Low-cost Microcontact Printing for Patterning Conductive Polymer (PEDOT:PSS) on Paper

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Abstract

Background: In this study, a simple, low-cost, and straight-forward fabrication method to fabricate stamps with micro-meter patterns that effectively minimize the amount of conductive polymer (PEDOT:PSS) deposited on paper using top-down deposition technique (microcontact printing) was successfully developed without the need for a cleanroom facility.

Method: Two approaches are introduced:
1) micro-milling and 2) customized self-ink rubber stamp. Two-step processes are involved in micro-milling method (machining of Perspex mold and multi-molding of soft litho-graphy). The customized self-ink stamp modified from a common ink-stamp. Characterizations of stamp dimensions and the corresponding stamped patterns, with resulting resistivity of conductive polymer were done to assess the effectiveness of both methods. Estimated fabrication cost of both techniques when compared to conventional photolitho-graphy is presented.

Results: Results show micro-milling enables fabrication of stamp down to ≥40 um dimension, whereby customized self-ink stamp can reach to ≥200 um. Due to varying paper porosity, patterns and resistivity of stamped ink vary. Both micro-milling and customized self-ink stamp can reduce fabrication cost up to ~94.2% and ~99.5%, respectively.

Conclusion: Results suggest that the fabrication of a master stamp using inexpensive micro-milling method can produce a soft stamp that can pattern biological and non-biological inks on paper. Both methods are promising to fabricate biosensors for biomedical and environmental applications.

Problem Statement

In patterning microelectrodes for biosensing, a method to control the pattern and amount of biological and non-biological liquids on substrate is needed due to the cost of both materials being expensive.

Moreover photolithography, a common method in microfabrication requires access to cleanroom facilities, silicon wafer substrates, photolithography aligner and highly skilled technician, making the process costly and inaccessible.

Project Objectives

1. To characterize microcontact printing of stamp fabricated from micro-milling and customized self-ink stamp.
2. To analyze patterned conductive polymer (PEDOT:PSS) inks on paper with varying porosity.

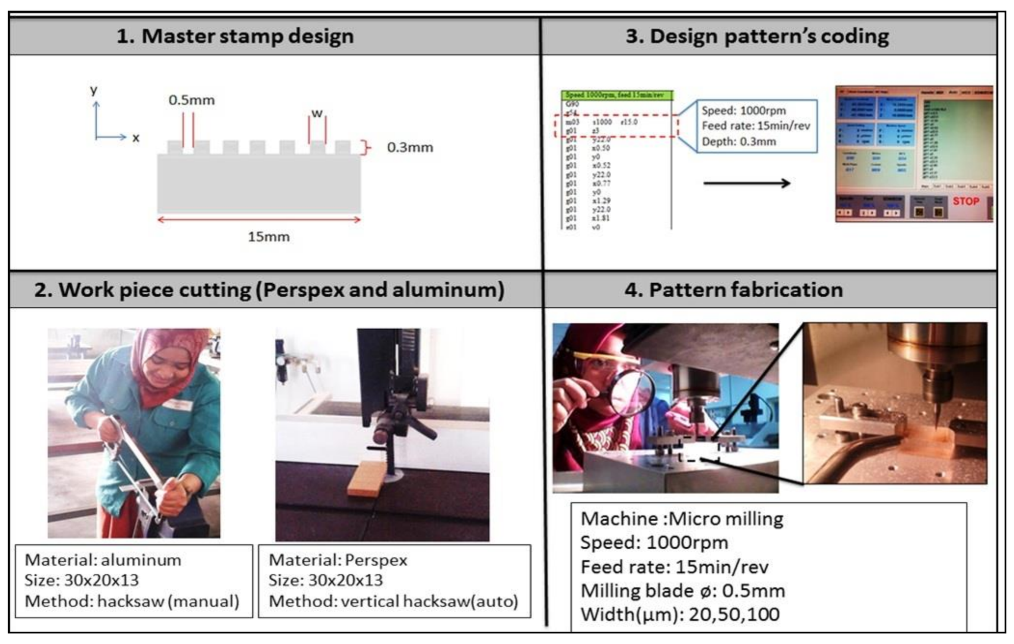
Motivation

By using micro-milling technique or customized self-ink stamp, it is promising to fabricate biosensors for biomedical and environmental applications, with feature dimensions of micrometer, without the same stringent requirements of photolithography. Both techniques open huge potential for:

