SIMULATION OF FLEXIBLE ELECTRONICS INKJET PRINTING CAPACITORS CHARACTERISTIC

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DEDICATION

To my beloved parents who give me their full support by brightening me up when the day is cloudy.

To my comrades that creates a very positive learning environment to motivate us during the hard time among the process to finish this thesis.

To my future wife, who always gives me her back, help me to settle most of the life trivia among all the weekends during this master's degree.

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ABSTRACT

Flexible electronics which are a disruptive science that requires multi-disciplinary research is developing rapidly in many electronic sectors recently. To achieve flexible electronics, inkjet printing is one of the most promising ways to print the circuit ingredients with almost using any substrates. For this study, the metal-insulator-metal capacitor (MIMCAP) is the target to design. MIMCAP is playing a crucial part in integrated electronic circuits, it is formed by sandwiching two parallel metal plates with a thin dielectric in the middle of the two metals. From the research, most of the materials that are used to print MIMCAP are based on the combination of heat-curable silver and poly-4-vinylphenol (PVP). Due to the usage of the nano silver-based ink for current technology is not really budget friendly which costs about RM1800 for 100g. Therefore, this study focuses on investigating the materials that can replace silver. The objectives of this project are to design the MIMCAP by using a material that has a better electronic performance by optimizing the device structure design, to analyse the electronic performance of the designed MIMCAP, and to validate the proposed device structure with other similar works. The design and analysis of this study were carried out using COMSOL Multiphysics simulation tools. Several parameters such as variation of the gap between the metal and insulator, dimension of the MIMCAP, design structure of the MIMCAP, and the number of the layer coating of the insulator observed better electronic performance in terms of capacitance. Similarly, from the research, most of the MIMCAP capacitance that uses the nano silver-based ink is about 9 pF to 310 pF with the dimension from $1\ mm^2$ to $36\ mm^2$. The result of this study is shown by using the Barium Titanate and Graphene as the dielectric and conducting layer with the advanced MIMCAP design structure that stacks up together and forms a multilayer MIMCAP, the capacitance that the proposed design structure can generate is $1.5633\ \mu F$. With that so, all the parameters set inside the COMSOL Multiphysics follow the room temperature as the standard.

ABSTRAK

Elektronik fleksibel yang merupakan sains mengganggu yang memerlukan penyelidikan pelbagai disiplin berkembang pesat dalam banyak sektor elektronik baru-baru ini. Untuk mencapai elektronik yang fleksibel, percetakan inkjet adalah salah satu cara yang paling menjanjikan untuk mencetak bahan litar dengan hampir menggunakan mana-mana substrat. Untuk kajian ini, kapasitor logam-penebat-logam (MIMCAP) adalah sasaran untuk mereka bentuk. MIMCAP memainkan peranan penting dalam litar elektronik bersepadu, ia dibentuk dengan mengapit dua plat logam selari dengan dielektrik nipis di tengah-tengah dua logam. Daripada penyelidikan, kebanyakan bahan yang digunakan untuk mencetak MIMCAP adalah berasaskan gabungan perak yang boleh dirawat haba dan poli-4-vinilfenol (PVP). Disebabkan penggunaan dakwat berasaskan perak nano untuk teknologi semasa tidak begitu mesra bajet yang berharga kira-kira RM1800 untuk 100g. Oleh itu, kajian ini tertumpu kepada penyiasatan bahan yang boleh menggantikan perak. Objektif projek ini adalah untuk mereka bentuk MIMCAP dengan menggunakan bahan yang mempunyai prestasi elektronik yang lebih baik dengan mengoptimumkan reka bentuk struktur peranti, untuk menganalisis prestasi elektronik MIMCAP yang direka bentuk, dan untuk mengesahkan struktur peranti yang dicadangkan dengan kerja lain yang serupa. Reka bentuk dan analisis kajian ini dijalankan menggunakan alat simulasi Multifizik COMSOL. Beberapa parameter seperti variasi jurang antara logam dan penebat, dimensi MIMCAP, struktur reka bentuk MIMCAP, dan bilangan salutan lapisan penebat diperhatikan prestasi elektronik yang lebih baik dari segi kemuatan. Begitu juga, daripada penyelidikan, kebanyakan kapasiti MIMCAP yang menggunakan dakwat berasaskan perak nano adalah kira-kira 9 pF hingga 310 pF dengan dimensi dari 1 mm^2 hingga 36 mm^2. Hasil kajian ini ditunjukkan dengan menggunakan Barium Titanate dan Graphene sebagai lapisan dielektrik dan pengalir dengan struktur reka bentuk MIMCAP termaju yang disusun bersama dan membentuk MIMCAP berbilang lapisan, kapasiti yang boleh dihasilkan oleh struktur reka bentuk yang dicadangkan ialah 1.5633 μF. Dengan itu, semua parameter yang ditetapkan di dalam COMSOL Multiphysics mengikut suhu bilik sebagai standard.

