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# A Study on Printed Multiple Solid Line by Combining Micro-contact and Flexographic Printing Process for Microelectronic and Biomedical Applications

**M. I. Maksud[1], M. S.Yusof[1], M. Mahadi Abdul Jamil[2]**

[1]Faculty of Mechanical & Manufacturing Engineering, [2]Biomedical Modeling and Simulation Research Group (Biomems), Faculty of Electrical & Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor.

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**Abstract:** Micro-contact printing (µCP) is an outstanding surface patterning technique in micron scale and, also in nano scale. Surface science communities such as engineers and biologists have been promoting attention in µCP and, therefore enriching in improvement to the µCP process itself. However the process is relatively slow in production. In contrast, flexographic technique is a high speed roll to roll process, but low in resolution and still has limitation in printing of micro-scale size. Now a day, low cost fabrication is keys to the successful introduction of printed electronics and roll to roll manufacturing processes. Therefore, study to extend flexographic into the micro-scale size resolutions, may provide an economical commercialization path for electronic devices, given the fact that flexographic is a high speed technique commonly used for printing onto very large area flexible substrates. Although low resolution and poor registration are characteristics of today's flexographic process, it has many potential to realize fine solid line micro size by combining it to micro-contact printing because both of them having similarities in method of carrying printed pattern to a substrates. This work have demonstrated that a 10µm line with 10µm gap was successfully printed by these two combinations of printing techniques, using graphic ink and biological ink which is Fetal Bovine Serum.

**Keywords:** Micro-contact printing (µCP), Flexographic, Polydimethylsiloxone(PDMS), Printed Electronic

## 1. Introduction

Printing techniques to fabricate electronic circuits have recently been highlighted, since they have several advantages over conventional techniques like a photolithography. Printing process like a flexographic have been introduced by many researcher [1]–[5]. This is to achieve low cost manufacturing method, however concern remain of the quality and performance of the product outcomes. By printing method only fewer processing steps is needed, thus increase of productivity, and also more environmental friendly because less of waste.

## 1.1 Micro-contact Printing (µCP)

µCP printing is a soft lithography that uses the release patterns on a master polydimethylsiloxane (PDMS) stamp to form patterns of self-assembled monolayers (SAMs) of ink on the surface of a substrate through conformal contact. Its applications are wide ranging from microelectronics, to surface chemistry and cell biology [6]. In the original version of µCP, the micrometer-scale patterned chemical modification of a large surface area is obtained by transferring different types of compounds using a soft polymer stamp shown in Fig. 1 [7]. Polydimethylsiloxane (PDMS) is the material most frequently used to make the stamps, since it can be molded using a master where it resulted as a soft

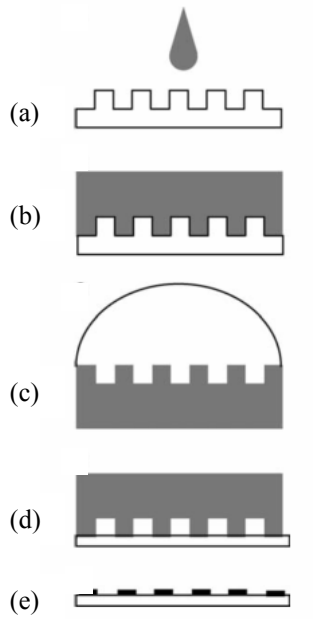



Fig.1. Schematics diagram of a µCP process. PDMS is applied to a master design (a) and allowed to cure (b), forming a mold/stamp. After peeling the stamp form the

*Corresponding author: midris1973@gmail.com

master ink is applied (c), and the ink is transferred to a substrate (d) by stamping. After removal of the stamp, the ink is patterned on the substrate (e) [7].
polymer, which allows for a conformal contact between the stamp and the surface to be modified. μCP significantly had a large impact on the study and control of cell growth [7], recently a study has been carried out for implementing this method to develop a printable electronic circuits on any substrates to cope with the growing demand for low-cost, flexible, and lightweight devices, such as roll-up displays, e-papers, connectors, and keyboards [8]. However, the μCP is relatively slow for production.

## 1.2 Flexographic Printing

Flexography, the printing form is a relief image produced onto a photopolymer material. The anilox roll is an engraved cylinder that transfers the ink onto the printing form. The surface of the anilox is covered with large numbers of finely engraved cells, which are filled with ink from an enclosed chamber, doctor blades are used to remove excess ink from the non-engraved surface of the anilox. The anilox roll is brought into contact with the printing form, also referred to as the plate, thus only allowing transfer of the ink from the anilox roll to the relief areas of the image. The printing form is then brought into contact with the substrate to complete the printing process as Fig. 2 [9].

