All-Inkjet Printed Flexible Capacitors Utilizing SU-8 and PVP Dielectric Inks

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Abstract. *This paper presents fabrication of printed interdigital capacitors on a flexible and lightweight polyester (PET) substrate. Capacitors were fabricated using inkjet printing technology and conventional low temperature (100-150°C) curing method. The surface of printed capacitors were covered with dielectric material, which lend capacitor a specific value of permittivity, but also serves as protective coating. Cross-linked poly-4-vinylphenol (cPVP) and SU-8 were applied as dielectric materials and experimental results are compared.*

Keywords

Inkjet, printed electronics, passive electronic components.

1. Introduction

The inkjet technology is known for the ability of a high precision used when depositing a liquid in a well-defined and pre-designed digital pattern. This makes it an essential and more popular technology for fabricating electronic devices and many applications. It is a computer printing technology and the main advantages are the low cost, minimal waste generation and efficient handling of expensive materials. Therefore, it is suitable for development of new technologies or patterns. It´s also relatively fast technology of fabrication of samples. And because there is no wasting of material it is more financial efficient.

In this article, inkjet printing is primarily used for the printing of capacitors. The electrical characteristic of the capacitor is strongly dependent on the morphology of the printed layers, the material used for printing and every printing parameter.

Referring to the manner how the electrodes are arranged in a capacitor, there exist two basic types – co-planar and parallel plates. Each of these types has a different and specific process of fabrication. A well-known and common type capacitor, consists of two parallel plates from conductive material, among which is placed the dielectric material. The capacity is then depending on the area of the plates, on gap between electrodes and on the permittivity of the dielectric material being used.

However, the production of this type by inkjet printing is very difficult, because it requires a specific dielectric material which would be used and has the ability to print the top electrode without problems (pinholes not formed in the dielectric film which would short circuits). Part of the production process requires that each material must be sintered in an oven and this requires precise positioning of the samples in order to fit next upper printed layers to correct place. Finally, it makes the production time expensive. [1-4]

The second type is a co-planar capacitor. That means that both electrodes are lying next to each other and are covered with dielectric material. To increase the value of capacity, co-planar capacitors have fingers which increase the area of electrodes and thus the capacity. Fabrication of this type is not so difficult, because there are only two layers of material which needs to be printed and therefore it is less time consuming. However, to achieve capacitance values of 1pF and more, then it is necessary to increase the printed are of the capacitor.

This type has another more utilization. Covering the pattern with sensitive material it could serve as a sensor of gases or humidity. A planar interdigital sensor functions based on the rule of two parallel plate capacitors, where electrodes open up with the electric field lines surrounding the material under test. The parallel in-plane electrodes create a digit-like or finger-like periodic pattern and that's why the ''interdigital'' term is used. This electric field generated by the sensor has the ability to change the impedance. A response to the interaction between the layers provides the ability to measure the change in capacitance or impedance. The capacitive reactance is a function of system properties and with the sensor behaving similarly to a capacitor, these properties can be evaluated by measuring the capacitance. The output would be a high signal-to-noise ratio impacted by the coplanar positioning of the electrodes and stronger signal can be achieved by repeating the pattern.

Combination of printed capacitor and resistor can be created all-inkjet printed RC circuit as can be seen on Fig. 3. There also can be seen Amphenol FCI Clincher™ Flex connector, which makes measurement much easier and does not cause damage of structure.

Substrate for printing can be selected a lot of materials. As examples, let's mention Polyethylene terephthalate (PET), Polyethylene naphthalene (PEN), Polyimide (PI), or Photo paper. What material will be used depends on thermal condition of ink, substrate and purpose of usage of final product. To protect printed layers/patterns can be used transparent ink or for better protection is good to use thin lamination foil well known from lamination of paper documents.

2. Fabrication method

Fig. 1. shows the schematic representation of the fabricated capacitor. Whole pattern is printed on PET foil which has one side pretreated for printing. On the top of the meander is printed capacitor is covered from a dielectric material. Every capacitor have height of 20 mm. Dimensions can be seen in Tab. 1.

