ANALISIS UNSUR TERHINGGA PENGGERAK DALAM PENGAPLIKASIAN MEMS

(FINITE ELEMENT ANALYSIS OF AN ACTUATOR IN MEMS APPLICATION)

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ABSTRACT

There have many applications in MEMS can be developed by a PZT actuator such as in data storage system, medical and RF system. This project focuses on high density data storage system which the PZT actuator namely microheater was placed. The main function of this microheater in high density data storage system is to write and read a data. Thermal performance of this microheater can be measured from experimental or finite element analysis. When a voltage or current was applied on microheater a displacement, resonant frequency and temperatures can be determined. So to evaluate a thermal performance of this microheater, a thermal analysis of this microheater has been done by ANSYS simulation. With the simulation, the tip temperature for thermal writing step at the fixed time can be determined and the time period for thermal cooling step closed to the room temperature, 27 ^{0}C can be predicted. The parametric studies have been done to compare the thermal performance of others parameter of the microheater. The first parametric studies; varied cone tip size, which the cone tip is smaller than cone tip size in verification analysis. Decrease in cone tip size causes the highest tip temperature for thermal writing step due to small size of light doped region. The second parametric studies; varied the shape of microheater and microcantilever give the lowest tip temperature for thermal writing step due to size of doped region and cone tip are more than other two analyses. The longest time period for thermal cooling step give a tip temperature near the room temperature. From the graph, thermal time constant can been found. The thermal time constant has desired to identify a thermal behavior of microheater which the smallest time constant, the fastest of microheater write or read a data. The MEMS fabrication and packaging also can be applied when a thermal performance of microheater has been recognized.

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CHAPTER 1: INTRODUCTION

1.1 Introduction to Project

Basically, the project is about Finite Element Analysis of an Actuator in MEMS. It does also describe about design, materials, structures and fabrication technique for MEMS devices especially an actuator changes due to its requirement. The MEMS devices requirement was determined by analysis using ANSYS software to ensure any factors can be match properly. As a result, the packaging technique will also apply depend on these factors. Various technologies for MEMS packaging for two different application particularly actuator will be investigated. For this purpose, a microheater actuated by a PZT microcantilever for high density data storage was used to further analysis as an above listed factor. Fig 1.1 shows that the principle of thermomechanical data writing. The microheater in the free end of the cantilever is quickly heated up to a proper temperature adapted to the media. If the heated tip is in contact with the media, it can soften and mechanically deform a submicron pit on a surface. In the cooling step after the writing, the heat in the heated region of media and the microheater is dissipated mainly by conduction to the media substrate and to the base through the cantilever body, respectively. This microheater can be categorized in hard disk drive (HDD) servo system actuator type. Recently, there have been many research developed on enable finite element analysis of microheater in MEMS-based data storage system. With ANSYS, a thermal transient analysis of this microheater has been done.

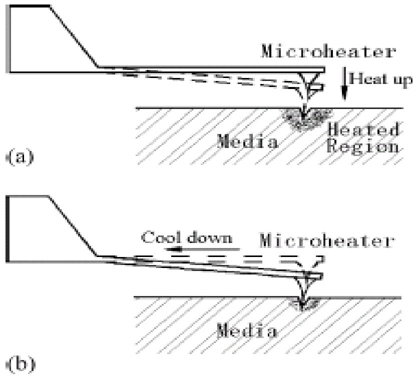


Fig 1.1 Principle of thermomechanical data: (a) writing step; (b) cooling step [6].

1.2 Introductions to MEMS

MEMS stand for Micro Electro Mechanical Systems. But more descriptive definition could be the following; any devices or systems, partially or fully manufactured using micro-fabrication [20]. This definition is broad enough to cover not only micro-devices, but also systems that employ micro-devices. About the size definitions of small devices, there are three categories often used; meso, micro and nano [20]. Meso sized devices have featured sizes between 500 mm and 2 mm. Micro sized devices have featured sizes between 500 nm and 500 mm. Meanwhile a nano sized devices have featured sized between 1 nm and 500 nm. But commonly speaking, the term of MEMS is often used to describe devices with all three feature sizes. Traditionally, most MEMS devices have been realized in Silicon based technology, largely borrowed from microelectronics technology. However, in recent years a variety of other materials have been used to create MEMS devices, including polymers, ceramic, GaAs, SiC and plated metals. There are many examples of MEMS devices including accelerometer, gyroscopes, temperature sensors, chemical sensors, AFM (atomic force microscope) probes, micro-lenses, comb drive actuators and piezoelectric actuators.

In the United States, the technology is known as MEMS, in Europe as microsystems technology (MST) and in Japan as micromachines. MEMS are integrated microdevices, or systems combining electrical, mechanical, fluidic, optical components and all physical domains. Interest in the development of MEMS has mushroomed during the past decade. In the most general sense, MEMS attempts to exploit and extend the fabrication techniques developed for the integrated circuit (IC) industry to add mechanical elements, such as beams, gears, diaphragms, and springs, to the electrical circuits to make integrated microsystems for view and control of the physical world. MEMS devices are already being used in a number of commercial applications, including projection displays and the measurement of pressure and acceleration. MEMS is the batch-fabricated integrated microscale system (motion, electromagnetic, radiating energy and optical microdevices/microstructutres- driving/sensing circuitry-controlling/processing ICs) that converts physical stimuli, events, and parameters to electrical, mechanical and optical signals, performs actuation, sensing and other functions.

MEMS comprises control (intelligence, decision-making, evolutionary learning, adaptation, self-organization), diagnostics, signal processing and data acquisition features. MEMS are comprised and built using microscale subsystems, devices and structures. New applications are emerging as the existing technology is applied to the miniaturization and integration of conventional devices. However, the devices should be free from residual stresses that are present in the course of the packaging processes and additional stresses during thermal cycling. It will be therefore essential to understand the origin of the stress and its evolution in improving reliability of MEMS packaging systems.