- Frugal innovation or "innovation within reach".
- Enabling institutions without cleanroom facilities to produce micro-devices.

Research Methodology

Micro-milling

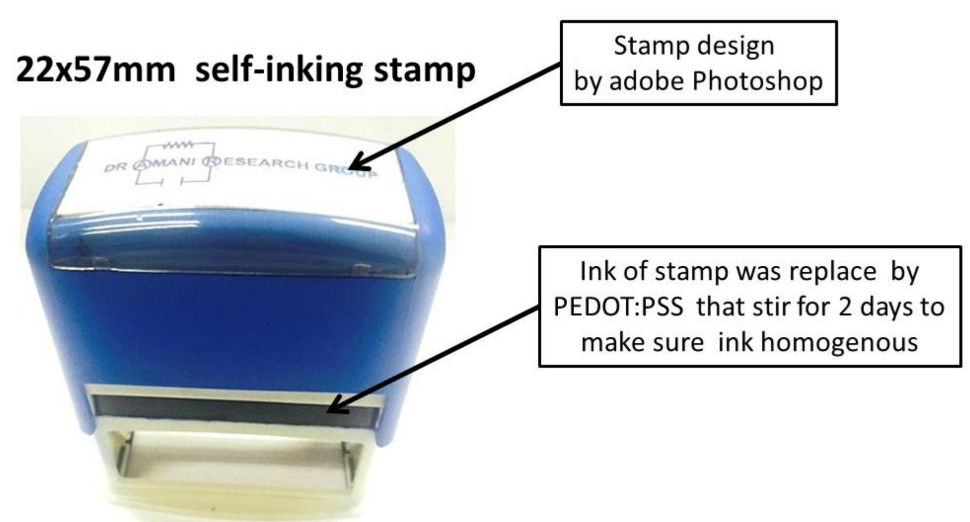


Step 1 (machining): Micro-milling of Perspex material with optimized speed and feed rate. The difference between diced region is the technique to obtain micrometer dimension with milling edge of 0.5 mm.

PARAMETER	SOFT STAMP	
	A	B
PDMS:curing agent	10:1	10:1
Weight (g):	PDMS: 5.055 Curing Agent: 0.4693 TOTAL: 5.5243	PDMS: 5.01 Curing Agent: 0.4593 TOTAL: 5.4693
Vacuum time (h): Solidified time (h):	3 (until no bubbles seen) 24	3 (until no bubbles seen) 24

Step 2 (soft multi-molding): Soft stamp made from polydimethylsiloxane (PDMS) was the multi-mold product of the micro-milled master stamp

