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MICROFLUIDIC CHANNEL FABRICATION WITH TAILORED WALL ROUGHNESS

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Introduction

Extensive studies during the past century indicate that surface roughness affects fluid flow behavior in microscale channels. Study on nanoscale roughness effect on laminar flow [1] indicated that increasing surface autocorrelation length has measurable impact on the transverse flow. Studies on the effect of surface roughness on friction force [2], pressure drop [3-4], heat transfer in single-phase flow [5] and laminar-turbulent transition [6] indicated the necessity of precise control of the surface morphology inside the fluidic device for the purpose of enhancing the reliability and performance of the fluidic system.

In most of the current studies, surface was processed by micro-machining or micro-fabrication techniques and the roughness was therefore large and deterministic. It is well known that almost all mechanical or chemical processing inherently produces random roughness on realistic surfaces and consequently most engineering surfaces are random [7]. However, the impact of small scale random roughness on microfluidic flow behavior still remains relatively unexplored. This aspect becomes increasingly important as channel sizes continue to decrease in micro/nanofluidic applications.

In order to study the effect of realistic surface roughness on microfluidic flow behavior, random roughness needs to be generated and tailored inside microfluidic channels on micro/nano scale. Experimental study [8] shows that hydrofluoric etching is capable of generating roughness on glass substrate in a certain range: autocorrelation length increases in the range of 1 μm to 4 μm. Compared to wet etching, dry etching is another widely used MEMS technology which provides high aspect ratio and precise etch rate.

In this study, we report a surface texture tailoring method which combines Reactive Ion Etching and colloidal masking technique. Quartz which is a common microfluidic channel fabrication material was used as the substrate. The processed surface was further incorporated into microfluidic channel fabrication.

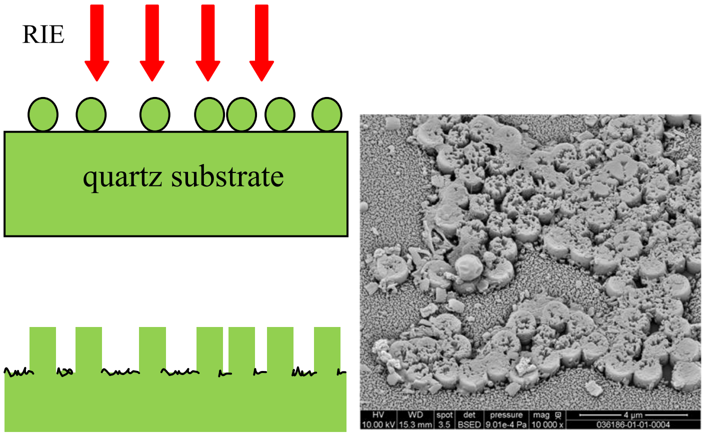

Figure 1. Schematic of Polystyrene particle masking and RIE process and the surface after etch

The surface texturing process and the resulted surface is shown in figure 1. Polystyrene particles are used to mask the quartz substrate while RIE treatment. Due to the random deposition process of particles and the nature of RIE etch, the final surface can be considered as a sum of two random surfaces as shown. By varying particle coverage and size, the surface roughness can be tuned as expected. A mathematical model was developed to predict the amplitude and spatial roughness. Equation 1 and 2 show the expression for center line average and autocorrelation length:

$$Ra = -2Hp^2 + 2Hp \tag{1}$$

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$$\frac{2p}{d_{eff}}\beta^* = \ln\sigma_2{}^2 - \ln\left[\frac{\sigma_1{}^2+\sigma_2{}^2}{\mathrm{e}} - \sigma_1{}^2\exp\left(\frac{-\beta^*}{\beta_1^*}\right)\right] \quad (2)$$

The comparison between the experimental roughness and the prediction shown in figure 3 and 4 indicate that the model matches the experimental results well.

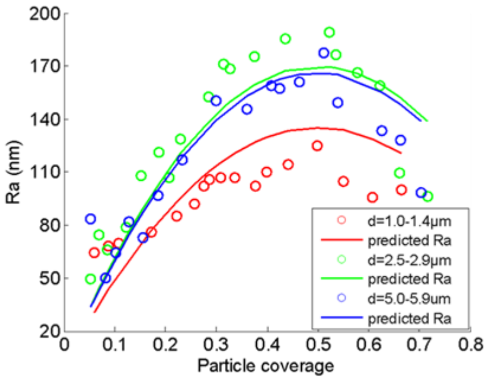

Figure 3. Ra comparison between experimental results and the mathematical prediction

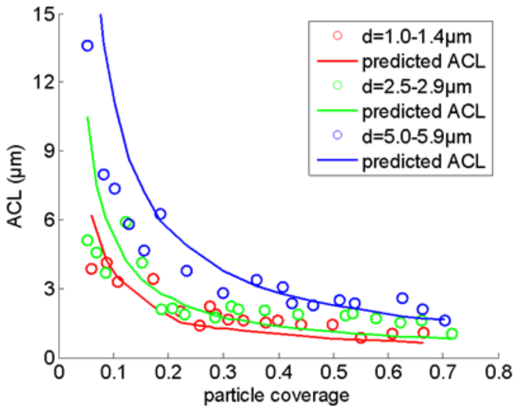

Figure 4. ACL comparison between experimental results and the mathematical prediction

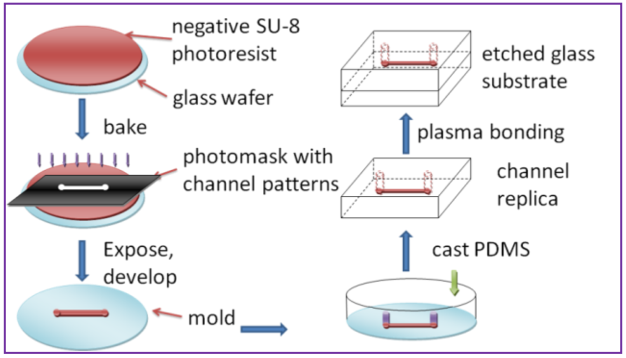

Figure 5. Process flow of the microfluidic device fabrication

Based on the technique, a process flow for microfluidic channel fabrication with tailored nanoscale random roughness was developed and shown in figure 5. The final device was further used for microflow velocity study.

References

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