Investigation of Micro-flexographic Printing Method in Fine Solid Lines Printing Structure by Graphene Ink

S. Hassan, M.S.Yusof, M.I. Maksud, and M.N. Nodin

***Abstract*—**Micro-flexographic is a new printing method which is combination of flexography printing and micro-contact printing technique. Flexography printing is one of the high speeds production in roll to roll printing technique which commonly use in graphic printing industry. Micro-contact printing method usually use for micro to nano scale image especially in fine solid lines image structure. Ink is also one of the important parameter in micro to nano scale image printing. Graphene is a low cost material that suitable to use as a printing ink. Graphene ink has a capability in producing or printing image and electronic device in micro to nano scale structure. This research elaborates the use of graphene as a printing ink in combination of flexography and micro-contact printing method which known as micro-flexographic printing for micro to nano scale fine solid lines image. Here, it is proposed that extending micro-flexographic printing technique into the multiple micro to nano scale printing fine solid lines image onto biaxially oriented polypropylene (BOPP) substrate. This paper will investigate the capability of Micro-flexographic printing method in producing micro to nano fine solid lines image by using graphene ink for future printing development and application of printing electronic, graphic and bio-medical purpose.

***Keywords*—**Flexography, micro-contact printing, micro-flexographic, graphene ink, micro to nano scale, fine solid lines.

I. Introduction

PRINTING technology has been expanded and improved from one day to another day. Many developments have been done successfully to achieve some targets or goals in printing technology for example in printing micro to nano scale image for the low cost production. Some researchs have been done on printing parameters like ink and printing plate to reduce the printing and production cost. In electronic printing area, manufacturing costs have became a critical issues for electronic industry in producing high volume products[1].

Recently, researchers have shown that all printing components like ink, printing plate, substrate, speed, rollers engagement and others, play an important roles in producing the micro to nano scale fine solid lines image. Ink, subtrate and printing plate properties play the main role to achieve the best quality of printing which is fine solid lines width and gap of below 10 µm. The ink properties can be described into ink chemistry, viscosity, rheological behavior, solvent evaporation rate, drying and others [2].

Previous research by Maksud had discussed about flexography printing technique in using carbon nanotubes (CNT) as a new ink for printing purposes. There were two types of CNT inks which were water base and solvent base. The author used four type of substrates which were silica, biaxially oriented polypropylene (BOPP), white blank office paper and woven cloth for electric conductivity comparison purpose. The result concluded that CNTs water base ink was the best ink compared to CNTs solvent base ink which could be printed onto many substrates with maintain high electric conductivity [3].

The previous research done by Yusof [4] stated that by using photopolymer as a printing plate or image carrier in roll to roll printing technique which was web press industrial printing method, the author managed to print out 50µm line width and 50µm line gap by using carbon graphic ink as printing ink liked showing in Fig. 1. This technique used photopolymer as a material in mold making which play a role to transfer the ink from plate roller to substrate. Polymer was the alternative way in reducing the manufacturing printing cost.

Micro-contact printing (µCP) is a related printing technique in micro to nano scale pattern that manages to print fine solid line smaller than flexography printing technique. Previous study by Perl showed that µCP could produce fine solid lines image below 1µm liked showing in Fig. 2 [5]. This work employed the modification of Polydimethylsiloxane (PDMS) printing plate to achieve high mechanical stability of the micro to nano structures and good capability to form conformal contact down to the nanometer scale despite potential substrate roughness.

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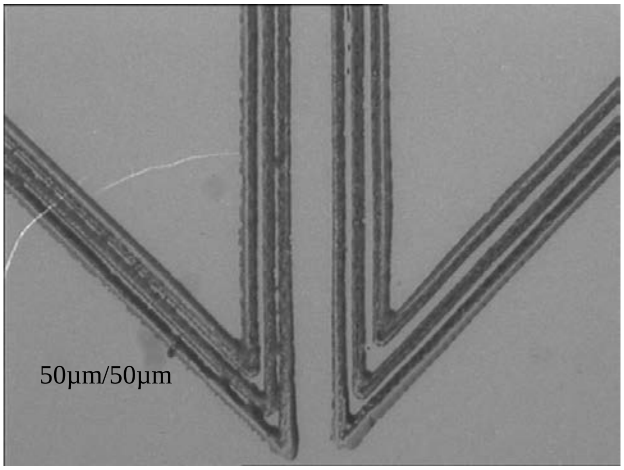

