ANALYSIS OF DEVICE DESIGN AND MATERIAL STRUCTURE ON MEMS VARIABLE CAPACITOR

LOW CHUN KANG

UNIVERSITI TEKNOLOGI MALAYSIA

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LOW CHUN KANG

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DEDICATION

To my parents, siblings, friends, and supervisor

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ABSTRACT

Micro-electromechanical system (MEMS) has been one of the most promising technologies for the 21st century. With this technology, MEMS components are not only depending on the electrical properties but also other physics properties. MEMS components can generate the effect as good as the conventional components despite the size of micrometres. In this research, the tuneable capacitor has been designed based on this technology. Nowadays, to improve capacitance range of tuneable capacitor, most of the researches focus on enhancing the gap tuning structure. However, with the moving parts in the structure, pull-in effect has become a major concern. To solve this problem, solution of applying temperature dependent dielectric materials into capacitors is suggested. Different dielectric materials are applied into the first phase simulation carried out by the COMSOL Multiphysics software to find out the best dielectric material based on their capacitance range. Then, the capacitor is put into second phase simulation to investigate the effect of different dimension variables. From the simulation results, Strontium Titanate has the largest tuning range 67.48% among the dielectric material candidates. For the dimension variables, the capacitance is inversely proportional to the thickness of dielectric layer decreasing from 49.479 pF to 10.023 pF in the range of 0.1 nm to 0.5 nm but directly proportional to the length of trench opening increasing from 11.236 pF to 21.969 pF in the range of 1 nm to 5 nm as well as depth of the trench increasing from 6.8256 pF to 16.605 pF in the range of 0 nm to 10 nm. In the end, a proposed tuneable capacitor with Strontium Titanate as dielectric layer, 0.3 µm of dielectric layer thickness, 3 µm of trench opening and 10 µm of trench depth is designed and put to the comparison with previous reported capacitors. The maximum capacitance of proposed capacitor is the second highest 16.605 pF but its tuning range 67.48% is the lowest in the comparison. Although the tuning range of proposed capacitor is not the highest among these capacitors, it does show a new idea to this topic.

ABSTRAK

Sistem mikro-elektromekanikal (MEMS) telah menjadi salah satu teknologi yang paling menjanjikan kepada abad ke-21. Dengan teknologi ini, komponen MEMS bukan sahaja bergantung kepada sifat elektrik tetapi juga sifat fizik yang lain. Komponen MEMS boleh menjana kesan sebaik komponen konvensional walaupun bersaiz mikrometer. Dalam penyelidikan ini, kapasitor boleh tala telah direka bentuk berdasarkan teknologi ini. Pada masa kini, untuk menambah baik julat kapasitansi kapasitor boleh tala, kebanyakan penyelidikan memfokuskan pada mempertingkatkan struktur talaan jurang. Walau bagaimanapun, dengan bahagian yang bergerak dalam struktur, kesan tarik masuk telah menjadi kebimbangan utama. Untuk menyelesaikan masalah ini, penyelesaian menggunakan bahan dielektrik bergantung suhu ke dalam kapasitor dicadangkan. Bahan dielektrik yang berbeza digunakan dalam simulasi fasa pertama yang dijalankan oleh perisian COMSOL Multiphysics untuk mengetahui bahan dielektrik terbaik berdasarkan julat kapasitansinya. Kemudian, kapasitor terus disiasat dalam simulasi fasa kedua tentang kesan pembolehubah dimensi yang berbeza. Daripada hasil simulasi, Strontium Titanate mempunyai julat penalaan terbesar 67.48% dalam kalangan calon bahan dielektrik. Bagi pembolehubah dimensi, kapasitansi adalah berkadar songsang dengan ketebalan lapisan dielektrik berkurang daripada 49.479 pF kepada 10.023 pF dalam julat 0.1 nm hingga 0.5 nm tetapi berkadar terus dengan panjang bukaan parit meningkat daripada 11.236 pF kepada 21.969 pF dalam julat 1 nm 5 nm serta kedalaman parit meningkat daripada 6.8256 pF kepada 16.605 pF dalam julat 0 nm hingga 10 nm. Pada akhirnya, cadangan kapasitor boleh tala dengan Strontium Titanate sebagai lapisan dielektrik, 0.3 μm ketebalan lapisan dielektrik, 3 μm bukaan parit dan 10 μm kedalaman parit direka bentuk dan dibandingkan dengan kapasitor yang dilaporkan sebelumnya. Kapasiti maksimum kapasitor yang dicadangkan 16.605 pF adalah yang kedua tertinggi tetapi julat penalaannya 67.48% adalah yang paling rendah dalam perbandingan. Walaupun julat penalaan kapasitor yang dicadangkan bukanlah yang tertinggi di antara kapasitor ini, ia menunjukkan idea baharu kepada topik ini.

