DESIGN AND ANALYSIS OF THE SILICON-BASED INTEGRATED METAL-INSULATOR-METAL CAPACITOR

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DEDICATION

This project report is dedicated to my family and friends who has been my source of strength and inspiration when I thought of giving up. And, to those who has been contributed directly or indirectly during this work.

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ABSTRACT

At present, the high possible of miniaturization of a component has become an urgent necessity, particularly in silicon-based integrated circuit design. One of the keys to enhance the integrated circuits by constructing a Metal-Insulator-Metal (MIM) capacitors in the silicon-based of electronic application. Hence, it requires significantly increased specific capacitances by utilization of high-k dielectric materials. These dielectrics must be formed in three-dimensional capacitor structures in order to attain high capacitance per chip area. In this present work, the capacitor designed for silicon based integrated MIM capacitor using COMSOL Multiphysics software to create its cylindrical operational model. The identical structural parameters' capacitance levels and characteristics been simulated and analyzed such as the effect of different dielectric materials properties in the aspect of K value, distance and area of the material. It also investigated the effect of metallic plate area and thickness for the silicon based integrated MIM capacitor applied. Consequently, the high K-value of dielectric materials performance shown that the optimized parameters that suitable to be paired with Silicon-based integrated MIM capacitor where the surface area that perform good stability and capacitance is the surface area of 314.16 mm^2 and 500 μm of its thickness. It is expected that this study provided a good simulation result, which verified the rationality of the silicon based integrated MIM capacitor design with its relationship of the material chosen and its optimized parameter for this MIM capacitor. Thus, this study offers a capable and competent way for the research of ideal materials for high-performance and the efficiency of an integrated MIM capacitor for flexible electronic applications.

ABSTRAK

Pada masa ini, kebarangkalian terhadap pengecilan komponen yang tinggi telah menjadi keperluan segera, terutamanya dalam reka bentuk litar bersepadu berasaskan silikon. Salah satu kunci untuk meningkatkan litar bersepadu dengan membina kapasitor logam-penebat-logam dalam aplikasi elektronik berasaskan silikon. Oleh itu, ini memerlukan kapasitans khusus yang meningkat dengan ketara dengan penggunaan bahan dielektrik tinggi-K. Dielektrik ini mesti dibentuk dalam struktur kapasitor tiga dimensi untuk mencapai kemuatan tinggi bagi setiap kawasan cip. Dalam kerja ini, kapasitor direka untuk kapasitor MIM bersepadu berasaskan silikon menggunakan perisian COMSOL Multiphysics untuk mencipta model operasi silindernya. Parameter struktur yang sama tahap dan ciri kemuatan telah disimulasikan dan dianalisis seperti kesan sifat bahan dielektrik yang berbeza dalam aspek nilai K, jarak dan luas bahan. Ini juga menyiasat kesan kawasan plat logam dan ketebalan untuk kapasitor MIM bersepadu berasaskan silikon yang digunakan. Akibatnya, nilai K yang tinggi bagi prestasi bahan dielektrik menunjukkan bahawa parameter yang dioptimumkan yang sesuai untuk dipasangkan dengan kapasitor MIM bersepadu berasaskan silikon di mana kawasan permukaan yang menunjukkan kestabilan dan kemuatan yang baik ialah luas permukaan 314.16 mm2 dan 500 μm daripadanya. ketebalan. Kajian ini diharapkan dapat memberikan hasil simulasi yang baik, yang mengesahkan rasional reka bentuk kapasitor MIM bersepadu berasaskan silikon dengan hubungan bahan yang dipilih dan parameter dioptimumkannya untuk kapasitor MIM ini. Oleh itu, kajian ini menawarkan cara yang berkebolehan dan cekap untuk penyelidikan bahan yang ideal untuk prestasi tinggi dan kecekapan kapasitor MIM bersepadu untuk aplikasi elektronik yang fleksibel.

