Inkjet-Fabricated Capacitors on Paper and Textile Fabrics

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Abstract- **In recent years, much attention has been given to various printing techniques to produce low-cost electronic ingredients and equipment. Inkjet printing is one of the most promising methods for printing circuit ingredients in one step almost on any substrates. In this study, the inkjet printing technique was employed for chemical deposition of silver nanoparticles by ejecting aqueous solutions of silver nitrate as metal salt and ascorbic acid as reducing agent on flexible substrates such as paper and fabric. Inkjet-deposited silver patterns were used as capacitors in electrical circuits and their performance was tested. Different values of capacitance were gained by a simple change in the size and shape of the printed capacitor. The highest capacitance values gained on an inkjet-deposited capacitor (a parallel plate capacitor with 1 cm^2 overlapped area) on paper and fabric were 85.1 and 1370 pF, respectively. Inkjet-printed capacitors (interdigital capacitors with six fingers) could display a capacitance around 20 and 6 pF on paper and fabric, respectively. Levels of capacitance achieved by the new inkjet deposition technique can successfully match and exceed the capacitance levels of conventional capacitors produced using current multi-step fabricating methods.**

***Keywords*: silver nanoparticles, inkjet printing, inkjet deposition, printed electronics, printed capacitors**

I. INTRODUCTION

In the manufacturing of passive and active electronics (such as conductors, semiconductors, and insulators), many methods, including lithography, spin coating, thermal evaporation, and printing have been used. Various printing methods such as screen printing, inkjet printing, and microcontact printing have been considered. In recent years, inkjet printing has attracted more attention because it has the advantages of simplicity of fabrication, compatibility with various substrates, non-contact, additive, low-cost and user-friendly applications [1-4].

Inkjet printing technique is the most promising printing method because of its non-contact and flexible nature. Inkjet printing methods are approximately divided into the piezoelectric type and the thermal type and each type has advantages and disadvantages. In athermal system, ink is ejected by creating and exploding an air bubble by boiling the ink, but in the piezoelectric system, mechanical pressure exerted by a piezoelectric element expels the droplet from the tiny nozzles of the printing head. The thermal system achieves higher speeds by increasing nozzles count, but in the piezoelectric system, ink motion is controlled by the voltage for precise and variable droplet size and high-speed ejection. Thermal inkjet printers can achieve at most two droplet sizes by using printheads with nozzles of different sizes. Piezoelectric inkjet printers allow for precise and variable sized drops of ink of up to five different sizes to be ejected onto the medium, resulting in sharper, grain-free photo prints with smoother tonal transitions. Thermal systems are limited to ink options because of the extreme heat involved in the droplet formation mechanism. Ultraviolet and solvent inks are too volatile and are not suitable for use in the high heat operation of conventional thermal inkjet printers. The low-temperature operation of piezoelectric printheads makes them compatible with a wide range of inks, including dye and pigment types, solvent inks, and ultraviolet curable inks. Thermal inkjet printheads need to be changed regularly because of the extreme heat involved in their operation that will damage them with prolonged use. Therefore, expensive new printheads are usually built into ink cartridges and are replaced with every cartridge change. Piezoelectric printheads run much cooler than thermal inkjet ones and can provide reliable operation for the life span of the printer [5,6].

This printing technology can be used in the fabrication of different ingredients and devices. Fabricating a Frequency Selective Surface (FSS) was one of the applications of

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inkjet in which conductive lines were deposited on thin polymeric substrates [1]. Inkjet printing was also used for embedding power sources and integration of sensors and integrated circuits (ICs) on low-cost organic substrates, such as liquid crystal polymer (LCP) and paper. The proposed strategy could potentially revolutionize RFID tags allowing for integrated sensing capabilities for various applications such as security, military, logistics, automation, and pharmaceutics [7]. All-polymer capacitors have been fabricated only by the inkjet printing technique where a conductive polymer, poly(3,4-ethylenedioxythiophene), has been employed as the electrode material of the capacitor [2]. To make a full-color PLED display, where a simple blanket deposition technique such as spin-coating is clearly not appropriate and subtractive pattern such as photolithography technique needs harsh processing conditions and extra cost, inkjet printing is the most promising technique which allows a controlled number of drops of the polymer solution (or "ink") to be deposited at specified locations on the display substrate [8]. This technique is also used in fabricating thin-film transistors by using conductive ink containing silver nanoparticles. In this process, conductive silver containing ink is printed on a silicon substrate to form electrodes of a thin film transistor [9]. Inkjet printing has also capable of manufacturing biologically friendly polymer solar cells. The fabricating of solar cellsby this method could be a cheap alternative to expensive and conventional solar cells, which are based on silicon [10].

