Sudan University of Science and Technology
College of Graduate Studies
School of Mechanical Engineering

DESIGN OF ELECTROSTATICALLY ACTUATED MICROGRIPPER FOR MEDICAL APPLICATIONS

تصميم المقبض المصغر الالكتروستاتيكى الحث للتطبيقات الطبيه

A Project Submitted In Partial Fulfillment for the requirements of M.Sc. (Honor) In Mechatronics Engineering

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الايـة

قال تعالى:

(قُل لَّوْ كَانَ الْبَحْرُ مِدَادًا لِّكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ قَبْلَ أَن تَنفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِهِ مَدَدًا)

صدق الله العظيم

DEDICATION

This project is dedicated to…

My beloved ***Mother*** *and* ***Father***

For their endless love, support and encouragement.

Brothers *and* ***Sisters***

and

To those who accompanied me in path of friendship

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Am thankful to Almighty *ALLAH*, most gracious, who in his infinite mercy has guided me to complete this project.

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Abstract

Last decades, the importance of micro biomedical instrument has grown at a rate even faster than in previous. This acceleration was primary due to the increasing demand for high quality medical care in highly developed countries, and also due expansion in MEMS technologies. MEMS based micro gripper is one of the major focuses for many medical applications such as microsurgery, micro assembling and testing of micro components, and measuring properties of biological cells and small-scale tissue manipulation.

This research presents electrostatically actuated cantilever beam used as micro gripper in medical application. This electrostatic comb drive micro gripper is designed using different materials (Si, SiO_2, ,poly silicon ,Si_3N_4) then analyzed the main characteristics of the micro gripper using a model designed by finite elements method (ANSYS). In addition, the displacement of gripper arms, stress in comb drive, and temperature that generated from actuating were determined. Also the forces applied to the grasped object were studied. Finally kinematics characterization of different analyzed topologies of the micro gripper is discussed and couples of suggestion are given to increase the accuracy of the design.

مستخلص

تزايدت فى العقد الاخير أهمية المعدات الطبية الحيوية الصغيرة بمعدل أسرع مما كان عليه في العقود السابقة، وكان هذا التسارع نتيجه للطلب المتزايد على الرعاية الطبية الحديثه عالية الجودة في البلدان المتقدمة جدا، وأيضا نسبه للتوسع في تقنيات MEMS، يعتبر المقبض المصغر هو محور رئيسي للعديد من التطبيقات الطبية مثل الجراحة المصغره,عمليات التجميع الجزئي ,إختبار المكونات الصغرى و قياس خصائص الخلايا البيولوجية والتلاعب بالأنسجة على نطاق صغير.

فى هذا البحث تمت دراسه العمود الالكتروساتكى التشغيل الذى يتم استخدامه كمقبض مصغر في الاستخدامات الطبية، هذا المقبض تم تصميمه باستخدام مجموعة مختلفة من المواد، ثم تم تحليل الخصائص الرئيسية للمقبض عن طريق تصميم نموذج يستخدم طريقه (FEM) وبرنامج محاكاة ANSYS بالإضافة إلى ذلك، تم تحديد نسبة المسافه التى تتحركها الاذرع، ومعرفه اعلى إجهاد في منطقه الأمشاط، ودرجة الحرارة التي تمت توليدها، كما تمت دراسه القوه اللازمه للقبض بالاضافه الى خصائص الحركه للمقبض وفى النهايه تم وضع عدد من الاقتراحات لزياده الدقه فى التصميم.

TABLE OF CONTENT

TITLE **PAGE**

TITLE **PAGE**

TITLE	**PAGE**

List of Tables

List of Figures

FIGURE NO	TITLE	PAGE

FIGURE NO	TITLE	PAGE

List of abbreviation

MEMS	Micro electromechanical systems
SMA	Scanning Electron Microscope
ESD	Endoscopic Sub-Mucosal Dissection
FEM	Finite Element Method
SMA	Shape Memory Alloys

List of Symbols

ε_r = relative permittivity of the dielectric material between the two plates.

$\varepsilon_\circ$=Relative permittivity of free space.

F= electrostatic force.

d = gab between comb finger.

t= thickness of comb.

N= number of comb pair.

a= acceleration.

g= acceleration of earth.

F_G= gripping force.

G= weight.

µ= friction value.

ὰ= jaw opening angle.

S= distance.

$\mathbf{F_H}$= Force to lift

$\mathbf{F_S}$= Force to fall

Fv= Force to displace

CHAPTER ONE

Introduction

CHAPTER ONE

INTRODUCTION

1.1 Introduction:

As noted by (J.Allen & James 2005)," micro electromechanical systems (MEMS) is a technology of miniaturization that has been largely adopted from the integrated circuit (IC) industry and applied to the miniaturization of all systems not only electrical systems but also mechanical, optical, fluid, magnetic, etc" .

Miniaturized systems that combine sensors and actuators with high performance embedded processors becoming increasingly very popular as it enable building very complex systems with high performance at a fraction of the cost and size of ordinary systems, as such, these systems are the enabling technology for today's explosive growth in computer, biomedical, communication, magnetic storage, transportation, and many other technologies and industries (J.Allen & James 2005).

With the growing development of micro and nanotechnologies, there is a great demand for micro tools suitable for manipulation of small scale objects, applications of mechanical micro gripper are diverse and include equipment for micro assembling of complex MEMS structures, biological micro grippers in micro surgeries, micro robots for biomedical and aerospace applications, among the different actuating principles employed for the design of micromanipulators, the most popular are electrostatic, electro thermal (Varona et al. 2009).

1.2 Research problem:

As stated by (Fukuda, Niimi & Obinata 2013, p. 86) "in order to reduce invasiveness such as scars in medical field, it is important to miniaturize the endoscope and surgical tools, while maintaining the performance of devices". In addition, medical doctors would like to add some functions for improvement of safety and usability of surgical tools during treatments. Therefore, small and thin instrument with high-function are highly required, and MEMS makes a substantial contribution to fabricate and integrate such novel tools and systems.

On the other hand, target of scientists in bioscience filed has changed from tissue to single cell level for specific investigation and understanding of biological function. Since investigation of mechanical characteristics of cells is important to know functions and growth factors of cell, micro actuators are highly required to stimulate and measure the response of single cell.

Basically the aim of this research is to design micro gripper actuator able to firmly hold object of interest with a force that is sufficiently high to keep it within the grips but at the same time sufficiently low to avoid damaging the material. Most popular micro gripper are electro thermal actuating micro gripper because of low voltages and they offer large output force but its applicability in biological and medical field is limited due to the high power consumption and high operating temperatures that are unsuitable because "increases temperature even in small ratio could be enough to damage to biological samples. Hence for one of the future direction of microsurgical robot, new design approach is required to drastically improve the performance of the micro gripper" (Dario et al. 2000), so the goal of this research to achieve high performance tools both in flexibility and the biocompatibility of micro gripper design to avoid damage of tissues and biological samples.

The electrostatic actuation has been chosen as the driving force due to the low power consumption and its functionality at room temperature, in addition " MEMS electrostatic actuators are well known for their large deflections, generating high forces and their compatibility with existing fabrication technologies " (Varona et al. 2009), so it will be introduced how to designed electrostatic micro gripper that is used for actual medical and bioscience applications.

1.3 Objectives:

The main objectives of this research are:

1. To design micro gripper which operates in lower voltage, have small size, and ensuring the movement at both jaws to enhance the gripper force.

2. To study the relation between the applied voltage and displacement of gripper.

3. To study effective stress in the micro gripper.

4. To study the relation between voltage and generated temperature.

5. To figure the relation between voltage and gripping force.

1.4 Methodology :

The methodology used in this research was to determine the objectives of the project and how to achieve it. Secondly to collect more information about micro gripper and electro static actuating and to know more about medical application of micro gripper. Thirdly to review previous studies and researches in the area of electro statically actuated cantilever beams as micro gripper in medical application. Fourthly to choose the gripping mechanism to achieve the best performance, then building actuator design and choose the best material and then building a simulated design to check the validity of the design and testing the system performance using (ANSYS 15.0) software.

1.5 Research outlines:

Chapter one includes introduction, problem statement, proposed solution, objectives and methodology. Chapter two includes theoretical background and literature review. Chapter three include block diagram, and system component. Chapter four contain the system simulation design result, chapter five contain calculation and analysis, and finally chapter six include conclusion and recommendations.

CHAPTER TWO

Theoretical Background

&

Literature Review

CHAPTER TWO

Theoretical background and literature review

2.1 Background:

Smart technology is a term extensively used in all branches of science and engineering due to its immense potential in application areas of very high significance to mankind, (Varadan, Vinoy & Gopalakrishnan 2006) conclude that "smart technology has already been used in addressing several remaining challenges in aerospace, automotive, civil, mechanical, and biomedical and communication engineering disciplines, this has been made possible by a series of innovations in developing materials which exhibit features such as electromechanical mechanical coupling, in other words, these materials could be used to convert one form of energy (say electrical) to another (mechanical force, vibration, displacement, etc.)".

Researchers over the world have devised various ways to embeded these components in order to introduce ‘smartness’ in a system, this science is increasingly leaning towards miniaturization with the popularization of micro electromechanical systems (MEMS) (Varadan, Vinoy & Gopalakrishnan 2006).

In another words MEMS is a micrometer-sized device with three-dimensional properties, namely sensors, actuators pumps, and valves all capable of sensing and manipulating physical parameters.

Advancements in the miniaturization of semiconductor devices have been made possible by new methods of micro fabrication techniques. These innovations have been among the motivations giving birth to micro electromechanical systems (MEMS) technology.

2.2 Micro-mechatronics systems:

MEMS technology enables the fabrication of a vast variety of miniaturized sensing and actuating devices, in our daily life, various devices are applied for automobiles, computer peripheries, printers, cameras, amusements, robotics, automation, environmental monitoring, energy resource, biological/medical treatments, and so on Microtechnology was commonly used to realize high efficiency, high-integration, high-functionality, low-energy consumption, low-cost, and so on by miniaturizing the elemental devices on sensors, actuators, and computers in micro-scale, Micromechatronics came up as the one of the important technology" (Fukuda, Niimi & Obinata 2013).

Recently, Microtechnology has an important role in the industrial applications , micro- mechatronics is basically defined to integrate major three technologies Controller, Sensor and Actuator based on the electronics and mechanical engineering, figure (2-1) shows the demands of micro-mechatronics for various social and industrial applications for various applications for industry, some techniques are important especially microfabrication, assembly, control, material, and evaluation techniques, micro- mechatronics is based on various technologies, especially life science, medicine, sensing, actuating, material science, energy, power, and design, control from social aspects, human resource, environmental issue, saving energy, safety, medical, and aging population are currently demanded from industrial aspects, service robots, dependable products, alternative energy, techno care service, environmental friendly products, are particularly demanded (Fukuda, Niimi & Obinata 2013).

