Engaging Students in Circuit Theory Laboratory Course by Incorporating Advanced Techniques in Directed Metallization and Student-Based Component Design

Reza Kamali-Sarvestani, Ephraim Nielson, and Jared Laufiso
Department of Computer Science and Engineering, Utah Valley University, Orem Utah

Abstract

Student learning and knowledge is directly related to the engagement and active participation in the classroom. Moreover, retention has been shown to increase for students who practically use their theory studies. This creates a need for students to have more practical applications of materials learned and knowledge of tools used in engineering fields. This paper explains the application of the advanced fine image printing in the Circuit Theory laboratory experiments to fabricate components and circuits. In a sequence of laboratory experiments students practice to fabricate resistors, inductors, and capacitors. In each lab they exercise their own fabricated component and compare it with the similar available commercial component. Laboratory practices end with fabrication of resonator circuits and inductive/capacitive sensors by finishing this state of the art laboratory work, participants not only can learn the fundamentals of Circuit Theory Laboratory but also improve their knowledge of current technologies in their field.

Keywords

Circuit Printing, Nano Particles, Sensors, Conductive Ink, Capacitors.

Introduction

Interdigitales capacitores(IDC) can be made using the Dimatix DMP 2800 ink-jet printer. The capacitor is designed using CAD software such as Adobe Microsoft and is printed on to paper substrate. The factors that have effect on capacitance of an IDC are the finger length, finger width, gap between fingers, end gap, number of fingers and dielectric constant. These parameters will be varied through several different IDCs, students will record and analyze the data. The dielectric constant depends on the environment of the IDC by exposing the IDC to different environments students can measure the change and learn the basics of capacitance sensing.

Each component design, fabrication, and test considered as a practice. Every practice is easy and fast enough to be done in the standard laboratory time. Fine Image Printing is environmentally safe technology and currently in use for fabrication of flexible electronics[1,2]. Developing this practice helps to achieve all academic goals of the course as well as improving engagement and retention.

This paper explains practical experiences in designing, developing and fabricating components for testing. This course will go over design, fundamentals of CAD software currently in use, by user made designs to prepare for fabrication, learning the fabrication process, and further analysis and testing of components created. This will give students practical knowledge, encourage student enthusiasm, and give opportunity for them to participate in the development of new technologies available. Assessment of the course includes students grade and their survey of the study.

Background

Paper based electronics have been attracting attention because they are low cost and environmentally friendly[3,4]. Compared with the conventional printed circuit board (PCB) process, which uses a subtractive method of etching away metal foil. With Drop on Demand (DoD) Fine Image Printing, droplets of conductive ink are placed only where desired, this eliminates extra costs and waste, and requires fewer steps than traditional PCB manufacturing techniques[5]. Another great advantage of ink-jet printing is the ability to print onto organic substrates. Hence ink-jet printing is an environmentally friendly process.

Methodology

The Dimatix Drop Manager software requires a monochromatic bitmap image. Patterns can be designed using any computer aided design (CAD) software that can produce a bitmap image. Microsoft Paint or Adobe Photoshop are examples of such CAD software tools. Each pixel will represent where a drop may be placed. To calculate the size of the printed image it is necessary to take into account the drop diameter of an ink droplet.

In order to accurately print the IDC designs it is necessary to find the drop diameter[6,7]. For this project we used Diamond Jet Silver Nano Ink printed on to Epson paper. Using the DMP-2800 fiducial camera the drop diameter was measured to be 30 µm. If the drop spacing is to close, then the ink tends to pool up causing inconsistent print quality. If the drop spacing is too large then the ink may not be continuous. We found that using a drop spacing of 25 µm provided sufficient overlap and avoided pooling up of the ink. In one of the samples it was observed that the resistivity was not uniform on the x and y axis. In the x direction the resistivity measures about 0.5 Ω/cm, however in the y direction it measured 100 KΩ. This is due to drop spacing being too large and the tendency of the ink to flow in the direction of the printing head movement. It was found that with a drop diameter of 30 µm, 25 µm produced a uniform conductivity in both the x and y directions with 0.5 Ω/cm.