1.3 Finite Element Analysis (FEA)

Approaches to study the packaging stresses, numerical modeling and simulation tools such as finite element method (FEM) are also implemented. One advantage of this simulation tool is that it can aid to explore a much larger range of parameter space (temperature, materials, geometry, etc.) than is practical experimentally. The collective information is used to better understand certain experimental observations, and also to steer into the development of the improved packaging system. Analytical and numerical methods must be developed in order to analyze the dynamics, 3-D geometry, bonding and other features of atoms and molecules. In order to accomplish this analysis, complex electro-magnetic, mechanical, and other physical and chemical properties must be studied. Finite element analysis (FEA) is a numerical method of analyzing complex multi-physical (structural or thermal) problems. Either linear or non-linear simulations can be performed in order to predict the behavior of the structure through numerical interpretations. ABAQUS, ALGOR, ANSYS, COSMOS and NASTRAN are the examples of the finite element analysis software. ANSYS has been chosen to this thesis analysis.

ANSYS is a general-purpose finite-element program for engineering analysis, and includes preprocessing, solution, and post processing functions [21]. ANSYS is used in a wide range of disciplines for solutions to mechanical, thermal, and electronic problems. It has excellent pre-processing facilities and is very easy to use. The pre-processing, solution and post-processing drivers are all contained within the same graphical user interface.To obtain the best results from ANSYS, or for that matter any Finite Element program it is important to understand the basic concepts and limitations of the Finite Element Method. The Finite Element Method is a technique for approximating the governing differential equations for a continuous system with a set of algebraic equations relating a finite number of variables. These methods are popular because they can be easily programmed. The FE techniques were initially developed for structural problems but they have been extended to numerous field problems.

The basic steps involved in any FE Analysis consist of the following.

i) PREPROCESSING

- Create and discretize the solution domain into finite elements. This involves dividing up the domain into sub-domains, called 'elements', and selecting points, called nodes, on the inter-element boundaries or in the interior of the elements.
- Assume a function to represent the behavior of the element. This function is approximate and continuous and is called the "shape function".
- Develop equations for an element.
- Assemble the elements to represent the complete problem.
- Apply boundary conditions, initial conditions, and the loading.

ii) SOLVING

Solve a set of linear or nonlinear algebraic equations simultaneously to obtain nodal results, such as displacement values, or temperature values, depending on the type of problem.

iii) POST-PROCESSING

This stage involves processing the nodal data to get other information such as values of principal stresses, heat fluxes, etc.

1.4 Objectives of Project

i. To investigate the thermal analysis of actuators and its MEMS package using ANSYS.
ii. To do parametric studies on lead-zirconium-titanate (PZT) actuator used in high density data storage.
iii. To determine an available design, materials, structures and fabrication techniques for MEMS devices change depending upon a devices requirement and their application for actuators.
iv. To determine an available MEMS packaging for actuator depending on their thermal and mechanical behavior stimulation.

CHAPTER 2: LITERATURE REVIEW

2.1 Types of Actuator

The development of microactuators is less mature than that of microsensors because of the initial lack of appropriate applications and the difficulty to reliably couple microactuators to the macroscopic world [7]. Although the earliest microactuators were driven by electrostatic forces, devices now exist that are driven by thermal, thermal phase-change, shape-memory alloy, magnetic and piezoelectric forces to name a few. Each method has its own advantages, disadvantages and appropriate set of applications. The following sections discuss each types of actuator from the Rajeshuni *et al* [1].

High Aspect Ratio Electrostatic Resonator: This type was fabricated with a high energy photon light source and electrodeposition method. To identify a thick polymethyle methacrylate (PMMA or Plexiglas) mold for electroplated materials, the high energy photons come from an x-ray synchrotron was used. In this resonator, the center mass, springs and electrostatic fingers are free, while the rest of the structure is fixed to substrate. Movement occurs by applying a voltage between the center structure and one of the side's fixed structures. The overlapping fingers allow this voltage to occur over a large area, resulting in a larger attractive force. This is an example of linear actuator, which can be used as a switch, precise positioner, or part of a resonating sensor.

Piezoelectricity: Some crystals exhibit the property of producing an electric field when subjected to an external force. They also expand or contract in response to an externally applied voltage. Piezoelectric crystals are common in many modern applications, for example as clock oscillators in computers and as ringers in cellular telephones. They are attractive for MEMS, because they can be used as sensor as well as actuators.

Thermal Actuators: Early thermal actuators are straightforward bi-morph designs that take advantage of a considerable difference in the thermal expansion coefficient of each material in the device [7]. A clever design can achieve a similar extent of actuation with the nonsymmetrical heating of a single layer of patterned material. Another unique design takes advantage of the considerable force created during the phase change from liquid to vapor. Also, a special class of materials known as shape memory alloys can undergo a radical change in shape and size when heated. The cooling of heat-dissipating thermal actuator devices requires understanding and controlling the sources of temperatures fluctuations which may adversely affect the performance of an actuator. Thermal actuators commonly used are either of bimetallic type or that rely on the expansion of a liquid or gas.

Comb-drives: These are particularly popular with surface micromachined devices. They consist of many interdigitized fingers. When a voltage is applied, an attractive force is developed between the fingers, which move together. The increase in capacitance is proportional to the number of fingers; so to generate large forces, a large number of fingers are required. Examples a comb drive actuator like Fig 2.1.

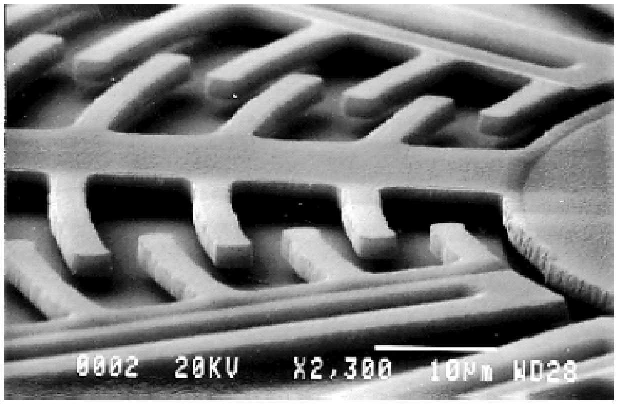


Fig 2.1 Electrostatic comb drive [7].