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LIST OF ABBREVIATIONS

Al	Aluminum
Al_2O_3	Aluminum oxide
Cu	Copper
Er_2O_3	Erbium oxide
HfO_2	Hafnium oxide
MIM	Metal-Insulator-Metal
Si	Silicon
SiO_2	Silicon dioxide
TiO_2	Titanium dioxide
TiN	Titanium nitride
ZrO_2	Zirconium oxide

LIST OF SYMBOLS

Π	Pie
R	Resistance
r	Radius
D, d	Distance, thickness
%	Percentage
C	Capacitance
V	Voltage, electric potential
I	Current
T	Time
J	Joule
Q	Charge

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CHAPTER 1

INTRODUCTION

1.0 Introduction

With the recent increase of equipment, the demand for electronic application miniaturization has risen unexpectedly. In the aspect of metal material, silicon-based material has become the first choice from all the metal material. Silicon is widely used for electronics device because it has a special element with very special properties. Through its properties, it been extremely used in the semiconductor where the silicon-based material can conduct electricity under some conditions and also can acts as an insulator under certain conditions. Furthermore, the benefits of using silicon-based material in a high-density capacitor are it is important for sustainable energy storage system, low cost, easy processibility and it can be abundant source. In terms of silicon design, it shows a demand of its material because of high stability, reliability, high tolerance to high temperature, can be an electroactive material with great flexibility and give a very high energy and its power densities. Thus, it makes a great choice to use in harsh environment applications.

Dielectric material is an insulating material or known as very poor conductor of an electric current. When dielectric material is placed in an electric field, no current will flow as they do not have any closely bound or free electrons that could drift through the material. However, the presence of the dielectric material in high density capacitor is important such it has an effect to other electrical properties. For instance, the force between two electric charges in a dielectric will be less than a vacuum, while the quantity of energy stored in electric filed per unit volume of the dielectric is much greater. The effects of dielectric material on electrical properties are described such as dielectric constant and permittivity.

Capacitance is associated storage of electrical energy. It is also a property of an electric conductor that is measured by the amount of separated electric charge that can be stored on it per unit change in electric potential. Besides that, it also one of the essential technologies for system in package, where its ability to complement a traditional mount capacitor with lower series resistance and inductance for high-speed and high-technology circuits. More passive devices are unexpectedly increasing in silicon-based integrated circuits due to high CMOS technology integration.

Additionally, several researchers investigated that the consequences of different material of dielectric with silicon-based material for MIM capacitor. For instance, Momota, M et al. [1] and Zhang, R et al. [2] reported that they designed the MIM capacitor in rectangular model. They also simulated and analyzed the different plate size and the layer of thickness of the dielectric material for a few dielectric materials. The results demonstrate a good agreement towards its simulations results.

Consequently, in this project work, the integrated MIM capacitor have been designed in a cylinder model and the material properties have been analyzed accordingly towards its distance, surface area and the thickness of the metal material properties and dielectric material properties.

1.1 Problem Statement

In current new technology, choosing a best material to be the best companion on both metal and insulator material are one of crucial aspects in designing an integrated high density of a capacitor. This is because not many materials are suitable for each other especially for energy storage application and some of the materials could be corrosive to each other or even resulting a harmful chemical toward an environment. Therefore, to have the best design and analysis of MIM capacitor structure, it is needed to recognize the properties of dielectric resource in the aspects of high K-value and low K-value of dielectric material choose. Furthermore, this analysis and designing the MIM capacitor also will be needed to determine the optimum area and the thickness of the materials which resulting an excellent quality of the MIM capacitor.

1.2 Research Objective

The objectives of the research are:

(a) To design silicon based integrated MIM capacitor structure

(b) To analyze the effect of dielectric material properties towards MIM capacitor performance

(c) To characterize the metal properties towards MIM capacitor performance

1.3 Research Scope

The scopes of the research are:

a) Structure model, capacitance values and electric properties will be simulated and plotted using COMSOL Multiphysics version 5.6

b) The design range is between 11 mm to 20 mm.

c) The parameters of dielectric material will be varied in terms of distance (2 mm to 15 mm) and the area (1520.53 mm^2 to 5026.55 mm^2).

d) The parameters of metal material will be varied in terms of thickness (200 µm to 800 µm) and the surface area (50.27 mm^2 to 1017.88 mm^2).

e) The parameters of MIM capacitor structure will be concluded based on the optimum capacitance.

1.4 Thesis Organization

This project work is categorized into 5 chapter which in Chapter 1 provides an overview of research includes silicon, dielectric material, problems, objectives, and scopes of research are also highlighted in this chapter. Next, chapter 2 elaborates in detail literature review of research involves. Chapter 3 delivers the parameter that used in the simulation and design methodology implemented in this research includes structure of the MIM capacitor, analysis of its capacitance, electric potential and electric energy. Furthermore, in chapter 4 describes the results obtained and discussion for each electrical properties of metal material and dielectric material. Lastly, in chapter 5 concludes the overall findings of research with objectives stated and recommendations for future work.

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