As stated by (Fukuda, Niimi & Obinata 2013)" the micro mechatronics is a key technology to solve those problems and leading conventional technologies for future, the applications of micro-nano mechatronics are mainly categorized into the Mechanical, Electrical, and Biological /Medical applications", the figure (2-1) show Micro-Nano mechatronics application.

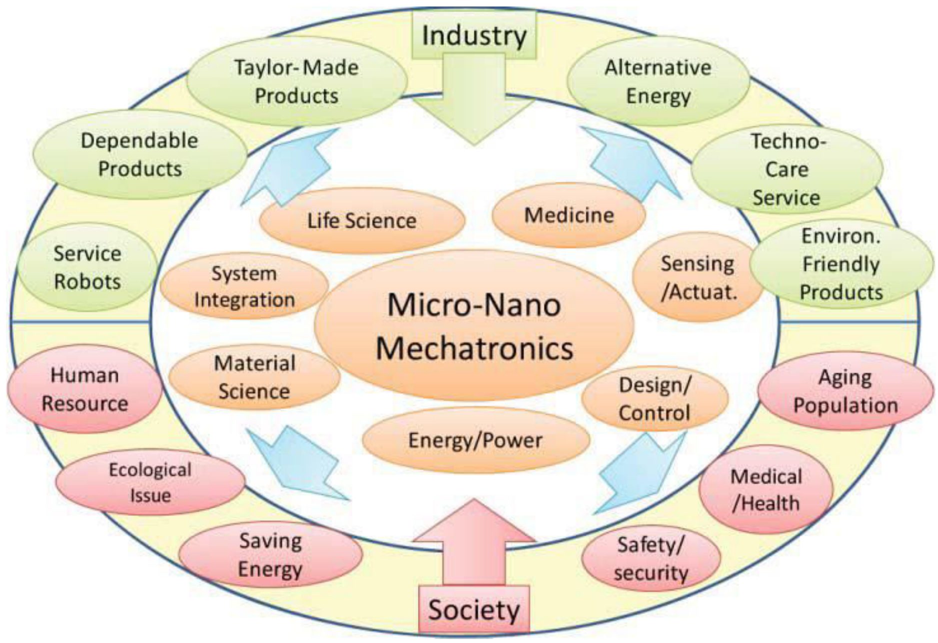


Figure 2-1 Micro-Nano mechatronics application (Fukuda, Niimi & Obinata 2013, p. 11)

2.3 MEMS in medical applications:

There is a lot of technological challenges in medical application for example inspection and diagnosis of different diseases ,generative medicine, gene therapy and life science, monitoring diseases, neuro Science, cell diagnosis and surgery, new drug and medicine, DDS, minimally invasive surgery, rehabilitation, techno-care, So to achieve solution to all those challenges it appear the need to developed and improve medical MEMS devices, one of the important medical surgical simulating technologies is Patient blood vessel simulator, figure 2-2 illustrate this future techniques.

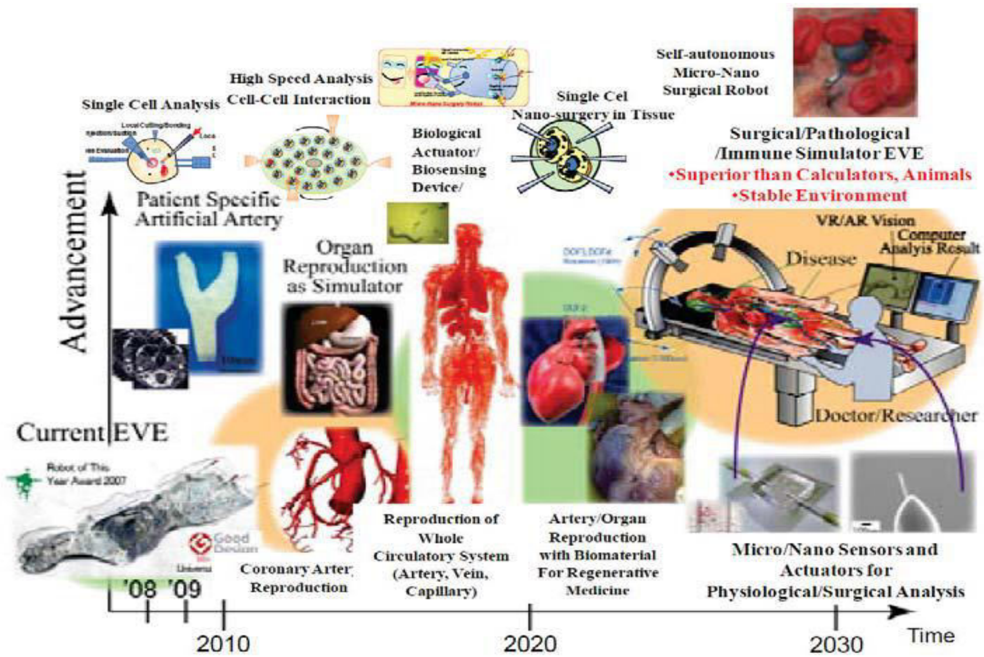


Figure 2-2 Blood vessel simulator and surgical operation system (Fukuda, Niimi & Obinata 2013, p. 14)

2.3.1 Bio-MEMS :

The term "Bio-MEMS" has been a popular terminology in the MEMS industry in recent years due to the many break-through in this technology, which many believe to be a viable lead to mitigate the sky-rocketing costs in healthcare costs in many industrialized countries (Hsu & Tai-Ran 2008). Bio-MEMS include the following three major areas:

(1) Biosensors for identification and measurement of biological substances.

(2) Bio-instruments and surgical tools.

(3) Bio-analytical systems for testing and diagnoses.

2.3.1.1 Major technical issues in Bio-MEMS products:

(1) Functionality for the intended biomedical operations.

(2) Adaptive to existing instruments and equipment.

(3) Compatibility with biological systems of the patients.

(4) Controllability, mobility, and easy navigation for operations such as those required in laparoscope's surgery.

2.3.1.2 Bio-MEMS tool:

Small and thin instrument with high-function are highly required in Bio MEMS tools field, Endoscopic Sub-mucosal Dissection and Scanning Electron Microscopy are one of the most popular Bio-MEMS tool.

2.3.1.2.1 Endoscopic Sub-mucosal Dissection (ESD):

Among the greatest advantages of MEMS technology is the ability to manipulation of micro objects in a controlled fashion is of great interest and hence manipulation devices like endoscope with micro gripper`s end, that can controllably and tunable grasp small-scale objects becoming increasly demanded in most of medical application.

Recently, MEMS-based micro grippers have been employed in a wide range of applications such as biomedical analysis, and minimally invasive surgery is a well-established method in modern medicine, in particular, Endoscopic Sub-mucosal Dissection (ESD) is well known for availability of cancer excision, in ESD a doctor inserts an oral endoscope into a stomach, and performs surgical procedures by using narrow tools for removing tumor tissues, therefore, since large incisions are not required this operation is a minimally invasive procedure to apply a quick recovery for patients (Fukuda, Niimi & Obinata 2013).

A basic technical principle of the surgical resection is the resection of appropriate tissues, which is forced to stand out by injecting saline under the tumor, however, this endoscopic surgery is one arm surgery that it can only insert one endoscope to cut and exfoliate the lesion, ideally, one arm is pulling the lesion and another arm to cut would improve the efficiency and reduce the risk of complications, such as bleeding and perforation from cutting the unconfirmed blood vessels (Fukuda, Niimi & Obinata 2013), the figure (2-3) Show endoscope surgery tool, and figure (2.4) illustrated Endoscopic Sub mucosal Dissection.

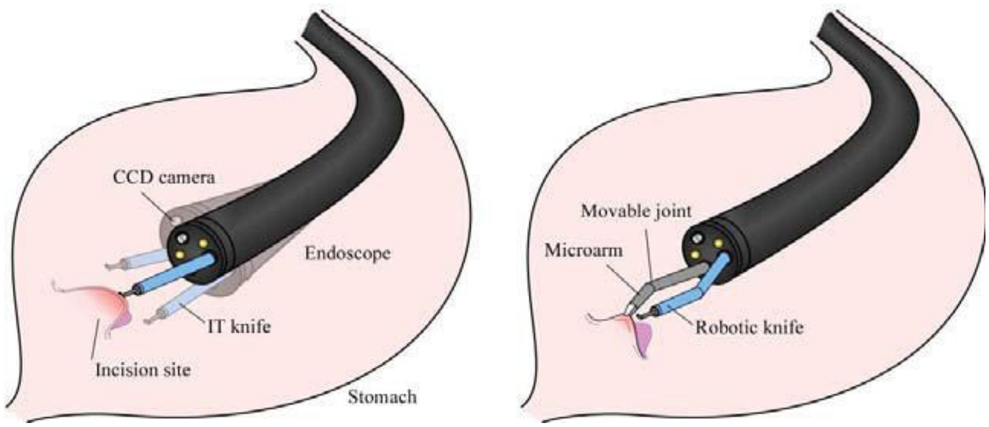


Figure 2-3 Conceptual image of robotic endoscope surgery (Fukuda, Niimi & Obinata 2013, p. 88)

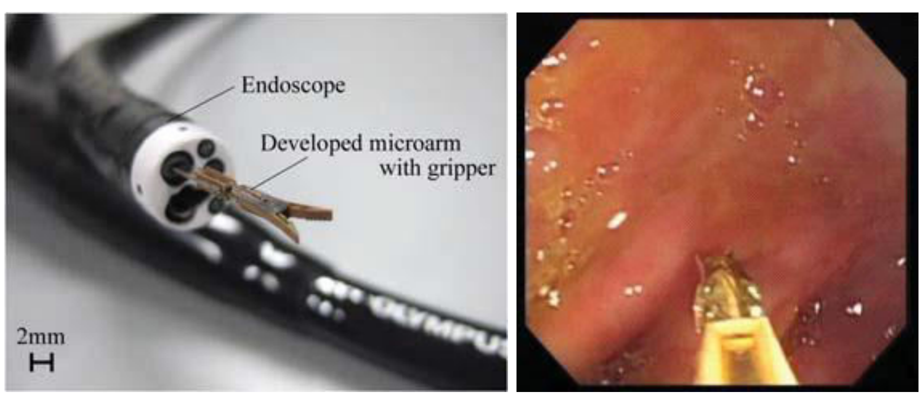


Figure 2.4 Endoscopic Sub-mucosal Dissection (Fukuda, Niimi & Obinata 2013, p. 99)

2.3.1.2.2 Scanning Electron Microscopy (SEM):

It is type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons, the electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition (ANON 2013), the electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image , SEM can achieve resolution better than 1 nanometer , shown below figure(2.5) sample of 10 µm liver tissues taken by SEM.