Fig. 1 Printing solid lines by web press [4]

The previous research in using PDMS printing plate for flexography printing process by Maksud shown that micro scale fine solid lines was succesful printed. The research was focused on the developement of low cost mass production UHF (Ultra-high Frequency) passive RFID (Radio Frequency Identification) sensor for biomedical liked monitoring the movement of healing limbds to warn about too large movement and for monitoring chest breathing movements. The key factor from the research were changing photopolymer which was normally used in µCP printing to become a printing plate for flexography printing process [6].

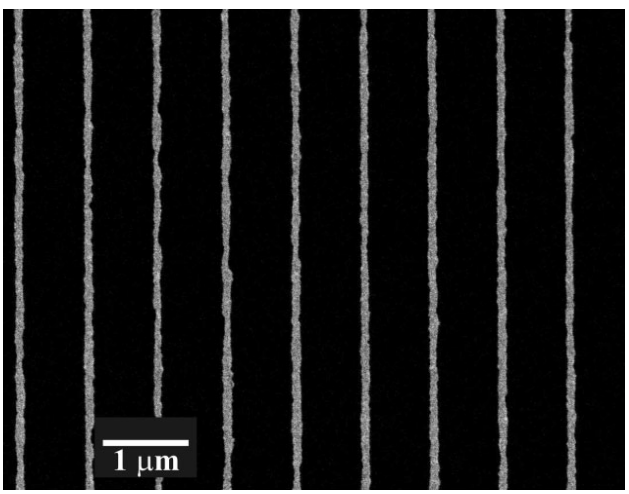

Fig. 2 Printing solid lines by µCP process [5]

Micro-contact printing and flexography 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. The knowledge gap in printing plate preparation, engage contact mechanism, ink spreading mechanism and other important factors are still under further development. Previous work by Maksud et al had demonstrated that a 10 µm line width with 10 µm line gap was successfully printed as shown in Fig. 3 by emerging the two combinations of printing techniques while using PDMS material as printing plate [7]. 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 flexography roll to roll printing techniques.

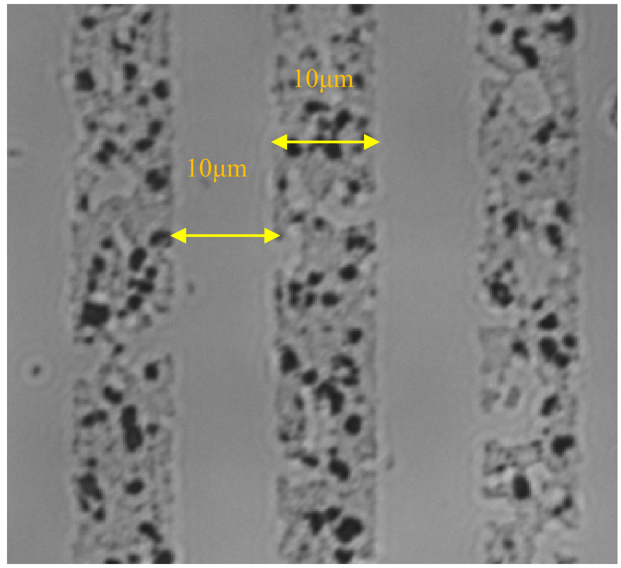

Fig. 3 Printing fine solid lines by µCP and flexography [7]

The fine solid lines image printed by flexography and µCP technique could be developed in designing chipless Radio Frequency Identification (RFID) tags. Previous research had shown that the flexography printing managed to print RFID strips with good pressure and anilox liked showing in Fig. 4. The author used paper as substrate for experimental printing trials. The production cost for RFID tag could be minimized and reasonable [8]. The research showed the potential of chipless RFID technology for representing a very good choice for identification applications or electronic device in the future. The other printing parameter liked plate characteristic was influenced printing lines quality which will affect the electrical performance of printed track [9].

