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Characterization of Microfluidic chips Fabricated by a low-cost technique using a vinyl cutter

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Abstract

In laboratory, a prototype of microfluidic chips (µFCs) developed for lab-on-chip devices is typically made from polydimethysiloxane (PDMS) polymerized on a silicon wafer master mold. Making the master mold needs expensive and complicated facilities; e.g., the clean room, the UV exposure machine, and the mask aligner, so that the mold is costly, especially in low- and middle-income countries. Recently researchers have been developing low-cost techniques for fabricating µFCs. Xurography or "blade writing" is one of the techniques by carving microchannels on plastic films. Eventhough this method has been proposed for a decade, the manufacturing needs to be optimized and clarified. The aims of this study are (1) to investigate the effect of manufacturing parameters such as cutting forces and speeds on dimensions of microchannels as well as (2) to propose the µFC fabrication from laminating plastic films. The vinyl cutter of Silhouette Cameo™, Graphtec, USA was used for engraving the polyvinyl chloride films. All channels' dimension was measured and evaluated by the ImageJ program with Analyze Stripes add-on. It was found that the root-mean-square edge roughnesses (ER_{rms}) effected by the cutting forces were not significantly different. However the cutting speed significantly affected on ER_{rms}, i.e. the higher the cutting speed, the higher ER_{rms}. Moreover, the ER_{rms} were less than 15 micrometers. The average widths of the cut channels were mostly bigger than which of the designed ones. The carved films were cover by laminating films before rolled in a hot laminating machine at 140 degree C. The final µFCs were then fabricated with total thickness of 375 micrometers. The cost was about 0.6 Baht (0.02USD) per chip, meanwhile the overall process time was less than 10 min. The xurographic technique with plastic films is promising for prototyping microfluidic chips with cost-effective and rapid processes.

Keywords*:* Microfluidic chip, Cutting plotter, Line edge roughness, Microchannel

1. Introduction

Biochips established by lab-on-chip devices is one of the emerging technology in the phase of technology trigger according to the Gartner's hype cycle[1]. The most important element of biochips is microchannels. Samples in form of liquid will flow through the channels into other areas of the chips such as mixing, reaction, and detection zones. Channel features therefore play an important role in the chip performance. Traditionally, chips are fabricated by soft lithography which is basically based on master mold of silicon wafer and polydimethylsiloxane (PDMS)[2]. This technique thus is not suitable for resource-poor countries and also maker experience is needed. Therefore this technique is not proper for product prototyping and mass production.

Many researches have been proposed methods for microfluidic fabrication[3], [4]. Xurography [5] or plotter-cutting is one of the low-cost and rapid prototyping using worldwide. However the surface roughness and dimension stability which are important for microfluidic phenomena such as flow velocity profile have not been evaluated clearly.

The aims of this study are (1) to investigate the effect of manufacturing parameters such as cutting forces and speeds on dimensions of microchannels as well as (2) to propose the µFC fabrication from laminating plastic films and a home-use vinyl cutter.

2. Material and Methods

The home-use vinyl cutter of Silhouette Cameo™ (Graphtec, USA) was used for engraving microchannel on plastic films of polystyrene. A FGK-320 laminator was employed for enclosing and hermetically sealing chips.

2.1 Microchannel drawing and design

The CAD software of Solid Edge (2D Drafting ST6 Free License, Siemens Product Lifecycle Management Software Inc.) was performed to design the microchannel layouts as shown in Fig.1(a). The DXF file layouts of the CAD software were then imported to Silhouette Studio® V3 software for cutting control of cutting speeds and forces.

2.2 Microchannel fabrication

The designed layouts of microchannels were cut onto polyvinyl chloride plastic films as shown in Fig.1(b). The die-cutting mode was employed in all experiments, therefore the cutting force was chosen from #21.

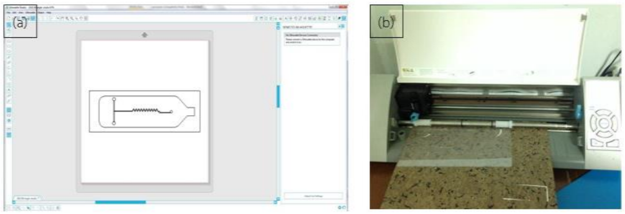

Fig. 1 (a) CAD program and (b) the cutting plotter of Silhouette Cameo™ with supporting mat

2.3 Line edge measurement on microchannels

Optical micrographs were investigated and recorded digitally via a light microscope with 10X-objective lens and phase contrast filter (CKX41, Olympus, Japan with D90, Nikon). The ImageJ program with Analyze Stripes add-on was used for analyzing sidewall surface roughness and the width of line edges of microchannels as shown in Fig.2. The root-mean-square edge roughness was calculated by customized java script on ImageJ.

