# FEASIBLE LASER PARAMETER IN FABRICATION OF MEMS STRUCTURE ON PMMA

SIMON LOH HOCK HUA

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## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

Signature: ………………………………….
Name of Supervisor: DR DAW THET THET MON
Position: LECTURER
Date: 6th DECEMBER 2010

## STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature: …………………………….
Name: SIMON LOH HOCK HUA
ID Number: ME07049
Date: 6th DECEMBER 2010

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## ABSTRACT

Micro electromechanical systems (MEMS) fabrication leads to new requirements in production technology as the demands of high performance, small size and low cost devices are increasing. This research was conducted using a solid state pulsed Nd:YAG laser machine with a 3-axis motion controller to generate MEMS structure on PMMA. The MEMS structure generated on PMMA includes laser lines and laser spots. The effects of various laser parameters on the PMMA specimen were studied and measured under optical microscope before transferring the data to STATISTICA software for analysis. From the results, the feasible laser parameter combinations can be determined to generate the smallest possible micro feature on PMMA. Pulse energy and cutting speed from the process parameters show significant response to the line width for generation of laser lines geometry. As for the generation of laser spots geometry, pulse width from the process parameters significantly affects the diameter length of the spots. The usage of assist gas has generally decreases the laser spots diameter for generation of both micro-holes and line width for generation of micro-lines but it also causes inconsistency to the cutting quality of the laser machine. The feasible parameters for structuring laser lines (micro-channels) geometry without assist gas are found to be in the range of 40 – 90 mm/min for traverse speed and 0.01 - 0.02 J for pulse energy. On the other hand, the feasible parameters for laser lines geometry with assist gas are found to in the range of 80 - 120 mm/min for traverse speed and 0.01 – 0.02 J for pulse energy. As for structuring laser spots (micro-holes), the feasible parameters for generating laser spots geometry without assist gas are found to be in the range of 18 – 26 % for pulse height and 0.15 – 0.21 ms for pulse width. On the other hand, the feasible parameters for laser spots geometry with assist gas are found to be in the range of 24 – 36 % for pulse height and 0.15 – 0.20 ms for pulse width.

# ABSTRAK

Fabrikasi Sistem Mikro Elektromekanis (MEMS) telah menyebabkan keperluan baru dalam teknologi kerana tuntutan pengeluaran yang prestasi tinggi, saiz kecil dan peranti kos rendah semakin meningkat. Penyelidikan ini dilakukan dengan menggunakan Nd: YAG laser dalam keadaan statik dengan mesin kawalan gerak 3-axis untuk menghasilkan struktur MEMS pada PMMA. Struktur MEMS yang dihasilkan pada PMMA termasuk garis laser dan bintik laser. Pengaruhan daripada pelbagai parameter laser pada spesimen PMMA dikaji dan diukur di bawah pemerhatian mikroskop optik sebelum memindahkan data ke peranti perisian STATISTICA untuk analisis. Berdasarkan analisis daripada STATISTICA, kombinasi laser parameter yang sesuai boleh ditentukan untuk menghasilkan size geometri terkecil yang mungkin pada PMMA. Denyutan tenaga dan kelajuan pemotongan menunjukkan respon yang signifikasi dengan ketebalan garisan bagi penghasilan garis laser. Selain itu, denyutan lebar pula menunjukkan responsi yang signifikasi kepada saiz diameter bagi penghasilan bintik laser. Pengunaan bantuan gas secara umumnya telah megurangkan diameter titik laser untuk penghasilan lubang mikro dan lebar untuk penghasilan garis mikro tetapi ia juga menyebabkan ketidakstabilan terhadap kualiti permotongan mesin laser. Parameter yang sesuai untuk menghasilkan garis laser geometri tanpa bantuan gas ditemui di jarak 40 - 90 mm/minit kelajuan laser mesin dan 0.01-0.02 J untuk tenaga pulsa. Selain itu, parameter yang sesuai untuk garisan laser dengan bantuan gas ditemui dalam jarak 80 - 120 mm/minit untuk kelajuan mesin laser dan 0.01 - 0.02 J untuk tenaga pulsa. Untuk penghasilan titik laser pula, parameter yang sesuai untuk menghasilkan geometri titik laser tanpa bantuan gas dijumpai berada di jarak 18 - 26% untuk kualiti pulsa dan 0.15-0.21 ms untuk lebar pulsa. Selain daripada itu, parameter yang sesuai untuk geometri titik laser dengan bantuan gas ditemui berada dalam julat 24 - 36% untuk kualiti pulsa dan 0.15-0.20 ms untuk lebar pulsa.