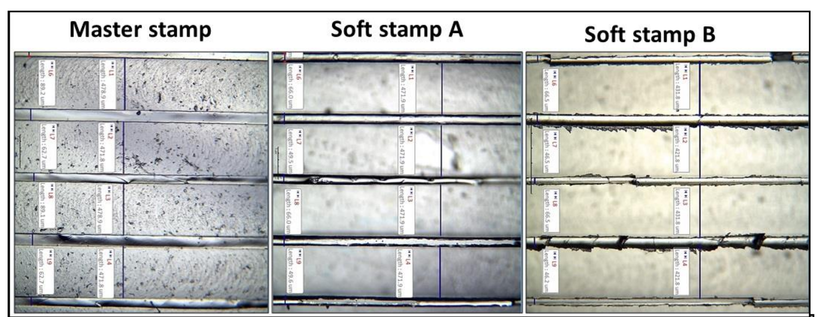
Customized Self-ink Stamp

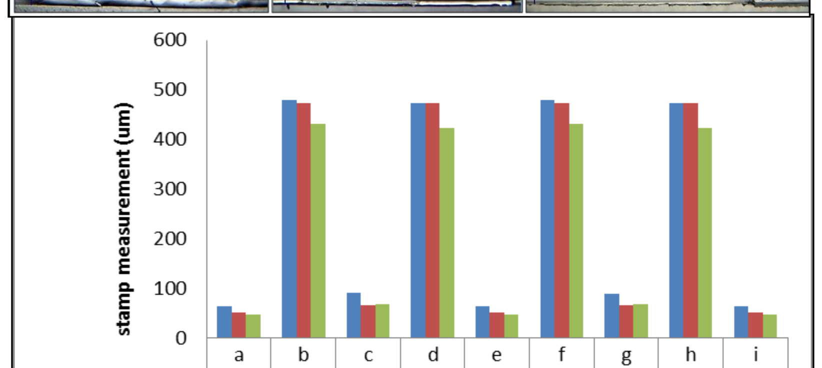


Patterns of the self-ink rubber stamp were designed using Adobe Photoshop.

Results and Discussion

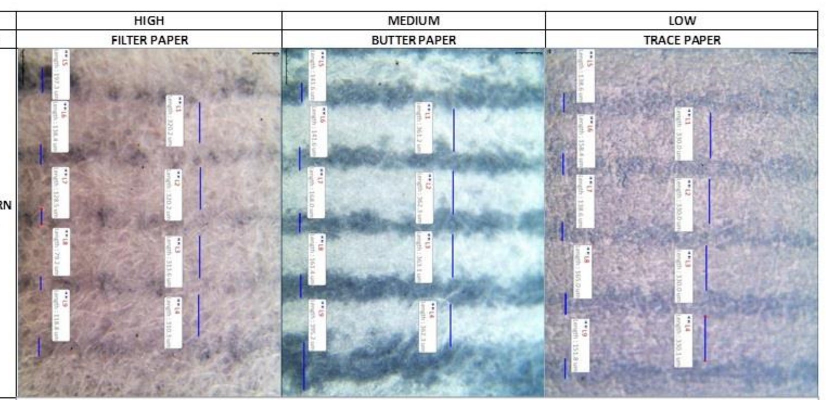
Objective 1

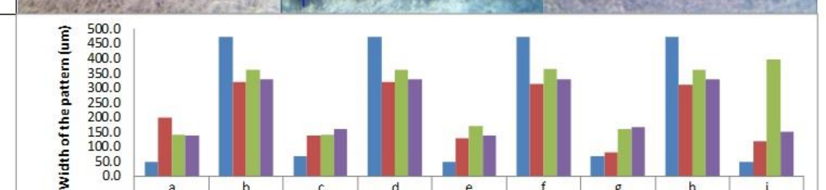




	a	b	c	d	e	f	g	h	i
master stamp	62.2	478.9	89.2	471.8	62.7	478.9	89.1	471.8	62.7
soft stamp A	49.5	471.9	66	471.9	49.5	471.9	66	471.9	49.6
soft stamp B	46.5	431.8	66.5	421.8	46.5	431.8	66.5	421.8	46.2

