Journal of Engineering and Applied Sciences 12 (Special Issue 1): 5644-5649, 2017
ISSN: 1816-949X

A Study of PDMS Printing Plate for Fine Solid Lines Image in Micro-Flexographic Printing Process

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Abstract: Printing plate is one of the printing component that play an important roles in producing the micro to nano scale printing image for graphic, biomedical and electronic device on variable substrates by using various inks. The Polydimethylsiloxane (PDMS) material was used as printing plate due to low cost material and easy to handle which usually used in producing micro to nano scale image and electronic devices. In this study, the PDMS was developed as a printing plate into the multiple micro to nano scale printing fine solid line onto substrate for micro-flexographic printing machine. Micro-flexographic printing machine was developed by combining the flexographic and micro-contact printing technique. Micro-flexographic was a high speed roll to roll printing technique which could be used in micro to nano scale pattern. This research was successful developed fine solid lines PDMS printing plate below 5 μ. This study illustrates the use of PDMS material as printing plate in producing multiple micro solid lines printing capability for the application of printing graphic, electronic and bio-medical purpose.

Key words: Flexography, printing plate, PDMS, micro-contact, micro-flexographic printing, solid line

INTRODUCTION

Printing is a technique for reproducing the images by using image carrier or printing plate for micro to nano scale pattern. All roll to roll printing components like ink, printing plate, substrate and others, play an important roles in producing the micro to nano scale fine solid line. Printing plate properties play the main role to achieve the best quality of printing which has fine solid line width of below 5 μm. The inconsistency of printing plate making technique was affected the print quality and consistency (Galton, 2003). Printing plate application was affected the quality of reproducing fine solid line image in roll to roll printing process (Yusof *et al*., 2007).

Flexographic printing process is a method of direct rotary printing that uses mold printing die or printing plate which is made from rubber or photopolymer. In roll to roll flexographic printing process, ink was transferred to the printing plate by using an engraved cylinder known as an anilox roll as shown in Fig. 1. The anilox roll was the primary control of the quantity of ink transferred to the plate and subsequently the printed (Deganello *et al*., 2010).

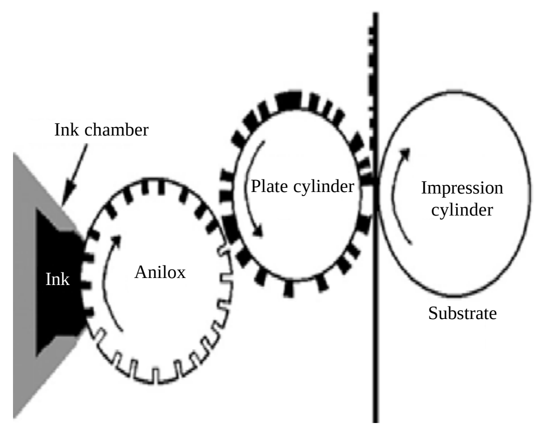

Fig. 1: Schematic description of the flexographic printing process (Deganello *et al*., 2010)

Polydimethylsiloxane (PDMS) is a suitable low cost material in producing printing plate for flexographic printing process. Several methods have been study by the previous researchers to reduce the deflecting deformations of PDMS property. Figure 2 shows the microstructure form of PDMS layer and silicon plate which reduce from 3-0.42% in average residual strains. The maximum deflections also have been reduced by around four times (Luo *et al*., 2006).

Photopolymer is a common material that use to produce printing plate in flexography printing process.

