Ain Shams University
Faculty of Engineering
Electronics and Communications Department

SiC Based High Quality Micro-Electro-Mechanical Systems (MEMS)

A Thesis
Submitted in partial fulfillment of the requirements of Master of Science degree in Electrical Engineering

Submitted by:
Bichoy Waguih Azmy Bahr
B.Sc. of Electrical Engineering
(Electronics and Communications Department)
Ain Shams University, 2008

Supervised by:
Prof. Dr. Hany Fikry
Prof. Dr. Adel El-Hennawy
Prof. Dr. Mourad El-Gamal

Cairo, 2012

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CAIRO - EGYPT

Examiners Committee

Name : **Bichoy Waguih Azmy Bahr**
Thesis: **SiC Based High Quality Micro-Electro-Mechanical Systems (MEMS)**
Degree: **Master of Science in Electrical Engineering (Electronics and Communications Engineering)**

Name, Title and Affiliation	Signature
Prof. Dr. Serag El-Din El-Sayed Habib Electronics and Communication Eng. Dept. Faculty of Engineering – Cairo University	
Prof. Dr. Abdel-Halim Abdel-Nabi Zekri Electronics and Communication Eng. Dept. Faculty of Engineering - Ain Shams University	Zekry
Prof. Dr. Adel Ezzat El-Hennawy Electronics and Communication Eng. Dept. Faculty of Engineering - Ain Shams University	El-Hennawy
Prof. Dr. Hani Fikri Ragai Electronics and Communication Eng. Dept. Faculty of Engineering - Ain Shams University	

Date: 14/6/2012

Statement

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).
The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
No part of this thesis was submitted for a degree or a qualification at any other university or institution.

Name: Bichoy Waguih Azmy Bahr
Date: 1/04/2012

Curriculum Vitae

Name: Bichoy Waguih Azmy Bahr
Date of Birth: 24/10/1985
Place of Birth: Cairo, Egypt
First University Degree: B.Sc. in Electrical Engineering
Name of University: Ain Shams University
Date of Degree: June 2008

Acknowledgments

All praise goes to God, without Whom, I would not have lived to write these words. He deserves all the thanks and all the praise for His generosity and kindness.

My cordial thanks goes first to my family, and especially to my parents. Those who supported me and cared for me all along my life. Words fail to express my gratitude to them and their support.

This thesis work would have never been possible without the guidance and surveillance of my exceptional professor, Dr. Hani Fikry Ragai. I am quite grateful to this help and guidance during all these years. His invaluable suggestions and directions have defined this work in its current shape. Prof. Ragai has always had the vision to rectify my work and inspire me with new ideas.

I am also grateful to my professors, Prof. Dr. Mourad El-Gamal and Prof. Dr. Adel El-Hennawy for their invaluable help and support during all these years. Their comments and suggestions were always the right addition to my work.

My deep appreciation goes to my colleagues at the Integrated Circuits Laboratory (ICL). Especially, Eng. Dina Reda El-Damak. She helped me a lot, both as a TA and as a co-worker in ICL. Her robust experience with CMUTs was very beneficial to my work.

My cordial thanks goes as well to Eng. Joseph Riad for his invaluable help in the presentation of this thesis. Also, Eng. Amr Misbah, Eng. Mohamed El-Badry and Eng. Ayman Ossama have all my appreciation for their help and support.

I would also like to thank my professor, Prof. Dr. Emad Hegazi who had the major role in my early formation and interaction with the integrated circuits.

I am also grateful to my co-workers at MEMS Vision Egypt, Eng. Muhammad El-Nafarawi, Eng. Mohamed Atef and Eng. Ahmed Emara for the useful discussions that we used to have.

Finally, I would like to thank the examination committe, Prof. Dr. Serag El-Din Habib, Prof. Dr. Abdel Halim Abdel Nabi Zekry, Prof. Dr. Adel El-Hennawy and Prof. Dr. Hani Fikry Ragai for their efforts in reviewing and evaluating this work.

Bichoy Waguih Azmy Bahr
Electrical and Communications Department
Faculty of Engineering
Ain Shams University
Cairo, Egypt
2012

Abstract

Bichoy Waguih Azmy Bahr, "SiC Based High Quality Micro-Electro-Mechanical Systems (MEMS)", Master of Science dissertation, Ain Shams University, 2012.