One of the ultimate goals in electronics is the ability to directly write electronic components and circuits. Recent scientific and technical articles have emphasized the role of inkjet printing technology in the modern electronic industry for fabrication of items, which has been named printed electronics. Printed electronics area promising technology that has received tremendous interest as a mass production process of low-cost electronic devices because it increases manufacturing flexibility and decreases manufacturing costs [11,12]. Metal nanoparticles suspended in liquids are used mainly as inks or pastes to create electronic conductive designs on different substrates [13]. As an example, inkjet printing was used to fabricate an all inkjet printed metal-insulator-metal (MIM) capacitor with the structure of Ag electrode/$BaTiO_3$-resin hybrid film/Ag electrode on Al_2O_3-resin hybrid film (substrate). All the layers of MIM capacitor, as well as the substrate layers, were prepared by inkjet-printing [3]. Inkjet printing technique was also used to fabricate an all inkjet printed capacitor on a flexible substrate for future use in wearable electronics. Silver ink is used as the conductor and the dielectric is inkjet printable SU-8 photoresist [4]. Low stability of such inks and their high cost are their main disadvantages limiting their applications for printed electronics. Recently a novel method of printing metallic conductive patterns on different substrates by inkjet printing of metal salt solutions and reducing agents has been developed. This two-step printing method, compared to conventional nanoparticle printing procedures is much simpler and cheaper, environment and user-friendly and capable of producing conductive patterns in ambient conditions [14]. The developed inkjet deposition of metals is one of the most convenient methods of inserting conductive materials into the textile texture compared to other methods such as sewing, embroidery, weaving, and knitting [15,16]. In an earlier work, inkjet printing technique was used for deposition of silver printed designs for use as circuit components like conductors, resistors, capacitors, and inductors. The highest electrical conductivity was achieved on paper as 5.54×10^5 S/m [17]. Inkjet deposition technology is used in the current research for the direct writing of parallel plate and interdigital capacitors on different flexible substrates. It is the main aim of the present paper to compare the capacitance of the capacitors fabricated by the inkjet printing technique with same capacitors made by conventional methods.

II. EXPERIMENTAL

A. Materials and Methods

Silver nitrate ($AgNO_3$; 99.5% degree of purity; Acros America Manufacturing Co.) and ascorbic acid ($C_6H_8O_6$; 99.5%; Merck Germany Manufacturing Co.) were used for metal salt and reducing ink, respectively. Doubly distilled water was used as solvent for inkjet ink preparation. An hp thermal head inkjet printer (Apollo p-1200) with a black cartridge (hp26) and resolution of 300 dpi was used. Substrates with a maximum thickness of 1500 µm could be fed into this printer and the Microsoft Office 2007 was employed as printer controlling software to print out the necessary designs and patterns. A4 paper (80 g/m^2, thickness=100 µm) and woven fabric (CO/PE, warp spun yarns 65% cotton, 35% polyester, and 30 ends/cm and multifilament polyester yarn as weft, 24 wefts/cm, fabric weight per unit area of 150 g/m^2, thickness=330 µm) were used as substrates for inkjet fabrication of capacitors. Hydrophilic substrates (i.e. paper and fabric) were used because of the water-based nature of the inks. An LCR 400 PRECISION LCR BRIDGE device was used for measuring the capacitance of printed capacitors. A digital thickness Gauge (Nasj Sanj Co.) was used for measuring the thickness of substrates, i.e. paper and textile fabric. A four-point probe was used for measuring the conductivity of printed patterns.

