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A Feasibility Study of Roll to Roll Printing on Graphene

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Abstract. Roll to roll process is one of the famous printing techniques that are possible to create graphic and electronic device on variable substrate by using conductive ink. Graphene is an example of material that can be used as printing ink which usually used in producing micro-scale electronic devices. Here, it is proposed that extending roll to roll printing technique into the multiple micro-scale printing fine solid line onto substrate by using graphene as a printing ink. Flexography is a high speed roll to roll printing technique commonly used in paper printing industry. And this study elaborates the feasibility of graphene as a printing ink use in combination of flexography and micro-contact or micro-flexo printing for micro fine solid line. This paper will illustrates the review of graphene in producing multiple micro-solid lines printing capability for the application of printing electronic, graphic and bio-medical.

Introduction

Recently, researchers have shown that all roll to roll printing components like ink, printing plate, substrate and others, play an important roles in producing the micro-scale fine solid line. Subtrate and ink properties play the main role to achieve the best quality of printing which has solid line width of below 20µm. The example of ink properties can be ink chemistry, viscosity, rheological behavior, solvent evaporation rate, drying and etc. [1].

In previous research on flexography printing technique has been discuss by Maksud et al [2] in using carbon nanotubes (CNT) as a new type of ink for printing purposes. Two types of CNT inks which were water and solvent base were utilised. Four types of substrates which are silica, biaxially oriented polypropylene (BOPP), white blank office paper and woven cloth had been used. CNTs water base ink is the best ink which can be printed onto many substrates but maintain high electric conductivity [2].

The research done by Yusof [3] stated that by using roll to roll which is web press industrial method, the author managed to print out 50µm line width and 50µm line gap by using carbon graphic inks as printing inks as shown in Figure 1 [3]. This technique used photopolymer as a mold to transfer the ink from plate roller to substrate.

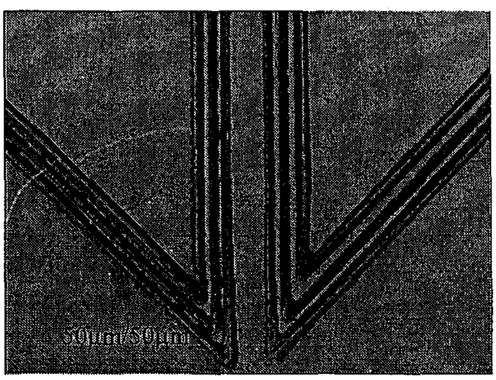


Figure 1 Printing solid lines by web press [3].

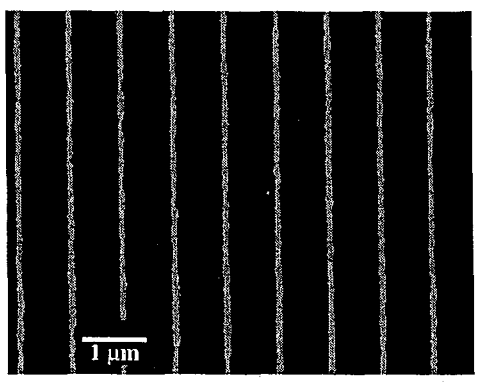


Figure 2 Printing solid lines by µCP process [4].

In other printing technique, micro-contact printing (µCP) manages to print fine solid line smaller than flexography printing. Research by Perl show that µCP can produce fine solid line below 1µm as seen in Figure 2 [4]. This work employed heavy-weight dendritic thioethers as inks and octadecanethiol as backfilling agent.

The previous research in micro-contact printing technique, by Lackowski shown that 25-nm-thick polymer layers having critical lateral dimensions on the order of 1 μm can be patterned by using a combination of μCP and polymer grafting [5].

Both printing technique which is micro-contact and flexographic have its own advantages and disadvantages. By combining both printing techniques, a new era of printing technology can be explored. The knowledge gap in contact mechanism, ink spreading mechanism and other important factors are still under further development. Previous work by Maksud et al had demonstrated that a 10μm line width with 10μm line gap was successfully printed as shown in Figure 3 by merging the two combinations of printing techniques while using graphic ink and biological ink (Fetal Bovine Serum) [6]. This achievement was attributed to the PDMS plate making technique while improving the slow production and low productivity of μCP printing techniques to much faster and excellent registration control in flexographic roll to roll printing techniques.