Micro-electro mechanical systems (MEMS) technology has rapidly evolved over the past decade. Owing to its material properties, silicon-based MEMS devices represent a non-feasible solution for many important applications. This thesis studies silicon carbide (SiC) as a potential structural material for MEMS devices, which has gained a significant interest lately. Being a good example on bio-medical MEMS devices that can benefit from the superior characteristics of SiC, capacitive micro-machined ultrasonic transducers (CMUTs) were selected as a good candidate for the study presented in this thesis. The thesis starts by presenting the structure and conventional modeling techniques for the CMUT devices. A conventional finite element model (FEM) is presented as being the most accurate modeling technique for CMUT devices. An accurate frequency domain model that focuses on fluid loading for CMUTs in immersion is suggested. A novel GPU-accelerated time-domain finite-difference CMUT simulator module was developed. This module can be called from within commercial EDA tools, allowing for accurate MEMS-CMOS full system verification and simulation. The thesis concludes by a discussion about the obtained results and the possible future work.

Summary

Silicon carbide (SiC) has gained interest over the last two decades as a potential structural material for micro-electro-mechanical systems (MEMS) and devices. Owing to its high stiffness, chemical inertness and bio-compatibility, SiC is a natural candidate for MEMS devices intended for biomedical applications. A notable example of these devices that can strongly benefit from the superior characteristics of SiC are capacitive mircomachined ultrasonic transducers (CMUTs).

An optimized design of a CMUT device that takes advantage of the SiC superiority requires accurate and comprehensive mathematical modeling. Also, special models will eventually be needed to emulate the behavior of a CMUT in electronic design automation (EDA) tools. Such models are necessary to allow for complete system simulation, in order to make the implementation of a CMUT solution a feasible one.

This thesis focuses on modeling techniques for CMUT devices. Conventional modeling techniques are presented, alongside with new ones based on advanced concepts. The thesis is divided into five chapters and is organized as described hereafter.

Chapter 1 presents an introduction of SiC as a potential material for MEMS devices. The mechanical and chemical properties of SiC are discussed. CMUT devices are introduced in the context of being potential biomedical MEMS devices that can benefit from the SiC properties. The importance of accurate and comprehensive modeling of MEMS devices in general, and CMUT devices in particular, is highlighted in this chapter.

Chapter 2 presents an extensive description of the CMUT devices structure, as well as their principle of operation. Theory, analysis, and classical models of CMUT devices follow the description of their structure. Finite element modeling (FEM) is introduced as being the most accurate modeling technique of CMUT devices, especially when the latter are operated in immersion. Simulation results from both classical models and FEM models are compared.

Chapter 3 presents a proposed analytical model for circular CMUTs when operated in uniformly excited arrays. The model can accurately predict the frequency response of the uniform CMUT arrays, and it accounts for fluid loading on the CMUTs. The model emphasizes the importance of fluid loading on CMUT arrays, and how it can totally impede the operation of CMUT cells and prevent its radiation. The proposed model uses direct evaluation, which makes it much faster than FEM models. Results from the proposed model are compared to those from the FEM model.

Chapter 4 focuses on the electronics-CMUT co-simulation in commercial EDA software. A novel finite-difference, GPU-accelerated, time-domain simulator module is proposed. This module uses finite-difference methods to numerically solve the partial differential equations of a CMUT. The finite-difference method represents an accurate, yet simple, technique to model MEMS devices. It takes into account many non-idealities and secondary effects, such as the distributed nature of displacement, the finite electrode coverage, the non-linearity and the duffing effect. The module relies on the GPU to overcome the computationally intensive nature of the finite-difference method, without sacrificing the circuit simulator performance. This simulator can be called from within commercial EDA software through the standard Verilog Procedural Interface (VPI). The chapter concludes by demonstrating the results from the GPU-accelerated simulation module. The results are compared to those of the FEM model as well as to the proposed model.

Chapter 5 is a conclusion for the work of this thesis. The necessity of accurate and comprehensive MEMS models is revisited. A summary of the different modeling techniques is presented, highlighting the accuracy, speed and feasibility trade-offs inherent to each one of them. Future work is suggested in the form of a conclusion to this chapter.

Contents