Magnetic Actuators: Magnetic actuators are often fabricated by electroplating techniques using nickel. This is mostly familiar with LIGA. Nickel is a weakly ferromagnetic material, so it lends itself to use in magnetic microactuators.

Thielicke and Obermeier (2000) in their paper explain typical MEMS devices with their actuation principle like the Table 2.1 which have been successfully and realized and implemented in industrial applications and prototypes.

Table 2.1 MEMS devices and their actuation principle [10]

Actuation principle	**Typical MEMS devices**
Piezoelectric	Micropump, microvalve, HDD servo system
Electrostatic	Micromotor (shutter), microshutter, micromirror, microscanner, microrelay
Electromagnetic	Microrelay, micropump, valve
Thermomechanic	Microvalve, microgripper
Thermopneumatic	Micropump, microvalve, inkjet printhead
Shape memory	Microvalve, fiber-optic switch

Data storage systems, as well as atomic force microscope (AFM) and scanning tunneling microscope (STM) tools, use microactuators in their head carriers to reach ultra high density recording or scanning. Mostly piezoelectric microactuators are used for the piggy back actuators of hard disk drives, because they have a sufficiently rapid response and enough force to allow improved control of the servo system which maintains the recording sensor over the center of the track [10].

2.2 MEMS Devices, Fabrication and Packaging

There have been many research efforts on enabling Finite Element Analysis (FEA) actuators in MEMS. Some of the research was proposed to enhance any characteristics of actuators in MEMS application. The types of actuator usually were development in MEMS package are thermal actuator, high aspect ratio electrostatic resonator, piezoelectricity, comb drives and magnetic actuator as listed before. Many researches also were developed for microheater used in MEMS based data storage system. Despont *et al* (1999) and Mamin *et al* (1995) discuss a new technology based upon AFM. This design, developed at IBM's Zurich Research Laboratory, proposes using small indentations, made in a polymer layer by AFM tips, to represent stored bits that can be read out by the same tip that wrote them. High data rates can be achieved by the parallel operation of a larger number of tiny tips in a small area. This design is believed to reach storage densities of up to 80 Gbit/cm, which is approximately five times greater than the expected ultimate limit for magnetic storage.

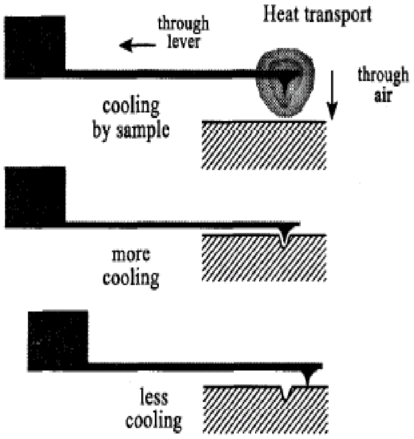


Fig 2.2 *Despont* thermal detection concept [13].

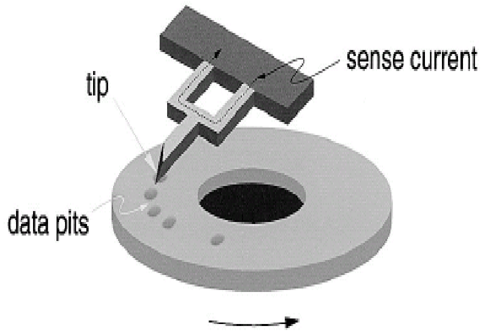


Fig 2.3 Concept of topographic data storage using an AFM tips [14].

In the state of the art manufacturing, MEMS are fabricated using manufacturing processes and tools borrowed from the microelectronics industry. Many of these processes and tools are used directly, while others have been modified to meet specific needs of MEMS. The devices are both produced using successive deposition and selective etching of polysilicon layers on top of the silicon surface (surface micromachining); by etching into the silicon substrate using anisotropic etchants and heavily doped etch stops (bulk micromachining) or high aspect ratio micromachining (HARM). Surface micromachining is defined as a process that employs two thin film materials; a structural material (polysilicon) and a sacrificial material (silicon dioxide) to fabricate MEMS microstructures [1]. Fig 2.4 shows the surface micromachining step. Gear train structures, microsteam engines and micromirrors for digital light processing area just some of the devices that can be fabricated using surface micromachining. Bulk micromachining is used to fabricate diverse microscale movable mechanical pin joints, springs, sealed cavities, cantilevers or channel as well as many complicated devices. In bulk micromachining, 3D features are etched into the bulk of crystalline and non crystalline materials [1]. Dry etching defined the surface features in x and y plane and wet etching release them from the plane by undercutting. HARM includes processes such as LIGA and deep reactive ion etching silicon. LIGA is a German acronym stand for *Lithographie, Galvanoformug and Abformong.* It refers to lithography, plating and molding; these processes are based on standard semiconductor IC fabrication techniques, and most importantly, on lithographic pattern transfer using x-ray instead of ultra- violet. Fig 2.6 shows the one of LIGA process.

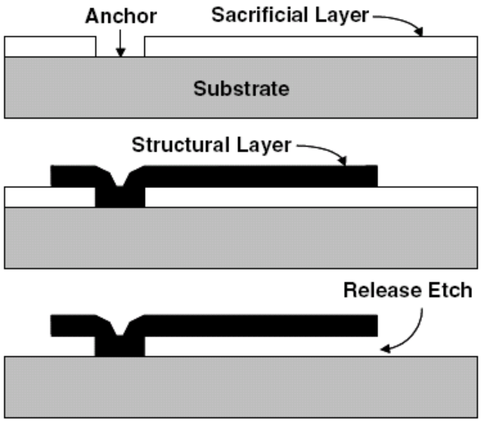


Fig 2.4 Surface micromachining step [7].