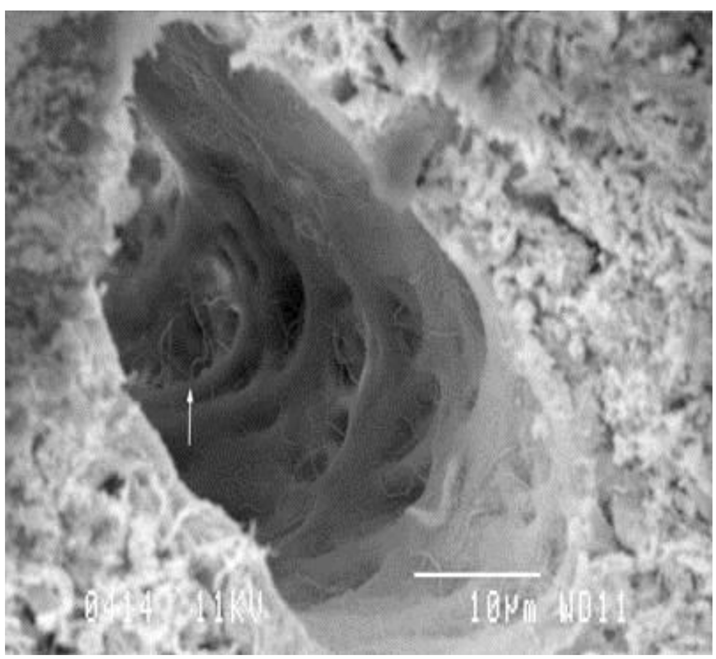


Figure (2.5) sample of 10 µm liver tissues (ANON 2013)

Electron microscopes are very powerful tools for visualizing biological samples, they enable scientists to view cells, tissues and small organisms in very great detail, but however these biological samples can't be viewed on electron microscopes whilst alive, instead the samples must undergo complex preparation steps to help them withstand the environment inside the microscope the figure (2.6) show all component of Scanning Electron Microscopy (SEM) (Kim et al. 2005).

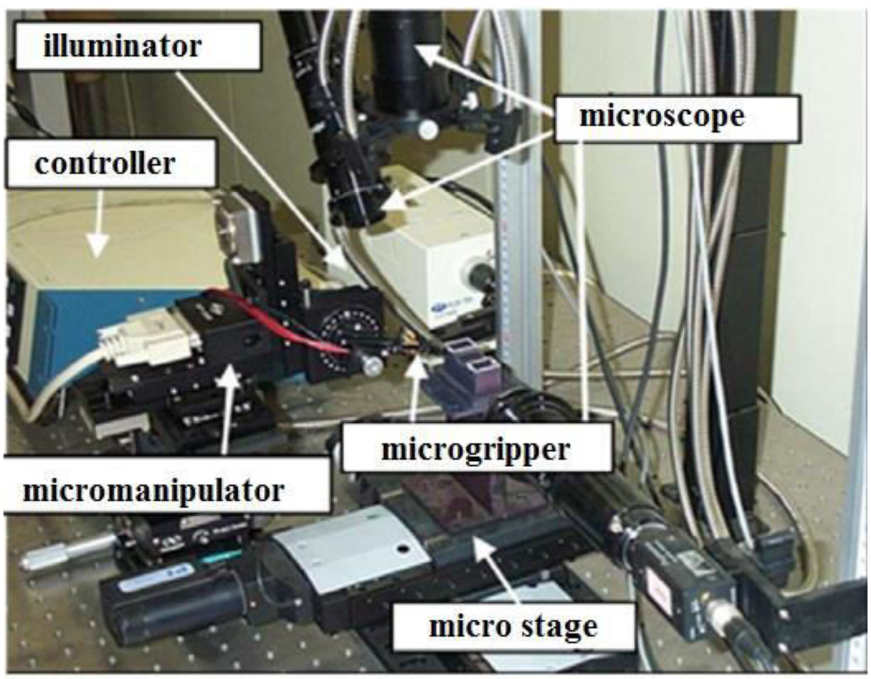


Figure 2.6 Scanning Electron Microscopy (SEM) (Kim et al. 2005, p. 8)

The preparation process demanding grapping the tissue and also cause changes in the sample's appearance, so we need to be able to cut a very thin slice of the sample and grape those sample to allow the electron beam to pass through, to do that we need micro gripper to makes it possible to handle those sample carefully.

2.4 Microactuator :

Microactuator is a device that converts an electrical signal into an action; it can create a force to manipulate itself, other mechanical devices, or the surrounding environment to perform some useful function (Hsu & Tai-Ran 2008).

The technologies for microactuator will be presented; their potential applications and their types can be divided into:

1. Thermal
2. Electrostatics
3. Piezoelectric

2.4.1 Working Principles for Microactuators :

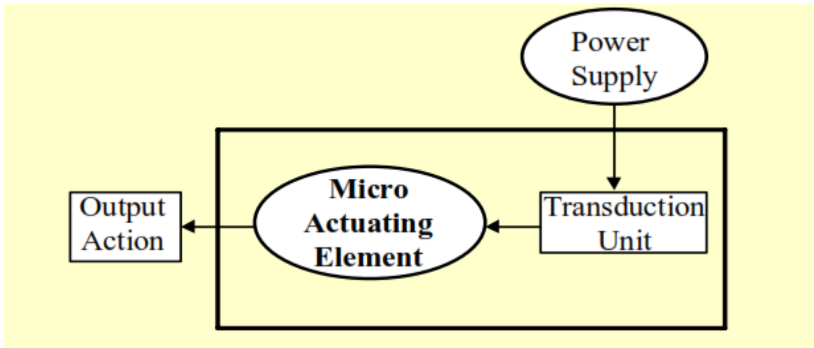


Figure 2.7 microactuation techniques (Hsu & Tai-Ran 2008, p. 3)

Mainly it consists of:

Power supply: Electrical current or voltage.

Transduction unit: To covert the appropriate form of power supply into the desired form of actions of the actuating element.

Actuating element: A material or component that moves with power Supply.

Output action: Usually in a prescribed motion.

2.5 Micro cantilever:

Micro cantilever is a mechanical structure having a beam with its one end fixed and having a seismic mass at its free-end, the cantilever can be easily designed to respond linearly to any desired environmental changes (Zaidi & Bazaz 2014), and hence, it is widely studied, in other words as stated by (Jiang et al. 2004) "the fabricated cantilevers can be considered to consist of two adjacent electrodes forming two plates of a variable capacitor. For such a structure, the cantilever constitutes the movable plate of the capacitor and its displacement is controlled by the voltage applied across the plates".

The growing interest in the development of a new kind of biological actuators based on micro cantilevers relies largely on the potential application for performing local, high resolution, and label free molecular recognition measurements on a portable device.

2.6 Theory of electrostatic actuation:

In general the electrostatic actuators operate according to the principle of attraction and repulsion between shipments where the use of two slices of substances that have conductivity to an electrical outlet, both slides are given shipment is different from the other , mechanical movement resulting from the effect of the electrostatic, conventional mechanical actuators are rarely driven by an electrostatic force because the force is usually too small to displace or lift mechanical parts unless the voltage used is extremely high, with the miniaturization of mechanical structures, the electrostatic force becomes high enough to generate force that can displace mechanical actuator (Millet et al. 2003) .

2.6.1 Electrostatic force between two electrically plates:

The polarization between two plates generates an electrostatic force between them, this fact can be used to actuate the device, on the other hand relative movement of two polarized plates generates an induced current that can be sensed, and the movement is proportional to the current (Hsu & Tai-Ran 2008).

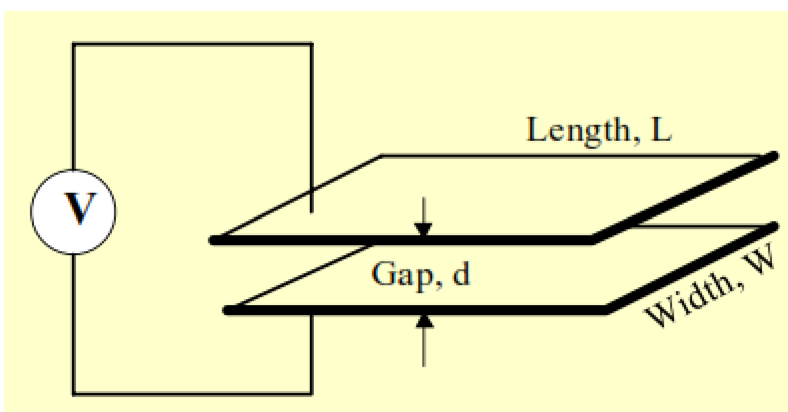


Figure 2.8 Electrostatic between electrically charged plates (Hsu & Tai-Ran 2008, p. 30)

The induced capacitance

$$C = \frac{\varepsilon_r \, \varepsilon_\circ \, A}{D} = \frac{\varepsilon_r \varepsilon_\circ \, W \, L}{D}$$

Where:

ε_r = relative permittivity of the dielectric material between the two plates.