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| | |
|---|---|
| $\lambda$ | Wavelength |
| $E$ | Photon energy |
| $t$ | Process time |
| $v$ | Speed |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| MEMS | Micro Electromechanical Systems |
| PMMA | Polymethyl-methacrylate |
| HAZ | Heat affected zone |
| IC | Integrated circuit |
| LAZ | Laser affected zone |
| UV | Ultraviolet |
| SEM | Scanning electron microscope |
| FYP | Final year project |
| DOE | Design of experiment |
| CNC | Computer numerical controlled |
| ANOVA | Analysis of variance |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

This thesis consists of five chapters. This chapter will provide the overview of the research which includes some basic ideas and parameters involved in this research. Chapter 2 reviews some theoretical background and previous research on laser-micro machining and MEMS fabrication on PMMA. The concept of methodology is explained in chapter 3 while the overall results and discussion are included in chapter 4. Finally, chapter 5 concludes the overall outcome for this project together with recommendation for future researches.

## 1.2 BACKGROUND OF STUDY

In recent years, laser machining has become a well-established sheet processing method due to its narrow cut kerfs. Literally, thousands type of lasers had been identified since the discovery of laser. However, only a relative few of these laser sources have found broadly based, practical applications such as $CO_2$ and Nd:YAG Laser. Different materials can be cut by different process depending on the thickness and properties. Few of the materials that mainly used for laser machining are steel, silicon and Acrylic plastics (PMMA).

Micro electromechanical systems (MEMS) fabrication leads to new requirements in production technology as the demands of high performance, small size and low cost devices are increasing. As micro-components are typically difficult to access and highly sensitive to mechanical forces and impacts, contact-free laser adjustment process offers a great potential for accurate manipulation of micro-devices. The applications for MEMS includes biomedical devices, and communication devices which combined electrical and mechanical components

In this project, the laser-micromachining experiment was conducted using a solid state pulsed Nd:YAG laser. This laser has been gaining interest in recent years for precision cutting because of its low mean beam power, high intensity, good focusing characteristics and narrow heat affected zone (HAZ). As for the type of material, polymethyl-methacrylate (PMMA) was selected due to its wide application in fabrication of micro-features and MEMS components. Simple line (micro-channel) and spot (micro-hole) geometries were generated on PMMA and analyzed. This project results will provide a common ground in fabrication of MEMS structure on PMMA using laser.

## 1.3 PROBLEM STATEMENT

Laser micro machining for MEMS structure are still under the subject of research, therefore there is no accurate information regarding to the laser machining process. Although there are several publish reports done regarding the usage of laser machine on PMMA, the feasible laser micro machining parameters for PMMA are still unknown as the optimum values are hard to obtain.

One of the problems faced are the effect of heat affected zone (HAZ) during laser micro machining for PMMA which would downgrade the overall surface quality of the micro feature. Furthermore, laser cutting mechanism is more on thermal process which would easily damage the PMMA specimen due to its low melting point.

## 1.4 OBJECTIVES OF THE RESEARCH

The objectives of this research are:

(i) To generate MEMS structures on PMMA using laser micro machining technique.
(ii) To identify the effect of laser parameters on the quality of PMMA's MEMS structure
(iii) To determine the feasible laser parameter combination to generate smallest possible micro feature on PMMA

## 1.5 SCOPE OF THE PROJECT

The list of scopes for this project:

(i) The MEMS structures considered were micro channel and micro spot.
(ii) Solid state pulse Nd:YAG laser integrated with 3-axis motion controller will be tested for micro machining.
(iii) Laser machining experiment were designed by using the STATISTICA software.
(iv) The laser parameters considered were pulse energy, assist gas, traverse velocity, laser height and laser width.
(v) Micro features were investigated with optical microscope.
(vi) Experimental results were analyzed in SATISTICA software.

## 1.6 LIMITATION OF THE RESEARCH

Only basic MEMS structure such as micro channel could be generated and studied as there is a limitation to the available laser machines in Malaysia. In this research, only feasible parameter values were able to be identified as the current information collected were not sufficient enough to obtain the optimum parameter values. Furthermore, laser-micromachining on PMMA is still in the subject of research.

## 1.7 SIGNIFICANCE OF STUDY

Since laser-micromachining on PMMA is still in the subject of research, this project would provide some basic ideas regarding the range and response of PMMA under the selected experimental parameters. The results discussed in this research paper would provide a better understanding and information so that further researches could be done in a much productive ways.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter explains the components and elements in this research which includes definitions and others related issues in a more detailed manner. It is divided into four main sections: Micro Electromechanical System, Laser Micromachining, Polymethyl-methacrylate and Laser Microstructuring on PMMA. The interconnections of these sections are showed in this chapter based on comments and facts from other researchers related to this topic as well as from research reports and journals.