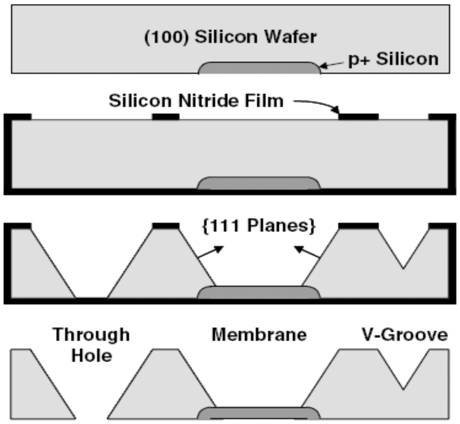


Fig 2.5 Bulk micromachining technique [7].

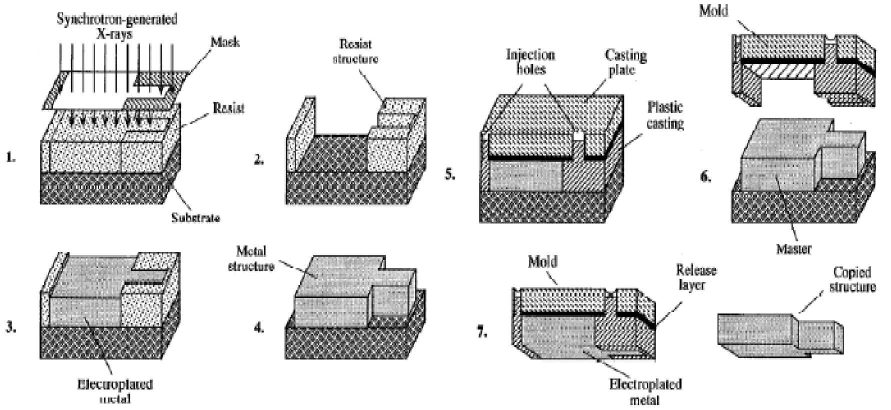


Fig 2.6 The schematic diagram of LIGA process [7].

Although fabrication techniques can be carried over from IC to MEMS fabrication, the requirement of MEMS packaging are so different from those of IC packaging. Unlike IC die packaging, MEMS dice need to interface with the environment for sensing, interconnection and actuation. MEMS packaging can be defined as all the integrations after the microfabrication of the device is complete. They include post-processing release, package/substrate fabrication, assembly, testing and reliability assurance. It is difficult to distinguish MEMS fabrication from packaging.

Elwenspoek and Wiegerink (2000) was defined five packaging technique for MEMS devices such as standard packages, wafer level packaging, interconnection technique, multichip modules and encapsulation process. Standard packages commonly used for sensor are usually based on derivatives of conventional semiconductor packaging. Plastic, ceramic and metal can packages can be categorized in this package. Wafer level packaging means that an entire wafer with sensors is bonded to another, usually silicon or glass- wafer which acts as a support and protection for the sensor chips during the remainder of the packaging process. In interconnection techniques, wire bonding, tape automated bonding (TAB) and flip chip technologies can be seen which used a bonding technique in packaging. In interesting in this technique is the use of a conductive seal that simplify clicking the five parts together. Multichip modules (MCM) technology offers an attractive approach to integrating and packaging MEMS devices because of the ability to support a variety of die types. Encapsulation processes commonly used to protect the sensor die against adverse influences from the environment like moisture, contaminants, mechanical vibration and shock.

T. Gessner *et al* [15] have classified MEMS packages can be done by distinguishing the integration degree on which the packages are realized (see Fig 2.7).

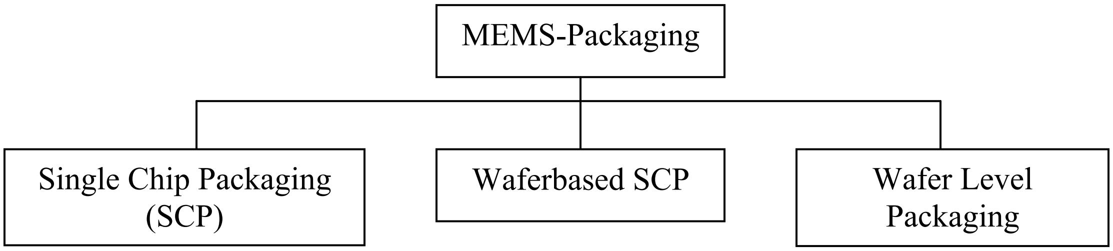


Fig 2.7 Classification of MEMS Packaging [15]

The packaging method is named single chip packaging (SCP) if typical integrated circuit standard packages or modified standard packages like TO-packages, ceramic packages or pre-formed injection moulded packages are used for single MEMS chips. The sealing techniques (soldering, welding, clogging, shedding) for these packages are compatible with the technology steps used for packaging of microelectronic devices. The wafer-based chip scale package is a technique where single chip covers are mounted on pre-fabricated wafers for example with pick and place equipment resulting in a substrate which can be machined again on wafer level after the packaging of single chips.

A relatively new field of packaging activity is the wafer level packaging (WLP) dealing with the integration of electrical, mechanical or also other components on wafer level. Presently there are manifold solutions of MEMS devices where the MEMS component is connected with an external electronic component. Additional substrate carriers and bus or redistribution systems reduce also the reliability of the whole system. Therefore the development of concepts for an automatic continuous processing of the pre-fabricated devices and an optimisation of the packaging technologies concerning a high volume production - if possible on wafer level - is necessary in near future. Suitable bonding and conducting techniques on wafer level connecting the bonded wafer electrically will contribute to fabricate innovative solutions. Two possible solutions for mounting of micromechanical and microelectrical components are demonstrated in Fig 2.8 and Fig 2.9.

