AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering Department

Optical Micro Electromechanical Scanner Systems

A Thesis

Submitted in partial fulfillment of the requirements of the degree of

Master of Science in Electrical Engineering

Submitted by

Alaa Eldin Samy Mohamed El-Hady Ahmed

B.Sc. of Electrical Engineering

(Electronics and Communications Engineering)

Ain Shams University, 2009

Supervised By

Prof. Dr. Diaa Abd El-Megeed Mohamed Khalil

Dr. Mohamed Ahmed El-Sheikh

Cairo, 2014

AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Cairo – Egypt

Examiners Committee

Name: Alaa eldin samy Mohamed el hady ahmed

Thesis: Optical Micro Electromechanical Scanner Systems

Name, title and affiliation Signature

Prof. Hany Fikry Ragay **……**

Electronics and communications department

Ain shams University

Prof. Serag Eldeen Habib **……**

Electronics and communications department

Cairo University

Prof. Diaa Abdelmageed Khalil **……**

Electronics and communications department

Ain shams University

Date

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: Alaa Eldin Samy Mohamed El-Hady Ahmed

Signature:

Date:

C.V

Name of the researcher: Alaa Eldin Samy Mohamed El-Hady Ahmed

Date of birth: 10th of July 1987

Place of birth: Cairo

Degree: B.Sc. in Electrical Engineering

Department: Electronics and Communication Engineering

Faculty: Faculty of Engineering

Date of Degree: June 2009

ABSTRACT OF THE THESIS
“Optical Micro Electromechanical Scanner Systems”

By

Alaa Eldin Samy Mohamed El-Hady Ahmed

A novel Micro Electro Mechanical Systems Scanner was proposed. The microscanner is a one dimensional monolithic compliant-spring based scanner with an in-plane actuator. It was fabricated on a SOI wafer using Deep Reactive Ion Etching technology. The scanner was tested and over 86° of optical scan at a resonance frequency of 2.6 kHz was achieved. It featured an alignment free assembly and was designed to be easily integrated with other optical modules.

The successful integration of MEMS scanners with a biomedical imaging system called Optical Coherence Tomography (OCT) was done using a novel Dual channel Common Path OCT probe. The system also shows promise in building two dimensional scanners by integrating it with another one dimensional out-of-plane scanner. The out-of-plane actuation was studied and improvements on the linearization its DC actuation was proposed.

The characterization of the MEMS scanner was done using conventional methods, but the optical characterization of fast moving reflected beams was done using an improvised technique especially designed for such techniques. The proposed technique was successful, and the beam was fully characterized at high speeds and at different angles whilst the scanner was working.

ACKNOWLEDGMENT

الحمد لله رب العالمين

All praise is to Allah, most gracious, most merciful, and whose help covers my entire life.

I hereby would like to thank my supervisors Prof. Dr. Diaa Khalil, and Dr. Mohamed El-Shiekh, for their patience, support, and continuous motivation.

Dr. Diaa provided me, not only with the scientific knowledge, and valuable advice, but also with the encouragement, and interest in my work. He taught me the mentality and attitude of effective research.

Dr. Mohamed helped me take my first steps in my studies and was patient with me in my initial stages and throughout the time of creating this work. He helped me discover the interesting world of MEMS.

I would also like to thank Dr. Mustafa Soliman, Dr. Yasser Sabry, Dr.Bassam El saadany, and Dr. Mohamed Yehia for their invaluable support and guidance. Also, many thanks go to the SWS (SiWare Systems) team for the time they invested in me and their helpful guidance, especially Mohamed Sadek, Mohamed Nagi, Basem Mortada, Khaled Hassan, and Yassin Nada.

I also thank SWS for the support in the fabrication of the prototype scanner. The fabrication itself took place in Ecole Superieure d'Ingenieurs en Electronique et Electrotechnique, ESIEE.

Moreover, I would like to thank ITIDA (Information Technology Industry Development Agency) and NTRA (National Telecommunications Regulatory Authority) for the financial support of the OCT project that covered my masters' research.