TABLE I
SOME SPECIFICATIONS OF THE SILVER NITRATE SOLUTION AND THE ASCORBIC ACID SOLUTION

	Density (g/cm^3)	pH	Solid content (%)
Silver nitrate solution	1.51	3.5	44
Ascorbic acid solution	1.10	6.5	23

B. Ink Preparations

Distilled water was used as solvent and was added to metal salt and a reducing agent to prepare ink concentrations of 50.25% for silver nitrate and 30% for ascorbic acid (Table I). The above concentrations were prepared based on the results of our previous experiments [17]. For the reducing ink and to increase the solubility of ascorbic acid in distilled water it was necessary to add NaOH 35 % w/v to adjust final pH at 5.5. The silver salt ink was kept in its original pH. Metal salt and reducing inkjet inks were stirred for 10 min for complete dissolution before loading into the inkjet cartridges using a syringe (Fig. 1, 1st step).

C. Inkjet Printing Procedure

Before loading the reactive inks (metal salt and reducing inks) for the deposition purpose, printer cartridge should be emptied and washed with distilled water until no trace of the black ink is visible inside the cartridge. Each of the two reactive solutions (i.e. metallic salt and reducing agent) was loaded into a separate cartridge and used in inkjet printing procedures one at a time. The ascorbic acid ink was inkjet-printed first onto the substratein one or multi-steps to build up the necessary concentration for a complete chemical reduction of subsequently printed silver nitrate ink which was ejected in the next steps on top of the reducing agent printed patterns (2nd and 3rd steps in Fig. 1).

Chemical redox reaction between the metal salt and reducing inks could deposit metallic silver nanoparticles in a pre-designed pattern format. Printing sequence of AAAAGG (A=ascorbic acid and G=silver nitrate; i.e. ascorbic acid is printed four times and silver nitrate is printed two times on top) was employed based on the previous optimization experiments for inkjet fabrication of conductive silver patterns on paper [17].

Textile fabrics because of their natural uneven surface built between their constructional units which are warp and weft yarns need athicker deposited silver layer to be able to deliver a cohesive layer of silver particles with enough adhesion for conducting the electrical current. The printing sequence for inkjet fabrication of capacitors on the textile fabric was (AAAAGG-AAAAGG-AAAAGG). Inkjet-printed patterns on textile fabrics were also rinsed and subsequently heated under a thermal press before being subjected to the conductivity and capacitance measuring test.

D. Inkjet Fabrication of Capacitors on Paper and Fabric

Two types of capacitors, parallel plate, and inter-digital are widely used in different electronic applications. By definition, aparallel plate capacitor consists of two conducting plates which have been separated by a layer of air or an insulator (dielectric). The value of capacitance in parallel plate capacitor [18] depends on the overlapped area between the top and bottom electrodes as well as the dielectric constant of the layer in between. In this study, parallel plate capacitors were fabricated in three different sizes by inkjet deposition of silver nanoparticles on both sides of the paper as substrate by subsequent ejection of reactive inks (silver nitrate and ascorbic acid). Hot pressing at 150 °C (hand press) for 20 s and further rinsing the printed surfaces with distilled water were used to increase final conductivity of the deposited silver layer by extracting the reactants residues from the surface and between the chemically formed silver particles as a result of the redox reaction of reducing agent and metal salt reactive inks (the

1st step	2nd step	3rd step	4th step	5th step	6th step
Refill inkjet cartridge with water-based ink	Inkjet printing of ascorbic acid ink (aqueous ink)	Inkjet printing of silver nitrate ink (aqueous ink)	Rinsing of printed pattern by distilled water	Hot pressing of the printed pattern	Final typical printed pattern

Fig. 1. Process of inkjet deposition of silver using reactive inkjet inks.

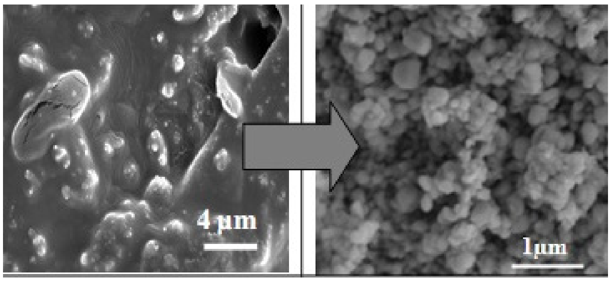


Fig. 2. SEM images of a typical silver deposited layer before and after heat treatment and rinsing: (a) silver layer deposited on paper (before hot pressing and rinsing) (×2000) and (b) silver layer deposited on paper (after hot pressing at 150 °C for 20 s and rinsing) (×8000).