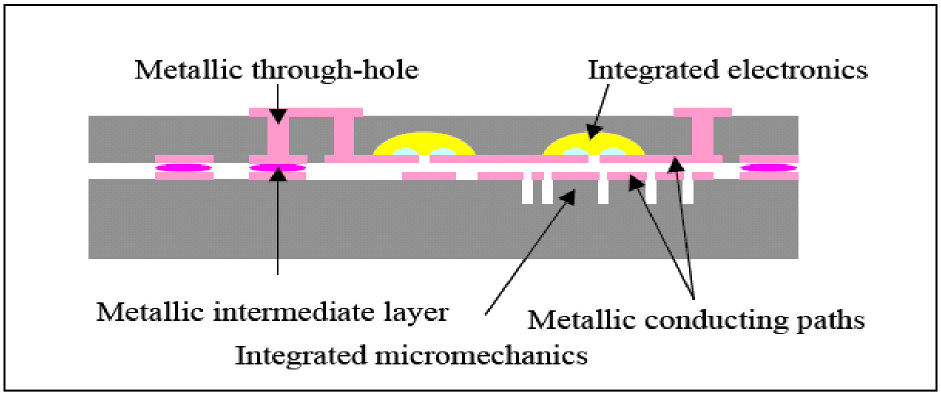


Fig 2.8 Mounting concept for micromechanical and microelectrical components by metallic interlayer [15].

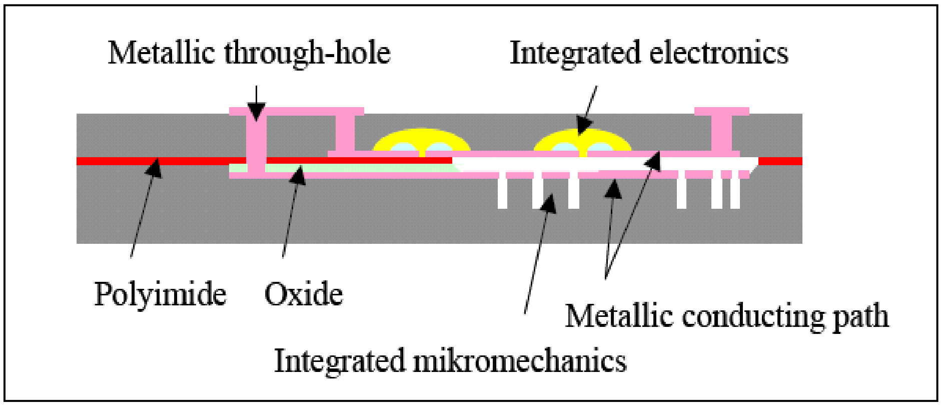


Fig 2.9 Mounting concept for micromechanical and microelectrical components by interlayers made of polyimide [15].

2.3 Use of PZT Actuators in MEMS

There have many applications in MEMS use a PZT actuator in order to complete the system. Chen *et al* (2002) mentioned that the PZT actuator initially developed for high dielectric capacitors during World War 11. The piezoelectric ceramics have found applications in a number of everyday devices, such as microphones, ink jet printers and ultrasonic medical equipment. Kim *et al* (2003) were fabricated a self-actuating high quality PZT cantilever with a piezoresistor for use in high speed atomic force microscopy (AFM) as a Fig 2.10. Atomic force microscopy is powerful tool for observing surface in nanometer resolution. The optimization use this integrated show the five times lower coupling voltage than the current cantilever structure.

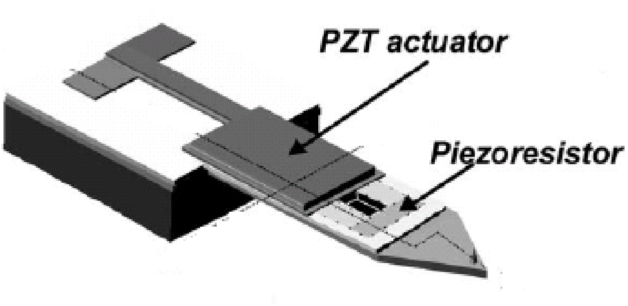


Fig 2.10 Self-actuating cantilever with an integrated piezoresistor in high speed AFM [17].

Cho *et al* (2002) were proposed a swing-arm-type dual positioning mechanism using a voice coil motor (VCM) and bimorph PZT actuators for the possible application to the future optical disc drive actuator. A VCM is used as a coarse motion actuator, and a set of piezoelectric actuators is used for fine motion. The two pairs of PZT actuators are arranged in parallel (Fig 2.11) and are carefully designed to deflect in ‘S’ shape such that tension and compression forces are generated.

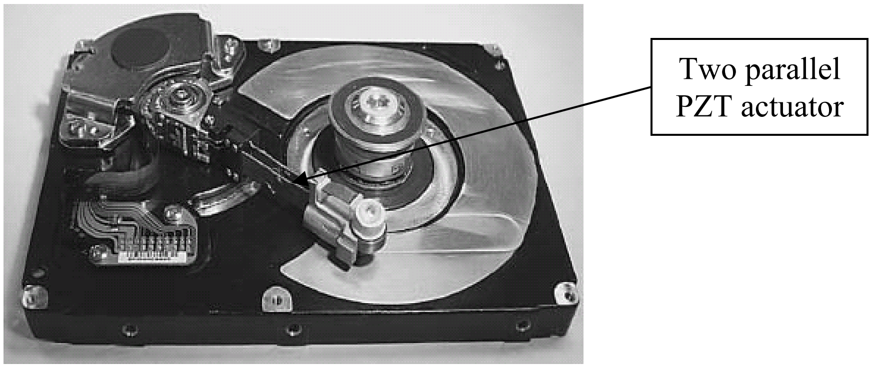


Fig 2.11 Swing arm type of PZT actuator for ODD [18].

The first widely-commercialized product using ceramic actuators is dot matrix printer [19]. Each character formed by such a printer is composed of a 24 x 24 dot matrix. A printing ribbon is subsequently impacted by a multiwire array. A sketch of the printer head appears in Fig.2.12. The printing element is composed of a multilayer piezoelectric device, in which 100 thin ceramic sheets 100 μm in thickness are stacked, together with a complicated magnification mechanism (Fig 2.13).