$\varepsilon_\circ$=Relative permittivity of free space

W= width

L=length

D= gab between two plates

A= cross section area

V=applied voltage

The induced normal force

$$F_D = \frac{1}{2} \frac{\varepsilon_r \varepsilon_\circ \, WL}{D^2} V^2$$

2.6.2 Electrostatic Micro gripper:

Mainly there are two electrostatic gripping methods:

1. Classical electrostatic microgripper.
2. Comb drive electrostatic microgripper.

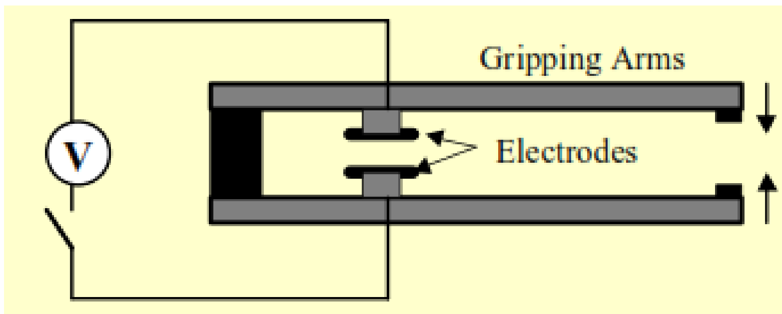


Figure 2.9 the classical electrostatic microgripper (Hsu & Tai-Ran 2008, p. 32)

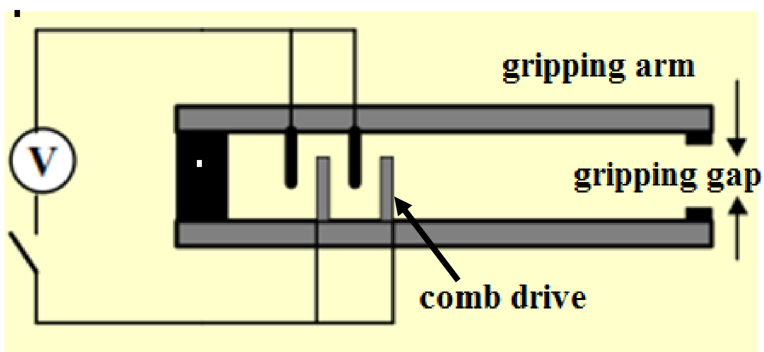


Figure 2.10 Comb drive electrostatic microgripper (Hsu & Tai-Ran 2008, p. 32)

Comb drive electro static micro gripper was chosen in this work for the following reasons:

1- The gripper itself forms part of the actuator and no additional mechanical coupling transmission is needed.

2- The capacitance (and thus the driving force) increases with the displacement of the clamping structures so that lower voltages per unit area are required for closing the gripper.

3- Stability and position control is easier when using a gripper where only fully open/close states are of interest.

2.7 Material for MEMS :

The performance of micro electronic and mechanical systems (MEMS) strongly depends on the mechanical properties of materials used; the evaluation of the mechanical properties of MEMS materials is indispensable for designing MEMS devices (Kumar, Reddy & Sreenivasulu n.d).

Accurate values of mechanical properties (elastic properties, internal stress, strength, and fatigue) are necessary for obtaining the optimum performances, for an example elastic properties are necessary in prediction of the amount of deflection from an applied force and material strength sets device operational limits, also in view of reliability and life time requirements (Kumar, Reddy & Sreenivasulu n.d).

Mechanical characterization of MEMS materials becomes increasingly important, small size of MEMS devices often leads to their usage in harsh environments, and good knowledge of mechanical properties may lead to elimination of some of the mechanical failure modes through proper material selection, design, fabrication and packaging processes, as the interest in MEMS grows the demand for applicable data increases. Reliability, accuracy and repeatability of evaluation methods also became an issue (J.Allen & James 2005).

2.7.1 Silicon (Si):

Silicon is the most abundant material on earth, it almost always exists in compounds with other elements, Single crystal silicon is the most widely used substrate material for MEMS and Microsystems .

The popularity of silicon for such application is primarily for the following reasons:

(1) It is mechanically stable and it is feasible to be integrated into electronics on the same substrate.

(2) Silicon is almost an ideal structure material, it has about the same Young's modulus as steel, but is as light as aluminum.

(3) It has a melting point at 1400 ºC, which is about twice higher than that of Aluminum, this high melting point makes silicon dimensionally stable even at elevated temperature (Hsu & Tai-Ran 2008).

(4) Silicon shows virtually no mechanical hysteresis, that is why it is an ideal Candidate material for sensors and actuators.

(5) Silicon wafers are extremely flat for coatings and additional thin film layers for either being integral structural parts, or performing precise electromechanical functions (Hsu & Tai-Ran 2008).

2.7.2 Silicon dioxide (SiO_2) :

It is inexpensive material to offer good thermal and electrical insulation, also used as low-cost material for “masks” in micro fabrication processes such as etching, deposition and diffusion.

Used as sacrificial material in surface micromachining, Above all, it is very easy to produce (Varadan, Vinoy & Gopalakrishnan 2006).

2.7.3 Silicon carbide (SiC):

Is a leading semiconductor material for devices designed for extreme operating conditions due to a unique collection of properties such as a large band gap, large breakdown field, great hardness, high wear resistivity, and excellent thermal conductivity (Jiang et al. 2004).

2.7.4 Silicon nitride ($Si_3 N_4$):

Used as excellent barrier to diffusion to water and ions, it has ultra strong resistance to oxidation and many etchants make it superior material for masks in deep etching, also used as high strength electric insulators (Hsu & Tai-Ran 2008).

2.7.5 Polycrystalline silicon:

It is usually called “Polysilicon” , and usually are highly doped silicon, they are deposited to the substrate surfaces to produce localized gates for transistors, it has excellent properties such as stability, low resistivity excellent conductivity, and material also shows greater stability under electric field and light-induced stress (Kumar, Reddy & Sreenivasulu n.d).

2.8 Design and simulation of MEMS device:

The aim of modeling stage is to calculate the parameters (design parameters) of the designed solution for a technical product that is why the design phase has central importance within the product development process of MEMS.

The design phase follows the conception of the total solution and forms the basis of the subsequent preparation of constructional documents. A physical model of the designed solution forms the basis of the conception (technical parameter definition for the designed solution).

The calculation of the design parameters is based on different simulation methods, the aims of these simulations are either the covering of predetermined design characteristics of the micro electromechanical system or the fulfillment of special optimization criteria like minimum energy consumption, minimum available space and mass or maximum operating frequency range, respectively, the verification of simulation results with the parameters of the requirement specification completes the design phase, if the result differs strongly from the target values with respect to the defined limits, the simulation will be repeated with changed parameter sets until we reach the optimal design (Varadan, Vinoy & Gopalakrishnan 2006). (Nakasone, Stolarski & Yoshimoto 2006)

To verify that the devices function, the designer has to model the MEMS device. The modeling involves writing the equation of motion or physical modeling of the performance of the device; finite-element techniques are used to solve these modeling equations.

There are a variety of computer aided design (CAD) tools to aid the designer in the simulation and modeling of the device such as ANSYS, COMSOL. In a very fundamental way, these tools are more complicated than the software for design of either solely ICs or solely mechanical devices. This is due to the close coupling of both electrical and mechanical effects within many MEMS. Consider a micro cantilever that is pulled down by electrostatic forces, its simulation has to take into account both the flow of electrical charge and mechanical elasticity and self consistent fashion. Models can be generated from the finite-element model or from written analytical equations; behavior models symbolic view can be generated (Nakasone, Stolarski & Yoshimoto 2006).

2.8.1 ANSYS:

ANSYS is engineering simulation software (computer-aided engineering, or CAE) Developer Company is headquartered Cecil Township, Pennsylvania, United States, ANSYS offers engineering simulation solution sets to design process requires, companies in a wide variety of industries use ANSYS software, the tools put a virtual product through a rigorous testing procedure before it becomes a physical object and is used in several fields, the database includes linear properties, stress-strain curves with temperature, fatigue, elastic and rate-dependent properties of metals, plastics, foams, rubber, wood and many other materials, we use the CAE Modeler software to convert data into common ANSYS Mechanical material models (Nakasone, Stolarski & Yoshimoto 2006).

2.8.2 Finite element method (FEM):

The finite element method (FEM) is a numerical approach by which these partial differential equations can be solved approximately. From an engineering standpoint, the FEM is a method for solving engineering problems such as stress analysis, heat transfer, fluid flow and electromagnetic by computer simulation (Kumar, Reddy & Sreenivasulu n.d).

2.9 Literature review:

A lot of previous papers discussed the electrostatic micro gripper ,one of these papers is (Electrostatic actuated micro gripper using an amplification mechanism) (Millet et al. 2003), this paper presents a micro gripper using an amplification mechanism coupled to an electrostatic linear motor. The gripper design, particularly the principle of the amplification mechanism based on the combination of ground-links and moving pin-joints, is explained, the linear motor is composed of scratch drive actuator inducing the use of electrostatic forces to obtain motion for high accuracy in micro positioning, to corroborate the design, the gripper mechanism has been modeled by finite elements method with different mesh elements via the simulator CASTEM 2000TM. Then, the amplification ratio of displacement, the critical buckling load and the force applied to the grasped object are determined. Moreover, the fabrication process requiring four levels of polysilicon and in the end A complete system has been successfully realized and kinematics characterization has been done with different used topologies.

Another successful paper is (Design and Fabrication of a Novel Microgripper Based on Electrostatic Actuation) (Varona et al. 2009) , the paper introduces a parallel-plate electrostatic microgripper fabricated in a standard surface micromachining technology and that microgripper design proposed in this work consists of two released polysilicon structures separated by a thin gap resembling the construction of a parallel plate capacitor, the two structures are supported by serpentine springs attached to an anchor pad in their far end, when a voltage difference is applied between the two structures, they will tend to collapse against each other due to electrostatic attraction thereby closing the gap, objects located within the gap may be gripped in this manner by the clamping structures, then the micro gripper has been analysis and modeling and finally was fabricated using the standard Multi-User MEMS Processes (MUMPs).

Another Paper discussed MEMS devices that are actuated using electrostatic forces is (Modeling the electrostatic actuation of) (Marquès, Castelló & Shkel 2005) , this paper presents a methodic overview of the existing techniques applied to the Micro-Electro-Mechanical Systems (MEMS) electrostatic actuation modeling and their implications to the dynamic behavior of the electromechanical system.

Last paper (Dry release fabrication and testing of SiC electrostatic cantilever actuators) (Jiang et al. 2004) , this paper discuss how Polycrystalline 3C–SiC electrostatic actuators have been fabricated using a surface micromachining process and theory for electrostatic actuation.

CHAPTER THREE

Design and modeling of the microgripper

CHAPTER THREE

DESIGN AND MODELING OF THE MICROGRIPPER

3.1 Introduction:

In this chapter we are going to study and calculate the electrostatic force in comb drive and force of gripping, also study the kinetic features, a couple of suggestion has been made to increase efficiency and accuracy and in the end the microgripper design and ANSYS programming are shown .

3.2 Comb drive:

Comb drives are basically capacitive actuators, which uses electrostatic force between two conducting combs, when voltage is applied between the combs, they tend to attract and move towards each other because of the attractive electrostatic force (Sujathaa, N.Vigneswaranb & Yacinc 2013), combs are designed in such a way that they occupy the intermediate slot in between them, in order to avoid the direct contact in between them, the electrostatic force between the plates is given by:

$$F = \frac{N\,\varepsilon_{\circ} T\, V^2}{2d^2}$$

Where:

F= electrostatic force

d =gab between comb finger

T=thickness of comb

N=number of comb pair

$\varepsilon_{\circ}$= permittivity of free space

From the above equations it is clear that the displacement produced is affected by the number of combs, actuation voltage applied, thickness of the comb and gap between the combs.