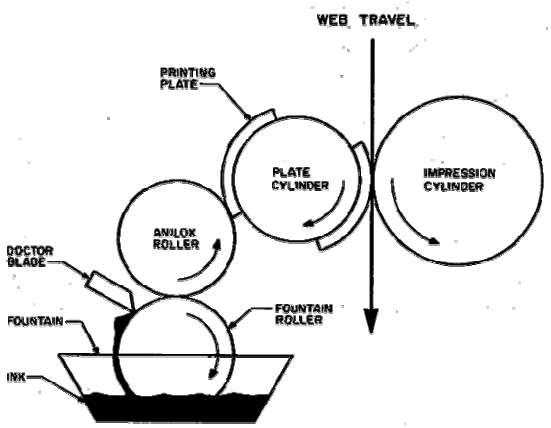
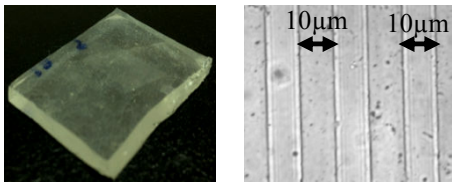



Fig. 2: Flexographic printing process illustration [9].

Even though the flexographic is favorable in speed and in mass production, nevertheless the limitation is in printing of micron scales ranges, which enable to be printed by μCP processes [10]. This is due to major contribution of PDMS properties in μCP such as flexible enough to make conformal contact even with rough surfaces and having enough mechanical stiffness to reproduce patterns in the micrometer range. Furthermore, PDMS is transparent, which is important for optical applications and process control by the eye and by microscopy. Additionally, PDMS stamps can be produced rather easily by thermally curing the cheap and commercially available pre-polymer for a few hours [11]. Those advantages allowed PDMS stamping plate in μCP to play an important role in fabrication printed pattern in nano and micron scale but not for flexographic printing plate which the best achievement in recent research is 20μm which was investigated by Yusof. Hence, an investigation has been done to utilize PDMS in μCP process onto flexography as printing plate. This has led to the novel finding that traditional printing process can be applied to the fabrication of nano-scale components such as RFID antenna and even for cell culture printing for biomedical application purposes.

## 2. Experimental Method

In this study PDMS stamp was prepared by replica molding and final PDMS stamp pattern is array of micrometer lines 10 μm width and 10 μm gap respectively shown in Fig. 3. The substrate selected to be printed on to is thin film plastic.




(a) (b)

Fig. 3: (a) PDMS printing plate, (b) Multiple solid lines pattern on PDMS, 10μm width and 10μm gap between the pattern lines.

In this study a customized roll to roll flexographic machine was prepared in laboratory scale. In this customize design apparatus, basic components of flexographic processes like impression cylinder, plate cylinder, anilox roller and doctor blade is replicated. The key factor is to change the photopolymer which is used normal flexographic to PDMS stamp that usually used in μCP. At this point, very fine multiple solid lines with 10micron width and 10micron gap between the lines is prepared. This fine line may not been achieved by photopolymer making in flexographic.

This pattern was selected because RFID antenna itself which need to have multiples solid line. This multiple pattern will increased the read range capability which crucial when the RFID is implanted in human body for biomedical application. The substrate that been used is flexible thin polymer. This flexible substrate is readily available for flexographic and important in printed RFID application for smart packaging. The two type of inks was investigated which are biological cell culture (Fetal Bovine serum) and graphic ink (supplied by Sakata). In this work the graphic ink was used instead of conductive ink as preliminary study. The printed pattern images were then scanned by Nikon ECLIPSE Ti microscope.

In this work, the most critical parameter the force applied will affected the engagement between printing plate cylinder and impression cylinder. Fig 7 shows the calculation of most critical parameter, which was engagements, that contributes to the success of this printing trial. This calculation method was established by Hamblyn and Yusof [12]. When the applied force is 10N

the engagement is 0.151mm. This fine engagement allowed fine line to be printed.

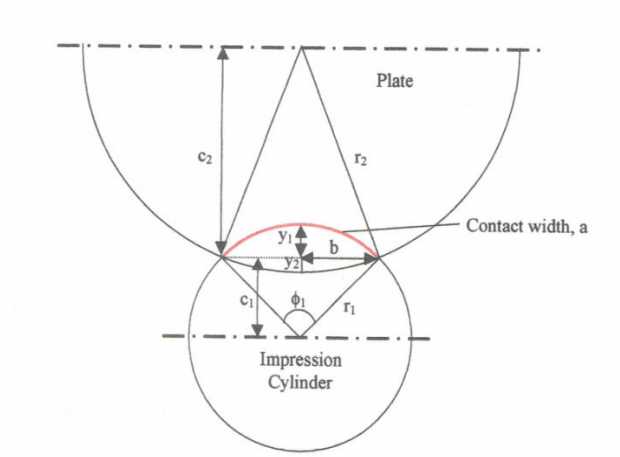



Fig. 7: Calculation converting load to engagement [12].

