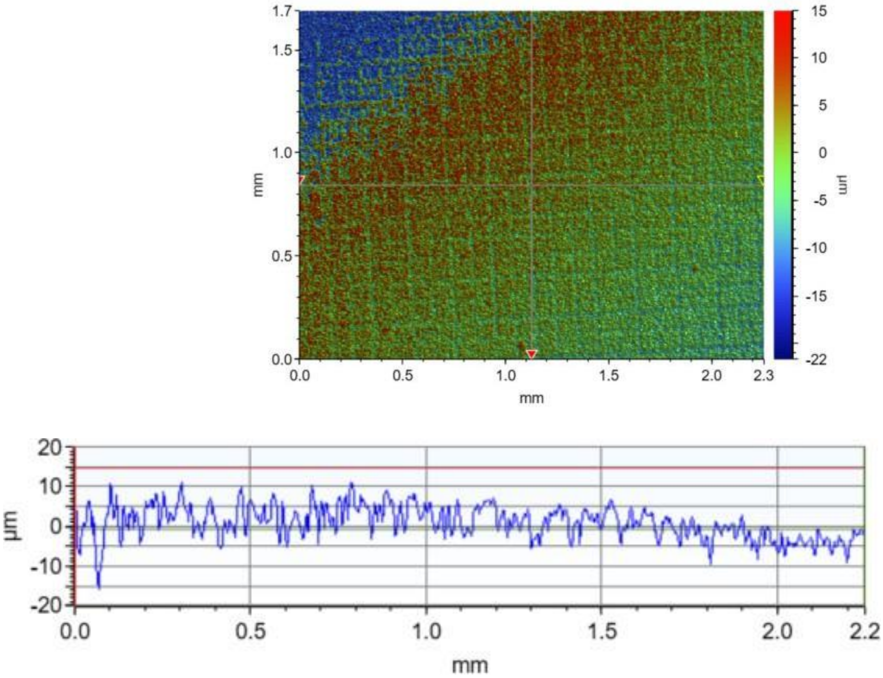


Figure 10: The 3D-profilometry image and graph of pO_2 silicone membrane, which was laser processed at 0.4 W laser power, 80 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatching distance.

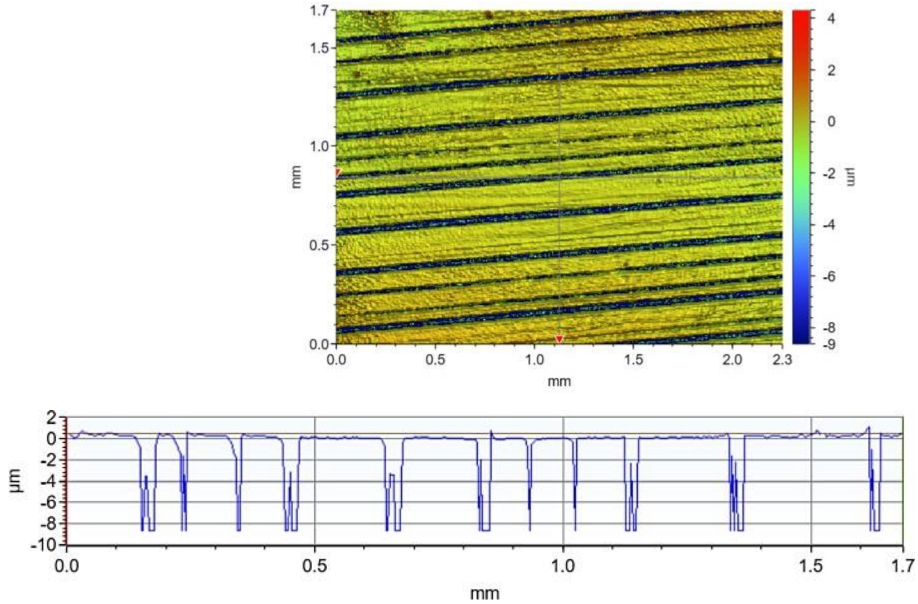
3.3. Depth of cut

To measure the depth of cut for the laser fabricated the periodic patterns Surface Analysis Bruker ContourGT Profilometer was used. Figures 11–12 depict the observed 3D surfaces and depth of cut. The maximum and minimum depth of cut observed for pCO_2 silicone samples were 15-18 µm and 10-12 µm respectively. The maximum and minimum WCA observed for pO_2 silicone samples were 16 µm and 8 µm respectively.



Depth = 10-12 µm

Figure 11: The 3D-profilometry image and graph of pCO_2 silicone membrane, which was laser processed at 0.4 W laser power, 100 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatching distance.



Depth = 8.2 µm

Figure 12: The 3D-profilometry image and graph of pO_2 silicone membrane, which was laser processed at 0.4 W laser power, 80 mm/s scanning speed, 500kHz pulse repetition rate, and 0.1 mm hatching distance.

Conclusion

This study describes an experimental examination of ultrafast laser surface texturing on silicone membranes. Silicone membranes such as pCO2 and pO2 were textured with a femtosecond laser source utilizing a galvo scanner at various laser powers, repetition rates, and scanning speed. The study found that laser power and scanning speed had a substantial effect on responses such as wetting behaviour and depth of cut of the substrate. Microstructural analysis indicates the effect of process parameters on the surface morphology of the fabricated textures. Following are the major outcome of the present study.

- Fabrication of different periodic structures on pCO2 and pO2 is feasible using ultrafast femtosecond laser.
- The acceptable depth of penetration and water contact angle on PO2 silicone membrane was 8.2 µm and 111.84⍰ respectively, at a parametric setting of 0.4 W laser power, 500 kHz, 80 mm/s scanning speed, 0.1 mm hatch distance and parallel pattern.
- The acceptable depth of penetration and water contact angle on PCO2 silicone membrane was 10-12 µm and 135.02⍰ respectively, at a parametric setting of 0.4 W laser power, 500 kHz, 100 mm/s scanning speed, 0.1 mm hatch distance and square pattern.
- The depth of penetration can be controlled by scanning speed.

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