Faculty of Engineering

ELECTROMAGNETIC MODELLING OF RF MEMS STRUCTURES

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Bachelor of Engineering with Honours
(Electronics and Telecommunications Engineering)
2008/2009

UNIVERSITI MALAYSIA SARAWAK

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BORANG PENGESAHAN STATUS TESIS

Judul: ELECTROMAGNETIC MODELLING OF RF MEMS STRUCTURES

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ELECTROMAGNETIC MODELLING OF RF MEMS STRUCTURES

EDWARD ANAK DAVID MIIEG

This project is submitted in partial fulfilment of
The requirements for the degree of Bachelor of Engineering with Honours
(Electronic and Telecommunication Engineering)

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2008/2009

EDWARD ANAK DAVID MIIEG

< When we were given any task in life, it might be complicated or hard to handle but *Nothing Is Impossible*. Have *Faith* in ourselves and we will *Succeed* >

ACKNOWLEDGEMENT

First of all, I would like to show my gratitude to my supervisor, Miss Shafrida Sahrani for her guidance, supervision and moral support throughout the project. Thank you for the consideration and the precious time she has given for correcting this project and helping me to improve. Under her supervision, I managed to complete this project which I considered as a great achievement for me.

I also would like to thank all of the lecturers and staffs that have taught and assisted me throughout my study in UNIMAS. Without their guidance and patient, I would not able to reach this level and finally be able to produce this project. Also thank you to my friends for their support and their knowledge shared with me during the project progress.

Last but not least, I would like to express my appreciation to my beloved family for their moral support. Thank you for supporting me financially and morally throughout my four years of study in UNIMAS. Without them, I do not think I can achieve what I have today. Thank you everyone.

ABSTRAK

Radio frekuensi Sistem-Mikro-Elektro-Mekanikal (RF MEMS) merupakan salah satu aplikasi yang kian maju dalam tekonologi MEMS yang lazimnya digunakan dalam antena, *phase-shifter* dan *filters*. Oleh itu, pengetahuan dan kefahaman terhadap bidang elektromagnetik seperti teori Maxwell amatlah penting dalam membina dan menguji kecekapan serta pencapaian alat MEMS,

Untuk projek ini, satu kaedah baru telah dibuat untuk menganalisis masalah yang menghadkan pergerakan dalam teknik lingkungan masa yang konvensional. Kaedah ini dengan terperincinya adalah untuk menganalisis pergerakan objek dalam alat MEMS yang menglibatkan kaedah FDTD dalam bidang elektromagnetik. Dengan mengaplikasikan transformasi dalam faktor masa, teknik grid dapat diaplikasikan dalam analisis teknnik lingkungan masa untuk pergerakan objek. Teknik ini akan diaplikasikan dalam menganalisis pergerakan dan struktur bentuk yang tidak sekata.

Simulasi untuk pembolehubah kapasitor RF MEMS diaplikasikan dalam mod dua dimensi TE. Daya pecut antara kepingan dalam model tersebut adalah dihasilkan daripada keseimbangan antara daya mekanikal dan elektrik. Peredam gerakan juga akan diaplikasikan dalam sistem untuk menganalsis pergerakan pembolehubah kapasitor frekuensi radio MEMS. Simulasi ini akan menguji kesan peredam terhadap pergerakan yang lazimnya dihasilkan oleh peredam mekanikal seperti peredam bendalir and peredam elektrik.

ABSTRACT

Radio Frequency Micro-Electro-Mechanical System (RF MEMS) is one of the emerging applications in MEMS technology which are used in phase-shifters, couplers, filters, tunes or antennas. In order to model and optimize the performance of the devices, an accurate knowledge and understanding of the electromagnetic field such as the Maxwell theorem is essential.

In this project, a new numerical method is introduced to analyze the problems which cause the limitation of the conventional time domain technique. The method is expanded to analyze MEMS devices with moving parts with the Finite Different Time Domain (FDTD) method for Electromagnetic (EM) field. By employing transformation in the time factor, the grid generation technique can be applied to the time-domain analysis of a moving object. These techniques are implemented in analyzing structure of uninformed shape and motion.

The simulation method for the RF MEMS variable capacitor is applied to the analysis of a two-dimensional (2D) Transverse Electric (TE) mode. The acceleration of the plates is derived from the equilibrium between the spring force and the electrical force. A damping constant is added into the system and the motion of the MEMS variable capacitor is analyzed. The simulation will analyze the damping effect towards the motion due to the damping mechanism such as fluids damping and electronics damping.