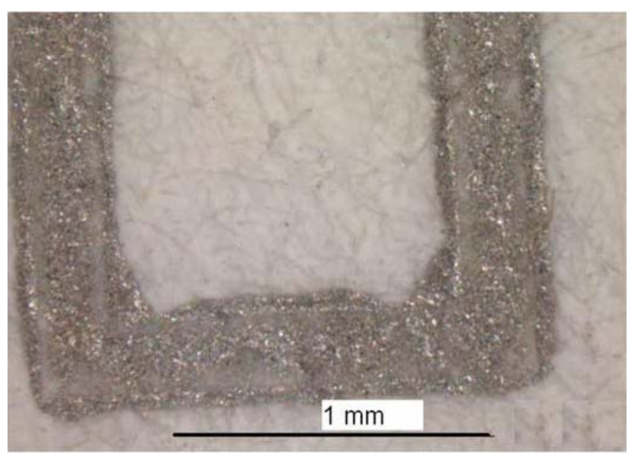

Fig. 4 Printed RFID strip with good pressure and anilox [8]

The applications of flexography and µCP method not only focus on graphic and electronic but also can be applied in biomedical development. Material selection plays an important role to reduce the surgery cost and the patient does not need to undergo second surgery as the material in a good quality and condition [10]. The fine solid lines printing technology can be applied on engineering surface for cell biology control and growth for micro to nano scale fabrication [11].

Ink is one of the important parameter in printing technique. Le et al. had discussed about graphene supercapacitor electrodes which known as electric double layer capacitor electrodes that was fabricated by inkjet printing [12]. Fig. 5 showed the circular Graphene Oxide (GO) dot as that produced with 20 printing passes at 20 min interval between passes. The research had approved that hydrophilic GO dispersed in water was found to be a stable ink for inkjet printing of GO with the lateral spatial resolution of 50µm. The research also showed that the ink properties were suitable in producing electronic parts in micro to nano scale. Graphene material had a good potential in electronic device manufacturing. In mechanical section, graphene was a high robustness and full integration in sensing electronic device application. This material also had high potential for molecular architecture in electronic information processing [13].

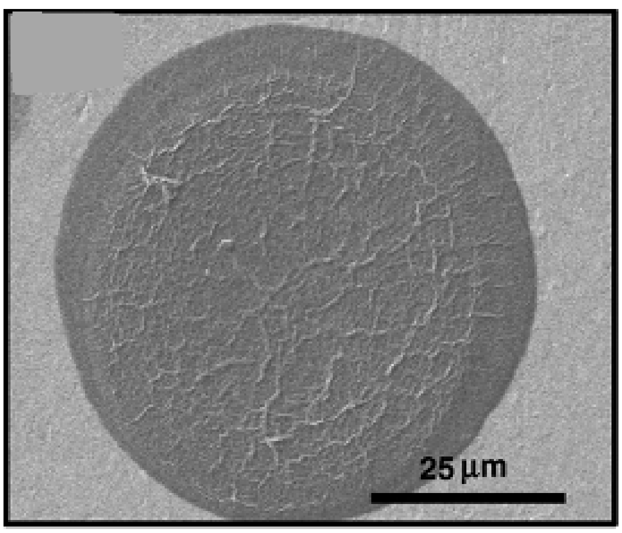

Fig. 5 Graphene Oxide (GO) dot printed on the Ti foil [12]

The succesful developement of combination micro-contact and flexography printing technique will lead to mass production and low cost of printed electronic devices. The micro-flexographic printing technique could be applied for flexible, bended or rolled consumer product liked a LCD display, printed RFID antenna and other electronic parts [14]. The study on PDMS material as a printing plate was a good achievement for printing technology. The parameters liked roller speed, engagement, ink and substrate were the important factors that could be effected the PDMS performance in mass production printing [15]. The PDMS printing plate also can be expand not only in electronic industry but also in graphic and bio-medical purpose.

Furthermore study into combination of flexography printing and micro-contact printing (µCP), the suitable of parameters setting was one of the most important issue [16]. This study was discussed about printing parameters that will affect the printing capability and image quality in producing fine solid lines image. Besides that, both of the printing techniques needed to be understood well. The main target of the study was to run the printing experimental by using graphene ink and PDMS material as printing plate that has been used in µCP to be employed in the combination of flexography printing and µCP to achieve the printing of multiple fine solid lines image on substrate below than 5µm width and gap. This study of micro to nano fine solid lines structure will be applied not only in graphic and electronic but also for biomedical purpose [17].

