KWARA STATE POLYTECHNIC

MODELING AND ANALYSIS OF MEMS DEVICE

BY

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF MECHATRONICS ENGINEERING, INSTITUTE OF TECHNOLOGY.

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CERTIFICATION

The undersigned certify that this project report prepared by **Abdulbasit Ayidey ABDULRASHEED**, **ND/23/MCT/FT/0074** Entitled: **Modeling And Analysis Of Mems Device** meets the requirement of the Department of Mechatronics Engineering for the award of National Diploma (ND) in Mechatronics Engineering, Kwara State Polytechnic, Ilorin.

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DECLARATION

I hereby declare that this research project titled **MODELING AND ANALYSIS OF MEMS DEVICE** is my work and has not been submitted by any other person for any degree or qualification at any higher institution, I also declare that the information provided therein is mine and those that are not mine are properly acknowledged.

____________________________ Student Name

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DEDICATION

This project is dedicated to Allah (SWT) and his holiest Prophet Muhammad (SAW)

ACKNOWLEDGEMENT

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ABSTRACT

This report presents the modeling and analysis of a MEMS capacitive accelerometer. The study employs analytical equations and Finite Element Method (FEM) simulations using COMSOL Multiphysics to investigate the mechanical deflection and resonant frequency of the device. The accelerometer comprises a proof mass suspended by micro beams, forming a variable capacitor. The simulation predicts a fundamental resonant frequency of approximately 12 kHz and a maximum displacement under 1g acceleration of 0.6 μm. These results validate the design for applications in consumer electronics and inertial navigation. Recommendations for future optimization are provided.

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CHAPTER ONE

1.0 INTRODUCTION

Micro-electro-mechanical systems (MEMS) represent a very important class of systems having applications ranging from small embedded sensors and actuators, passive components in RF and microwave fields, and micro-mirrors in the optical range. The importance of MEMS stems from their many advantages, among which are, their small compact size amendable to integration with other components, low loss and parameter variability.

Among the most widely used MEMS devices are accelerometers, crucial for motion sensing in smartphones, automotive airbags, and navigation systems. Due to the micro-scale dimensions and multiphysics nature of MEMS devices, modeling and analysis are critical to ensure optimal design, performance, and reliability before fabrication.

From structural point of view, each MEMS component is, by itself, a very small electromechanical system of heterogeneous structure composed of materials with different chemical composition (dielectric substrate, metal alloys and conducting wire) and different physical (electrical, thermal, mechanical) properties. Moreover, MEMS components may represent static systems or they may contain some moving parts, such as in variable capacitor, moving membranes and cantilevers. The dimensional scale of the different parts of MEMS components may vary from very small (microns or even nanometers) in one dimension, such as thickness of a plate, to comparatively large of few hundred microns in other dimensions, thus resulting in large aspect-ratios.

When MEMS components are put into oration, they constitute systems, in which electrical, thermal, mechanical, and other physical phenomena take place and interact with each other. From mathematical modeling and simulation point of view, this calls for multi-physics treatment, in which coupled systems of differential equations of different combinations of electromagnetic, mechanical, fluid, heat transfer and/or transport equations, are formulated then solved depending on the type of boundary conditions imposed by MEMS component under investigation.

Mathematical modeling and simulation has been used in all fields and disciplines of engineering for decades, for theoretical characterization of devices and systems before manufacturing, or even before prototyping, for a number of reasons among which are reduction in manufacturing cost and time. However, the heterogeneous nature of MEMS structures, coupled with multi-physics phenomena that take place during their operation, makes modeling and simulation of MEMS components, a complex and challenging task.

1.1 Background of the Study

Micro-electromechanical Systems (MEMS) are miniaturized mechanical and electro-mechanical devices that are widely used in sensors, actuators, RF systems, biomedical devices, and more. The performance and reliability of MEMS devices heavily depend on precise modeling and analysis of their mechanical, electrical, thermal, and coupled behaviors. Challenges arise due to multi-physics interactions, geometric non-linearity's, and material properties at micro scales, which often differ from bulk behavior.

1.2 Problem Statement

Despite advances in MEMS technology, many devices still suffer from performance degradation due to inadequate prediction of mechanical stresses, resonant frequencies, pull-in voltages, and thermal effects. This can lead to failure modes such as stiction, fatigue, or unexpected dynamic behaviors. Hence, there is a need for a robust modeling and analysis framework that can accurately capture the complex interactions in MEMS devices.

1.3 Aim

The aim of this report is to model and analyze the static and dynamic behavior of a MEMS capacitive accelerometer**.**

1.4 Objectives

- To develop a comprehensive multi-physics model of a MEMS device (e.g., cantilever beam, capacitive accelerometer, or RF switch).
- To analyze the static and dynamic responses under various operating conditions (electrical loading, mechanical forces, thermal variations).
- To identify critical parameters affecting the performance and reliability.
- To develop the geometry of the MEMS accelerometer using CAD tools.
- To perform static analysis to determine displacement under acceleration.
- To conduct modal analysis to find the natural frequency.
- To compare simulation results with analytical predictions.

1.5 Scope Of The Study

Develop analytical and/or numerical (FEM) models of the selected MEMS structure.

Perform static analysis to predict deflection, stress distribution, and pull-in voltage.

Conduct modal and harmonic analysis to determine resonant frequencies and dynamic stability.

Investigate thermal effects and coupled electro-thermal-mechanical behavior.

Propose design optimization strategies to improve performance

1.6 Significance Of The Study

Modeling and analysis are indispensable for ensuring MEMS devices are functional, reliable, cost-effective, and application-ready. They bridge the gap between theoretical design and practical implementation, enabling innovation in both academia and industry.

1.7 Limitation

While modeling and analysis are essential tools in MEMS design and development, they come with several inherent limitations and challenges, especially due to the complex, multi-domain nature of MEMS.

Although modeling and analysis are powerful for MEMS design, their limitations stem from scale-dependent physics, complex interactions, and computational demands. To overcome these, engineers must combine simulations with experimental data, careful assumptions, and advanced tools