DEVELOPMENT OF SURFACE-MICROMACHINED CAPACITIVE MICROELECTROMECHANICAL SYSTEMS (MEMS) MICROPHONES

SHALINI A/P P.JANASEKARAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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Nama Pelajar	SHALINI A/P P.JANASEKARAN																
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Tajuk Projek	DEVELOPMENT OF SURFACE-MICROMACHINED CAPACITIVE MICROELECTROMECHANICAL SYSTEMS (MEMS) MICROPHONES

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DEVELOPMENT OF SURFACE-MICROMACHINED CAPACITIVE MICROELECTROMECHANICAL SYSTEMS (MEMS) MICROPHONES

SHALINI A/P P.JANASEKARAN

This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Electronics Engineering (Industrial Electronics)

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)

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UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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Signature : …….…………………….....…………..
Supervisor's Name : DR. RHONIRA BINTI LATIF @ LATEH
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To my beloved father and mother

Who always give me courage to finish this thesis

Also, to those people who have guided and inspired me throughout my journey.

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ABSTRAK

Mikrofon mengubah rangkaian suara kepada rangkaian elektrik dan ia digunakan secara meluas dalam teknologi mudah alih seperti telefon bimbit, komputer dan mesin pendenggaran. Mikrofon jenis MEMs telah mula mendapat perhatian dan mengambil alih untuk menggantikan mikfon jenis elektret disebabkn saiz mikrofon electret yang besar dan nilai nisbah SNR (signal to noise) yang tinggi. Walau bagaimanapun, mikrofon jenis MEMs yang terdapat di pasaran kini tidak sesuai untuk process CMOS (complementary metal oxide semiconductor). Oleh yang demikian, mikrofon MEMs yang sesuai untuk process CMOS diperkenalkan dalam projek ini. Analisis matematik dan simulasi bentuk mikrofon MEMS yang sesuai telah direka untuk menangani masalah yang telah disebut. Projek ini juga akan membantu untuk process fabrikasi pada masa akan datang untuk penyesuaian proses CMOS.

ABSTRACT

Microphones transduce acoustic input into electrical signals and are essentially used in mobile phones, computers and hearing aids. The MEMS-type capacitive microphones have emerged to replace the conventional electret condenser microphones due to the compact size and high signal to noise ratio. However, the previous MEMS-type capacitive microphones are not compatible with CMOS (complementary metal oxide semiconductor) processes. Thus, surface-micromachined capacitive MEMS microphones are suggested in this study. Novel design and mathematical analysis (analytical and finite element models) of the proposed MEMS microphone will be conducted in order to obtain high sensitivity and fully CMOS-compatible process. The study will aid the fabrication of high sensitivity surface-micromachined capacitive MEMS microphones and can be possibly be integrated with other CMOS devices.

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CHAPTER 1

INTRODUCTION

Microphones are widely used in voice communication devices, hearing aids, surveillance and military applications and noise and vibration control system [1].Traditionally, electrets condenser microphone (ECM) is the most common type of microphone for home and mobile applications. Recent trends for mobile electronic devices have gravitated toward miniaturized, slim, lightweight and multifunctional devices. In order to satisfy these trends, miniaturization and integration of these components with CMOS processes is necessary for signal processing. However, ECMs have complex mechanical assemblies, and although they have been miniaturized tremendously over the years, further miniaturization will be difficult. Recently, MEMS-type capacitive microphones have been emerging to replace ECMs because of their compact size, high signal-to-noise ratio, quick response, long-term stability, and temperature stability. Previous MEMS microphones have usually been the condenser-type sensors fabricated by the bulk micromachining process. However, they have some fabrication issues because of their complicated back-side etching process and non-CMOS-compatible MEMS process.

MEMS microphones require a back-side photolithography process and a delicate substrate through an etching process. The polysilicon layer for the sensing membrane and the oxide sacrificial layer for the sensing air gap are not compatible with the CMOS process. In order to have a simple and CMOS-compatible process, surface-micromachined MEMS microphones are suggested. They are fabricated using fully CMOS-compatible processes and materials. In addition, they do not require a complicated back-side etching process. However, there are some problems with low sensitivity and poor frequency response owing to their small sensing gap, thin back-plate, and small back-chamber volume. The volume of the back-chamber is critical for the sensitivity of a MEMS microphone. When the air in the sensing gap is vented to the back-chamber through the back plate holes, the air resistance is increased if the back-chamber volume is not great enough. So bulk type MEMS microphones have a deep back chamber by penetrating the substrate.