Last but not least, it gives me great pleasure to thank my parents and my wife. Their outstanding patience and love are what made this work possible.

AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics and Communications Engineering Department

Summary

Name: Alaa Eldin Samy Mohamed El-Hady Ahmed
Title: Optical Micro Electromechanical Scanner Systems

The MEMS Scanner, or Microscanner, is a component of Micro-Opto-Electro-Mechanical systems (MOEMS).They are basically small mirrors (in the range of few μm to few mm) actuated by a MEMS actuator, to reflect a laser beam into a certain point in space. The movement of such mirrors is modulated as the application requires.

Indeed, microscanners have a large market in today's industry, as they serve many applications. From complex display systems, to simple barcode scanners; MEMS scanners offer numerous solutions to several technological challenges. Additionally, they are a key component in many biomedical imaging devices, like the Optical coherence tomography (OCT). However to reach industrial specifications, the fabrication methods must be simplified enough for the final product to become economically feasible. It also must become integrated with other optical components.

The work of this thesis is to design, implement, and test a MEMS based microscanner that meets certain specifications. Moreover, it features a cheap fabrication methodology that is compliant with the Deep Reactive Ion Etching (DRIE) technology. The final device needs also to be integrated with any other optical module, including the OCT system. This would further reduce the cost due to its simple fabrication and the corresponding simple alignment-free assembly. Moreover, the design was done using flat mirrors, which eliminated any optical constrictions on the nature of the beam used to perform the scan.

The main contribution of this thesis is comprised of:

1- The design and fabrication of a MEMS scanner that is in-plane and self-aligned where the Single Mode Fiber is inserted in a micro-machined fiber groove etched by DRIE.
2- Improvising a novel method to enable the optical characterization of reflected spots from scanners at high speeds while it's at resonance to draw the shape of this spot periodically.
3- The design and testing of a new probe configuration for a Common Path OCT head that enabled the use of complex optical devices like the scanner creating two and three dimensional images.

Furthermore, and since the out of plane actuator, staggered vertical comb drive, demonstrates a nonlinear behavior, its actuation is limited to resonant actuation only. To solve this issue, an algorithm for optimization of the design was proposed and tested by simulations, to achieve linear actuation. The results were promising and they were published. This allows a linear DC actuation scheme of out of plane actuation, and thus opens the door for many applications for the linear-2D scanner

This thesis consists of seven chapters. The first chapter of this thesis introduces the reader to the work presented, the objectives, and motivations. The second chapter will discuss the applications of MEMS scanners, as well as a survey on the current state of the art found in literature. Additionally, the main theory of the Optical Coherence Tomography (OCT) are explained as a direct application to our work and measurements.

The third chapter will present the concept of the actuator design as well as the spring system. Additionally, the design of the compliant springs used will be explained. It will also present the theory behind the new and novel work in these domains as well as their basic operation. Then the two dimensional scanners will be discussed in the fourth chapter, and the out of plane actuation required to build such scanners are explained.

Chapter five will be focused on the design, simulation, and fabrication of self-aligned in-plane scanners with monolithic compliant structures and flat mirrors. The use of compliant structures allowed for using simple lateral comb-drives to produce rotary actuation, and thus achieve scanning mechanisms that are in-plane and fully integrable with good optical properties and at custom operating frequencies that matches the specifications of the biomedical application chosen. Moreover, a brief theoretical background of the curved mirror scanners used for testing the possibility of using integrated scanners with OCT is provided.

As for the sixth chapter, it presents the experimental measurements of the novel method in building a biomedical probe as a direct application, as well as the novel compliant microscanner structure to confirm the theoretical allegation of such design. The Scanner achieved an optical deflection angle of more than eighty degrees at a resonance frequency of two thousand and six hundred Hz.

Lastly, chapter seven will present the conclusion and future work on the subject of the thesis, namely, MEMS scanners.