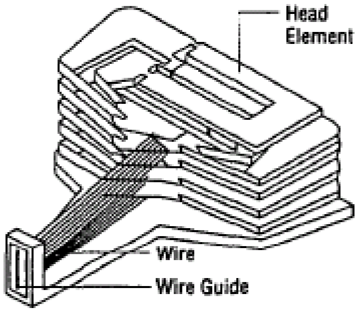


Fig 2.12 Printer head element [19]

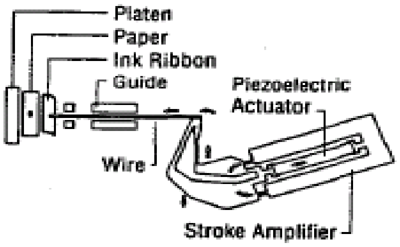


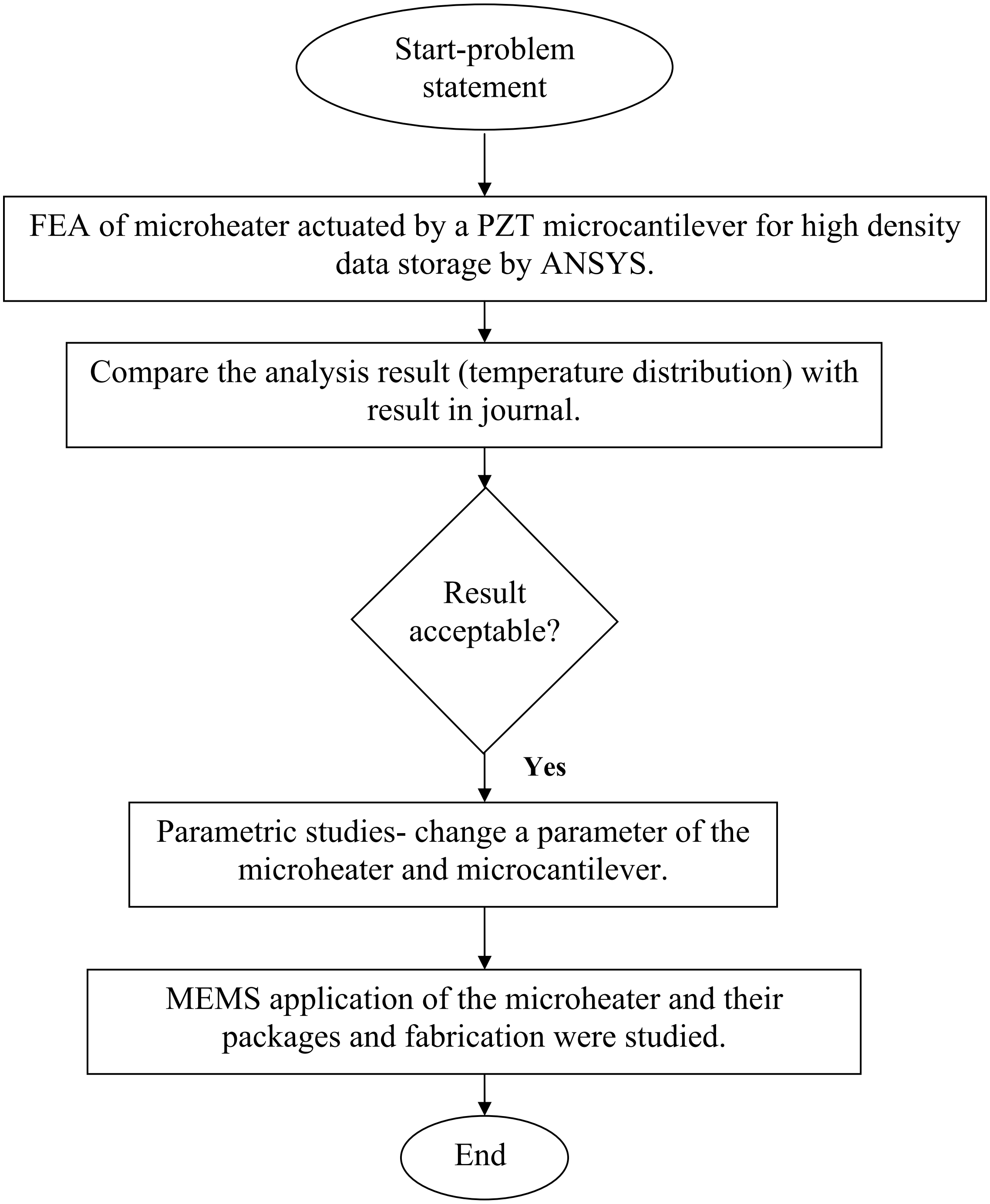
Fig 2.13 Piezoelectric actuator in printer head element [19].

CHAPTER 3: METHODOLOGY

3.1 Overview

This thesis about finite element analysis a microheater actuated by PZT microcantilever for high density data storage system, one of MEMS applications. Before the analysis was done, a research and study was implemented to improve an understanding about MEMS especially. A book, journal and website are main source of the purpose of study. This chapter explains the flow chart of analysis. Flow chart show that a flow methodology of an analysis roughly. After a problem statement have been seen a solution, finite element analysis of microheater actuated by a PZT microcantilever in high density data storage has be done by ANSYS software. In order to ensure the result is available, the reference journal was used as a guideline which a parameter of a microheater, material properties and the entire load options as same as a journal too. After the result have a good agreement with the journal result, a parametric studies has been done to compare a result when a varying occurred in a parameter. From the results, a discussion can be generated and an error also was studied to identify a main source of an inaccurate results. Flow chart also show a fabrication and packaging techniques for a microheater was applied to complete this packages in MEMS but not completely a packaging schemes for microheater, it just a suggestion or people’s work have been done before. The section of modeling and analysis by ANSYS were explains about summary step to complete the analysis.