On the other hand, the surface micromachined microphone makes a back chamber from the top surface so that the back chamber depth is only tens of micrometers. As a result, the air in the sensing gap is not vented easily to the back-chamber and the air resistance is maximized at the center. In this paper, we tried to make the air in the membrane center vented easily by simply implementing a small vent hole at the membrane center. A center venting hole is located at the center of the membrane so that the air under the membrane center can easily move in and out though the hole. By simply implementing the membrane center venting hole, both the sensitivity and the frequency response of the surface-micromachined MEMS microphone can be improved. In addition, the membrane center venting hole facilitates sacrificial layer removal and deep etching of the back-chamber during the surface-micromachining process and also back-plate supporting structures are formed under the back-plate.

1.1 OBJECTIVES

The main aim and objectives of this “Development of surface-micromachined capacitive microelectromechanical systems (MEMS) microphones” is to study and investigate the parameters of the membrane designed that would increase the sensitivity and at last propose the best among them. Lastly, the overall aim is to study and investigate the parameters of the membrane designed that would increase the sensitivity and conduct a novel design (analytical and finite element models) of the proposed MEMS microphone.

i. To study and analyze the characteristics of different materials to be used for designing the MEMS microphone.

ii. To design surface micromachined MEMS microphone that is fully CMOS-compatible.

iii. To provide a user friendly interface with high miniaturization and compatibility.

1.2 PROBLEM STATEMENT

There are various kind of microphones are available out there in the market. Previous studies have been conducted to replace the conventional electrets condenser microphones to MEMS-type capacitive microphones due to the compact size and high signal to noise ratio. However, the previous MEMS-type capacitive microphones are not compatible with CMOS processes. Thus, surface-micromachined capacitive MEMS microphones are suggested in this study. Novel design and mathematical analysis (analytical and finite element models) of the proposed MEMS microphone will be conducted in order to obtain high sensitivity and fully CMOS-compatible process.

1.3 SCOPE OF PROJECT

The scope of this research is to identify suitable methods that will be used for designing a fully CMOS compatible microphones with higher sensitivity. In this project, we will use MEMS developing software such as Comsol Multiphysics in order to gain the suitable design and material based on the calculation provided by this software. This project will not continue until the fabrication process. However, this study can be further continued in future research as the designs created would lead in fabricating successful MEMS microphones.

1.4 REPORT STRUCTURE & ARRANGEMENT

In order to complete this thesis, 5 requirements need to be completed, which are Introduction, Literature Review, Methodology, Result and Discussion, and the last chapter is a Conclusion and Further Development of the project.

Chapter 1 is about the introduction of the project. The basic idea of the project is introduced in this chapter together with the objectives and overall view about the project.

Chapter 2 is about the literature review on the component that is used in this project. This section contains the literature review and the methodologies that have been collected from different sources for the development of the MEMS microphones design.

Chapter 3 is about the design and methodology of the project. General concept of the project like the component that have been use to the project

Chapter 4 is about the analysis all the result and the limitation in completing this project.

Chapter 5 it consists of the conclusion and recommendation of the project.

CHAPTER 2

RESEARCH BACKGROUND

2.1 INTRODUCTION

The theory and description plus details about the project have taken as guidance in completing this project. By this chapter, an overview of some application that similar to the project and related project design is present.

The first part of literature will focus on the advantages and some background research in microelectromechanical systems (MEMs). It is then, followed by a brief explanation of MEMS microphone structure, operation, importance of project for sustainable development and project marketability in terms of entrepreneur skills.

2.2 ADVANTAGES OF MEMS [4]

The advantages of MEMs are that it can be manufactured using surface mounting, can withstand high reflow temperatures, easily integrated with CMOS processes and other audio electronics and has improved noise cancellation and immunity to radio frequency (RF)

According to Jelena Citakovic [1], silicon MEMS microphones that offer small size, ease of integration with CMOS electronics, and the ability to withstand lead-free solder reflow cycles, are becoming increasingly popular for high-volume consumer electronic products, and are competing in price and performance with traditional electrets condenser microphones. The design of a MEMS microphone, consisting of a compliant membrane and a stiff back-plate forming a variable capacitor, is a challenging task with a number of design trade-offs. For cost reasons, a small-area membrane is desired. However, lower acoustical noise is obtained with a larger membrane. It is also demonstrated a method to increase the SNR of a microphone system without the need for a complicated and risky MEMS die redesign. An SNR of 66dB is achieved using two microphones (instead of a single one) in a differential configuration, thus doubling the total membrane area

2.3 MEMS MICROPHONE SENSOR STRUCTURE

The output of a MEMS microphone does not come directly from the MEMS transducer element. The transducer is essentially a variable capacitor with extremely high output impedance in the Giga ohms range [6]. Inside the microphone package, the transducer's signal is sent to a preamplifier, whose first function is as an impedance converter to bring the output impedance down to something more usable when the microphone is connected in an audio signal chain. The microphone's output circuitry is also implemented in this preamp. For an analog MEMS microphone, this circuit, whose block diagram is shown in Figure 1, is basically an amplifier with specific output impedance. In a digital MEMS microphone, that amplifier is integrated with an analog-to-digital converter (ADC) to provide a digital output in either a pulse density modulated (PDM) or I2S format [7].