4th and 5th steps in Fig. 1). Removal of these impurities could be observed by SEM observations. The typical morphology of a deposited pattern is shown in magnified SEM images taken before and after heat treatment and rinsing procedures (Fig. 2).

The same routine with different printing sequence was employed in fabricating capacitors on paper and textile fabric as substrates due to their different surface roughness and ink receiving potentials. In theory, the thickness of the deposited silver layer on each substrate should be enough for building up sufficient adjacent silver particles to conduct electricity.

Conductivity level of each pattern deposited on paper and fabric measured using a four-point probe device was 5.54×10^5 S/m on paper and 1.4×10^5 S/m on fabric as reported in [17] for printed patterns with water-based inks (i.e. printing ascorbic acid solution and silver nitrate solution). Up to now, by this method, the amount of conductivity higher than is not obtained and the amount of conductivity up to 1.4×10^5 S/m is enough for printed capacitors.

Three parallel plate capacitors with different overlapped areas of 1 cm^2 (1 cm×1 cm), 4 cm^2 (2 cm×2 cm), and 9 cm^2 (3 cm×3 cm) were inkjet fabricated on paper (Fig. 3a) and a parallel plate capacitor with the 1×1 cm^2 overlapped area was inkjet printed on textile fabric (Fig. 3b).

Interdigital capacitors [18] have been formed on one side of the paper substrate simply by inkjet deposition of conductive parallel lines or rectangles. Conductive lines with different lengths were deposited side by side to form a hand-fingers format (Fig. 4 a-d) to provide different capacitances.

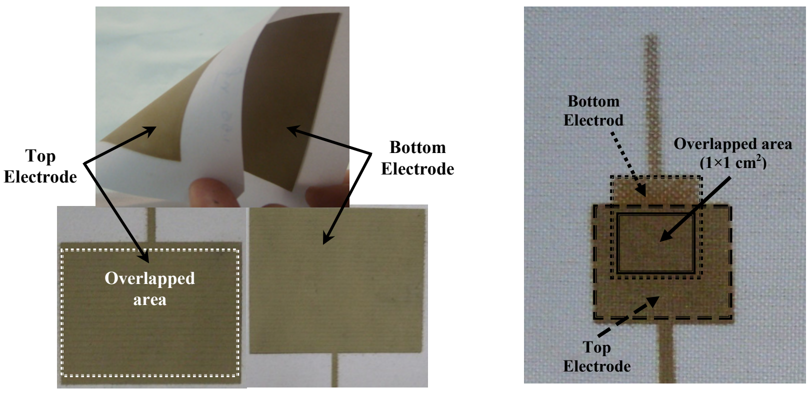
A similar procedure was also followed by deposition of silver patterns on a piece of textile fabric fed to the inkjet printer except for the printing sequence which was ejecting three times more reactive inks onto the substrate (3×AAAAGG). Higher ejection of reactive inks could build up a thicker layer of silver nanoparticles which should be cohesive and connected all over the uneven surface of the textile woven fabric. The interdigital capacitors fabricated on the textile fabric are shown in Fig. 4e.