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MEMS	-	Micro-Electro-Mechanical System
FDTD	-	Finite Difference Time Domain
CVD	-	Chemical Vapor Deposition
PVD	-	Physical Vapor Deposition
UV	-	UltraViolet
PR	-	PhotoResist
RF MEMS	-	Radio Frequency MicroElectroMechanical System
PCR	-	Polymerase Chain Reaction
STMs	-	Micromachined Scanning Tunneling Microscopes
BAW	-	Bulk Acoustic Wave
2D	-	Two Dimensional
3D	-	Three Dimensional
TE	-	Transverse Electric
TM	-	Transverse Magnetic
ABC	-	Absorbing Boundary Condition
SHM	-	Simple Harmonic Motion
ODE	-	Ordinary Differential Equation

CHAPTER 1

INTRODUCTION

1.1 RF MEMS Overview

Micro-Electro-Mechanical systems (MEMS) is an advance technology that will sense and manipulate the technologies in the near future. This technology is a combination of electrical and mechanical components into a small integrated devices or systems. MEMS are extremely small and capable of faster, more precise and more reliable operation than the conventional devices. One of the growing applications in MEMS technology is the radio frequency (RF) MEMS where the components are tunable, offer higher quality factors, Q and low switching loss. However the demanding of smaller, lighter products and faster performance are increasing from time-to-time. Thus many efforts in order to optimize the performance of the device have been conducted through various practical and computational ways.

The main purpose for this project is to analyze the problems of the limitation in the conventional time domain technique. The motion of the RF MEMS capacitor modeling structure is obtained by applying the Finite Difference Time Domain (FDTD) technique and Body Fitted Grid Generation Method into the numerical analysis.

1.2 Objective

The main objectives of this project are:

1. To model the RF MEMS structure and obtain the motion which is controlled by the coupling of the electrostatic and magnetic force.
2. To implement the effect of the damping factor into the RF MEMS modeling structure for analyze.
3. To manipulate the parameters such as voltage (*V*), spring constant (*k*), mass (*m*), damping constant (*b*) and mechanical resonance (ω) into this project and determine the effect towards the system.

Thus, a computational algorithm is defined from the FDTD technique and Body Fitted Grid Generation Method. The computational algorithm is then applied into the numerical analysis for simulation.

1.3 Statement of Problems

This project focuses on the moving parts of the MEMS devices with the FDTD method for Electromagnetic (EM) field. This project is conducted for the simulation and dynamic analysis. Due to the limitation of conventional numerical technique for the time changing boundaries, it is necessarily to solve these numerical problems in terms of the EM field.

1.4 Approach

For this project, the software used for the simulation is C programming. The software is a powerful general-purpose programming language which will be used to calculate the motion of the variable capacitor modeling for this project. The values are stored in variables and the programs are structured by defining and calling functions. Program flow is controlled using loops, if statements and function calls. The input and output can be directed to the terminal or to files and the related data are stored together in arrays or structures. From the simulation, the data will be saved into files then plotted using Microsoft Excel.

1.5 Expected Outcome

This project will provide more information on the motion in RF MEMS modeling structure. The effect of the damping factor towards the system will be analyzed. The parameters will be manipulated throughout this project. An improved and more accurate computational algorithm will be carried out and discussed.

1.6 Chapter Outline

Chapter 1 – This chapter presents a brief overview of RF MEMS and its benefit towards the future. Also discuss are the objectives and approach that will be used for this project and also the expected outcome.

Chapter 2 – This chapter reviews the properties of MEMS, the process of MEMS fabrication and benefit of MEMS technology. The future work and challenge of MEMS are presented. It also reviews the application of MEMS technology that is currently or maybe in the future implementation in MEMS technology such as RF MEMS.

Chapter 3 – This chapter discusses the methods of investigations, methodology development, analysis of the process and focuses on the designing of the system. It discusses the selection of methods in satisfying the design requirement. MEMS variable capacitor motion modelling incorporates the motion of the plates under the effects between the mechanical and electrical force combination. The FDTD technique and Body Fitted Grid Generation Method are studied and analyzed to obtain the computational algorithm.

Chapter 4 – This chapter contains the simulation results and a discussion which compares and analyse the motion of the variable capacitor modelling. The parameters that will affect the motion of the MEMS structure are manipulated. This approach and analysis is performed to achieve the objectives.