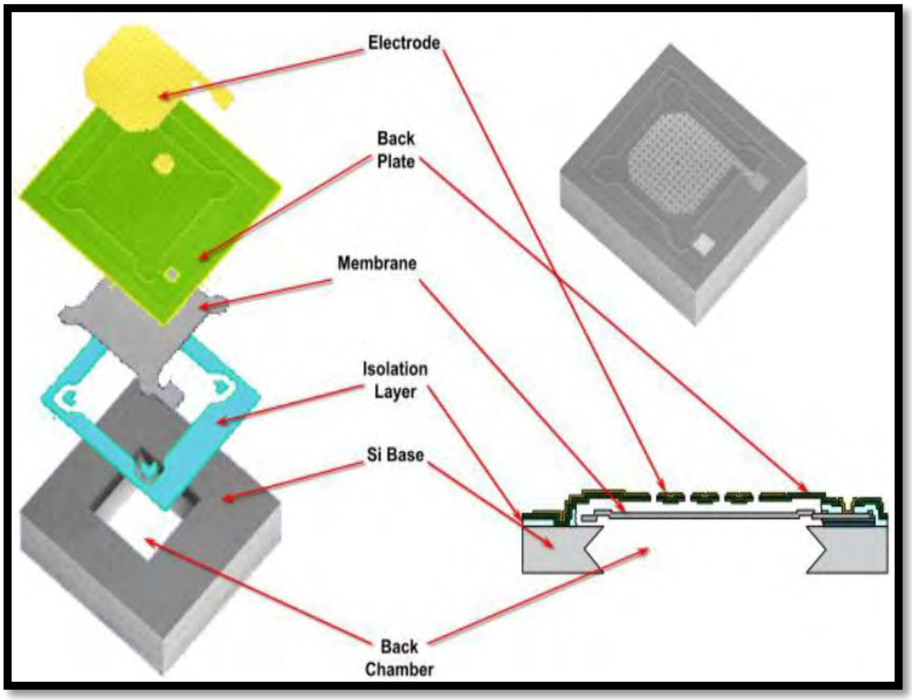

Figure 1: MEMS Microphone Sensor Structure

Based on Figure 1, it shows the division of the sub layers of a MEMS microphone. The structure starts from the upper part with electrodes, continued by back plate, membrane, isolation layer, silicon base and lastly the back chamber. The part that will be designed in this thesis is to create the membrane which is a moveable and conductive part in order to vibrate in accordance to sound signals. Suitable parameters will be examined to obtain and build the best MEMS microphone for the current market trend.

2.4 MEMS MICROPHONE OPERATION

Like ECMs, MEMS microphones operate as condenser microphones. MEMS microphones consist of a flexibly suspended diaphragm that is free to move above a fixed back plate, all fabricated on a silicon wafer. This structure forms a variable capacitor, with a fixed electrical charge applied between the diaphragm and back plate. An incoming sound pressure wave passing through holes in the back plate causes the diaphragm to move in proportion to the amplitude of the compression and rarefaction waves. This movement varies the distance between the diaphragm and the back plate, which in turn varies the capacitance, as shown in Figure 2. Given a constant charge, this capacitance change is converted into an electrical signal.