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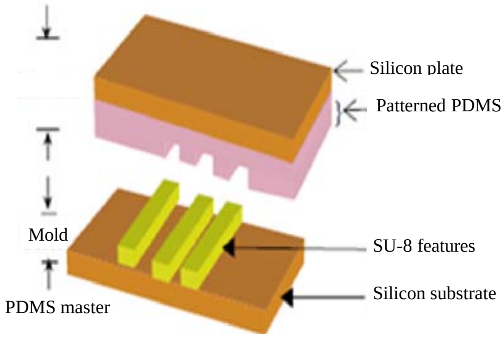

Fig. 2: Schematic of reinforce PDMS master mould (Luo *et al*., 2006)

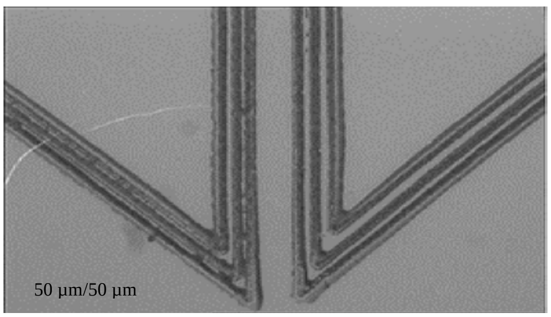

Fig. 3: Printing solid lines by photopolymer printing plate (Yusof, 2011)

This type of material is harden selectively when expose to Ultraviolet light (UV). During image plate manufacturing process, the starting point is an unexposed composite photopolymer sheet. Afterthat, it is attached to a clear polyester backing film. A negative image of the artwork is placed on the top and expose to UV which cures and hardens the unprotect area (Deganello, 2013).

The previous research done by Yusof *et al*. (2009) stated that by using photopolymer as a printing plate image carrier in roll to roll printing technique which was web press industrial method, the researcher managed to print out 50 µm line width and 50 µm line gap by using carbon graphic inks as printing ink as shown in Fig. 3. This technique used photopolymer as a material in mold making which played a role to transfer the ink from plate roller to substrate.

Micro-Contact Printing (µCP) is a related printing technique in micro scale pattern that manages to print fine solid line smaller than flexography printing. Previous studied by Perl, showed that µCP could produce fine solid line below 1 µm (Perl *et al*., 2009). This research employed the modification of PDMS printing plate to achieve high mechanical stability of the micro to nano structures and good capability to form conformal contacted down to the nanometer scale despite potential substrate roughness.

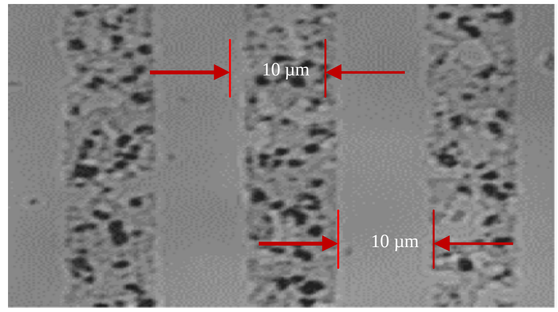

Fig. 4: Printing solid lines by µCP and flexography (Maksud *et al*., 2014a, b)

Micro-contact and flexographic printing technique have its own benefits in micro to nano printing pattern. The combination of both printing techniques will expand a new era of printing technology that can be explored in all aspects (Hassan *et al*., 2015a, b). The knowledge gap in printing plate preparation, engage contact mechanism, ink spreading mechanism and other important factors are still under further development.

Previous research by Maksud had demonstrated that a 10 µm line width with 10 µm line gap was successfully printed as shown in Fig. 4 by emerging the two combinations of printing techniques while using PDMS material as printing plate (Maksud *et al*., 2014a, b). This achievement was attributed to the PDMS plate making technique while improving the slow production and low productivity of µCP printing techniques to be faster and excellent registration control in flexographic roll to roll printing techniques.

The succesful developement of combination micro-contact and flexographic printing technique will lead to mass production and very low cost of printed electronic device like a flexible, bended or rolled consumer product for example, LCD display, printed RFID antenna and others (Maksud *et al*., 2014 a, b). The PDMS printing plate also can be expand not only in electronic industry but also in image and bio-medical purpose. In bio-medical application, cell culturing could be print in low cost with higher output (Hassan *et al*., 2015a, b).