3.2 Flow Chart of Analysis



3.3 Modeling and Analysis by ANSYS

For this thesis, ANSYS Multiphysics was used to achieve and simulation characteristics like thermal, mechanical and electrical behavior. The ANSYS Multiphysics solution allows a user to combine the effects of two or more different, yet interrelated physics, within one, unified simulation environment:

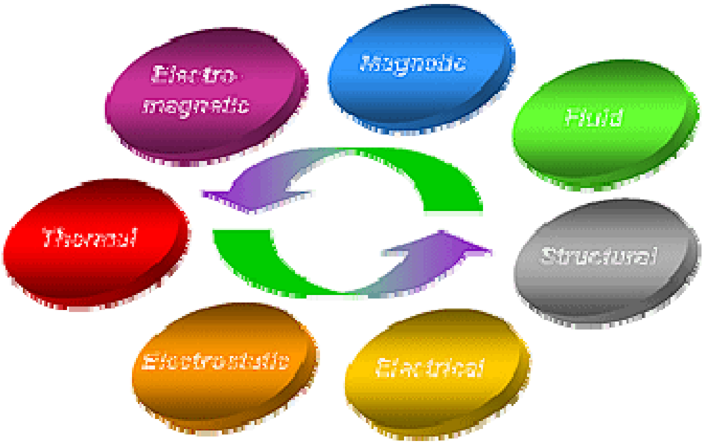


Fig 3.1 Simulation environment in ANSYS Multiphysics [21].

3.3.1 Problem Description

An analysis is demonstrates how to analyze a microheater actuated by a PZT microcantilever for high density data storage. The microheater is designed from single crystal silicon base of the cantilever, and composed of different phosphorus-doped regions functioning as electrodes contacting and heat generating. The required analysis is a thermal electric multiphysics analysis that accounts for thermal and electric fields. When the microheater works, an electrical pulse is applied on the upper surface of heavy doped region to elevate the temperature of the microheater. Because the electrical resistance of the lightly doped region is much larger than that of the heavily doped regions, significant Joule heat is deposited around the tip when the current flows through. For the high conductivity of the single crystal silicon, the tip will soon get heated and achieve the top temperature. When the electrical pulse is over, the heat around the tip is dissipated mainly by conduction through the cantilever to the base. The current flow and the resistivity of the silicon produce Joule heating (I^2R) in the cone tip. The Joule heating causes the cone tip to heat up. Temperatures in the range of 300 -500 K are generated. These temperatures produce thermal strain and thermally induced a thermal writing step. The main objective of the analysis is to determine a high temperature at the tip when voltage pulse was applied for thermal writing steps. Other objective is to predict the time period of thermal cooling down.

3.3.2 Summary of steps

1. Preprocessor
    - Create a model- 3D rectangular microcantilever with triangular microheater and cone tip.
    - Define element type- Solid 69
    - Define material properties- Thermal and Electromagnetic
    - Meshing the model

2. Solution
    - Define analysis type- Transient
    - Define loads- Temperature = 300 K, uniform temperature = 300 K and Voltage = 15V, 0V
    - Define load step options
        i. Time load step = 0.2 μs, Time step size = 1e-8 s
        ii. Size load step = 20
        iii. Write load step file = 1
        iv. Delete- all load data
        v. Repeat step i-iii for:
        Temperature = 300 K, uniform temperature = 300 K and
        Voltage = 0V
        Time load step = 12 μs, Time step size = 2e-8 s
        Size load step = 590
        Write load step file = 2

- Solve – From LS File
  Starting LS file number = 1
  Ending LS file number = 2
  File number increment = 1

3. General Postprocessor
   - Read results- By picking
   - Plot result- contour plot-Temperature
   - List results

4. Timehistory Postprocessor- plot graph
5. Quit

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Verification of Microheater

This verification was referred to earlier research of microheater actuated by a PZT microcantilever used in high density data storage from Zhao *et al* (2003). In their paper, a microheater actuated by a PZT microcantilever arrays was designed for equivalent high density data storage with high data rate and long lifetime. The mechanisms of thermomechanical data writing and heat dissipation from the microheater were studied. Only heat dissipation through conduction was considered in this analysis while heat dissipation through convection and radiation can be neglected.

4.1.1 Thermal and electrical analysis.

The simulation was performed as a transient analysis in which a voltage pulse was applied to the model and the temperature rise was calculated at the tip region. ANSYS 7.0/Multiphysics were used to simulate the thermal behaviors of the microheater. Three types of microheater first designed as shown in Fig 4.1. According to the experience data before and to get high resonance frequency, the dimensions of the three cantilevers are set as 30 μm in width, 100 μm (for type A) and 110 μm (for types B and C) in length. Microheater A is rectangle, and microheater B and C are both triangles. Using simple 2D models of each cantilever, the temperature-dependent material properties in Table 4.1 and the stimulating electrical pulse of 7 V in level, 0.3 μs in duration with a period of 5 μs, simulations were made for every cantilever.

Table 4.1 Temperature-dependent material properties used in ANSYS [6].

	Si	**Heavily doped**			**Lightly doped**		
Temperature (K)		300	400	600	300	400	600
Thermal Conductivity (W/mK)	148	106	74	46	127	89	55
Specific Heat (J/kgK)	702	712	790	867	712	790	867
Resistivity (μΩm)	10^{-6}	24	30	41	265	320	428
Density (kg/m^3)	2330	2330	2330	2330	2330	2330	2330

To define material properties for this analysis, the given standard MKS (meter, kilogram, second) units for specific heat, density, resistivity, and thermal conductivity must be converting to μMKSV (meter, kilogram, second, volt) units.

Table 4.2 Conversion factors for MKS to μMKSV [22].