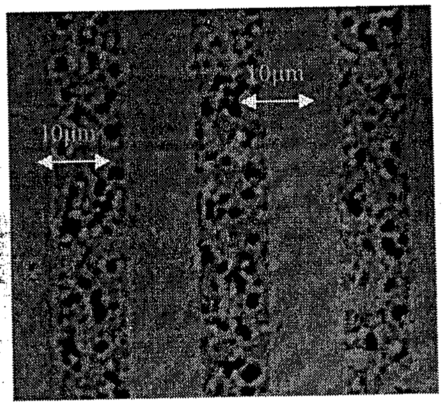


Figure 3 Printing solid lines by μCP and flexography [6].

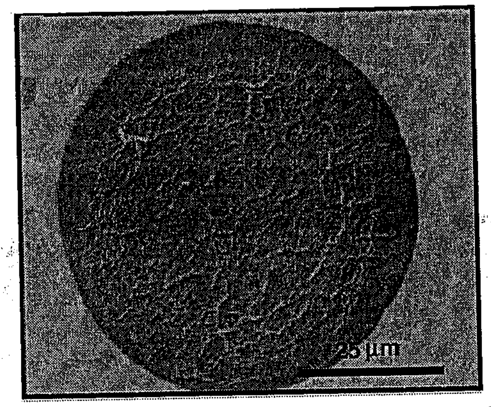


Figure 4 Graphene Oxide (GO) dot printed on the Ti foil [7].

In area of printing ink, the research done by Le et al. have discussed about graphene supercapacitor electrodes which known as electric double layer capacitor electrodes that was fabricated by inkjet printing [7]. The circular Graphene Oxide (GO) dot as shown in Figure 4 was produced with 20 printing passes at 20 min interval between passes. This 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.

Other research by Wu et al. discussed about vertical graphene field emission cathodes were fabricated using screen-printing and photo-etching techniques [8]. The properties of the screen-printed vertical graphene film were obtained with low turn on field, high maximum current density, and large field enhancement factor. The organic layer anchoring the vertical graphene sheets acted as negative feedback layer, which contributed to the high uniformity and stability of the field emission device. This study had showed that the field emission properties of the screen-printed vertical graphene cathodes are comparable and was considered low-cost method for applications of graphene in large-scale field emission devices [8].

In order to go deeply into combination of flexography printing and μCP, the suitable of graphene ink characteristics is one of the most important issue. This study will investigate other important parameters like printing speed and roller engagement that will affect the printing capability. Besides that, both of the printing techniques need to be understood well. The main target of the study is to investigate the feasibility of using graphene ink that has been use in inkjet printing to be employed in the combination of flexography printing and μCP to achieve the printing of multiple solid lines on substrate below than 10μm.

Research Methodology

Developement of Flexography Process with Graphene Ink. The printing process will start with the preparation of printing plate or stamp plate. A pattern of multiple solid line is designed on the stamp plate where the printing plate was attached to the plate roller or plate cylinder. In roll to roll or flexographic printing process [9], ink was transferred to the printing form using an engraved cylinder known as an anilox roll as shown in Figure 5. The anilox roll is the primary control of the quantity of ink transferred to the plate and subsequently the print. The volume it can hold is determined by the size, frequency and depth of the engraved cells.

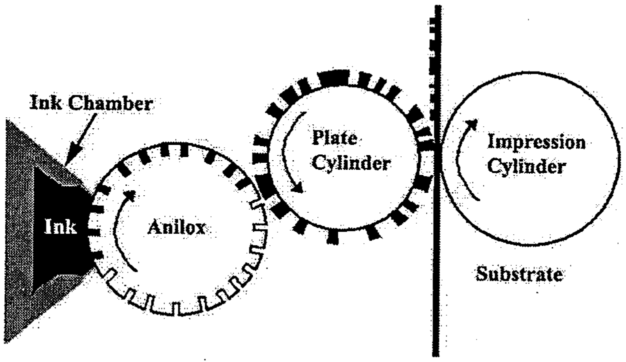
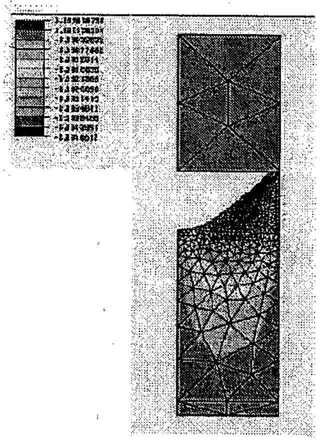


Figure 5 Schematic description of the flexographic process [9].

The printing capability is checked visually by adjusting processes parameters like printing speed and engagement between impression roller and substrates. These parameters need to be taken care during experiment due to the aim of this project are very critical in printing fine solid lines. From the printed image patterns observation, the factors which influence the defected patterns will include the ink properties, substrates, machine processes parameters and interfacial phenomena between the rolling contact [2].