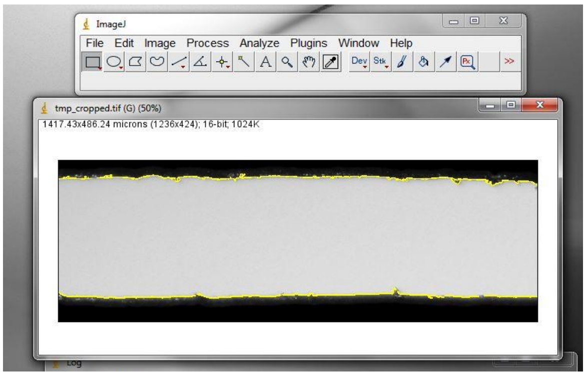

Fig. 2 Line Edge detection by Analyze Stripes in ImageJ

2.4 Statistical analysis

Analysis of variance (ANOVA) was applied for evaluating statistically difference among treatments. The two main factors of interest were cutting force (4 levels) and speed (5 levels), therefore there were 20 treatment combination. Each treatment combination obtained 3 replications.

3. Results and Discussion

The effects of cutting force and speed on ER_{rms} were evaluated as well as the microchannel dimension. Also the microfluidic fabrication was shown and discussed the cost and expenses.

3.1 The cutting force had no effect on edge roughness

The cutting force was varied from #21 to #33 which was equally the maximum value of 210 gmf. There was however no significantly different among the treatment of cutting forces shown in Fig. 3. The arithmetic average ER_{rms} was about 5.7 µm. Moreover, there was no combined influence of cutting force and speed (not shown).

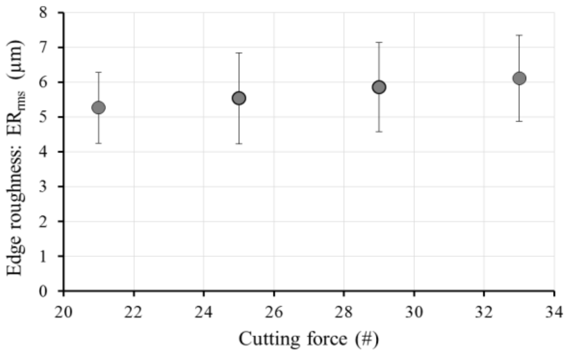

Fig. 3 The root-mean-square edge roughnesses (ER_{rms}) at different cutting forces

3.2 The cutting speed influenced edge roughness

The cutting speeds investigated were 1, 3, 5, 7, and 9 mm/sec to cover the capability of the cutting plotter of Silhouette Cameo™. The influence of cutting speed on ER_{rms} was statistically significant. The data was divided into two groups; the speed of 1 and 3 mm/sec offered roughly 4 µm ER_{rms}, meanwhile the other group of 5, 7, and 9 provided 7 µm ER_{rms} approximately.

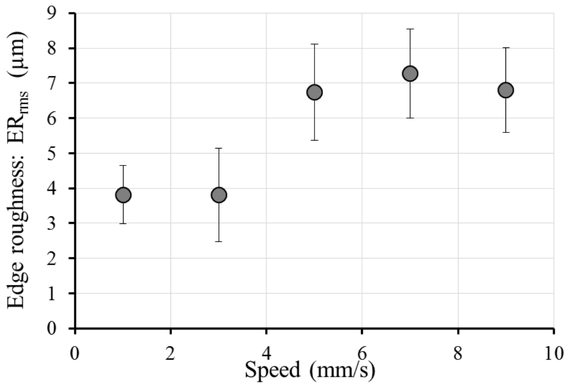

Fig. 4 The root-mean-square edge roughnesses (ER_{rms}) at different cutting speeds

The cutting forces used for die-cutting were higher than the ultimate strength of materials resulting in plastic deformation at the edge of cutting. However the force directions were in perpendicular to the edge, therefore there was no significantly influent on the roughness. Unlike the cutting speed which established mechanical forces parallel to the edge which the faster, the harder force. Consequently ratchet surface formed by lateral plastic flow was occured on sidewall, resulting in increasing of ER_{rms} [6]. The roughness would affect the flow behavior[7]. However this could be reduced by solvent vapor treatments[8].

3.3 The cut microchannels were wider than the drawing ones

Both axes of cutting; i.e. vertical and horizontal, were investigated according to the fact that the motorized movement of both axes are different. Fig. 5 shows the vertical cutting axis provided the closer dimension than the horizontal one. Furthermore, The actual widths were higher than the drawing, probably as a result of the thickness of the cutting blade. In addition, the narrowest microchannel was about 100 µm. Unlike half-cutting mode [9], the width was able to diminish towards 20 µm. However, the cross section of the half-cutting was triangular, while the die-cutting in this study was trapezoidal. These would affect the flow velocity profile[10].

