International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 06 | June-2016 www.irjet.net p-ISSN: 2395-0072

An All Inkjet Printed Capacitor on Glass Substrate Using Solvent Based (PVP) Ink

Khushbeen
Department of Printing Technology
GJUS&T, Hisar, Haryana, India
Email- khushveen12@gmail.com

Abstract- Inkjet printing is counted as one of the widely used technologies for printed electronics. This paper reports a flexible capacitor which has been all-inkjet printed on a glass substrate using solvent based (PVP) dielectric material. The optimization of the morphology of insulating layers to obtain a thin, homogeneous and pin-hole free layer is the key aspect behind the work. The parallel plate capacitor design uses a combination of heat curable silver ink and a new solvent based ink, printed on to the glass. This new inkjet printable dielectric ink is baked at 150°C for 40 minutes to achieve a thin dielectric film. A significant effect of ink has been realized over the printed dielectric layer. A well-defined morphology can affect linearly the functionality of a printed electronic device e.g. capacitor where the quality of the dielectric layer becomes a prime factor for the electrical performance and its application.

I. INTRODUCTION

Inkjet printing has become an essential technology for many applications. The ability of the inkjet technology to deposit the precise amount of a liquid in well-defined pattern makes it more popular for fabricating electronic devices. It is a computer to print technology [1], in which deposited layers follow a pre-designed digital pattern. As an additive technique this technology provides the advantage of fabricating the devices with low cost, minimal waste generation and efficient handling of expensive materials [2]. Many research initiatives and commercial applications have emphasized the increased uses of inkjet technology. Printed electronics [3] as a term can be included in this segment which refers the use of printing process to fabricate the electronic devices.

In the present work, inkjet printing has been selected as a key printing process for the printing of capacitors. The foremost criteria for printed electronics have always been accuracy and uninterrupted deposition of functional material [2]. This gives the possibility of fabricating the devices (active or passive) for the electrical functionality and its application. One of such device is a printed capacitor [4] which requires a uniform and a pin hole free dielectric layer. The term fully inkjet printed capacitors is used when the complete device is fabricated using inkjet technology without using any other deposition technique. The capacitors consist of three layers, one insulating dielectric and two conducting electrodes. Here an attempt has been made to get a thin, homogeneous and pin-hole free dielectric, so that a high capacitance can be achieved. The device was fabricated on glass substrate with silver nano-particle ink for electrodes and solvent based ink (PVP) for the dielectric. After deciding all parameters, the entire device was printed with the mentioned technique. Later on, the device was evaluated on the basis of the surface profile and electrical measurements. The conclusions were made on the basis of results which were obtained by the surface and electrical measurements of the device.

II. BACKGROUND

The capacitors can be fabricated by using inkjet technology in a number of ways. Excluding inkjet, other printing processes are also used to fabricate the capacitors [5, 6]. Every changed printing parameter and material used would influence the morphology of the printed layers, and therefore it would affect the electrical characteristic of the capacitor [7, 11]. Exploration and development of various materials have helped to deploy capacitors which are printed by inkjet process. Application of inkjet printing technology to fabricate a Metal-Insulator-Metal (MIM) capacitor is studied comprehensively. A MIM capacitor on Aluminum Oxide (Al_2O_3) resin hybrid film substrate with a structure of Barium Titanate ($BaTiO_3$) resin hybrid film sandwiched between two silver (Ag) electrodes is prepared by inkjet printing process. The essential prerequisites of interlayer integrity among the dissimilar layers used in MIM capacitors are considered. The steps taken to print the MIM capacitors: the initial step is to print Al_2O_3 resin hybrid film followed by printing silver bottom electrode on the hybrid printed film. The next step is printing of $BaTiO_3$ followed by inkjet printing of resin infiltration. The last step is to print the silver top electrode. A UJ 200 Inkjet printing unit was used for this purpose. The volume of ink was set to 30 pL for silver ink and 180 pL for $BaTiO_3$ ink. The inkjet ejection speed was 2.5 to 3.5 m/s. This study on MIM capacitor has recognized and established its usage in many application areas. The major challenge was to accomplish a uniform layer with no voids and pinholes especially in dielectric layer. The resin infiltration layer on top of $BaTiO_3$ layer ensures that the voids are completely filled. It was also demonstrated that the dissimilar layers are definite across the MIM capacitor, without intermixing or delamination among the layers. The results attained are a MIM capacitor with relative permittivity of around 70 at 1 MHz and the loss tangent is around 0.011 at 1 MHz. [8].