III. RESULTS AND DISCUSSION

A. Capacitance of Inkjet-Fabricated Parallel Plate Capacitors

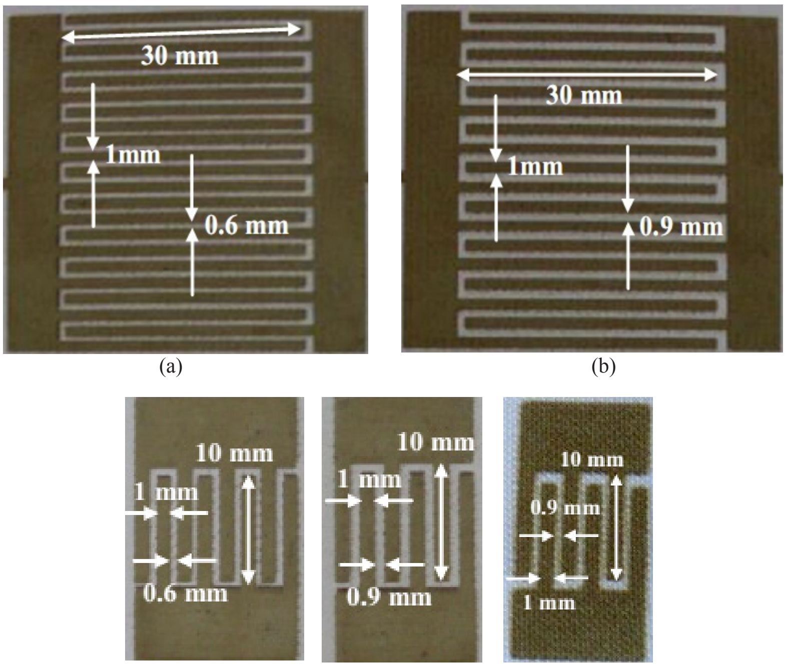
The capacitance of each deposited capacitor which was measured after connecting both plates of each capacitor to an LCR meteris shown in Table II. The capacitance of a hypothetical conventional parallel plate capacitor calculated using the following equation (Eq. (1)) was also shown in Table II in order to give an idea of the ratio between capacitance levels obtained from inkjet and conventionally fabricated capacitors. The hypothetical capacitor was presumed to be a parallel plate capacitor having metallic electrodes (plates) like aluminum separated by a layer of paper with athickness of 100 µm [2]. The capacitance of a parallel plate capacitor can be calculated using the following formula:

$$C = \varepsilon_0 \varepsilon_r A/d \tag{1}$$



(a) (b)

Fig. 3. Inkjet deposited parallel plate capacitor formed on paper having: (a) different overlapped areas and (b) textile fabric, as substrates.



(a) (b)

(c) (d) (e)

Fig. 4. Inkjet deposited interdigital capacitors by silver nanoparticles on: (a-d) paper and (e) fabric.

Where, C is the capacitance (F), A is the overlapped area of the two plates (m^2), ε_0 is the free space permittivity ($\varepsilon_0 \approx 8.8542\times10^{-12}$ $F.m^{-1}$), ε_r is the relative permittivity (sometimes called the dielectric constant) of the material between the plates (for paper, ε_r is approximately 3.4 at 800 MHz [20] and for CO/PE fabric, ε_r is approximately 1.56 at 2.45 GHz [19]), and d is the distance between the plates (m).

In all calculations, the same overlapping areas were considered for hypothetically ideal capacitors having paper as adielectric segment. The capacitance of the inkjet-fabricated capacitors can be compared to the hypothetically formed capacitor by judging the data depicted in Table II. According to the data (C_1/C_2), an inkjet-fabricated capacitor on paper can show capacitance nearly twice as the capacitance of a normal capacitor built by sandwiching a piece of paper with the same thickness between two metallic plates with identical overlapped areas. This increase in capacitance of the inkjet-fabricated capacitors can be explained by the diffusion of the reactive inks into the substrates texture during the printing procedure leading to the silver formation and deposition inside the superficial layers of the paper causing the actual thickness of the dielectric layer to be thinner than the paper thickness.

The capacitance of our 1×1 cm^2 deposited capacitor on paper was also compared to the capacitance of a capacitor built by inkjet printing technology using silver nanoparticle inks reported by Cook *et al.* [21]. Their inkjet fabricated parallel plate capacitor (with 1×1 mm^2 overlapped areas) was formed on PVP insulator (ε_{r1}=3, $A_1=10^{-6}$ m^2, and $d_1=0.8\times10^{-6}$) whilst our inkjet fabricated parallel plate capacitor (with 1×1 cm^2 overlapped areas) was fabricated on paper using water-based reactive inks (ε_{r2}=3.4, $A_2=10^{-4}$ m^2, and d_2= 100×10^{-6}m). In theoretical conditions forming capacitors with the above parameters using conventional methods and materials could give identical capacitance levels according to Eq. (1). Surprisingly, the capacitance of inkjet-fabricated capacitor using silver nanoparticle ink was reported as 28 pF [21] whilst our inkjet-fabricated capacitor employing water-based reactive inks could deliver capacitance of 85.1 pF which is three times higher. Diffusion of the water-based reactive inks into the insulator layer and formation of silver nanoparticles inside the layer which could actually shorten the distance between the deposited silver platesare responsible for the higher capacitance measured on inkjet-deposited capacitor.