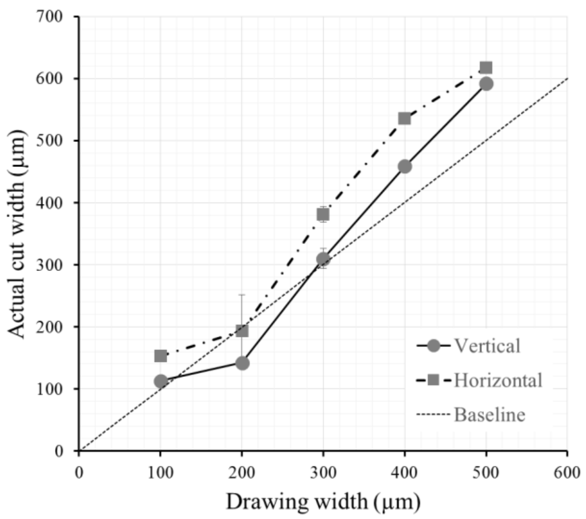

Fig. 5 The actual cut width on vertical (solid) and horizontal (dash) directions at different drawing widths

To fabricate a microfluidic chip therefore should optimize and compensate the drawing to obtain the desired dimension as well as the consideration of channel working width.

3.4 A microfluidic chip was fabricated by cutting plotter and lamination machine

In this study, the microfluidic chip was mad from PVC laminating films which is very cheap (0.005฿/cm^2) and convenient to purchase in a stationery shop. Therefore the material cost was about 0.6฿ (0.02USD) per chip. The fabrication processes were shown in Fig.6. Briefly, the design pattern was engraved on the film. After removing the unwanted part and cleaning, the carved layers were aligned and bonded by laminating machine at 140°C. Lastly, the final chip was trimmed (Fig. 7) and tested for leaking. Composing of 3 layers of films, the chip was 375 µm thick and spent less than 10 min. for overall processes.

3.5 Xurography was simple, rapid, and budget prototyping of microfluidic chips

The microfluidic chip made from xurographic technique would probably be suitable for rapid prototyping, especially for resource-limited laboratories. Comparing among techniques which are based on the similar procedures shown in Table 1, the xurographic method required affordable instrument 10 and 20 times lower than other techniques such as laser and CNC micromachining. However, the surface roughness must be improved. Because of low instrument and material costs, the xerographic method

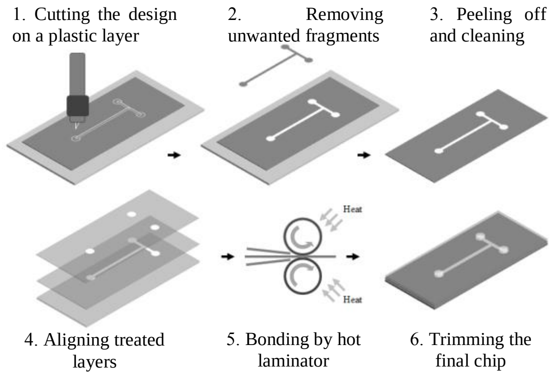

Fig. 6 The fabrication processes of a microfluidic chip

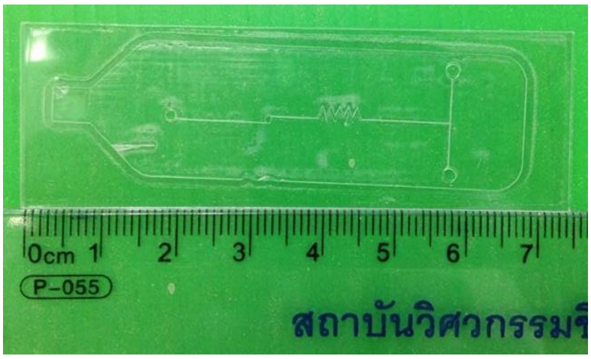

Fig. 7 Microfluidic chip fabricated by xurography and hot lamination

Table 1 Edge roughness comparison among techniques

Technique	Inst. cost	Material	ER_{rms}	[ref]
Laser micromachining	> ฿1,000,000	glass	1 µm	[11]
CNC micromilling	> ฿500,000	PS, PMMA, COC	0.4 – 1.5 µm	[12]
Xurography (Proposed method)	฿50,000	PVC (Laminating Plastic film)	3.8 – 7.2 µm	This study

would enhance research in microfluidic and lab-on-chip technologies.

4. Conclusion

The surface roughness ER_{rms} of microchannels made from a cutting plotter and laminating films was in the order of magnitude of 1 micron in average. The smallest channel was approximately 100 µm wide. The cost per chip was 0.6฿ (0.02USD). This technique would be promising to the rapid prototyping of microfluidics.

5. Acknowledgement

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