A. *An All Inkjet Printed Flexible Capacitor For Wearable Applications*

This study was done to fabricate a flexible capacitor, which is compatible with fabric for future use in wearable electronics. The inkjet printer used in this research was DMP 2831 with 10 pL drop volume. The capacitor was fabricated on to a 75 µm thick flexible polyimide film (Kapton). A silver nano-particle ink was used for conductive electrodes and an inkjet printable photoresist (SU-8) was chosen to print the dielectric layer. The bottom silver electrode was printed using a drop space of 15 µm and curing was done for 10 minutes at 150°C in a conventional oven. Then dielectric layer was printed using same drop space and cross linked in a UV chamber for 10 seconds. Finally, the top electrode was printed and cured with the same conditions as for the bottom electrode. The thickness of the SU-8 dielectric layer was found around 15 µm with a relative permittivity of 4.2. The value of attained capacitance with this capacitor was 48.5 pF at 100 Hz, 48.3 pF at 1 kHz, 46.5 pF at 100 kHz and 43.6 pF at 1 MHz [9].

III. MATERIAL AND FABRICATION

A. *Substrate and Ink*

The substrate used for this present work was glass (Microscope slides) provided by VWR. These glass slides were 1250 microns thick with a dimension of 76 mm x 26 mm.
The electrodes were printed with silver nano-particle based ink from SunChemical (SunTronic EMD5603). This ink is inflammable and contains a value of 25 % to 60 % of Ethanediol and 25 % to 60 % of Ethanol as the prime solvents [11].

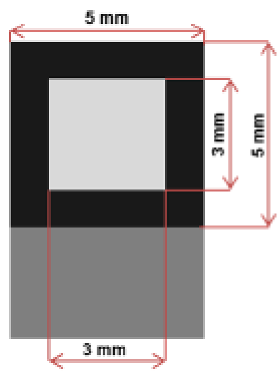
Solvent based Poly(4-vinyl phenol) (PVP) ink from Sigma Aldrich. This ink contains a monomer Poly(4-vinyl phenol) (PVP), a cross linking agent Poly(melamine-co-formaldehyde) methylated (PMF), and a solvent Propylene glycol monomethyl ether acetate (PGMEA) [46]. To prepare the ink (10 mL solution), PVP (1.8 g) was dissolved in PGMEA (10 mL) with addition of crosslinker PMF (0.36 g) at PVP solution before ink-jet printing. PGMEA is used as a substance to dissolve PVP. PMF is used as the cross linking agent to polymerize the PVP monomers into a chain. While the heat propagates to the wet layer, cross linking agent combine with the monomers to form a hardened phenolic polymer layer. This ink was used to get thinner dielectric and it is called as solvent ink in further sections.

B. *Inkjet printing*

The printer used for this work was Dimatix Material Printer 2831. It is based on piezo inkjet technology. The print heads with a nominal drop volume of 1 pL or 10 pL are provided with this. Within this work a drop volume of 10 pL was used to print conductive and dielectric layers. It has 16 individually controllable nozzles at 254 µm space. Ink is filled in cartridge with the help of a syringe and to compensate the viscosity of the ink, print head can be heated up to 70°C. Minimum achievable drop space in this printer is 5 µm with a resolution of 5080 dpi and with an angle of 1.1° [12].

C. *Device Fabrication*

The bottom & top electrodes were printed with a dimension of (5 mm x 8 mm) and (3 mm x 3mm) respectively. Once the silver ink was filled in the cartridge, necessary adjustments were done to initiate the printer. The basic printing parameters for the electrodes were varied, which in this case are the drop space and resolution. A drop space of 25 µm with a digital resolution of 1016 dpi was found optimal for printing this silver ink. To obtain even thinner and more comparable dielectric layers, a solvent based ink was demonstrated. The steps to print the capacitor, in which it involved the printing of the bottom conductive electrode using silver nano-particle ink, were kept constant. The printed layer was sintered on the hotplate at 150°C for 15 minutes. This layer was then pretreated with ethanol (to increase the surface energy) before printing the dielectric. Ethanol as a solvent helped the ink to adhere and spread on the conductive silver layer in a better way. Then a dielectric layer of 5 mm x 5 mm dimensions was printed.