II. Research Methodology

The printing process was started with the development of customized micro-flexographic printing machine in labaratory scale as shown in Fig. 6. Micro-flexographic printing machine was a combination of flexography printing and micro-contact printing technique. Flexography was one of the fastest printing process but it had limitation in achieving micro to nano printing scale image [18]. Compare with micro-contact printing method, it was slowed but it could print fine solid lines image from micro down to nano scale. The combination of both printings technique will lead to new era of high speed printing machine that could print micro down to nano scale image expecially in fine solid lines image for graphic, electronic and bio-medical purpose.

The basic components of flexography printing machine liked impression cylinder, plate cylinder, anilox roll and doctor blade were remained. Micro-flexographic printing machine also used the same concept liked flexography machine process. A pattern of multiple fine solid lines image was designed on the stamp plate or printing plate which was attached to the plate cylinder. In 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 [19].

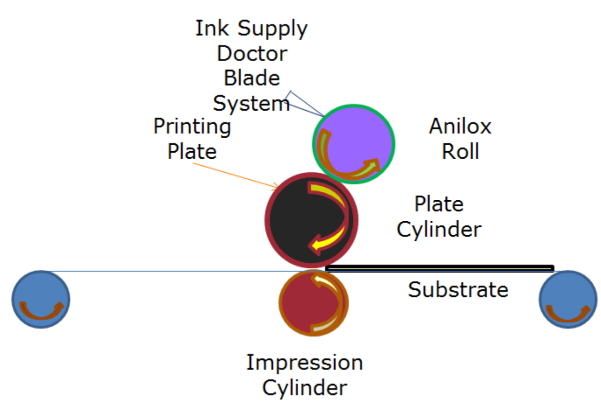

Fig. 6 Schematic diagram of the micro-flexographic printing process

Afterthat, the Polydimethylsiloxane (PDMS) printing plate was prepared by using acrylonitrile butadiene styrene (ABS) material as master mold. 3D printer machine which known as rapid prototype machine was used to build the master mold. Then, the PDMS was poured into the master mould with the silicon wafer that already inside the mould like showing in Fig. 7. The silicon wafer was used as micro to nano scale image to get the fine solid lines image for width and distance gap below 5µm.

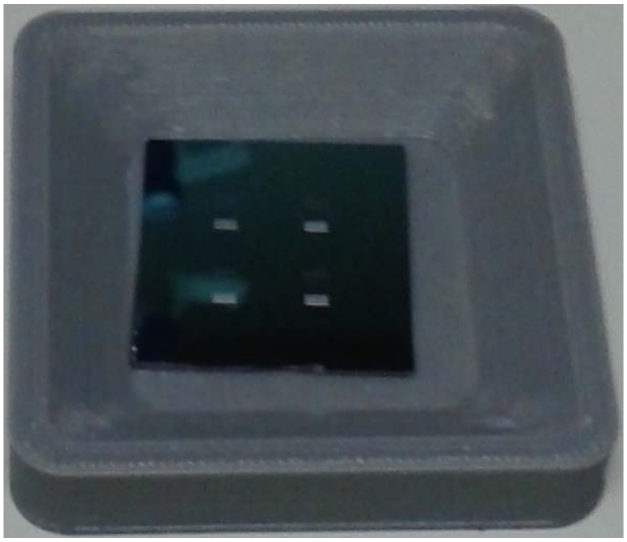

Fig. 7 Original multiple fine solid lines pattern on silica wafer was placed in master mold

The main target of this study was to achieve fine solid lines printed image below 5µm which was never been achieve in flexography printing technique. The size of the mould was defined the quantity or thickness of PDMS. Some bubbles were appeared during pouring liked showing in Fig. 8 which was removed by vacuum pump.

