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Fabrication of Nanochannels on PDMS Molds

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O. Abstract

Research has shown that by stretching a thin slayer of brittle material, which is attached to a compliant substrate, parallel cracking can be formed on the substrate. The average spacing between the cracks is proposal to the strain condition of the material. Based on these observations, a series of nanochannels with specific widths can be fabricated by implementing crack initiation sites on the substrate.

Polydimethylsiloxanes (PDMS) has been chosen for the compliment substrate. The brittle layer can be prepared either by coating a thin layer of gold or by bonding with oxidized PDMS. The crack initiating sites can be planted on the substrate by pre-printed on the mold.

Our research goal is to find a new method of printing more details on the substrate by laser. The first phase of the project is to determine the average spacing of the cracking. The second phase of the project is to use the automatic laser scribing machine to print the details. Throughout the project, we are able to finish the first phase. The second phase, however, is still yet to be achieved.

I. Introduction

Nanochannels are widely used in the study of chemistry, physics and biology. Some of the applications include molecule separation or sorting based on the size or chemical affinity as well as manipulation and elongation of single molecules such as DNA. The conventional nanofabrication techniques consist of multiple steps and are often expensive and tedious.

Recent developments show that tunnel cracking technique is a suitable way for nanochannel fabrications. Observations from experiments have shown that parallel cracking can be formed by stretching a thin slayer of brittle material, which is bonded to a compliant substrate. The average spacing between the cracks is proposal to the strain condition of the material. There are two common ways to form thin layers on the compliant substrates. First technique is to bond a thin metal layer on the compliant substrate. The metal layer has well-controlled properties and well-defined interface with the substrate. However, due to its complexity, this method does not possess a potential for further investigation within the limitation of the project. The other technique is to bond a 200 um oxidation layer of the substrate on itself. This method has been proven to be highly applicable and manageable. The substrate used is 10:1 polydimethylsiloxane (PDMS). The nanochannels are printed from a silicon mask.

The cracking on the brittle layer can be controlled by the crack initiation sites on the pattern. The pattern can be etched on the silicon wafer using soft lithography. However, since the crack initiation sites are small in scale as compare to the wafer, the formation of these initiation sites are not well-controlled. The sizes of these sites are not even because of the nature of etching. An alternative method is to remove the complimentary portion of these initiation sites. The pattern can be formed by two-fold soft-lithography by a polymer such as epoxy. This method avoids the removal of small scale components such as the crack initiation sites. The pattern can be fabricated in a more precise and cost-effective way. To determine the spacing of the crack initiation sites, the distance between naturally formed cracks are studied.

The ratio of the thicknesses of the substrate and brittle layer is crucial in determining the spacing and depth of the cracks on the brittle layer. The difference between the young's modulus of the materials is also important in the cracking of the brittle layer. These two sites can be controlled by the oxidation conditions of the brittle layer.

In addition, we also developed another method utilizing the laser to scribe the mold. Since the width of laser array is very small, it is possible to develop more specific details on the substrate. Previously by using manually controlled laser, we have scribed several defects as crack initiation sites on the polymer. Cracking has been notified to initiated from the scribed sites, as shown in Fig I. Our results have demonstrated that the laser array is suitable for designing cracking initiation sites on the substrate

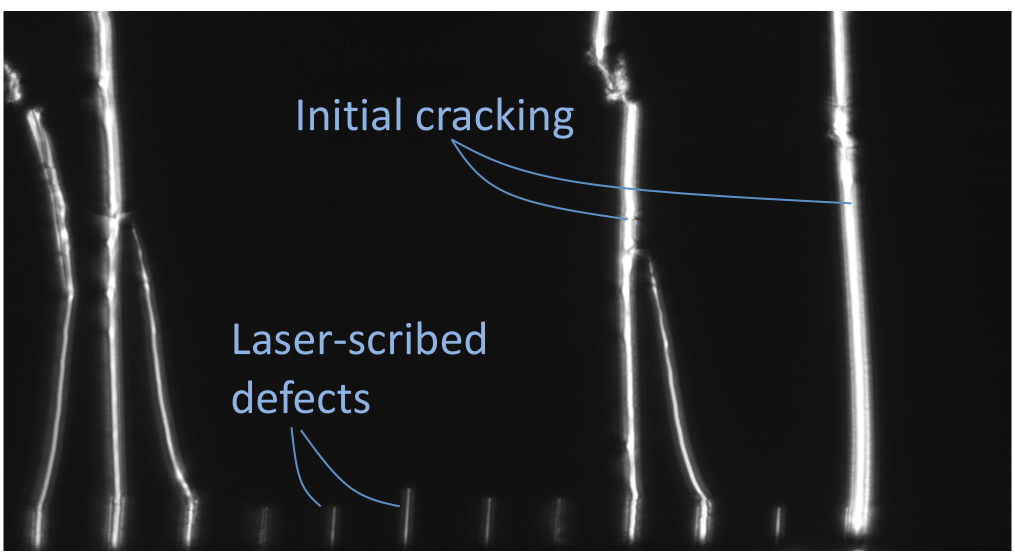


Figure I. Cracking initiated from the defects.