3.3 Gripping force:

Force are transmitted by gripper jaws so-called operating element of the micro gripper, the amount of force which needs to be applied depend on body mass or weight of object which the micro gripper able to handle, the direction of the micro gripper motion, surface friction and geometry of object to be handled (Wolf, Steinmann & Schunk 2005), the figure (3.1) below show all that forces.

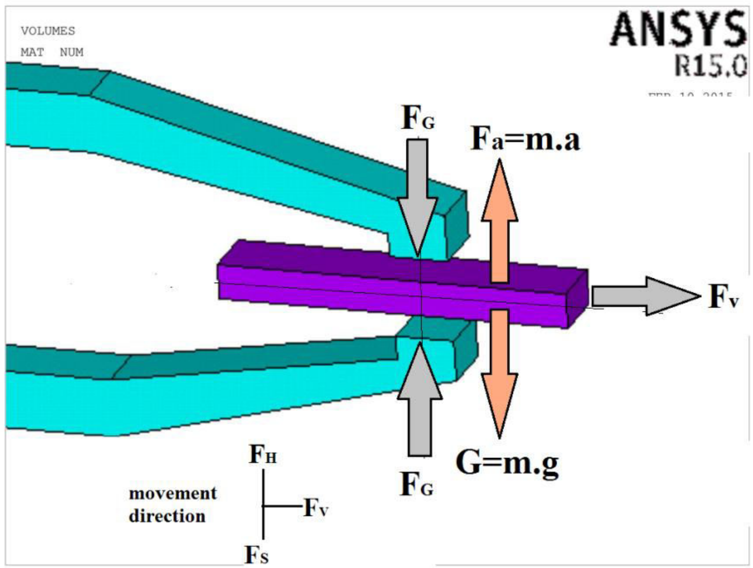


Figure 3.1 Micro gripper forces

The gripper is performing translator movement and according to direction of movement we have three types of forces:

3.3.1 Force to lift (F_H) Upward:

$$F_H = m \cdot g\,(1+ \frac{a}{g})$$

F_H =force to lift upward

3.3.2 Force to fall (Fs) downward:

$$F_S = m \cdot g\,(1- \frac{a}{g})$$

Where:

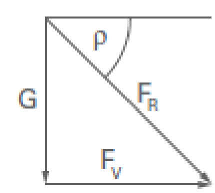
a=acceleration

g=acceleration of earth

m=mass

3.3.3 Force to displace (Fv) :

Force acting on work piece (object) while taking it from one point to another (Wolf, Steinmann & Schunk 2005).



$$F_R = \sqrt{G^2 + F_V^2} \qquad \rho = \arctan \frac{F_V}{G}$$

3.4 Kinetic effect on the required gripping force:

Not only criteria such as weight and dimension of both micro gripper and work pieces taken into account in the design of micro gripper, but also kinetic feature as Just as importance for gripping process, cause the movement of workpiece must be our concern to score high productivity

(Wolf, Steinmann & Schunk 2005), table (3.1) below show all possibility of kinematic effect on griping force

Table 3.1 Kinetic effect on the required gripping force (Wolf, Steinmann & Schunk 2005, p. 171):

installation options	direction of acceleration	force / required gripping force per gripper finger	
	↕	$F_G = m(a_z+g)\frac{\sin\frac{\alpha}{2}}{2\mu}S$	
	↗	$F_{G,z} = mg\frac{\sin\frac{\alpha}{2}}{2\mu}S$	$F_{G,x} = ma_x\frac{\tan\frac{\alpha}{2}}{2\mu}S$
	↘	$F_{G,z} = mg\frac{\sin\frac{\alpha}{2}}{2\mu}S$	$F_{G,y} = ma_y S$
	↕	$F_G = m(a_z+g)\frac{\tan\frac{\alpha}{2}}{2}S$	
	↗	$F_G = m\left(a_x+g\frac{\tan\frac{\alpha}{2}}{2}\right)S$	
	↘	$F_{G,z} = mg\frac{\tan\frac{\alpha}{2}}{2}S$	$F_{G,y} = ma_y\frac{\sin\frac{\alpha}{2}}{2\mu}S$
	↕	$F_G = m(a_z+g)S$	
	↗	$F_G = m\left(g+a_x\frac{\tan\frac{\alpha}{2}}{2}\right)S$	
	↘	$F_{G,z} = mgS$	$F_{G,y} = ma\frac{\sin\frac{\alpha}{2}}{2\mu}S$

Where:

a=acceleration

g=acceleration of earth

FG=gripping force

G=weight

μ=friction value

ὰ=jaw opening angle

S=distance

To ensure good grasping the gripping force must overlap the forces which result from the acceleration of the earth.

N= weight (G) X g

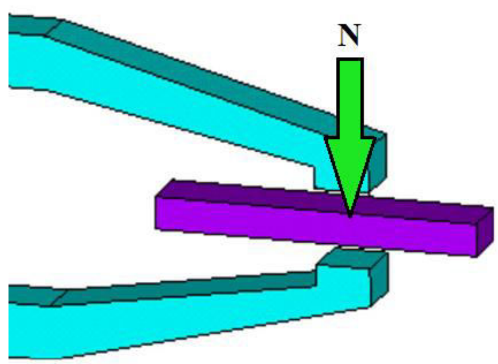


Figure 3.2 Weight force

If gripping force just needs to be transmitted via surface friction, pressure must be put on the object surface, for objects which easily react to pressure, the surface of which is easily to deformed or damaged, a maximum pressure must be determined (Wolf, Steinmann & Schunk 2005).

For safety reasons maximum pressure during gripping must be clearly lower than the approved pressure for the respective material.

Calculations of pressure for different contact bodies:

$$\textbf{Pressure} = \frac{force}{surface} = \frac{F}{A}$$

3.5 Micro gripper accuracy:

Precise and accurate gripping result during pick operation are essential for reliable place operation any error can be compensated by appropriate sensor system so that error can be compensate by feedback, also good Contact surfaces should be selected.

3.5.1 Capacitive contact sensor:

A transverse comb-drive based capacitive contact sensor should be included along each of the two central beams in between the gripper arm and actuator, the change in the gap between the overlap length of the sensor combs results in the change in capacitance. This change in capacitance is measured through universal capacitance readout chip, that produces voltage proportional to the change in capacitance, when the object is gripped between the gripper jaws, and then no capacitance change is detected by the universal capacitance readout chip, this indicates that the object has been grasped and thus, to avoid any damage to the object, no further actuation voltage is applied (Zaidi & Bazaz 2014).

3.5.1 Contact surfaces:

Contact surfaces effect calculation of gripping force,good contact between object and gripper jaws is essential for safe gripping at maximum force surfaces contact , for much efficient could use special coating to reduce the force required ,so called adhesive cushions made of Elastomers combined with Alminumum are available ,Elastomers offer good friction while Aluminum support plate to ensure stability (Wolf, Steinmann & Schunk 2005).

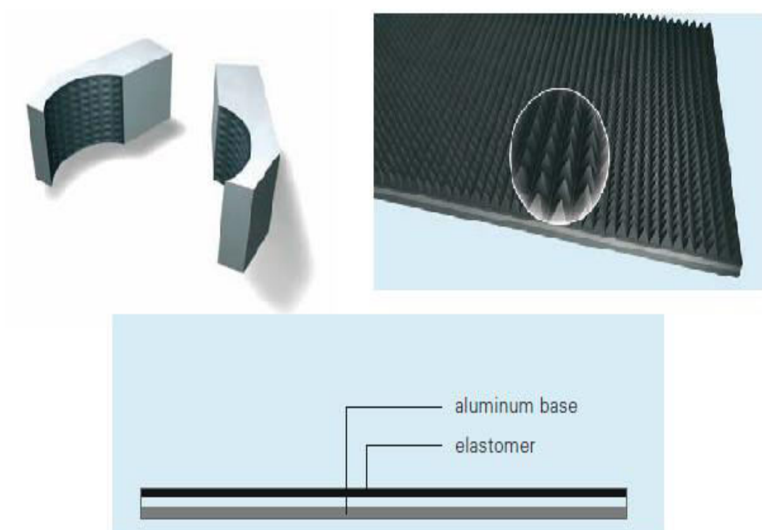


Figure 3.3 Contact surfaces (Wolf, Steinmann & Schunk 2005, p. 85)

3.6 Micro gripper design:

Basically a good micro gripper must be able to firmly hold the object of interest with a force that is sufficiently high to keep it within the grips but at the same time sufficiently low to avoid damaging the material.

The working mechanism principle is when a voltage difference is applied between the two structures; they will tend to collapse against each other due to electrostatic attraction thereby the gripper arm tending to move opposite each other, objects located within the gap may be gripped in this manner by the clamping structures by varied the voltage according to distance we want (Varona et al. 2009).

Micro gripper is designed to handle micro- and nano objects, the initial opening of the gripper arms is 20µm, the opening can be controlled with nano-meter precision sensor, the maximum stroke is 84µm (fully open). Due to the electrostatic actuation principle, there is almost no heating of the gripper arms.

As shown in figure (3.1) the micro gripper design proposed in this work consists of three main parts:

1. Base layer.

2. Isolator part (gripper arm).

3/ Actuator layer.

3.6.1 Base layer :

Represent the ground base, it is made of semi-conductors material such as Silicon or poly silicon, the dimensions of this layer are (750*150*100) µm.

3.6.2 Isolator part (gripper arm):

The gripper consist of two symmetrical arms with length of 1450 μm and thickness of 100 μm , and the tip has a gap of 20 μm (fully close) , This layer is made of isolated material such s silicon dioxide (SiO2) or silicon nitride (Si_3N_4) to grantee no electric charges would flow at the tip of gripper which may be damaging the biological sample.