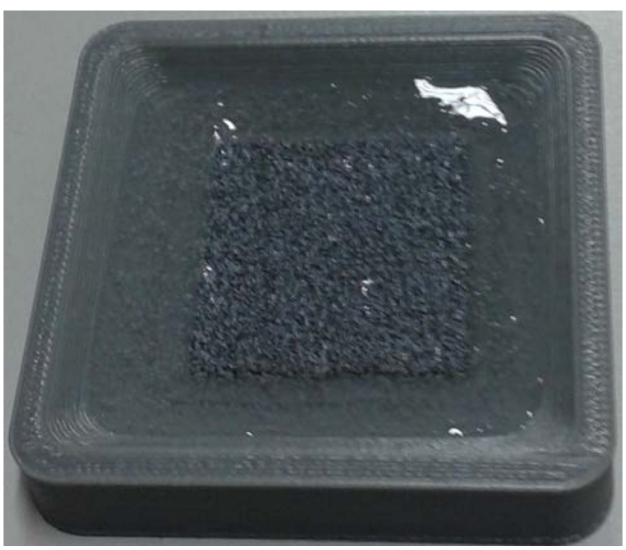

Fig. 8 Some bubbles were appeared during PDMS printing plate making

Fig. 9 showed the completed PDMS printing plate with fine solid lines image on the surface in range 10 µm down to 1 µm width. The PDMS printing plate was then attached to the micro-flexographic printing machine to start the experimental printing process. A good quality image of fine solid lines on PDMS printing plate surface will lead to the high quality fine solid lines image on printed substrate.

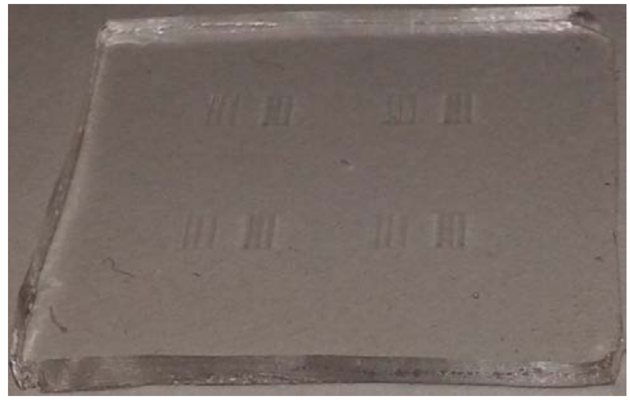

Fig. 9 PDMS printing plate

The printing capability was checked visually by adjusting processes parameters liked engagement between anilox and plate cylinder, engagement between plate cylinder and impression cylinder and speed. These parameters were taken care during experiment due to the aim of this project were very critical in printing micro to nano fine solid lines image.

Graphene ink was affectively used for these combination of flexography and micro-contact printing which known as micro-flexographic printing method for micro to nano fine solid lines scale image which newly developed method to deposit and pattern them over large areas and at higher resolution [20]. The study also stated that ink effects were viscosity, solvent and ink particle size that will affect the final result.

III. Result and Analysis

Experimental process was started by doing several printing trial by using micro-flexographic printing machine. The substrate used was biaxially oriented polypropylene (BOPP) film and graphene material as a low cost ink that usually used in micro-electronic industry. The PDMS printing plate pattern image comprised fine solid lines image range from 10 µm down to 1 µm was successfully fabricated from the silicon wafer image as master mold. This PDMS printing plate was designed in various fine straight lines width so that the printing trials in the future could be analyzed and gave several different results for comparing. From several types of different fine solid lines width, the lines with 3 µm width and 3 µm gap were chosen due to minimum lines width with clear lines fabricated liked showing in Fig. 10.

The printing result showed that the 3 µm width and 3 µm gap fine solid lines image was successful printed and achieved as shown in Fig. 11 which was never been done previously by flexography printing method. From previous research, the best result in fine solid lines image printing was claimed by Maksud et al. which were 10 µm width and 10 µm gap by using Fetal Bovine serum and graphic ink [7].