Furthermore, study into combination of flexography printing and µCP, the suitable of printing plate characteristics is one of the most important issue. This study is investigated printing plate characteristics that will affect the printing capability. Besides, that both of the printing techniques need to be understood well. Fine solid line image printed must be considered as an important functional device for electronic printing application (Yusof *et al*., 2013). The main target of the research is to investigate the printing plate of using PDMS material that has been use in µCP to be employed into the combination

Fig. 5: Original multiple fine solid line patterns on silica wafer was placed in master mold

of flexography printing and µCP to achieve the printing of multiple fine solid lines on variable substrates below than 5 µm width and gap.

MATERIALS AND METHODS

Experimental method: The PDMS printing plate development was started by preparing the master mold using Acrylonitrile Butadiene Styrene (ABS) material. 3D printer machine also known as rapid prototype machine was used to build the master mold. The main target of this experiment was to replace the basic photopolymer printing plate which normally used in flexography printing to PDMS plate. The PDMS usually used in micro-contact printing with fine solid line width down to 1 µm. Then, the PDMS material was poured into the master mold with the silicon wafer that already inside the mold liked showing in Fig. 5. The silicon wafer was used as a master image to get the fine solid lines for width and distance gap below 5 µm. The silicon wafer had several fine solid line images in range between 10 µm down to 1 µm width. The size of the mould was defined the quantity or thickness of PDMS. Some bubbles were appeared during pouring which was removed by vacuum pump. Figure 6 showed the completed PDMS printing plate with fine solid line image in range 10-1 µm width. The PDMS printing plate was then attached to the micro-flexography printing machine to start the printing process. A good quality image of fine solid line on PDMS printing plate surface will lead to the high quality fine solid line image on printed substrate.

Afterthat, the printing process was started with the development of customized roll to roll micro-flexographic printing machine in labaratory scale as shown in Fig. 7. Micro-flexographic was a combination of flexography and micro-contact printing method. Flexography was one of the fastest printing process but couldnot achieve micro or nano printing scale (Maksud *et al*., 2016). Micro-contact printing was slow but it can print down to nano scale image. The combination will lead to new era of high speed printing machine that could print micro down to nano

Fig. 6: PDMS printing plate with fine solid line image

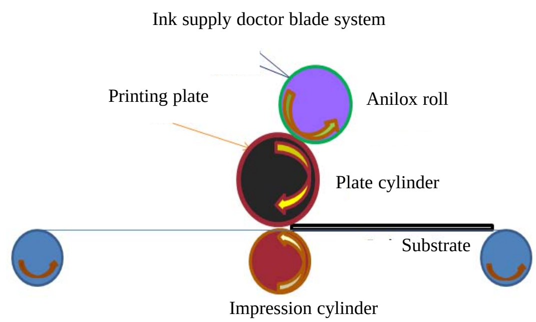

Fig. 7: Schematic diagram of the micro-flexographic printing process

scale image. The basic components of flexographic printing machine liked impression cylinder, plate cylinder, anilox roll and doctor blade were remained. Micro-flexographic printing machine also used the same concept liked flexographic machine process. A pattern of multiple fine solid line was designed on the stamp plate where the printing plate was attached to the plate cylinder (Hassan *et al*., 2016). In roll to roll micro-flexographic printing process, ink was transferred to the printing form using an engraved cylinder known as an anilox roll which consists of finely engraved cells (Bould *et al*., 2004a, b).

There were several major components that affected the printing parameters. Anilox roll and plate cylinder were affected the upper roller engagement parameter which were used to compresed the PDMS printing plate with ink attached on the surface. Secondly, the lower roller engagement between plate cylinder and impression cylinder. Both of the printing components were compressing the PDMS printing plate and substrate. Upper and lower engagement were different because the experimental process was considered the thickness of the printing plate and substrate. Last parameter involved during printing process was the printing speed. A gear motor with speed controller was attached at plate cylinder that play the role to control the printing speed.