The engagement affects the final print quality as elaborated by Yusof [10] due to the printing plate's deformation under the printing nip hence widening the targeted width. The author has discussed the importance of engagement at 25.4 μm (1/1000 inch) or less to enable the ability of printing under 20 μm line width features as shown in Figure 6 using finite element analysis (FEA).



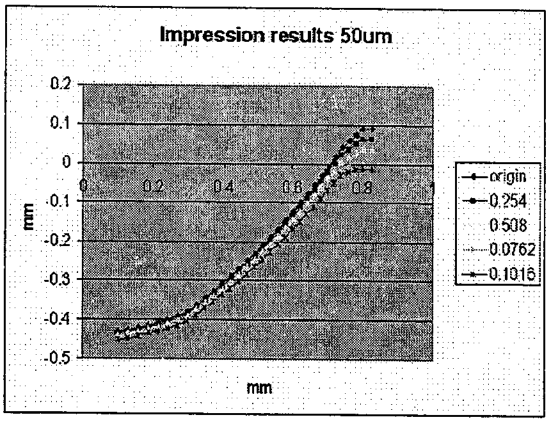


Figure 6 FEA model and impression results of 50 μm lines width [10].

An effective use of graphene ink for these roll to roll printing need a newly develop method to deposit and pattern them over large areas and at higher resolution, while meeting the requirement enforced by the nature of the target substrates [2]. The study also stated that ink effects were viscosity, solvent and ink particle size that will affect the final result.

Graphene Characteristics. A study of graphene characteristics is prior need to ensure that the material is really suitable for roll to roll printing. In high speed printing technique like flexography, the engagement between roller plate and subtract is very important due to high impact that can effect the quality of micro-printing.

Graphene is pure carbon in the form of a very thin. It is nearly transparent sheet and one atom thick. The average thickness of the graphene sheet with four layers is approximately 1.3 nm [11]. It is also remarkably strong for its very low weight and it conducts heat and electricity with a great efficiency. The material has high thermal conductivity too and because it is a two-dimensional material that is almost transparent, it interacts in other interesting and useful ways with light and with other materials. Graphene can be used in many applications but it still not commercially used.

A study done by Le stated that at room temperature, the viscosity and surface tension of the graphene oxide (GO) ink were 1.06 mPa s and 68 mN/m, respectively, and were similar to those of de-ionized water (0.99 mPa s and 72 mN/m). Therefore, graphene oxide nanosheets were stably dispersed in water, as a new method of fabricating inkjet printed graphene electrodes (IPGEs) for supercapacitors [7]. This method can be apply on roll to roll printing technique which is high speed prrinting and can be ran in large production.

Graphene material, which consists of a two-dimensional (2D) sheet of covalently bonded carbon atoms, forms the basis of both 3D graphite and 1D carbon nanotubes. Previous study by Lee prepared grahene material for experimental which 5-by-5-mm array of circular wells (diameters 1.5 mm and 1 mm, depth 500 nm) was patterned onto a Si substrate with a 300 nm SiO_2 epilayer by nanoimprint lithography and reactive ion etching. The study found that force displacement behavior is interpreted within a framework of nonlinear elastic stress-strain response, and yields second- and third-order elastic stiffnesses of 340 Newton per meter (Nm^{-1}) and −690 Nm^{-1}, respectively. The breaking strength is 42 Nm^{-1} and represents the intrinsic strength of a defect-free sheet. These quantities correspond to a Young's modulus of E = 1.0 terapascals, third-order elastic stiffness of D = −2.0 terapascals, and intrinsic strength of sint = 130 gigapascals for bulk graphite. These experiments establish graphene as the strongest material ever measured, and show that atomically perfect nanoscale materials can be mechanically tested to deformations well beyond the linear regime [12].

In other study, graphene performances as transistor channel and the compatibility of its production with existing industrial micro-electronic processes are being actively assessed in single gate, top–bottom gates and double side-gates configurations. Electrode contacts are better and current densities are potentially much higher than parallel nanotube carbon nanotubes - field effect transistor CNT-FET [13]. The graphene can be printed precisely into device active areas of a substrate, because both substrate and stamp can have prefabricated alignment marks and can be used during a transfer printing.

Conclusion

The preliminary study of roll to roll printing process of micro-contact and flexography printing is essential towards the combinations of both printing techniques prior to use graphene as ink. It is 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 feasibility study of graphene as a printing ink to be used in combination of flexography and micro-contact printing in producing multiple micro-solid lines are feasible due to the success in other printing techniques such as ink jet [7]. This work is practically used in electronic printing industries that aimed on printing multiple micro-solid lines where it can also be applied in other printing industries like graphic printing and biomedical purposes.

Acknowledgement

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