Parameter	**MKS unit**	**Multiply by**	**To obtain μMKSV**
Thermal conductivity	W/mK	10e6	pW/(μm)K
Specific heat	J/kgK	10e12	pJ/kgK
Resistivity	Ωm	10e-6	T Ωμm
Density	kg/m^3	10e-18	kg/(μm)^3

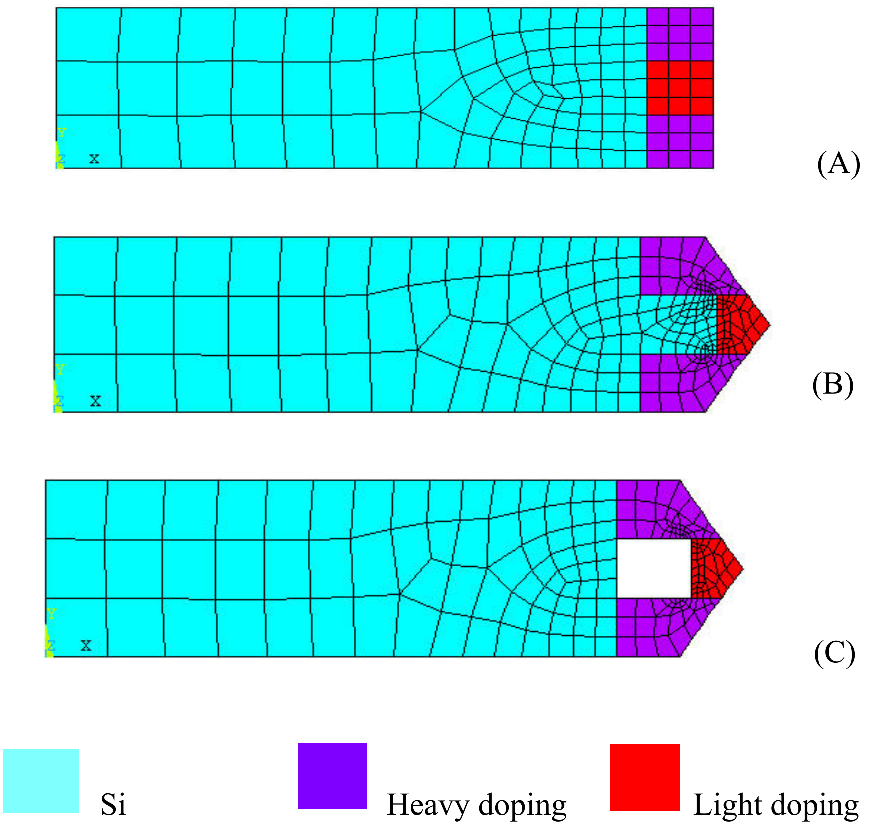


Fig 4.1 Three types of microheater with meshing in ANSYS (2D Model).

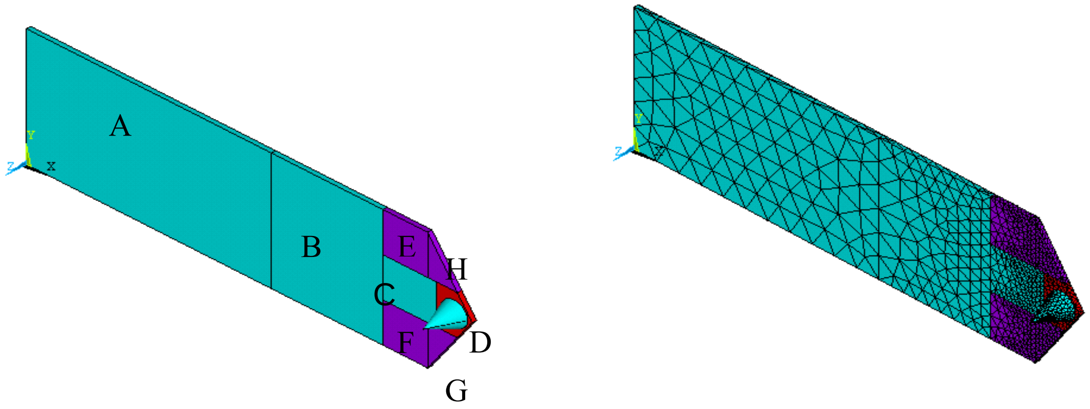
Table 4.3 Simulation result (2D model).

	T_U (K)	T_T (K)	T_E (K)	$(T_E - T_U)/(T_T - T_U)$
Type A	300	409	326	0.24
Type B	300	371	316	0.22
Type C	300	386	330	0.35

Table 4.3 shows the simulation result, in which T_U, T_T and T_E stand for uniform temperature, top temperature of the microheater and microheater temperature at the end of the pulse period, respectively. The most satisfied result is the status with relative high top temperature, which is not allowed so high as to get the Curie temperature of PZT, and low end temperature, which should near to the uniform temperature. Maluf (2000) defined the Curie temperature is temperature at which the crystal becomes cubic and losses its piezoelectric characteristics. From the last column of Table 4.3, type B is

considered to be the best scheme. So the following simulations of the 3D model are all based on type B.

According to type B, a 3D model with the length of 100 µm, the width of 30 µm and the thickness of 1 µm were built in ANSYS as shown in Fig 4.2 (a). The tip is assumed to be a cone of 6 µm in diameter and 7 µm in height. The material of volume A, B, C and the tip is single crystal silicon, volume D is lightly doped silicon and that of volume E, F, G and H is heavily doped silicon. The material properties are shown in Table 4.1. To save the calculating time with an acceptable accuracy, several mesh sizes for the volumes were used in the simulation. The mesh size of volume A is 5 µm, volume B is 3 µm and other volumes are all 1 µm, which is shown in Fig 4.2 (b). This is a thermal-electric coupled problem, so thermal load and electric load should be applied. Assume the base has an unlimited thermal capacity, so a constant temperature (300 K) as a surface load can be applied to the fixed end of the cantilever. The electric load is set as a voltage pulse uniformly distributed on the upper surface of volume E and F. An electrical pulse of 15 V in level and 0.2 µs in duration is chosen to be driving pulse. The simulation has also demonstrated that the period of 12 µs is long enough for cooling down the tip to near the room temperature.



(a) (b)

Fig 4.2 3D model (a) and the mesh (b) of the cantilever