The printing capability was checked visually by adjusting processes parameters liked printing plate, printing speed, engagement between impression roller and substrates. These parameters needed to be taken care during experimental process due to the aim of this project were very critical in printing fine solid lines. From the printed image patterns observation, the factors which influence the defected patterns was included the printing plate, ink properties, substrates, machine processes parameters and interfacial phenomena between the rolling contact (Maksud *et al*., 2014a, b).

Surface roughness of fine solid line image on PDMS printing plate was analysed using advanced surface roughness analysis techniques, known as Atomic Force Machine (AFM). The AFM works by scanning an extremely fine probe on the end of a cantilever across the surface of a material and profiling the surface by measuring the deflection of the cantilever. This allowed a 3D profile of the surface to produce at magnifications over one millions times, giving more topographical information than optical. Surface morphology was investigated by AFM to meet the aim of the research (Koidis *et al*., 2013). The analysis result was considered to most propose printing plate, inks and substrates for micro-flexographic printing process.

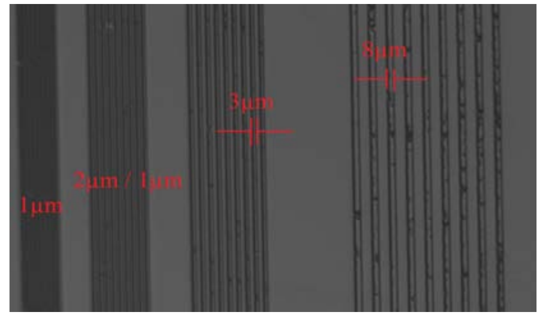

Fig. 8: Silicon wafer with fine solid line image from 10 μm down to 1 μm

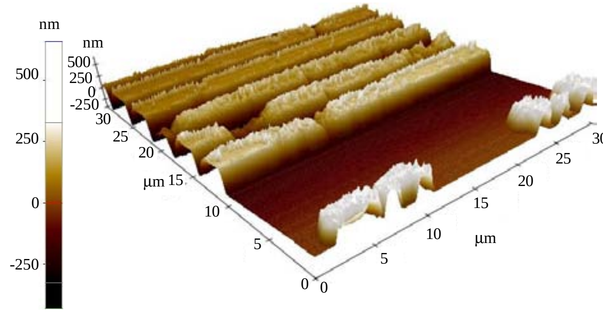

Fig. 9: AFM surface image of PDMS printing plate with scanning area 30×30 μm

RESULTS AND DISCUSSION

The PDMS printing plate pattern image comprised solid fine lines image range from 10 μm down to 1 was successfully fabricated from the silicon wafer image as shown in Fig. 8. Silicon, wafer that was created from electroplating process was used as a master image for this PDMS development. This PDMS printing plate was designed in various fine straight lines width so that the printing trials in the future can be analyzed and give several different result for comparing. From several types of different fine solid lines width, lines with 2 μm width and 1 μm gap was chosen due to minimum line width with clear lines fabricated.

The surface roughness of PDMS printing plate with fine solid line image pattern was investigated by AFM. In electronic printing, lower surface roughness wasa better result to have high performance of conductivity (Cui *et al*., 2014). By referring to Fig. 9, AFM morphology result showed the surface roughness was 0.259 μm. The lowest surface roughness value will give the high quality of PDMS fine solid line image surface. In printing process, printing plate also was used to capture the ink before printing on the surface of substrate. That caused the PDMS surface roughness was very important so that it can capture enough ink to transfer on substrate.

From the AFM analysis, the result also showed the actual result for fine solid line image size with 1.8 μm width, 1.2 μm gap and 250 μm height liked showing in Fig. 10 and 11. This new achievement of printing plate development will lead to the novel fine solid line image scale below 10 μ which was never achieved in flexography printing process. Furthermore, the micro-flexographic printing machine was a new achievement in printing process development.