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LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminum Oxide
CDM	-	Charge Device Model
DUT	-	Design Under Test
e-jet	-	Electrohydrodynamic inkjet
ESD	-	Electrostatic Discharge
HBM	-	Human Body Model
HfO_2	-	Hafnium oxide
IC	-	Integrated Circuit
LPE	-	Liquid-phase exfoliation
MIMCAP	-	Metal-Insulator-Metal Capacitor
MLCCs	-	Multilayer Ceramic Chip Capacitors
MSC	-	Micro-Super-Capacitor
PVP	-	Poly 4-vinylphenol
R2R	-	Roll-to-roll
Reynolds number	-	R_e
Si_3N_4	-	Silicon Nitride
SiO_2	-	Silicon Dioxide
We	-	Weber number

LIST OF SYMBOLS

ε_r	-	Relative Permittivity
k	-	Dielectric constant
ε_0	-	Vacuum permittivity ($8.85 \times 10^{-12} F$)
μ_0	-	Magnetic constant ($1.25663706 \times 10^{-6} m\ kg\ s^{-2} A^{-2}$)
Ω	-	Ohm
γ	-	Ink surface tension
η	-	Ink dynamic viscosity
p	-	Ink density
a	-	Printer nozzle radius
v	-	Ink drop velocity

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Electronic and electrical are one of the most important elements for quality life in this modern era. With the help of electronics, the work efficiency can improve significantly. To further improve the abilities of an electronic, the fundamental which is the silicon technology will also need to improve. According to Moore's Law, speed and capability of computers are expected to double every two years with an increase the number of transistors that a microchip can contain [1]. One of the ways to continue carrying on Moore's Law will be printing technologies. This technology is fundamentally different compared to the traditional silicon technology, where the final goal is to integrate the greatest number of the transistors within an area (as for 2021, the greatest count of the transistors within a processor is about 57 billion) with the drawback of extremely complicated processes. There are quite a few steps usually for the silicon IC chip production, from the materials for wafer preparation, designing to define the transistor and interconnects, verifications, production by lithography and etching, and finally packaging. With regards to the extremely high cost for the operation and setup, this end up the major semiconductor chip manufacturers in the market today are just about fingers on two hands[2].

On the contrary, the printing technologies aim to lower down the cost within an area and enable new applications with the combination of the high-throughput production process of large area electronics by using new functional materials [3]. With these good points, the future prospect of the printing technology for the devices, circuits, and the electronic components on a flexible material such as Polyethylene terephthalate (PET) and polyethylene naphthalate (PEN) are showing a rapid developing trend in several fields that is highly beneficial like health-monitoring system, flexible solar cells, wearables, sensors, and RFID-systems. With the wide range of technologies, the printing process is now able to design complex and functional demanding 3D or 2D objects with the aid of computers. To avoid misunderstanding, even though printed electronics and organic electronics are sometimes used interchangeably, they are not referring to the same group of technologies. Undeniably, organic electronics and printed electronics do share a lot of similar technologies and methodologies but strictly speaking, printed electronics refer to the electronic components that fabricate by either conventional or digital way of the printing technique.