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LIST OF ABBREVIATIONS

AFE	-	Antiferroelectric
CA	-	Citric Acid
CPW	-	Coplanar Waveguide
FE	-	Ferroelectric
IC	-	Integrated Circuit
MEMS	-	Micro-electromechanical system
MN	-	Metal Nitrate
PZT	-	Lead Zirconate Titanate
RF	-	Radio Frequency

LIST OF SYMBOLS

C	-	Capacitance
ε	-	Permittivity of dielectric
A	-	Area of plate overlap in square meters
d	-	Distance between plates in meters
L	-	The side length of the plates
T	-	Thickness of the dielectric layer
L	-	Length of the trench opening
D	-	Depth of the trench

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Micro-electromechanical system (MEMS) has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon-based microelectronics with micromachining technology. Its techniques and microsystem-based devices have the potential to dramatically affect all of our lives and the way we live. This process technology used to create integrated devices or systems that combine mechanical and electrical components in the size of micrometre but they can generate effects on macro scale when working in batches [1]. This technology has been applied into fabrication of wide range of components and devices including tuneable capacitor which is the component that are going to be studied in this research. Figure 1.1 shows the market trend of MEMS devices.

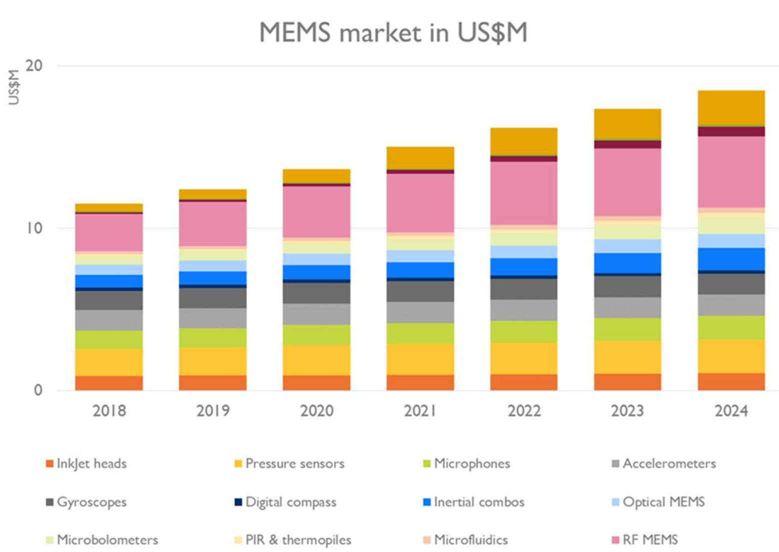

Figure 1.1 Market Trend of MEMS devices [2].

Tuneable capacitor where its capacitance is adjustable either by mechanical forces, electrostatic or thermal actuation. With this characteristic, it is often be used in L/C circuits to set the resonance frequency. Nowadays, it has been used in various applications such as oscillators or tuneable filters. The tuneable capacitor is usually determined by its range of tuning. Therefore, there is a lot of researches have been done trying to increase the range while keeping the fabrication cost as low as possible. This is where MEMS technology comes into place.

With MEMS technology, capacitors can be fabricated in miniature size but when working in batches their effect are just as same as conventional capacitors. What most important is that their fabrication cost is very low due to their capability to be mass produced on a silicon wafer. Besides that, with the size of micrometre, these capacitors could be applied into most of the circuit without the concern of area constraint. Figure 1.2 shows the basic structure of MEMS tuneable capacitor.

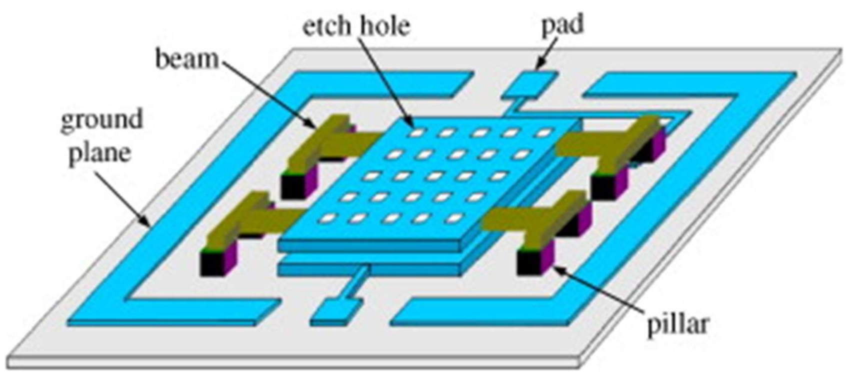

Figure 1.2 Basic structure of MEMS Tuneable Capacitor [3].