Substrate preparation:

As mentioned earlier, the substrate used for printing was pretreated from the production, so therefore it has ideal conditions for inkjet printing.

Printing:

The inks (silver nano-dispersion from Sigma-Aldrich PN-736465 and XP PriElex SU-8 polymer material from Microchem) were printed with the inkjet printer Fujifilm Dimatix DMP-2831. The platen temperature was set to 40 °C for silver ink and to 30 °C for SU-8 ink and the cartridge to 35 or 31 °C respectively. The drop spacing was set to 25 µm (1016 dpi), jetting frequency 2 kHz, jetting speed 11 m/s, as can be seen in Fig. 2. Curing was performed in laboratory oven at 140 °C for one hour. The printing result is shown in Fig. 3.

Further, I would like to mention that c-PVP dielectric material was prepared at laboratory in our university. The preparation requires the following steps.

- 10 ml of propylene glycol monomethyl acetate (PGMEA)
- Poly(melamine-co-formaldehyde) methylated (PMFM), 84 wt% in 1-butanol as a crosslinking agent
- The weight ratio of PVP to PMFM - 5:1
- Before printing, the PVP-based dielectric solution dilute in PGMEA (volume ratio 1:1) and filter with a 0.2 µ m syringe filter to remove residual agglomerations

3. Experimental results

Measurement of the capacity was performed for all the printed samples. As can be seen in Tab. 2., the measured values of capacity are in pF. Firstly, the samples with no added dielectric layer were measured. It was proven that doubling the printed area of the capacitor, it increases the value of capacity by almost twice. However, the absence of the dielectric material would question the stability of the measured values. The resulting capacity is affected by air and water vapor. Next measurement was carried out with dielectric material SU-8. In this case the capacity values increased by 21 % against the values where air was used as dielectric material. Still was maintained that the capacity raised by twice of its value while printing twice larger area of the capacitor. The other dielectric material used was c-PVP. In this case the capacity increased by about 0.8 % against the samples using SU-8. And still the capacity increased by using larger printing area of the capacitor. All values can be seen in Tab. 2 and are depict in Fig 5 and Fig 6. Next measurement was applied to sample with length and width of fingers set to 10 mm and the gap between the capacitor fingers was 500 µm. It has been investigated that there is an influence of adding layers of dielectric material. In Tab. 3 are shown the capacity values for samples with c-PVP layers from 0 up to 3 layers. It can be seen that the greatest impact is just by adding dielectric material. Adding more layers of the dielectric material does not influence much the values of the capacity.

The last measurement was applied on printed RC circuit, which is depicted on Fig. 4. Parameters of component were set to 2.3 kΩ for resistor and 20 pF for capacitor, which correspond to 3.46 MHz limit frequency. Experimentally was found that resistor has value of 2.3 kΩ and capacitor 21 pF. I received limit frequency 3.5 MHz what fit our assumption.

Width of IDC fingers	Space between IDC fingers	Length of IDC fingers
500 µm	500 µm	5 mm
250µm	250µm	10 mm
		20 mm

Tab. 1. Dimensions of capacitors, which were printed in combination

	_S043	_S044	_S045
Air	3,75 pF	6,38 pF	11,82 pF
SU-8	4,58 pF	7,71 pF	14,49 pF
c-PVP	4,92 pF	8,38 pF	15,84 pF

Tab. 2. Values of capacity of a sample which has the same dimensions but different dielectric material