3.6.3 Actuator layer :

This layer is the most important layer it control actuator characteristics and micro gripper has two actuator comb part each on in dimension (750*100*100) µm, and each one consist of 4 comb drive the size of each one *(50*50*100)*µm made of Silicon or poly silicon, the figure (3.4) illustrate the micro gripper all part

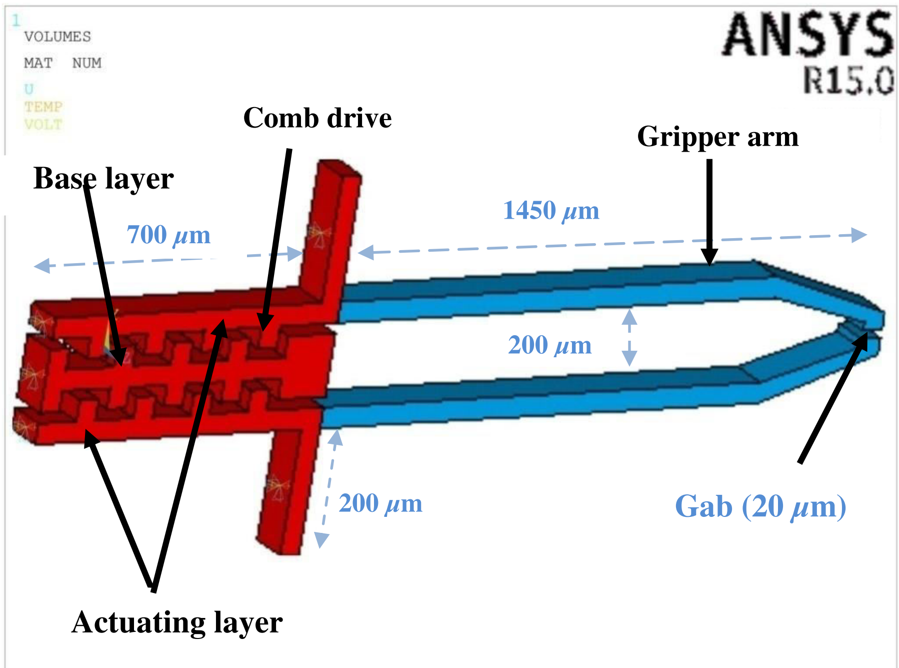


Figure 3.4 micro gripper parts

3.7 Material properties defining:

The design of MEMS devices involves knowledge of the sequence of materials to be used to realize the device, in which case a standard technology process may be used in conjunction with other processing steps, for example, post processing, the sequence of materials to be used could be custom designed by the designer, which requires knowledge of the materials and their properties.

Designers usually design the device and identify the material to be used and then use CAD tools to verify the performance, iteration procedures are part of the design until the required performance is reached.

After satisfactory simulation performance, the device is sent to fabrication foundries. ANSYS treat the material according to its properties which makes the definition of material properties accurately very important to have good result; in our design we used two set of materials to study the performance in each set, the following table shows the material set properties:

Table 3.2 material set (1) properties (Hsu & Tai-Ran 2008, pp. 12,14) :

prop / material	Elastic modules (E),Gap	Poison ratio(PR)	Density(ρ) ,Kg/m^3	Thermal conductivity (k),w/m.c	Thermal expansion coefficient t(α), 1/c	Resistivity (R),Ωm	Thermal convection (h),w/m^2c	Specific Heat C,j/kg.k
SI	185	.28	2300	157	2.33e-6	6400	10	385
SIO2	73	.23	2270	1.4	.5e-6	1e20	5	0

Table 3.3 material set (2) properties (Kumar, Reddy & Sreenivasulu n.d, p. 3):

proprites / material	S.NO	Young's Modulus (Mpa)	Poisson's ratio	co-efficient of thermal expansion (/ ° K)	Thermal Conductivity (Pw/μm° K)	Resistivity (tera ohm-μm)
poly silicon	1	$169X10^3$	0.22	$2.9X10^{-6}$	$15.4X10^6$	$2.3X10^{-15}$
Si 3Nt 4	2	$383x10^3$	0.27	$0.80x10^{-6}$	$0.19x10^6$	10^{17}

3.8 ANSYS programming:

After selection structural, thermal and electric as references ANSYS program has four major steps for analysis first Pre-process stage in which we select element type (couple field 227 has been used as element type) and define material properties, then importing design geometry, second major stage is Meshing where the FEM dividing the model to small elements, this element are divided by many points which named as nodes, nodes are considered as centre of element and all parameters are calculated, the following figure (3.5) shows attributed mesh .

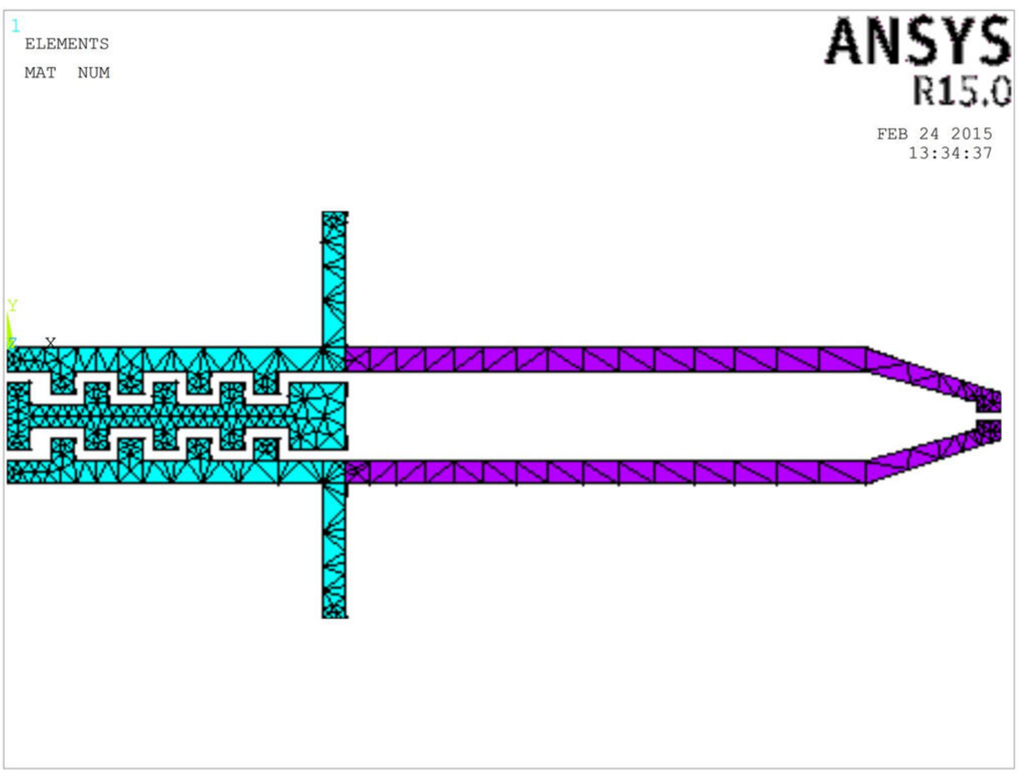
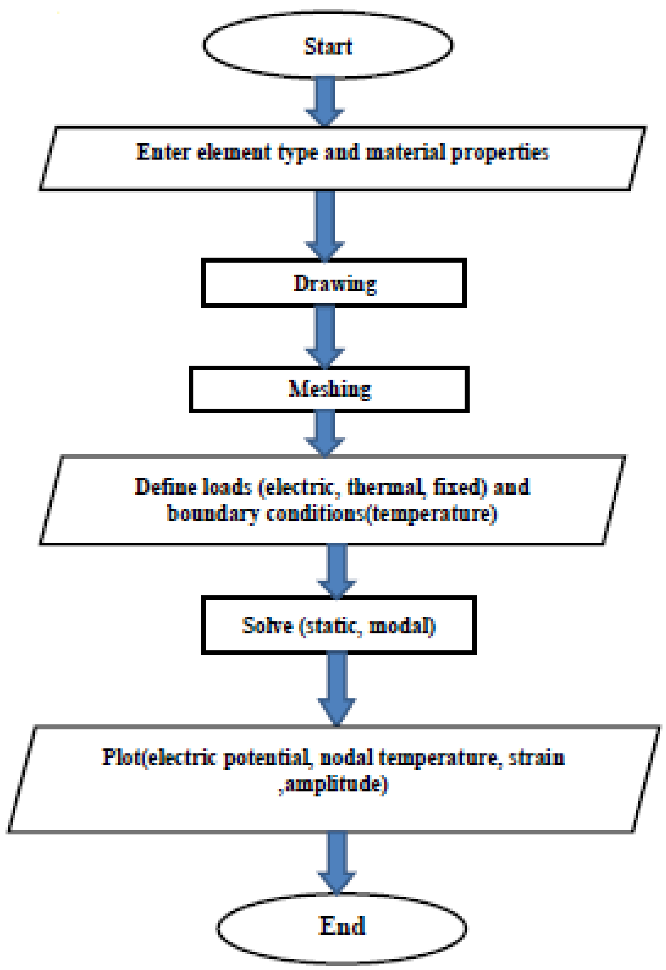


Figure 3.5 meshing model

Third stage is Load definition, in this stage both boundary conditions and electrical, thermal and structural loads are applied and finally the process stage where the program is solving the equations of loads and boundary conditions, the flow chart(3.1) below display the hole process .



Flow chart 3.1 ANSYS programming process

CHAPTER FOUR

Results and Analysis

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CHAPTER FOUR
Results and Analysis

4.1 Introduction:

Structure of the microgripper was designed and analyzed using the ANSYS (15.0). Analysis has been carried out by applying voltage ranging from 0 V to 100 V, and then the corresponding displacements of the arms, body temperature and stress at the micro gripper were obtained.

It is noticed that the maximum voltage potential concentrated in the actuator part which has the highest electrical conductivity. However the amount of electricity reduced to zero in isolator layer and gripper arm end to avoid damaging the biological samples, the figure (4.1) shows Electrical potential under applied voltage 30V.