From the result, the study of PDMS printing plate making was used in combination of flexographic and micro-contact printing technique which known as micro-flexographic in producing multiple micro to nano fine solid lines which were feasible due to the success in other printing techniques. The application of PDMS printing plate in fine solid line printing will assist to micro scale Radio Frequency Identification (RFID) in mass production with a low cost raw material and process (Maksud *et al*., 2013a, b). This research was practically used in electronic printing industries that aimed on printing multiple micro to nano fine solid lines where it could also be applied in other printing industries liked graphic printing and biomedical purposes.

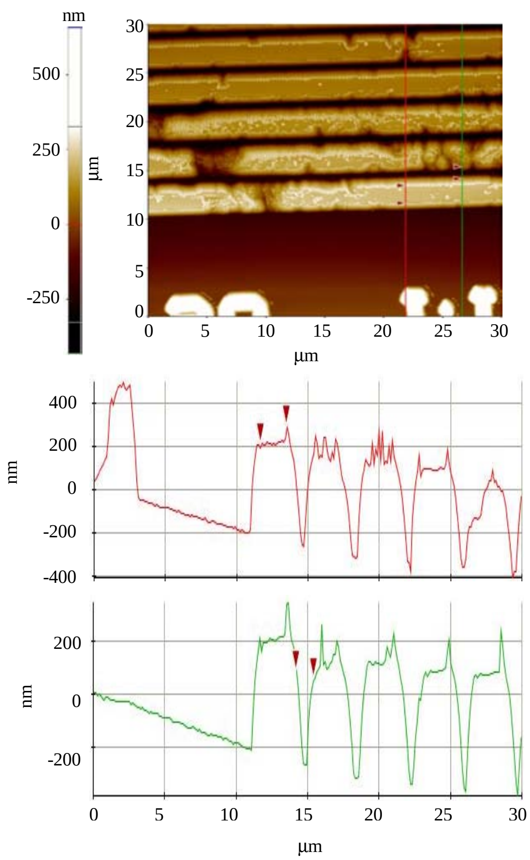

Fig. 10: AFM resulted of PDMS printing plate fine solid line image (Cursor: Red, Red; ΔX (μm): 1.861, 1.230; ΔY(μm): 82.691, -28.271; Angle (deg): 2.607, -1.316); Line profile: green-228

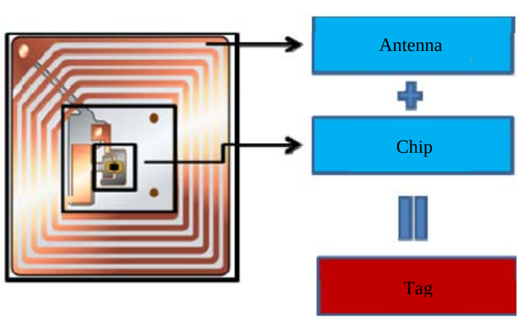

Fig. 11: RFID tags component (Maksud *et al*., 2013a, b)

CONCLUSION

The development of PDMS Printing Plate for micro-flexographic printing process was successfully produced fine solid lines with 2 μm width, 1 μm gap and 250 nm height. Silicon wafer was used as a master fine solid lines image for PDMS printing plate. It was a step to move forward in order to achieve micro to nano structure or solid lines printing in graphic, electronic and bio-medical purpose with simple, rapid, low cost method, less waste and roll-to-roll capability. The Micro-flexographic printing concept also could be applied in money printing process for security features.

The new Micro-flexographic printing technique will assist toward printed micro to nano scale of RFID (Radio Frequency Identification) antenna and Organic Field Effect Transistor (OFET) which was used in many sectors for example in electronic devices, biomedical application, security and, etc. The interest of RFID technology met the emerging demands in the automation process (Maksud *et al*., 2012). These RFID components demonstrated by this technology in relation to other existing identification systems as shown in Fig. 11.

ACKNOWLEDGEMENT

This project was supported by ‘Skim Latihan Akademik Bumiputera’s and ‘GIPS 1383 and U048 from Universiti Tun Hussein Onn Malaysia, Ministry of High Education Malaysia.

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