0 layers	1 layer	2 layers	3 layers
2,65 pF	2,83 pF	2,92 pF	2,98 pF

Tab. 3. Values of capacity depending on different count of dielectric layers

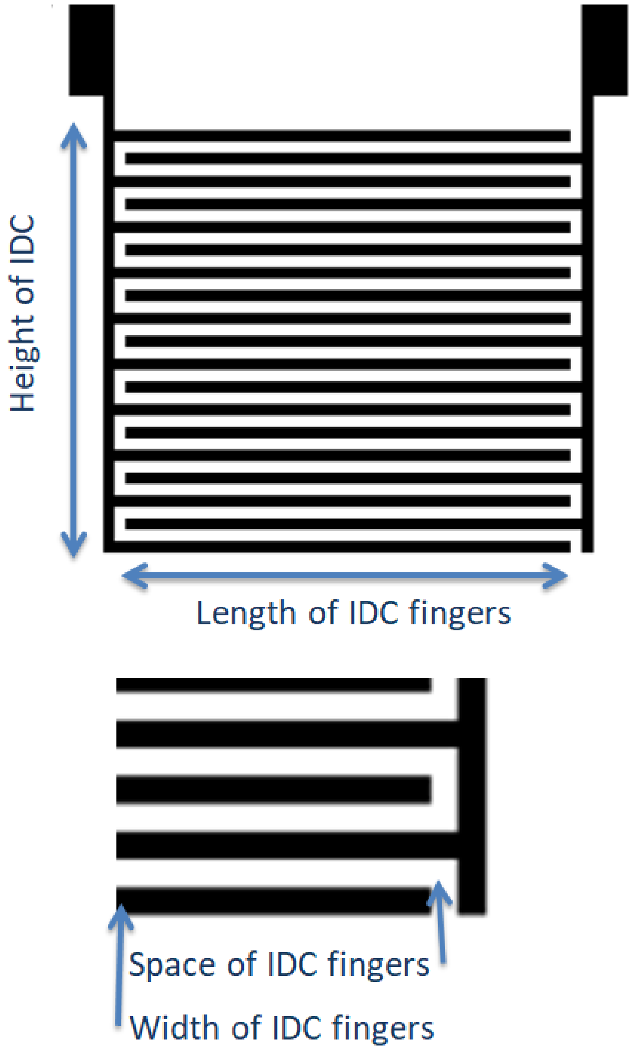

Fig 1 Dimensions of printed capacitors

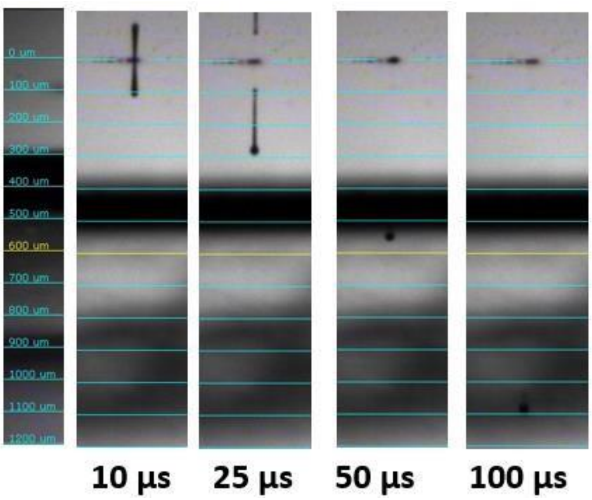

Fig. 2. Drop watcher window

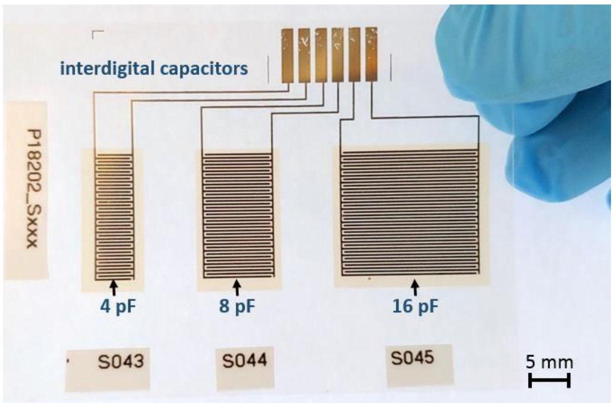

Fig. 3. Three types of capacitors have capacities of 4, 8 and 16 pF depending on the capacitor area dimensions. These three examples are covered with SU-8 dielectric material.