$$C = \frac{\varepsilon A}{d} \tag{1.1}$$

Capacitance equation is shown in equation 1.1. From the equation 1.1, we can see that the capacitance is influenced by three factors which are dielectric permittivity (ε), plate overlapping area (A) and distance between plates (d) [4]. Conventionally, MEMS tuneable capacitor researches are focusing on structures such as parallel plate, torsional, continuous beam, etc. to enhance capacitance and tuning range. In these structures, capacitances are changed due to the movement or rotation of plates.

However, tuning will be limited by having the moving parts in these structures due to pull-in effect happens. At small voltages, the electrostatic voltage is countered by the spring force but as voltage is increased the plates will eventually snap (pull-in) together. Theoretically, the system become unstable when the plates reach 2/3 of their original position, hence, reduce the maximum tuning range [5]. The common solutions to overcome this problem is by increasing the stiffness of the plate arm and/or adding support to the plate. Although these solutions have been proven its effectiveness in delaying the pull-in effect, the effect is not entirely eliminated. Therefore, there is necessary to find another approach to overcome this issue.

1.2 Problem Statement

Pull-in effect is one of the major problems in the tuneable capacitance because these types of capacitors usually rely on the effective overlapped plates areas (area tuning) or the distance between the electrode plates (gap tuning). This effect happens due to the overshoot of the voltage causing the system to be instable. It is more severe in MEMS devices due to the miniature size of MEMS capacitors and slightly high input voltage might cause this effect, hence, affect the controllability of effective tunning range. Although there are some proposed solutions to overcome this effect, the effect is just delayed instead of eliminated. New proposed solution should show the benefits over the current solution in either manufacturing process, cost or sustainability.

While keeping this pull effect low, it is also important to ensure the tuning range is large enough, so that it can fit to more applications such as miniaturized radio frequency (RF) or microwave communication module and systems. Therefore, the investigation on alternative material might benefits this requirement. The final result of capacitance range should at least on par if not greater than previous work to meet industry standard.

Last but not least, other than large tuning range and consideration of pull-in effect, the size of the capacitors should be considered as well. With small size, the capacitors can fit into any application conveniently without concern of taking up too much space in the system. Besides that, the dimension variables are important during fabrication. More capacitors can be fabricated on a single silicon wafer, consequently reducing the manufacturing cost. In conclusion, different types of materials used as dielectric layer and dimension variable must be studied so that their effect can be understood.

1.3 Research Objectives

The objectives of this research are:

a) To design a MEMS tuneable capacitor with pull-in effect eliminated.

b) To analyse the effect of dielectric materials and structure dimension variables in term of the range of capacitance.

c) To validate the designed tuneable capacitor with other similar works.

1.4 Research Scope

In this proposal, only simulation will be done, thus no fabrication process will be carried out and discussed. COMSOL Multiphysics software will be used to run the simulation. Besides that, manipulation of permittivity of dielectric is the main method used in changing the capacitance. Therefore, material that can change its relative dielectric constant based on temperature will be selected as potential candidate. The idea of micro-heater is proposed so that material temperature can be controlled by thermal actuator. However, during the simulation, the micro-heater will not be constructed and the effect of temperature to the dielectric materials is presented by changing their relative permittivity which obtained from previous researchers' work. In this research, capacitance range is the main parameter to compare among the materials and optimum design is determined based on capacitance value and capacitor size.

1.5 Thesis Outline

This thesis is divided into five chapters, which are Introduction, Literature Review, Methodology, Result and Discussion and Conclusion. Introduction is the first chapter of this research which describes about the research background, problem statement, objectives of the research, scope of research and the thesis outline. The following chapter discusses about the literature review of previous works that related to this research. Some of the theoretical background of the research, capacitors with different actuation method and temperature dependent dielectric material are discussed. Chapter 3 shares the methodology of the research. The workflow of the research will be discussed step by step in detail. Simulation tool, proposed device structure and characterisation and data analysis of materials used are highlighted in this chapter. The next chapter discusses about the results obtained after the completion of the workflow of the research. Results from simulation are presented in this chapter to discuss about the performances of capacitors using different materials and dimensions. The last chapter summarises the overall research. Suggestions for further improvements in the future are discussed in this chapter too.

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