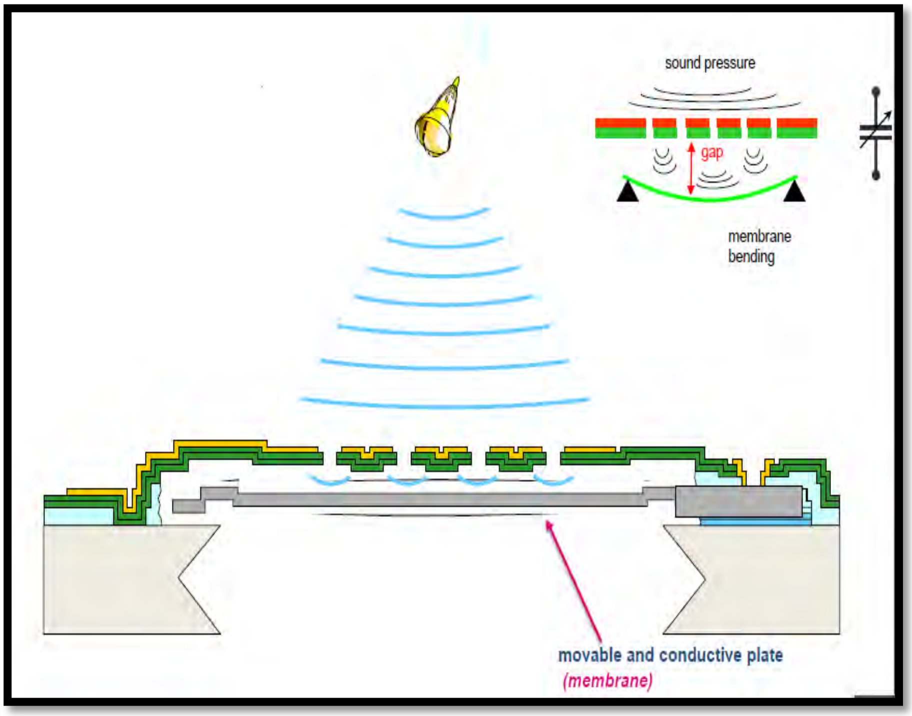

Figure 2: MEMS Microphone Operation

In accordance to Figure 2, transduction principle is the coupled capacitance change between a fixed plate and a movable plate. Capacitance of MEMS microphone varies with amplitude of acoustic wave whereby the capacitance change indicates the sensitivity of the MEMS microphones.

2.5 IMPORTANCE OF PROJECT FOR SUSTAINABLE DEVELOPMENT

- To investigate the importance of varying the membrane size & material
- To provide information on the impact of total surface displacement & frequency that increases sensitivity
- To identify the performance of MEMS microphone in current trends application such as in smart phone, tablets & etc

2.6 PROJECT MARKET-ABILITY IN TERMS OF ENTREPRENEUR SKILLS

MEMS microphones have developed to the point where they are now the default choice for many audio capture applications that require small size and high performance, but most commercial grade microphones are unsuitable for the hearing aid industry, which requires significantly smaller parts with lower power consumption; better noise performance; and improved reliability, environmental stability, and device-to-device repeatability. MEMS microphones technology is now at the stage where all of these can be offered with ultra small packages, very low power consumption, and very low equivalent input noise.

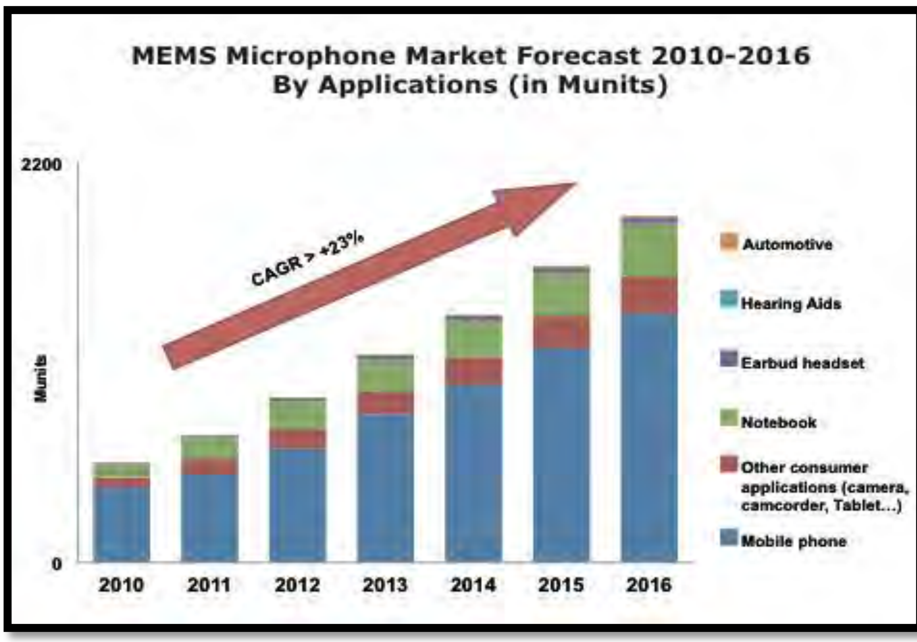

Figure 3: MEMS Microphone Current Market Trend

The above Figure 3 shows the current market trend of MEMS microphones. It can clearly be seen that the forecast shows within six years the applications using MEMS microphones actually increases by more than 23 % as in year 2016 compared to year 2010. The legend shows the vast implementation of MEMS microphones will be in mobile phones and notebook. Other than that, it is also being implemented in hearing aids, automotive, ear bud headset and other consumer applications such as camera, camcorder, tablet and etc.