Objective 2

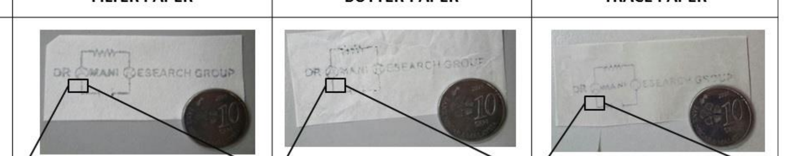
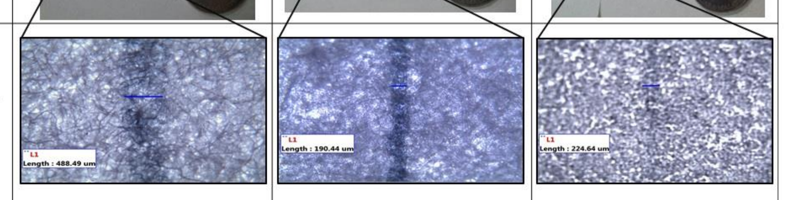
POROSITY	HIGH	MEDIUM	LOW
TYPE OF PAPER	FILTER PAPER	BUTTER PAPER	TRACE PAPER
IMAGE OF PATTERN STAMPED ON PAPER			



	a	b	c	d	e	f	g	h	i
soft stamp B	49.5	471.9	66.0	471.9	49.5	471.9	66.0	471.9	49.6
filter paper	197.3	320.2	138.4	320.2	128.5	313.6	79.2	310.3	118.8
butter paper	141.6	361.2	141.6	362.3	168.0	363.1	161.4	362.3	395.2
trace paper	138.6	330.0	158.4	330.0	138.6	330.0	165.0	330.1	151.8

	HIGH	MEDIUM	LOW
RESISTIVITY (MΩ/cm)	0.003 - 0.100	1.220 - 30.000	0.249 - 2.900
DISCUSSION	Different porosity of paper influence pattern and conductivity of PEDOT:PSS deposited from soft stamp B. Trace paper > butter paper > filter paper (in terms of pattern transfer) Filter paper > trace paper > butter paper (in terms of conductivity)		

Objectives 1 & 2

POROSITY	HIGH	MEDIUM	LOW
PAPER	FILTER PAPER	BUTTER PAPER	TRACE PAPER
IMAGE OF PATTERN STAMPED ON PAPER			
IMAGE OF PAPER UNDER MICROSCOPE			
DIMENSION (um)	488.49	190.44	224.62
RESISTIVITY (MΩ/cm)	~0.86-6.20	~22.2-24.6	~13.0-18.8
*WIDTH (PATTERN-STAMP) (Δℓ)	**+267.85um**	**-30.2um**	**+3.98um**
DISCUSSION	Different porosity of paper influence pattern and conductivity of PEDOT:PSS deposited from self-ink stamp Trace paper > butter paper > filter paper (in terms of pattern transfer) Filter paper > trace paper > butter paper (in terms of conductivity)		

*Original stamp measurement = 220.64 um

Cost Estimation

Table 1: Fabrication cost estimation microcontact printing fabricated from customized self-ink stamp, micro-milling and photolithography methods.

Method	Customized self-ink		Micro-milling		Photolithography	
	Item	Cost (RM)	Item	Cost (RM)	Item	Cost (RM)
Facilities	Customized stamp	32/stamp	Machine workshop	-	Clean room	5000/month acces
Material	-	-	Perspex SYLGARD® 184 silicone elastomer kit	19/sqm 400/kit	Glass mask SU8 aligmer Silicon wafer SYLGARD® 184 silicone elastomer kit	720/inch 500/use 120/wafer 400/kit
Total cost estimation	RM 32.00 Reduce ~99.5% fabrication cost		RM 419.00 Reduce ~94.2% fabrication cost		RM 6,740.00	
Dimension capability (um)	≥200		≥40		≥0.5	

Conclusions

Two low-cost microcontact printing methods were introduced: micro-milling and modified self-ink rubber stamp. Both techniques are able to deposit conductive polymer PEDOT:PSS inks with specific patterns on paper with varying porosity. Resistance of the stamped ink varies according to the paper porosity. Furthermore, filter paper shows the best conductivity as a result of high porosity. These results show two frugal techniques to fabricate electrodes on paper for development of disposal electrochemical biosensor.

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