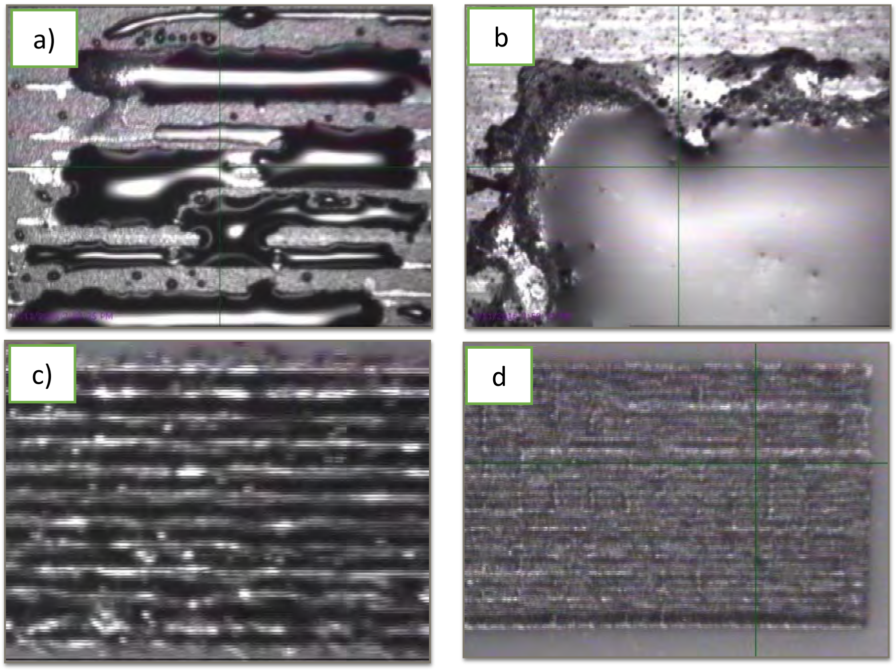

Figure 1. a) Top Left: Substrate is too hydrophobic. b) Top Right: Drop spacing is too close causing pooling. c) Bottom Left: Drop spacing is too large causing nonuniform conductivity d) Bottom Right: Uniform drop spacing, in this case drop spacing was 25µm.

In this study we included the Circuit Theory class. We had the students design IDCs of varying parameters. The specific parameters we left open for the students to choose. We used a DMM to measure the capacitance of the various capacitors. Electing the IDC with the best capacitance, we then varied the gap size between the fingers and the number of fingers to observe the change and optimize the capacitance of the IDC.

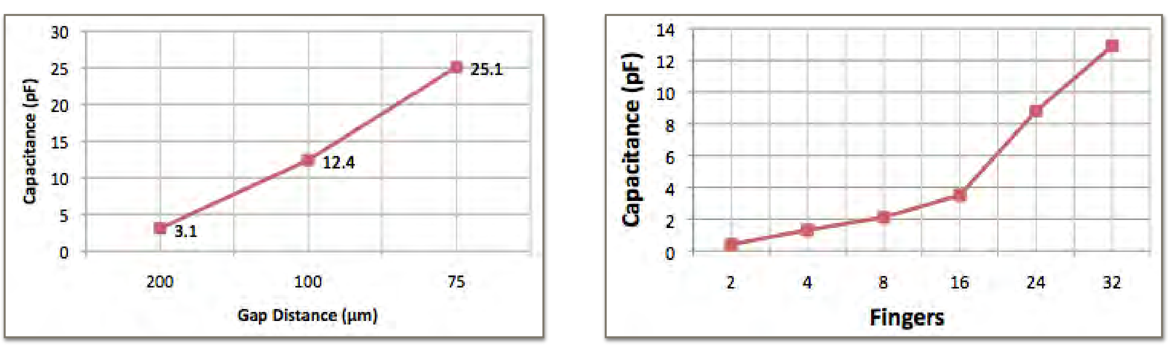

Figure 2. a) Right when decreased the gap size from 200 µm to 75 µm increased the capacitance form 3pF to 12.4 pF. b) Right: Varying number of fingers.

An IDC can be used as a sensor by changing the Dielectric constant and then measuring the change in the capacitance. Figure 3 illustrates the application of an IDC as a liquid level sensor by immersing the IDC in a liquid and measuring the change in capacitance.

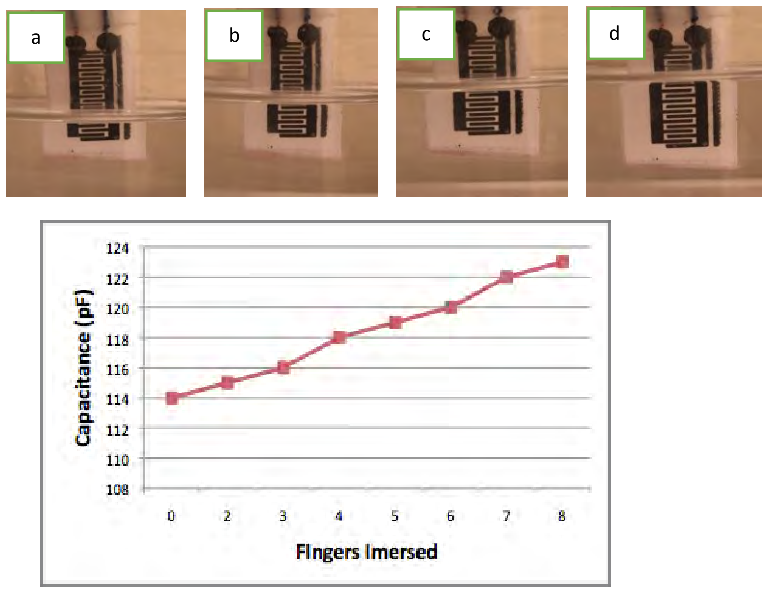

Figure 3. Change in capacitance verse liquid level.