Table 1: Cylinder dimension information and 10N force calculation.

| Parameter | Value(mm) |
|---|---|
| Impression Cylinder radius, $r_1$ | 34.985 |
| Plate cylinder radius (including plate), $r_2$ | 85.480 |
| 10N contact width, $a_{10N}$ | 5.433 |

From the Fig. 7,

$$\emptyset_1 = \frac{a}{r_1} \quad (1)$$

$$b = \frac{r_1 \tan \emptyset_1}{2} \quad (2)$$

$$c_1 = \sqrt{r_1^2 - b^2} \quad (3)$$

$$y_1 = r_1 - c_1 \quad (4)$$

$$c_2 = \sqrt{r_2^2 - b^2} \quad (5)$$

Therefore the engagement is,

$$\text{Engagement} = y_1 + y_2 \quad (6)$$

When the applied force is 10N the engagement is 0.151mm. This fine engagement allowed fine line to be printed.

## Results and Discussion

After printing trials had been done, the best printed images are selected as preliminary result was shown in Fig. 5 for Fetal Bovine of biological base and Fig. 6 for graphic Sakata inks respectively, for micro multiple solid line conductive tracks for printed electronic. The big breakthrough in this work is finest multiple patterns which were 10µm width and 10µm gap were successfully achieved which is never been done previously. The best result before this is claimed by Yusof which were 20µm [12]. This achievement is attributed by the PDMS role while improving the slow production and low productivity of µCP printing techniques, by combining it flexographic roll to roll printing. Meanwhile, finer multiple solid lines successfully printed which improve the flexographic printing techniques, by replacing the printing plate from photopolymer to PDMS.

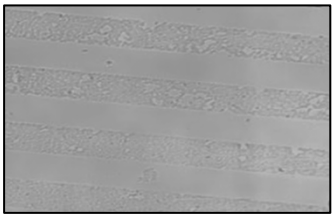


Fig. 5: Printed image of Fetal Bovine Serum, the grid line clearly transferred to substrate from PDMS stamp, 10µm width and 10µm gap, scanned by Nikon ECLIPSE Ti microscope.

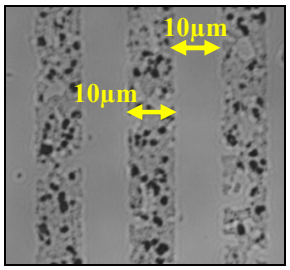



Fig. 6: Printed image of Graphic Sakata Ink, multiple lines of RFID antennas have been successfully printed, 10µm width and 10µm gap scanned by Nikon ECLIPSE Ti microscope.

Although the printed images are shown the successful experimental result, there are four majors concern which involved in this study which is machine parameter setting, inks, printing plate (PDMS) and printing substrates. Those four items were well manipulated so that good result as Fig. 5 and Fig. 6 can be achieved. Therefore it also needs to be investigated further in order to get better result in the future. Therefore the parameter of "microFlexographic" printer setting likes applied roller speeds, PDMS stamp, forces applied and inking process, will much concerned to the printed image quality.

During this study we also found out a lot of challenges like misprinting, cut off pattern and PDMS deformation. When using PDMS as printing plate, the critical element is to carefully control the force applied on the stamp during the contact as shown in Fig. 7 and Table 1. Furthermore the contact time between PDMS relief pattern stamp to substrate is also crucial. Different ink

viscosity will give different result. Stamp deformation also major issue in this work, those including pairing, buckling and roof collapse deformation. However the counter action had been taken, allowing multiple solid lines images had been printed.

## 3. Conclusions

Combining μCP and flexographic printing (microFlexographic) was successfully combined to produce multiple fine solid lines with below 10μm line with and 10μm gap between the 2 adjacent lines on the polymer thin film flexible substrate. Both "ink" which are Biological cell culture named Bovine Fatal Serum and Graphic ink effectively printed using is new laboratory scale customize "microFlexographic" printing machine.

This invention will assist toward printed micro scale of electronic devices such as flexible, bended or rolled consumer product like LCD display, smart phone, printed RFID antenna for low cost mass production. In aspect of biomedical application, cell culturing also can be printed in less expensive way but very higher throughput. In it hopes that MicroFlexographic will accelerate development of micro-scale of RFID as wearable electronics, increasing usage for monitoring human bodily functions. Appling this principle in biomedical, would avoid the use of and batteries or wired connections, which decreases the overall size of the device. This may offer a new way of embedding of RFID transponder into a structures. Possibility of production in micro size in flexible substrate may enable micro-scale RFID to be inserted inside the human living cell to provide a sub-cellular remote controlled interface. For the future work, the conductive with nano particle inks will be used instead of graphic ink, allowing printing to be done micro-scale pattern such as silver nano particle, carbon nanotube and etc.

## 5. Acknowledgement

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