Inkjet printing capacitor is the main topic for this project where the capacitor is fabricated by using a printing device. There are some materials as the comparison for the capacitance for the printed capacitor that can be produced. To print a capacitor, the basic structure is a parallel plate which is known as Metal-Insulator-Metal Capacitor (MIMCAP). MIMCAP has several advantages that show it is one of a crucial component inside the semiconductor field, especially for IC.

1.2 Problem Statement

For printing electronics, one of the most crucial elements to have a high yield is the functional materials. To fabricate the inkjet printing capacitor or MIMCAP, the materials that are used for the conductor and the insulator must be different to have higher capacitance. From the most research, the typical functional materials that are used as the conductor layer for the MIMCAP is silver which the silver ink is always pricey, costing about RM2000 for only 100g. Since silver is not only the functional materials that can construct the MIMCAP, but the functional material that has more budget efficiency in the market which provides a better electronic performance is the main effort for the research.

With the basic MIMCAP design structure, the capacitance of the MIMCAP that can produce is limited. To have a higher capacitance of the MIMCAP, the better electronic structure is needed to rebuild together with the better functional material.

1.3 Research Motivation and Objectives

Most of the available conventional MIMCAP only have 3 metal layers to produce capacitance for the IC. Since the MIMCAP has the capability to eliminate the electrostatic discharge with a certain amount of capacitance, the higher capacitance shows better protection. With a higher capacitance MIMCAP, the conventional electronic structure of the MIMCAP is not applicable anymore and this is the opportunity to introduce a better design structure with a better functional material at a lower cost. This is not only to lower the cost but also can help to improve the reliability and the performance of the IC.

There are 3 objectives for this project which are mainly to improve the conventional MIMCAP and compare the improved MIMCAP with other similar works.

The objectives of the research are :

(a) To design the MIMCAP by using a material that having better electronic performance by optimizing the decide structure design.

(b) To analyse the electronic performance for the designed MIMCAP.

(c) To validate the proposed device structure with other similar works.

1.4 Research Scope

The printed electronic is a huge area of research in which they are multitudes of ways to address the better fabrication. However, for this project, it will only focus on the capacitance improvement for the MIMCAP with the help of the simulation tools. Following are the project scopes:

1. Research and re-design on the MIMCAP electronic structure to replace the conventional MIMCAP.
2. Replace the common functional material (Silver) to a functional material that having better electronic performances.
3. Showing the steps, precaution, and the practicality during the fabrication process.
4. Analyzing the design capacitance by using the COMSOL Multiphysics simulation tool.
5. Having some comparison or benchmarking with other similar work to prove the proposed MIMCAP is having a better performance.

1.5 Report Outline

This project report is divided into five chapters, which are Introduction, Literature Review, Research Methodology, Result and Discussion, and Conclusion. Chapter 1 covers the background, problem statement, research motivation and objectives and research scope. For Chapter 2, this chapter will cover all the researched papers and the information that is helpful for this thesis. Chapter 3 will cover the project flows, the steps for starting the simulation and some simulation results. Chapter 4 will cover all the results from the simulation and the result will be summarized into a graph chart. For Chapter 5 will cover the conclusion and future works.

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APPENDIX

The simulation files for the COMSOL Multiphysics in this project are uploaded into google drive which is in the link below:
https://drive.google.com/drive/folders/1328H3xUEUxle7rH0ILhaGU5foeMfPj7_?usp=sharing

EndNote library file:
https://drive.google.com/drive/folders/1_6C9ZnmCisMBgg9LTb9P4lpAGrDgR9J2?usp=sharing