Each environment that an IDC is exposed to has a unique dielectric constant, by measuring the capacitance it is possible to identify or speculate what types of materials are present. To help the students build intuition of this principle, students exposed their IDC to various materials and noted the unique capacitance due to the dielectric constant of each material.

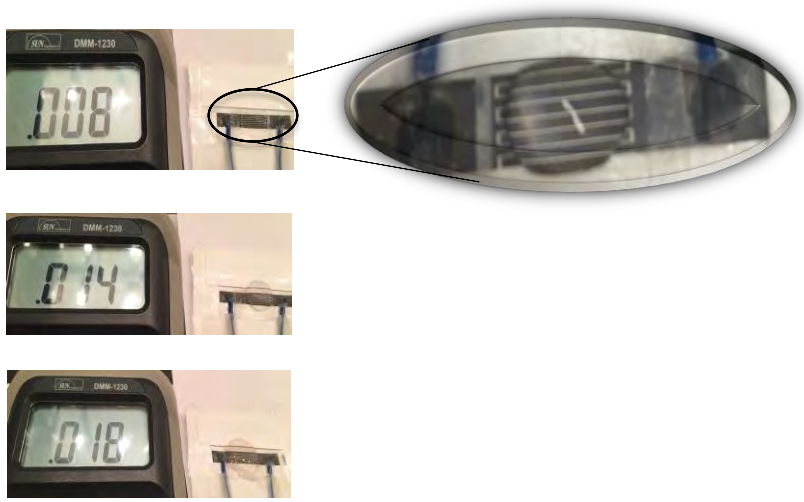

Figure 4. Top Left: Exposed to air. Bottom Left: Exposed to tap water. Top Right: IDC with a droplet of water.   Bottom Right: exposed to dish soap.

Conclusion

In this study inkjet printing has been performed as a method of metallization. It can be performed on different substrates with different textures, with the proper surface treatment to ensure good conductivity. Compared to the traditional electrolytic method (subtractive) for PCB manufacturing, the additive process water-based process greatly reduces the number of manufacturing steps, eliminates the need for toxic solvents, and greatly reduces metallic and chemical waste. Circuit patterns made using this technology have broad application and can be applied to many future PCB demands of the marketplace such as medical circuits, flexible material, and sustainable electronics. Using this technology student of Circuit Theory Laboratory course, designed fabricated and tested their own capacitors and sensors. It was fast and reliable experiment and engaged students in laboratory works.

References

1 S. Karsten, et al., "Environmental Management in Semiconductor and Printed Circuit Board Industry in India – Part II: Benchmarking and International Best Practice Sharing," *Asian Green Electronics, 2004. AGEC. Proceedings of 2004 International IEEE Conferenc* , 2004, pp.150,157.

2 B. Arfaei, et al., "Dependence of solder joint reliability on solder volume, composition, and printed circuit board surface finish," Electro. Components & Tech. Conf., 2014, pp. 655-665.

3 R. Kamali-Sarvestani, E. Nielson and P. Weber, "Sustainability in printed circuit board manufacturing decreasing waste using additive technology," *Technologies for Sustainability (SusTech), 2015 IEEE Conference on*, Ogden, UT, 2015, pp. 67-72.

4 G. Shaker, S. Safavi-Naeini, N. Sangary and M. M. Tentzeris, "Inkjet Printing of Ultrawideband (UWB) Antennas on Paper-Based Substrates," in *IEEE Antennas and Wireless Propagation Letters*, vol. 10, no. , pp. 111-114, 2011.

5 A. Rida, L. Yang, R. Vyas and M. M. Tentzeris, "Conductive Inkjet-Printed Antennas on Flexible Low-Cost Paper-Based Substrates for RFID and WSN Applications," in *IEEE Antennas and Propagation Magazine*, vol. 51, no. 3, pp. 13-23, June 2009.

6 A. Manut, A. S. Zoolfakar, N. A. Muhammad and M. Zolkapli, "Characterization of Inter Digital capacitor for water level sensor," *Micro and Nanoelectronics (RSM), 2011 IEEE Regional Symposium on*, Kota Kinabalu, 2011, pp. 359-363.

7 Y. Shirahama, R. Shigeta, Y. Kawahara, T. Asami, Y. Kojima and K. Nishioka, "Implementation of wide range soil moisture profile probe by coplanar plate capacitor on film substrate," *SENSORS, 2015 IEEE*, Busan, 2015, pp. 1-4.