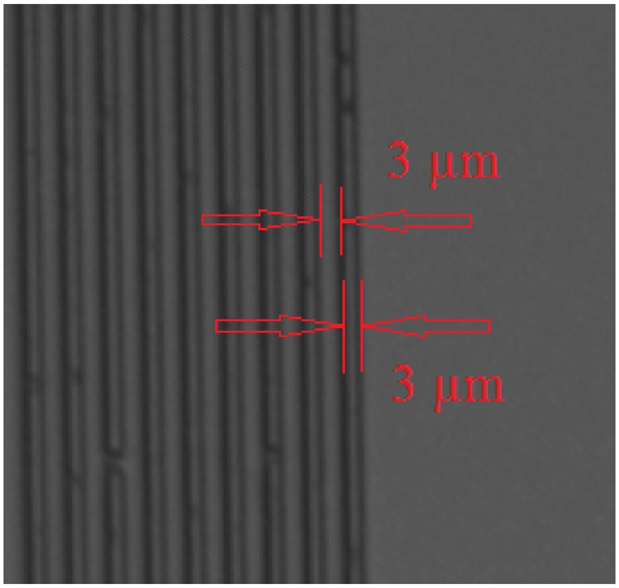

Fig. 10 PDMS printing plate with fine solid lines with 3 µm width and 3 µm gap

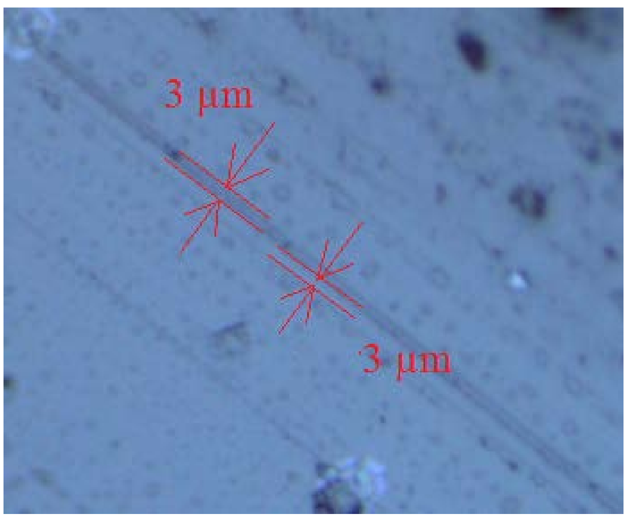

Fig. 11 Printed fine solid line image of graphene ink with 3 µm width and 3 µm gap scanned by Olympus BX60M microscope

During printing trial, there were several concerns that must be considered. The concerns were the machine parameters setting which were engagement between anilox roll and plate cylinder, engagement between plate cylinder and impression cylinder and lastly the speed. Those items were manipulated to achieve fine solid lines image as the good result.

IV. Conclusion

The study in printing process of flexography printing and micro-contact printing was essential towards the combinations of both printing techniques prior to use graphene as printing ink. The combination of both printing method was known as Micro-flexographic printing technique was successfully achieved. Micro-flexographic printing had a capability in producing the lowest lines width and gap. This new printing technique could print 3 µm width and 3 µm gap fine solid lines image on BOPP substrate by using graphene as printing ink medium. This achievement was a step to move forward in order to achieve high speed printing in electronic with simple, rapid, low cost method, less waste and roll-to-roll capability.

The study of graphene rare earth metal as a printing ink that used in combination of flexography and micro-contact printing in producing multiple fine solid lines were due to the success in other printing techniques such as ink jet printing. This work was practically used in electronic printing industries that aimed on printing multiple solid lines from micro to nano size where it could also be applied in other printing industries liked graphic printing and bio-medical purposed.

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References

[1] J. Zhang, P. Brazis, A. R. Chowdhuri, J. Szczech, and D. Gamota, "Investigation of using contact and non-contact printing technologies for organic transistor fabrication," in *MRS Proceedings*, 2002, p. P6. 3.

[2] E. Hrehorova, A. Pekarovicova, and P. D. Fleming, "Gravure printability of conducting polymer inks," in *NIP & Digital Fabrication Conference*, 2006, pp. 107-110.

[3] M. I. Maksud, M. S. Yusof, Z. Embong, M. N. Nodin, and N. A. Rejab, "An Investigation on Printability of Carbon Nanotube (CNTs) Inks by Flexographic onto Various Substrates," *International Journal of Materials Science and Engineering,* vol. Vol. 2, 2014.

[4] M. S. Yusof, "Printing Fine Solid Lines in Flexographic Printing Process," Degree of Doctor of Philosophy, School Of Engineering, Swansea University, Swansea, 2011.