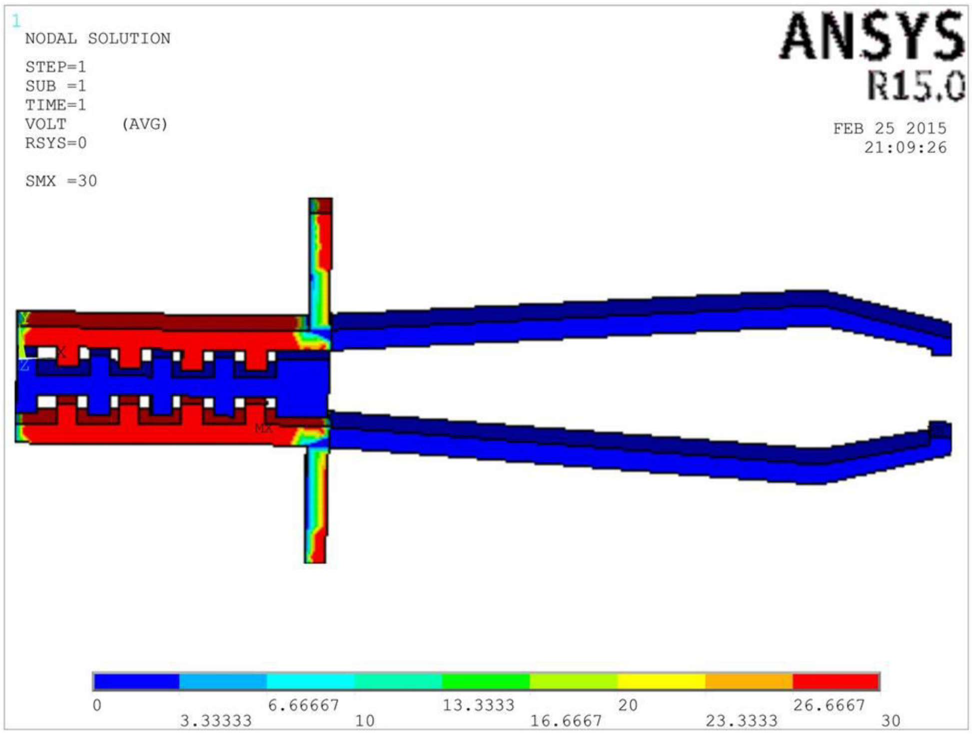

Figure 4.1 Electrical potential under applied voltage 30V

Two sets of results were obtained for different materials, one for silicon and silicon dioxide design (Si/SiO_2), and another for poly silicon and silicon nitride design (poly silicon/Si_3N_4). Behavior of the structure under different applied voltages was studied.

4.2 Displacement of the microgripper :

Analysis has been carried out for the range of 0 V to 100 V and its corresponding displacement is measured with both set of materials. Voltage is applied to the comb drive by which they tend to attract and come closer, due to the electrostatic actuation. This in turn produces the displacement along the grasping tip. Thus based on the application of the voltage along the comb drive, grapping action can be obtained.

For the applied voltage of 100 V, the maximum displacement produced is 32.5 μm with material set (Si/SiO_2), and for the same voltage the material set(poly silicon/Si_3N_4) produced displacement 19.66 μm as shown in figure (4.3)

(Si/SiO_2) material set produced maximum displacement for low applied voltage, so by using this set of material the displacement increases with the applied voltage as shown in figure (4.2).

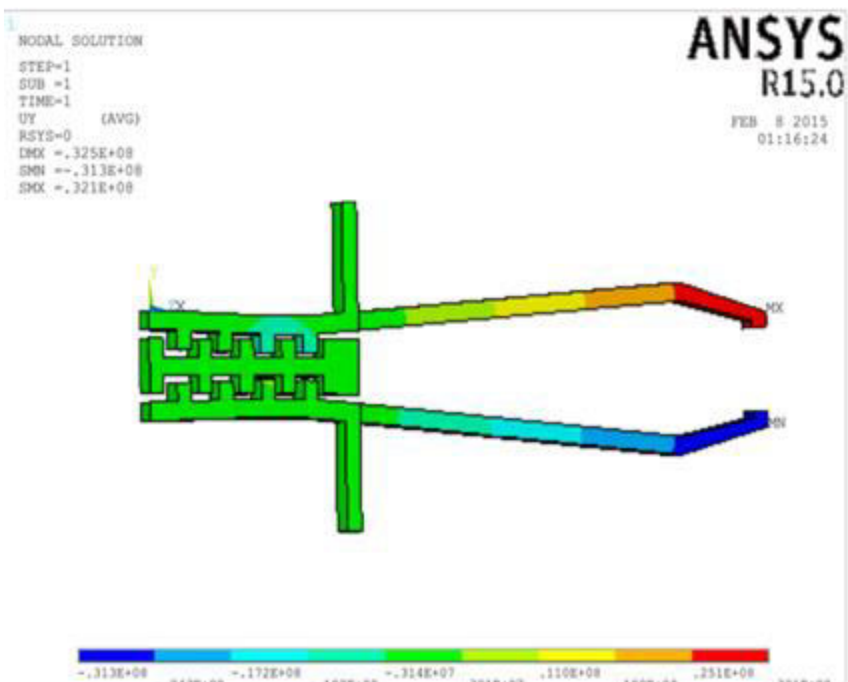

Figure 4.2 Material set (Si/SiO_2) displacement result at applied voltage of 100 V

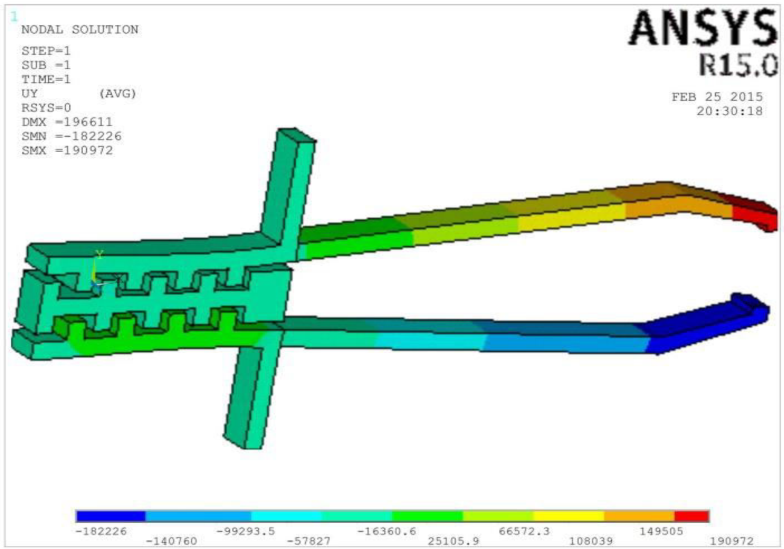

Figure 4.3 Material set (Polysilicon/Si_3Ni_4) displacement result at applied voltage of 100

Figure(4.4) shows the relation between displacement and voltage to both set of materials.

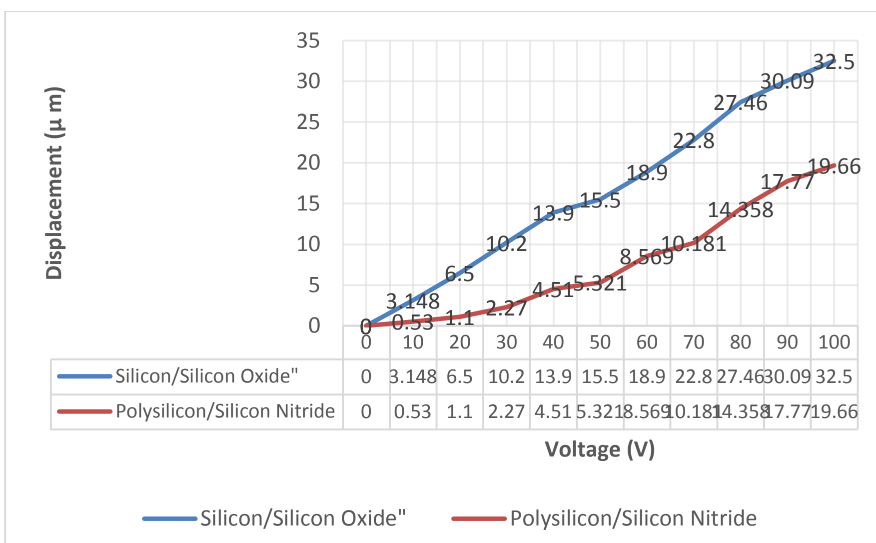

Figure 4.4 Relation between displacement and voltage

4.2. Stress analysis in the microgripper:

In the micro gripper structure Stress produced at both set of material are studied over the applied voltage range of 0-100 V, the maximum stress occurs at the comb drive part with 0.63 Mpa for the material set(Si/SiO_2) which is far below yield stress of silicon, other parts have low induced stress.

The material set (poly silicon/Si_3N_4) have high stress level on comb drive part (0.34 Mpa), which is below yield stress of poly silicon. Indeed no ruptures can appear during functioning of microgripper.

Stress produced increases with the increase of applied voltage as shown in figure (4.5) and (4.6)

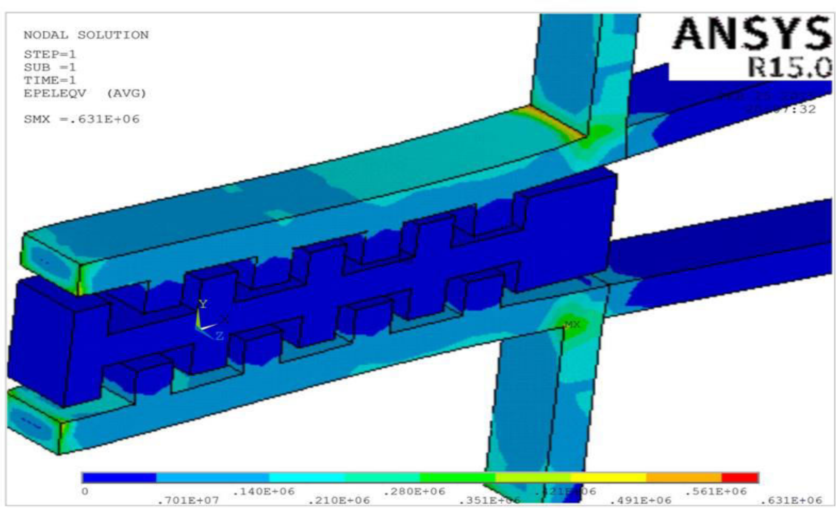

Figure 4.5 Material set (Si/SiO_2) stress result at applied voltage of 100 V

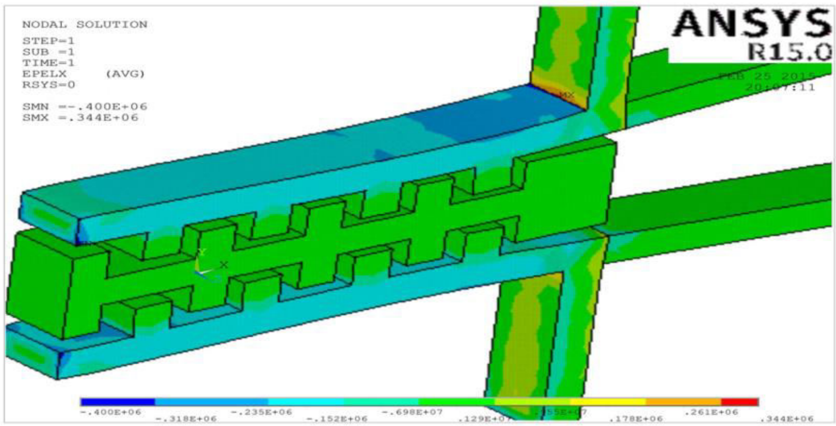

Figure 4.6 Material set (poly silicon/Si3N4) stress result at applied voltage of 100 V