II. Experimental

The substrate and the oxidation layer are both form by 10:1 PDMS. The thickness of the substrate is controlled within the range from 3.00 mm to 4.50 mm. The profiles of the nanochannels are pre-scribed on the silicon wafer by photolithography. The uncured PDMS and curing agent with the ratio of 10:1 was poured on it. Upon curing, the profiles of the nanochannels were printed on the PDMS.

A thin layer made from the same ratio of PDMS was prepared by spin-coating machine. The thickness of the layer was controlled as 200 µm. Both of the substrate and the thin layer were put in plasma oxidation machine for surface modification. Different combinations of the oxidation conditions were used to prepare the brittle oxidation layer. The oxidation layers are then bonded to the substrates by attaching them together right after the oxidation. The devices were put under stretched along the nanochannel to examine the crack spacing. The strains were confined within 20%.

However, due to the constraints of the equipment and the lack of understanding of the technique, the laser scribing experiment, however, was not successful. But we strongly believe that the laser scribing could fabricate molds with more specific details.

III. Results.

In total, 22 sets of experiments were conducted. The average spacing and strain conditions for 8 samples are recorded. The oxidation conditions of each sample and the cracking initiation strains are shown in Table I.

Table I. Oxidation condition and cracking initiation strain of each recorded sample

Sample	Condition	Cracking Initiation strain
1	200W 6min	4%
2	200W 6min	2%
3	100W 6min	2%
4	200W 7min	3%
5	200W 10min	2%
6	200W 6min	7%
7	200W 6min	4%
8	200W 6min	2%

The average spacing of sample 6 in each strain condition was plotted in Fig II. As shown in the results, the spacing between the cracks is approximately inversely proportional to the strain.

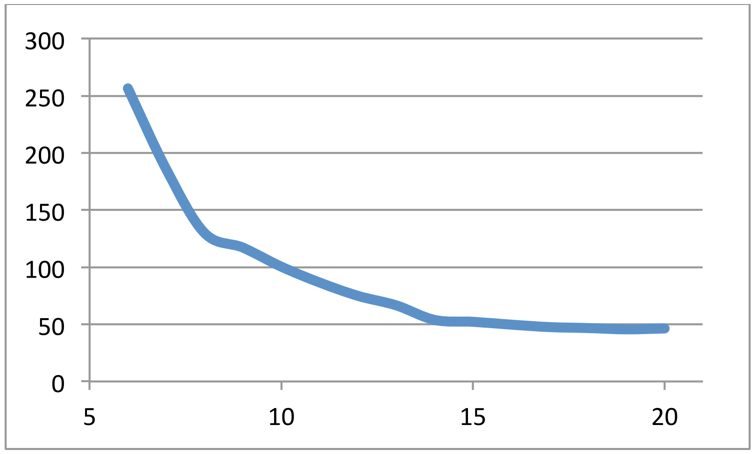
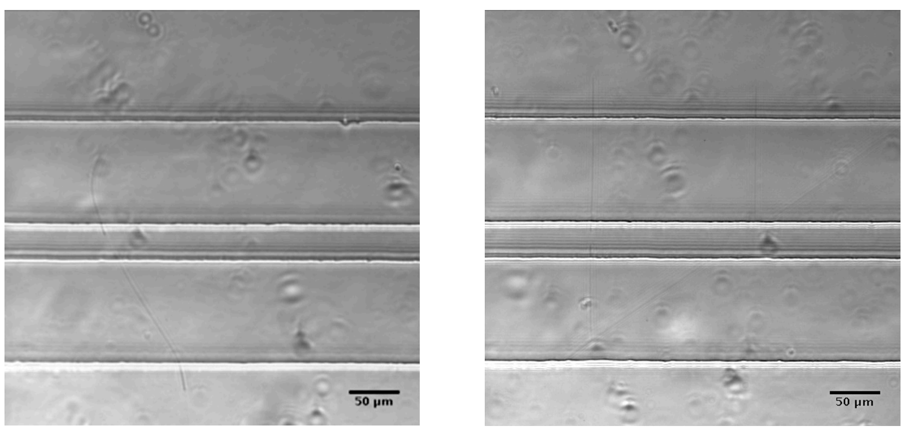


Figure II. The relationship between average spacing and strain condition

Due to the limitations of the method employed, static cracks were observed in most of the samples, as shown in Fig III. These static cracks are the results of peeling off the sample from the slides as well as the initial defects in the substrates.