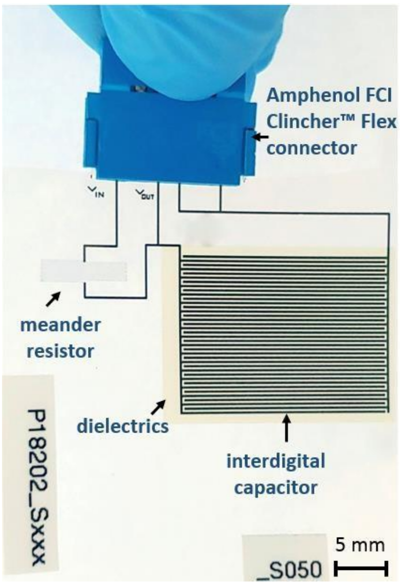

Fig. 4. All inkjet printed RC circuit with connector

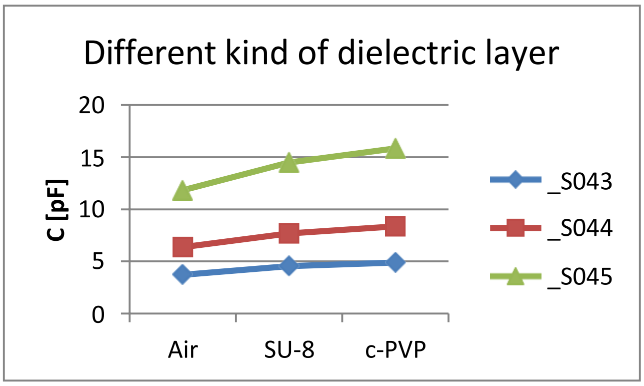

Fig. 5. Influence of dielectric material on capacity

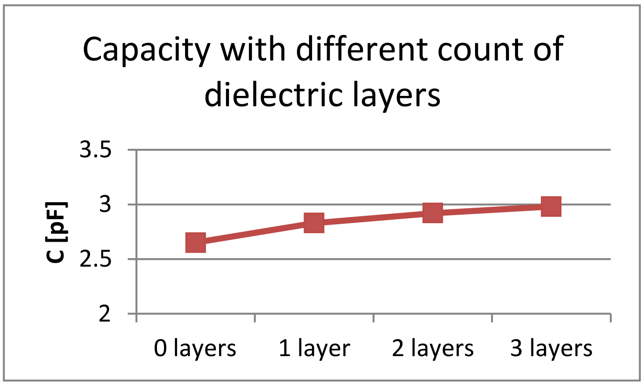

Fig. 6. Influence of number of dielectric layers

Conclusion

We established a printing process for fabrication of printed capacitors with dielectric cover material. Samples were subsequently characterized in terms of capacity, stability and repeatability. Then were studied influence of count of dielectric layer. There were obtained that 2 layers of dielectric material should be ideal. Further we printed RC circuit, for which was firstly counted limit frequency. By measuring was verified that we can print RC circuit with our desired properties. The results are still preliminary and further research will be continued.

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About Authors...

Vojtěch POVOLNÝ was born in May 1992 in Prague, Czech Republic. In February 2017 he received his Bachelor degree in Electrical Engineering from CTU in Prague (Prague, Czech Republic). He continued his master studies at CTU in Prague focusing on all inkjet printed capacitors on flexible substrates.

Florian PUCI was born on 10 July 1989 in Tirana, Albania. In the years 2004-2008 studied the "Sami Frasheri" high school in Tirana. In 2008 moved to Czech Republic to follow the preparation course for Czech language, which is part of the Charles University in Prague. In 2012, Florian PUCI graduated with a Bachelor Degree from the Czech Technical University in Prague in the study program Communication, Multimedia and Electronics, in the branch of Applied Electronics. After successfully completing the Master Study in the CTU of Prague in Electronics, in 2014 received the title Ing. Currently Florian is a Ph.D. student of the Department of Microelectronics in the Czech Technical University in Prague.