[5] A. Perl, D. N. Reinhoudt, and J. Huskens, "Microcontact printing: limitations and achievements," *Advanced Materials,* vol. 21, pp. 2257-2268, 2009.

[6] M. Maksud, M. Yusof, and M. Mahadi Abd Jamil, "Optimizing a polydimethylsiloxone (PDMS) into flexographic printing process for RFID biomedical devices and cell cultures," in *Biomedical Engineering International Conference (BMEiCON), 2013 6th*, 2013, pp. 1-4.

[7] M. Maksud, M. Yusof, and M. M. Abdul Jamil, "A Study on Printed Multiple Solid Line by Combining Microcontact and Flexographic Printing Process for Microelectronic and Biomedical Applications," *International Journal of Integrated Engineering,* vol. 5, 2014.

[8] A. Vena, E. Perret, S. Tedjini, G. E. P. Tourtollet, A. Delattre, F. Garet, *et al.*, "Design of chipless RFID tags printed on paper by flexography," *Antennas and Propagation, IEEE Transactions on,* vol. 61, pp. 5868-5877, 2013.

[9] M. Maksud, M. S. Yusof, and M. M. Abdul Jamil, "Study on finite element analysis of fine solid lines by flexographic printing in printed antennas for RFID transponder," *International Journal of Integrated Engineering,* vol. 4, 2013.

[10] N. A. Rejab, M. S. Yusof, M. Maksud, and M. N. Nodin, "A study on the hard wearing UV treated photopolymer printing plate for articular replacement/arthroplasty (biomedical)," *Advanced Materials Research,* vol. 911, pp. 362-365, 2014.

[11] M. I. Maksud, M. S. Yusof, and M. M. A. Jamil, "An investigation of parameter effect on microcontact printing and feasibility study for application in microelectronic and biomedical," in *Biomedical Engineering International Conference (BMEiCON), 2013 6th*, 2013, pp. 1-4.

[12] L. T. Le, M. H. Ervin, H. Qiu, B. E. Fuchs, and W. Y. Lee, "Graphene supercapacitor electrodes fabricated by inkjet printing and thermal reduction of graphene oxide," *Electrochemistry Communications,* vol. 13, pp. 355-358, 2011.

[13] C. Soldano, A. Mahmood, and E. Dujardin, "Production, properties and potential of graphene," *Carbon,* vol. 48, pp. 2127-2150, 2010.

[14] M. Maksud, M. Yusof, and M. Jamil, "An Investigation onto Polydimethylsiloxane (PDMS) Printing Plate of Multiple Functional Solid Line by Flexographic," *Advanced Materials Research,* vol. 844, pp. 158-161, 2014.
[15] M. N. Nodin and M. S. Yusof, "A Preliminary Study of PDMS Stamp towards Flexography Printing Technique: An Overview," *Advanced Materials Research*, vol. Vol. 844, pp. pp 201-204, 2014.
[16] S. Hassan, M. S. Yusof, Z. Embong, and M. I. Maksud, "Angle resolved x-ray photoelectron spectroscopy (ARXPS) analysis of lanthanum oxide for micro-flexography printing," *AIP Conference Proceedings,* vol. 1704, p. 040002, 2016.
[17] S. Hassan, M. S. Yusof, M. Maksud, M. Nodin, N. A. Rejab, and K. Mamat, "A study of nano structure by roll to roll imprint lithography," in *International Symposium on Technology Management and Emerging Technologies (ISTMET)*, 2015, pp. 132-135.
[18] M. I. Maksud, M. N. Nodin, M. S. Yusof, and S. Hassan, "Utilizing rapid prototyping 3D printer for fabricating flexographic PDMS printing plate," *ARPN Journal of Engineering and Applied Sciences,* vol. 11, pp. 7728-7734, 2016.
[19] D. Bould, T. Claypole, and M. Bohan, "An investigation into plate deformation in flexographic printing," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* vol. 218, pp. 1499-1511, 2004.
[20] S. Hassan, M. S. Yusof, M. I. Maksud, M. N. Nodin, and N. A. Rejab, "A Feasibility Study of Roll to Roll Printing on Graphene," *Applied Mechanics and Materials,* vol. 799-800, pp. 402-406, 2015.

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