(a) (b)

Figure III. (a) Non-parallel static cracks presented in the sample before applying strain. (b) Parallel static cracks presented in the sample before applying strain.

Another observation is that the cracks in the PDMS will close even under constant strain. The relationship between the average spacing and strain condition of sample 3 was shown in Fig IV. The average spacing between cracks under the strain between 7% and 9% were measured over 1 hour. The increase of the spacing between the cracks does not satisfy the relations aforementioned. This abnormality can be explained by the self-closure of the PDMS over time and poor curing condition of the samples.

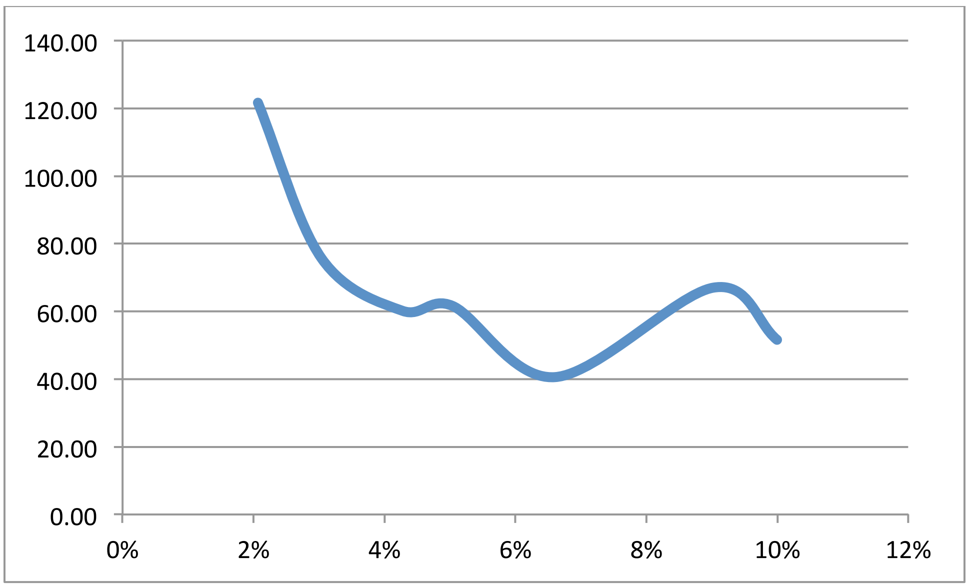


Figure IV. The relationship between average spacing and strain condition

The relationship between the strain conditions of the initial cracking and oxidation condition is unknown, as shown in table 1. However, it can be predicted that the cracking initiating strain of PDMS is about 2-4%.

The average spacing over the strain of 1-10% is also presented in Table II.

Table II. the average spacing over 1-10% strain of each sample

Sample	Condition	Average spacing over 1-10%
1	200W 6min	41.07
2	200W 6min	160
3	100W 6min	59.46
4	200W 7min	56.85
5	200W 10min	56.7
6	200W 6min	104.87
7	200W 6min	157.88
8	200W 6min	68.87

The minimum average spacing is about 40 μm. This result is useful for further development of the devices. The large range of average spacing may due to the random defects and different curing conditions of the samples.

IV. Discussion

The results show that the average spacing between cracks is approximately inversely proportional to the tensile strain. Such a trend has been testified by other researches, too.

As shown in the data, the average spacing of the different samples are different. The affecting factors may include oxidation and manual techniques employed. Therefore, the conventional fabrication method is proven to be highly unpredictable and hard to repeat. For further development of the producing the device, the average spacing of 40 um is chosen for the design of the pattern. This spacing is reasonable as considering all of the experiment. The oxidation conditions do not affect the spacing as much as expected. However, because of the non-repeatable nature of the experiment and other random cracks present in the sample, the results are omitted from the report.

V. Conclusion

The results obtained from the experiment have shown the following findings:

(1) The average spacing for the pattern should be set as 40 μm;
(2) The non-repeatable nature of the experiment makes it necessary for an alternative method;
(3) The oxidation conditions of the brittle layer will not affect the spacing

In general, the results are within a large range. There is not a clear trend showing that oxidation conditions will affect the average spacing of the cracks. The most valuable result is to set the average spacing of the designed patterns as 40 μm.

There is still room for further improvement. However, due to the limitation of the experiments and project, such improvements have not been implemented.