Parallel plate capacitor built on fabric showed a surprising level of capacitance which is nearly 16 times higher than the level of capacitance observed from a capacitor built on a piece of paper having an identical overlapping area (1×1 cm^2). This higher capacitance can be explained by the deeper diffusion of the reactive inks ejected three times more on fabric surface compared to the paper. Silver formation in deeper layers of textile fabric can become thinner the actual dielectric layer between the two inkjet-deposited conductive silver layers increasing the

TABLE II
CAPACITANCE OF THE BEST-DEPOSITED CAPACITORS FABRICATED ON PAPER AND ON FABRIC SUBSTRATES

	Overlapped area of the parallel plates (cm^2)	Measured capacitance of the real inkjet-fabricated capacitor (pF) (C_1)	Calculated capacitance of the hypothetical capacitor (pF) (C_2)	Ratio (C_1/C_2)
Printed on paper (Fig. 3a)	1	85.1	30.1	2.8
	4	275.7	120.4	2.3
	9	596.7	271	2.2
Printed on fabric (Fig. 3b)	1	1370	4.2	326.2

capacitance dramatically.

The capacitance of our 1×1 cm^2 deposited capacitor on the fabric was also compared to the capacitance of a capacitor built by inkjet printing technology using silver nanoparticle inks reported by McKerricher *et al.* [22]. Their inkjet-fabricated parallel plate capacitors (with 1.05×1.05 mm^2 overlapped areas) was formed on PVP insulator (ε_{r1}=3.3, A_1=1.1×10^{-6} m^2, and d_1=0.7×10^{-6} m) whilst our inkjet-fabricated parallel plate capacitor (with 1×1 cm^2 overlapped areas) was fabricated on the fabric using water-based reactive inks (ε_{r2}=1.56, A_2=10^{-4} m^2, and d_2=330×10^{-6} m).

Accordingto Eq. (1), thecapacitance of our inkjet-deposited capacitor should be one-fifth of the capacitance of McKerricher's capacitor. Contrary to the theory, capacitance of inkjet-fabricated capacitor using silver nanoparticle ink was reported as 50 pF which was 1.08 times of expected theoretical capacitance,whilst our inkjet-fabricated capacitor employing water-based reactive inks could deliver capacitance of 1370 pF which is 326 times higher than the theoretical capacitance meaning a 300 times (326/1.08) better performance compared to the reported silver nanoparticle printed capacitor. Our inkjet-printed capacitor on the fabric also showed much better performance compared to another report from the above-mentioned researchers [23] proving 354 times (326/0.92) higher performance. As mentioned before, diffusion of water-based reactive inks into the insulator and formation of silver nanoparticles inside its superficial layers could actually shorten the distance between the deposited silver plates and increase the capacitance.

B. Inkjet Fabrication of Interdigital Capacitor on Paper and Fabric

Two sides of each inkjet-fabricated interdigital capacitor were finally connected to the LCR meter using silver conductive paste and the capacitance of each capacitor fabricated in different size and thickness of the linear tracks was measured and shown in Table III. The capacitance of interdigital capacitors could be theoretically calculated using the following equation (Eq. (2)) [18]:

$$C = (\varepsilon_r + 1) \times l \times [(N-3)A_1 + A_2] \tag{2}$$

Where, C is the capacitance of the interdigital capacitor (pF), ε_r is the dielectric constant of the substrate (for paper, ε_r is approximately 3.4 at 800 MHz [20] and for polyester/cotton fabric, ε_r is approximately 1.56 at 2.45 GHz [19]). l is the finger length of interdigital capacitors (µm), N is the number of fingers of interdigital capacitors, A_1 and A_2 are the capacitances per unit length of the fingers for an identical imaginary capacitor which can be calculated by the following equations:

$$A_1 = 4.409 \times \tanh\left[0.55\left(h/w\right)^{0.45}\right] \times 10^{-6} \quad (\mathrm{pF}/\mu\mathrm{m}) \tag{3}$$

$$A_2 = 9.92 \times \tanh\left[0.52\left(h/w\right)^{0.5}\right] \times 10^{-6} \quad (\mathrm{pF}/\mu\mathrm{m}) \tag{4}$$

Where, h is the thickness of the substrate (mm), w is the finger width of interdigital capacitors (mm) which is 1 mm for all inkjet-fabricated interdigital capacitors.