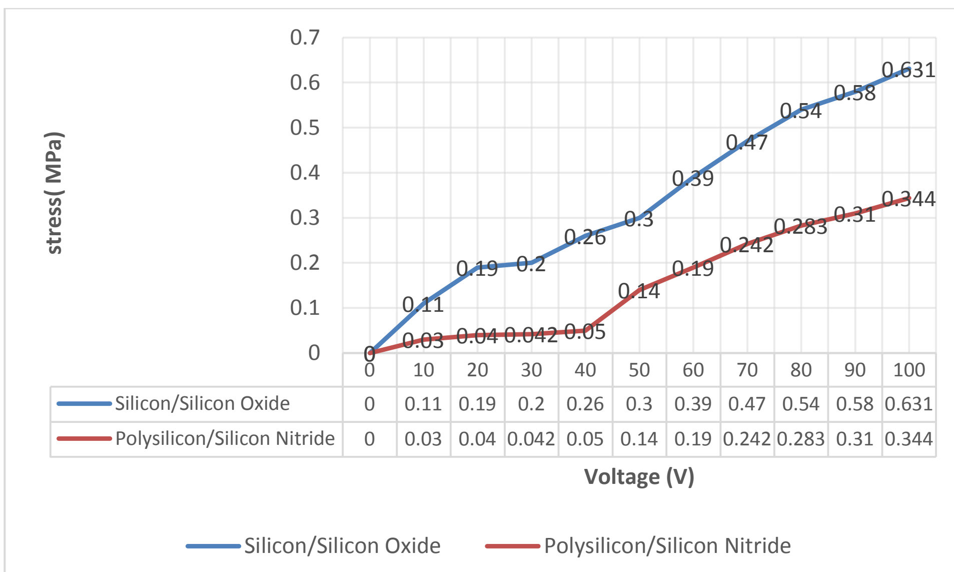

Figure 4.7 Relation between stress and voltage

4.3 Thermal distribution:

When ANSYS was programmed the initial temperature condition was 0˚c .It is clear from the result that increasing in temperature generated from applied voltage has a maximum value (2.033 ˚c for material set (Si/SiO_2) in actuator comb drive layer, which has direct contact with electric source. The heat flows, and the thermal distribution reduced until it reaches temperature 0 ˚c in the base layer,, the figure (4.8) show those result clearly.

For material set (poly silicon/Si_3N_4) the heat is lower than that in set (Si/SiO_2), maximum value (0.1˚c) in actuator comb drive layer as you can see below in figure (4.8).

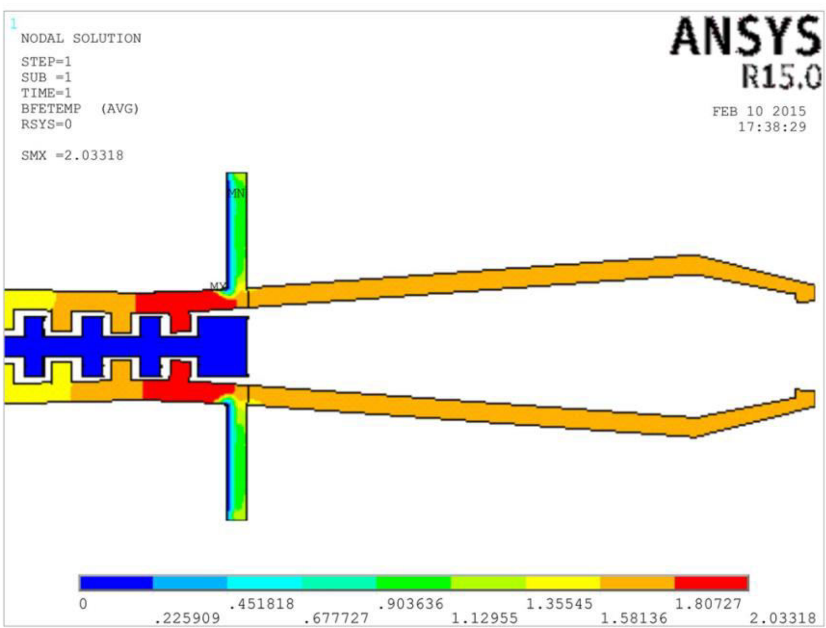

Figure 4.8 Material set (Si/SiO_2) temperature distribution at applied voltage of 100 V

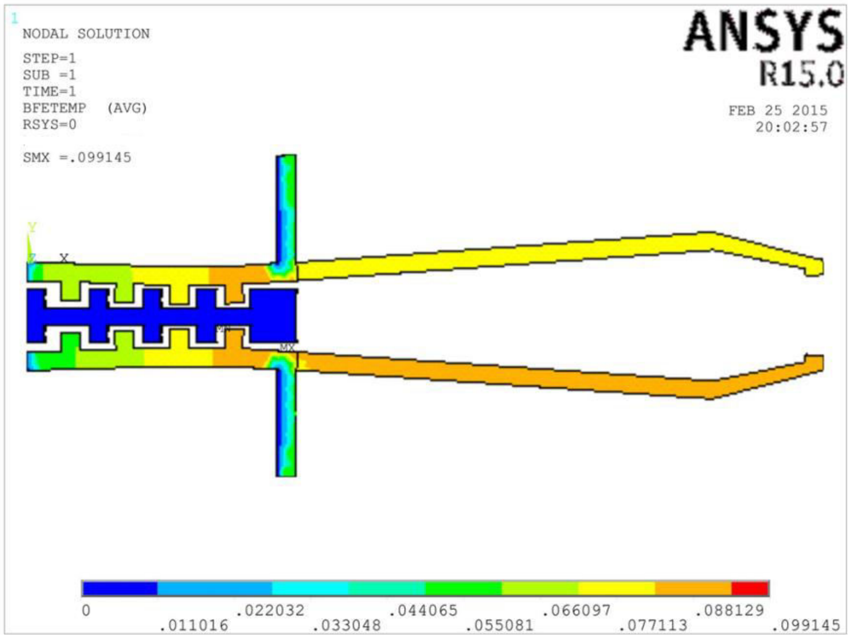

Figure 4.9 Material set (poly silicon/Si3N4) temperature distribution at applied voltage of 100v

You can notice from the figure 4.9 that temperature increased gradually according to increase of voltage that applied, and material set (poly silicon/Si_3N_4) has the lower temperature values.

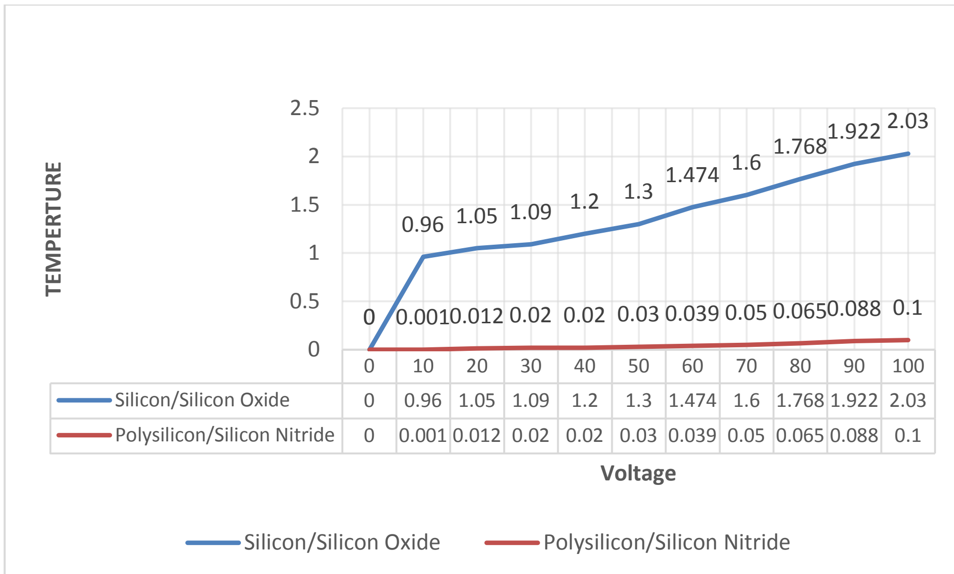

Figure 4.10 Temperature relation and voltage

4.4 Conclusion:

Although stress and temperature are both lower in material set (poly silicon/Si_3N_4) but still it is recommended to made micro gripper from material set (Si/SiO_2) since the gripper arm can move to larger displacement for low applied voltage, which mean large range of object dimension that gripper can hold.

CHAPTER FIVE

Conclusion

And

Recommendation

CHAPTER FIVE

Conclusion and recommendation

5.1 Conclusion:

Design and modeling of electrostatic comb based micro gripper was performed using finite element method via simulator ANSYS(15.0). This device can be used to handle the particles of size from 20 μm to less than 84 μm.

Two sets of materials were suggested. The first set used was silicon and silicon oxide (Si/SiO_2), while the second set of material used was Polysilicon and silicon nitride (Si_3Ni_4). The model was used to measure the displacement of the micro gripper as result of changing the applied electrostatic voltage.

Also, stress distributions as well as temperature distribution were investigated as result of changing the applied voltage. Stresses distribution, temperature produced at the micro gripper and displacement produced increases with the applied voltage.

0.63) MPa ,and maximum temperature value was approximately (2˚c) , where as material set (poly silicon/Si_3N_4) produces displacement in the range of (0-19) μm ,and stress (0-0.34)MP and much lower temperature value than that in set (Si/SiO_2) was approximately (1˚c). The kinematics parameters, gripping force and electro static mechanism has been demonstrated.

Although stress and temperature are both lower in material set (poly silicon/Si_3N_4) which is better, but still it is recommended to made micro gripper from material set (Si/SiO_2) since the gripper arm can move to a larger displacement for low applied voltage, which mean large range of object dimension that gripper can hold.

5.2 Recommendation:

1. The design can be improved by implementing sensory so that error can be compensated.
2. One can also study the piezoelectric actuated techniques and compare the results with results obtained in this work.
3. Also it is recommended to use another semi-conductor material to build the micro gripper in order to obtain the most efficient actuator by trying to decrease the generated temperature to the lowest possible level in order to avoid damaging the biological samples, and it is also recommended to increase the number of combs in order to increase the gripping force.

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