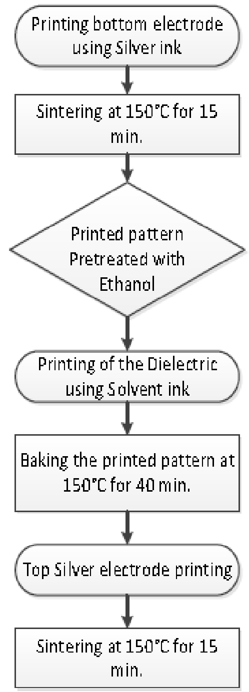


Figure 1: Architectures of the capacitor **Figure 2: Process representation of solvent ink**

The printed sample was baked on the hotplate at 150°C for 40 minutes for drying. The drying takes place by the solvent evaporation and thermal cross-linking was performed at a higher temperature. Due to the hydrophilic functional group already exist within this dielectric ink, corona treatment or any other pretreatment procedure was really not required. Henceforth the top electrode was printed on the dielectric layer and sintered at 150°C for 15 minutes. Comparable printing procedure was used to print rest of the similar devices. Figure 2 represent the steps taken to print the device.

IV. RESULTS AND DISCUSSION

A. Silver

The surface characterization for silver layer was performed with the help of Dektak 150. For the measurements, two silver layers were printed with a dimension of 8 mm in x direction and 8 mm in y direction on a glass substrate. The roughness and thickness of the printed layers was measured by placing the test sample on the manual table with vacuum activated. The used stylus radius (an L shape needle) was 12.5 µm and the amount of force exerted by the stylus during the measurements was 3.0 mg. The resolution for the scanning was set at 3.0 µm per sample and the scanning length was set according to the layer dimensions. The scan duration was determined according to the adjusted scanning length and resolution per sample. The other parameter was measurement range, which was found optimum at 6.5 µm. All parameters were set and then the measurement was performed with the scan along and across the dimension of the silver layer. The scan was done five times along and five times across the print direction to get an average thickness of the silver layers.

B. Solvent ink

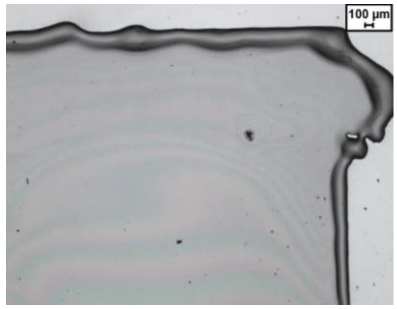
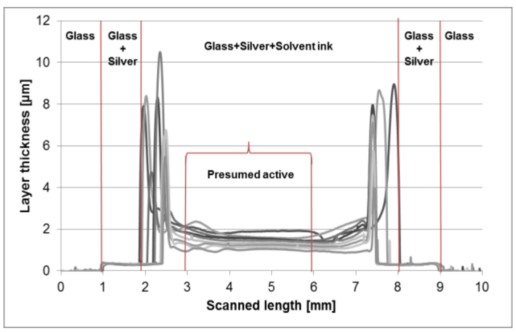


Figure 3: Microscopic image of the dielectric layer printed with solvent ink.



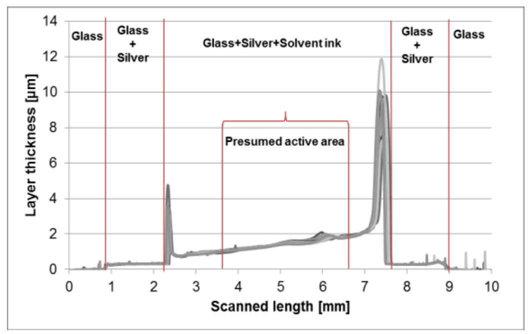


Figure 4: The surface profile of the dielectric layer including bottom silver electrode with presumed active area for the solvent ink at a drop space of 20 µm (a) along print direction (b) across print direction; with representation of ten scans (with a distance of 0.3 mm between each) from dark grey color to light grey color for first to last scan respectively