Chapter 5 – This chapter concludes and summarizes the overall process and performance of the project. In addition, further work which can be implemented also will be discussed. The improvement of the project is also being discussed for future advancement.

CHAPTER 2

LITERATURE REVIEW

2.1 Micro-Electro-Mechanical System (MEMS)

Micro-Electro-Mechanical Systems (MEMS) are systems based on a range of technologies. It combines computer chips with micro-components such as sensors, gears, flow-channels, mirrors and actuators. MEMS are made up of components between 1 to 100 micrometers in size (i.e. 0.001 to 0.1 mm) and MEMS devices generally range in size from 20 micrometers (20 millionth of a meter) to a millimeter (thousandth of a meter) [1]. It is not primarily about the size even though MEMS has made possible electrically-driven motors smaller than the diameter of a human hair.

Figure 2.1: Micro-Electro-Mechanical System (MEMS) Scanning Mirror

MEMS is a highly miniaturized device that mostly created on silicon wafers which can also add up with other substrate types as well. It can perform one or more optical, mechanical or electrical function on its single chip. By combining together the silicon-based microelectronic and micromachining technology, MEMS produce a complete systems-on-a-chip.

This new technology will be the gateway into the next century for its potential of development for smart product, computational ability of microelectronics and control capabilities of microactuators and microcensors. Many new application as well as new designs will emerge and expand beyond what is already exist or known.

2.2 MEMS Fabrication Process

In the fabrication process for MEMS, it generally involves many steps including deposition, photolithography (pattern definition) and etching (removal). Each plays an important role in the fabrication process [2]. Without one of it, the next step for fabricating the chips cannot proceed as each steps relying to each other. In fabrication, the process may also be repeated for several times depend on the types of products.

Deposition is where a thin film will be applied to the silicon substrate. The deposition process in the MEMS technology is classified into two groups which are chemical reaction and the physical reaction deposition. Types of chemical reaction are Chemical Vapor Deposition (CVD), electrodeposition, epitaxy and thermal oxidation. The chemical reaction of gaseous will react at the surface of the substrate. This causes the deposition of a solid film on the surface where the solid product is left while other gaseous are removed. The types of physical reaction are Physical Vapor Deposition (PVD) and Casting. No chemical reaction is reacted to form the film on the substrate as the material deposited is physically moved on to the substrate.

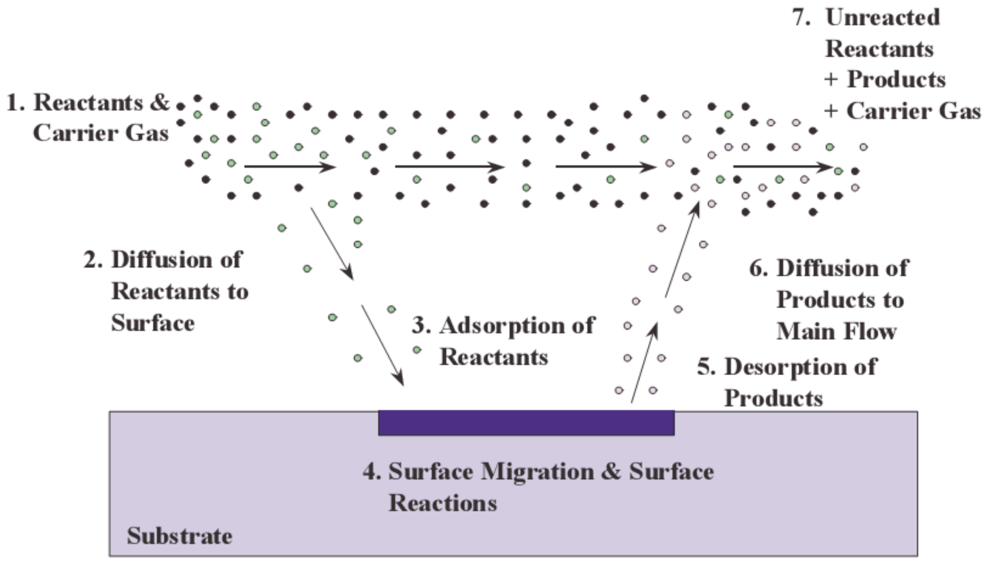

Figure 2.2: CVD film formation

Photolithography process is to pattern the design onto the wafer. Ultraviolet (UV) light is used to transfer a geometric pattern from a photo mask to a light-sensitive chemical on the substrate. The Photoresist (PR), is a light sensitive material that resists etching processes.