According to Eqs. (2), (3), and (4), it can be concluded that design factors of interdigital capacitor, including length and width of the fingers (lines), distance between fingers (gap), number of fingers, thickness of substrate, capacitance per unit length of the fingers and dielectric constant of the substrate can change the level of capacitance, which we expect from each capacitor. Interdigital capacitors with longer and thinner fingers, the lower gap distance between the fingers, and the higher dielectric constant of the substrate [24,25] possess higher capacitance due to a higher potential for storing electric charge. Capacitances measured on real capacitors having different design factors are in accordance with our expectations from the theoretical regulations.

Based on the data shown in Table III, the capacitances obtained on inkjet-printed capacitors are 19 to 114 times higher than the levels expected from the formulas which work on conventionally built capacitors. The inkjet-fabricated interdigital capacitors having shorter fingers proved to have higher capacitances probably because of the inaccuracy in the ink ejection on all parts of the substrate

TABLE III
CAPACITANCE OF INKJET-FABRICATED INTERDIGITAL CAPACITORS ON PAPER AND FABRIC SUBSTRATES

	Capacitor sample	Number of fingers	Finger length (μm)	Measured capacitance of inkjet-fabricated capacitor (pF) (C_1)	A_1 (pF/μm)	A_2 (pF/μm)	Calculated capacitance of the imaginary capacitor (pF) (C_2)	Ratio (C_1/C_2)
Printed on paper	Fig. 4a	22	30000	45.1	0.85×10^{-6}	1.62×10^{-6}	2.34	19.3
	Fig. 4b	18	30000	40.4	0.85×10^{-6}	1.62×10^{-6}	1.90	21.3
	Fig. 4c	8	10000	25.1	0.85×10^{-6}	1.62×10^{-6}	0.26	96.5
	Fig. 4d	6	10000	20.5	0.85×10^{-6}	1.62×10^{-6}	0.18	114
Printed on fabric	Fig. 4e	6	10000	6.2	1.42×10^{-6}	2.88×10^{-6}	0.18	34.4

by our non-professional office inkjet printer used in the fabrication procedures. Identical interdigital capacitors formed on paper and textile fabric showed different levels of capacitance which was almost three times higher on fabric. This phenomenon could be based on the more regular surface of paper compared to the uneven surface of fabric making the substrate geometry a vital parameter in the fabrication of interdigital capacitors.

IV. CONCLUSION

Inkjet printing due to its ability to directly produce conductive patterns on almost all substrates along with its other advantages, such as digital control, short process time, low-cost and low waste, simplicity and cleanliness of the process can be considered as a new fabricating method for manufacturing electronic components from metallic nanoparticles. In the present study, inkjet printing technology was utilized to deposit silver particles from a direct reaction between two reactive inks of silver nitrate and ascorbic acid. The technique was used for fabricating different designs of capacitors (parallel plate and interdigital) on paper and textile fabric as substrate. The substrate itself plays the role of the dielectric layer in all inkjet-fabricated capacitors where conductive silver electrodes were formed in situ on the surface of the substrate. The parallel plate capacitors fabricated on the fabric showed a very high level of capacitance due to a very high absorbing potential of the textile fabric which forms silver nanoparticles in deeper layers of the substrate which automatically decreases the thickness of the dielectric layer. The interdigital capacitors were also fabricated using the current depositing technique proving to give a 19 to 114 times higher capacity than that of conventionally designed and manufactured capacitors. The inkjet-fabricated capacitors formed on the paper and the textile fabrics can be used as effective as normal capacitors inlast single step production of electronic devices.

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