Here, Figure 4 shows ten different measurements performed with solvent ink. The measurements are shown in dark grey color to light grey color from first to last scan respectively. To print the dielectric layer with solvent ink the silver layer was pretreated with ethanol solvent to enhance the surface energy and for better spreading of the ink. The surface profile for the layer was analyzed to determine the thickness of the dielectric layer. The dielectric layer which was printed with solvent ink had a thicker border at the edges than at the center. The cause of high peaks at the edges of the layer can be correlated to the coffee ring effect phenomenon. This causes by the evaporation of the dissolved constituents in an ink deposit particularly at the edge [13, 14]. The drying process of this layer was followed by evaporating the solvent while baking it on the hotplate at 150°C for 40 minutes. This evaporation leads to the deposition of dissolved material on the edges of the layer. The peaks at the edges were observed reaching till 11 µm. Also, an increase in the layer thickness was also observed (in across print direction) while going towards the right side of the layer. It was also perceived that the layer was not having a flat surface at the center also. The reason for the increase in the thickness might be the evaporation of the solvent from the first printed line. Due to this, the dissolved material from the subsequent lines gets migrated to the first line and so on. This leads to the deposition of more material at the right side of the layer (the area which was printed first). The measurements also showed that the printed layer also had similar physical characteristics for all the scans performed in same direction. The average of nominal height of the curves excluding bottom silver electrode (250 nm), where presumed active area starts and where peak points were occurring (at edges in dielectric area), was measured. And this average was accounted as the thickness of the layer. The average height of the dielectric layer for 20 µm drop space was found around (1.1 ± 0.23) µm.

V. CONCLUSION

An all inkjet printed parallel plate capacitor has been printed on pre-treated glass substrate. The device is constructed from silver ink and a new solvent based PVP dielectric ink was used to fabricate the dielectric layer. The surface and electrical properties has been measured. The capacitance of the devices was measured with respect to drop space at a frequency of 50 kHz. Solvent ink had shown a high capacitance value (4.52 ± 0.15) nF/sq.cm at a drop space of 20 µm and the achievable thickness of the dielectric was also very less (1.1 ± 0.23) µm. But, because of the creation of pin-holes in the dielectric layer, the device was not found electrically insulating with higher drop space.

VI. REFERENCES

1. H. Kipphan. *Handbook of Print Media.* Berlin, Germany: Springer, 2001, pp. 711-725.

2. Jolke Perelaer, Patrick J. Smith, Dario Mager, Daniel Soltman, Steven K. Volkman, Vivek Subramanian, Jan G. Korvinkdf and Ulrich S. Schubert. ―Printed electronics: the challenges involved in printing devices, interconnects, and contacts based on inorganic materials‖. *J. Mater. Chem.*, vol. 20, pp. 8446–8453, June 2010.

3. Vivek Subramanian. "Printed Electronics" in *The Chemistry of Inkjet Inks*, Shlomo Magdassi, Ed. Singapore: World Scientific Publishing Co. Pte. Ltd., 2010, pp. 283-318.

4. Rabindra N. Das, Mark D. Poliks, John M. Lauffer and Voya R. Markovich. ―High Capacitance, Large Area, Thin Film, Nanocomposite Based Embedded Capacitors.‖ In *Proc. 56th Electronic Components and Technology Conference*, 2006, pp. 1510-1515.

5. Alejandro De la Fuente Vornbrock. ―Roll Printed Electronics: Development and Scaling of Gravure Printing Techniques.‖ Ph.D thesis, University of California, Berkeley, 2009.

6. Yi Liu, Tianhong Cui, Kody Varahramyan. ―All-polymer capacitor fabricated with inkjet printing technique‖. *Solid-State Electronics*, vol.47, pp.1543–1548, 2003.

7. Jongwoo Lim, Jihoon Kim, Young Joon Yoon, Hyotae Kim, Ho Gyu Yoon, Sung-Nam Lee, Jonghee Kim. ―All inkjet printed Metal Insulator Metal (MIM) capacitor‖. *Current Applied Physics,* vol. 12, pp. e14-e17, 2012.

9. Yi Li, Russel Torah, Steve Beeby and John Tudor. ―An all-inkjet printed flexible capacitor for wearable applications‖. In *Proc. DTIP,* 2012, pp. 192-195.

10. Yi Li, Russel Torah, Steve Beeby and John Tudor. ―An all-inkjet printed flexible capacitor on a textile using a new poly(4-vinylphenol) dielectric ink for wearable applications.‖ in *Proc. Sensors IEEE*, 2012, pp. 1-4.

11. Safety data sheet, Sun Jet, Sun Tronic U5603. SDS No. : 12751.

12. Dimatix Material Printer DMP-2800 Series User Manual

13. Peter J. Yunker, Tim Still, Matthew A. Lohr and A.G. Yodh. ―Suppression of the coffee-ring effect by shape-dependent capillary interactions.‖ *Nature*, vol. 476, pp. 308-311, Aug. 18, 2011.

14. Dan Soltman and Vivek Subramanian. ―Inkjet-Printed Line Morphologies and Temperature Control of the Coffee Ring Effect.‖ *Langmuir,* vol. 24, pp. 2224-2231, 2008.