## 2.2 MICRO ELECTROMECHANICAL SYSTEM

The development of Micro electromechanical systems (MEMS) structure has advanced in a rapid rate as the needs for high performance, small size and low cost devices are increasing. MEMS refer to devices that have a characteristic length of less than 1mm but more than 1μm, which combine electrical and mechanical components. MEMS is an emerging technology which utilizes integrated circuit (IC) fabrication techniques to produce integrated microsensors, microelectronics and microactuators to fabricate micronsized devices which can sense and act on the local environment (Zorman et al., 1997). Example of MEMS structure can be seen in Figure 2.1.

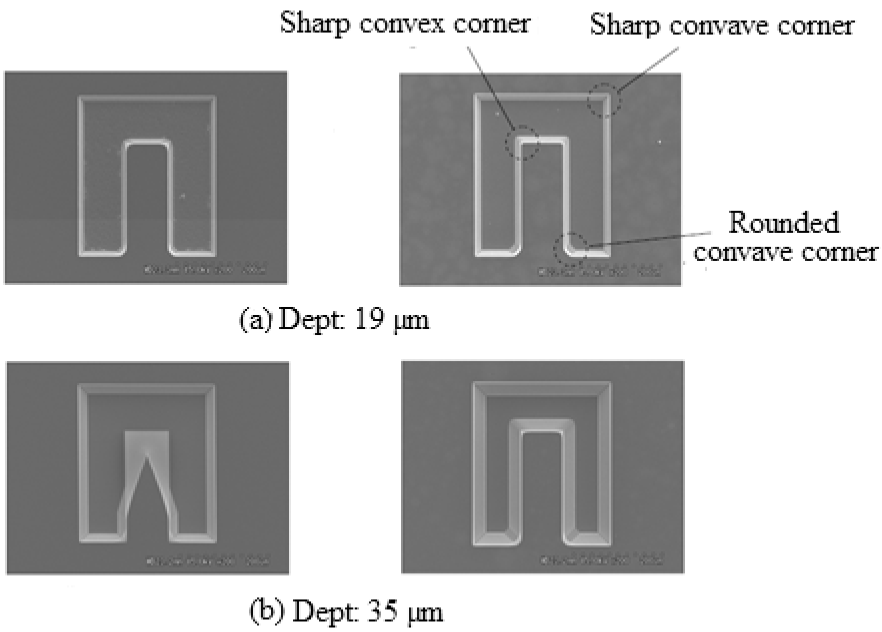


**Figure 2.1:** Micro electromechanical systems (MEMS) structure

Source: Sato et al. (2007)

### 2.2.1 Application of MEMS

MEMS structure has been widely applied in remote controls and communication devices which combined electrical and mechanical components. Significant efforts have been directed toward MEMS fabrication in device innovation, integration, and commercialization such as the commercial MEMS sensors which is widely used in automobile airbag deployment systems (Ratcliffe et al., 2008). Other applications for MEMS include biomedical devices and microphones.

### 2.2.2 Fabrication of MEMS

Laser micromachining is widely used to fabricate MEMS because of its materials flexibility and 3D capabilities. The fabrication approach conveys the advantages of miniaturization, multiple components and microelectronics to the design and construction of integrated electromechanical systems. With increasing complexity of microsystems, the importance of simulation for MEMS products increased in value which results in difficulty to resolve the interdependencies of the particular parameters (Nagler et al., 1998). The traditional and Laser direct write system for fabrication of MEMS component can be seen in Figure 2.2 and 2.3.

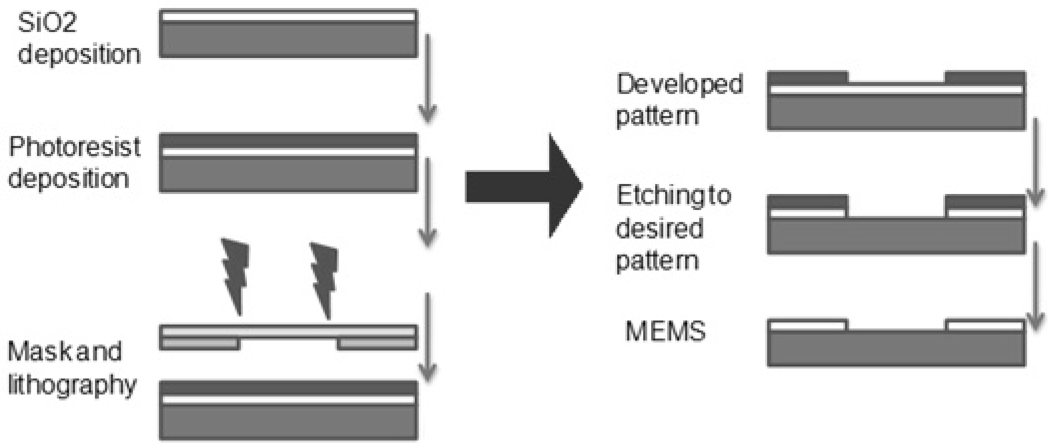


**Figure 2.2:** Traditional fabrication of MEMS component

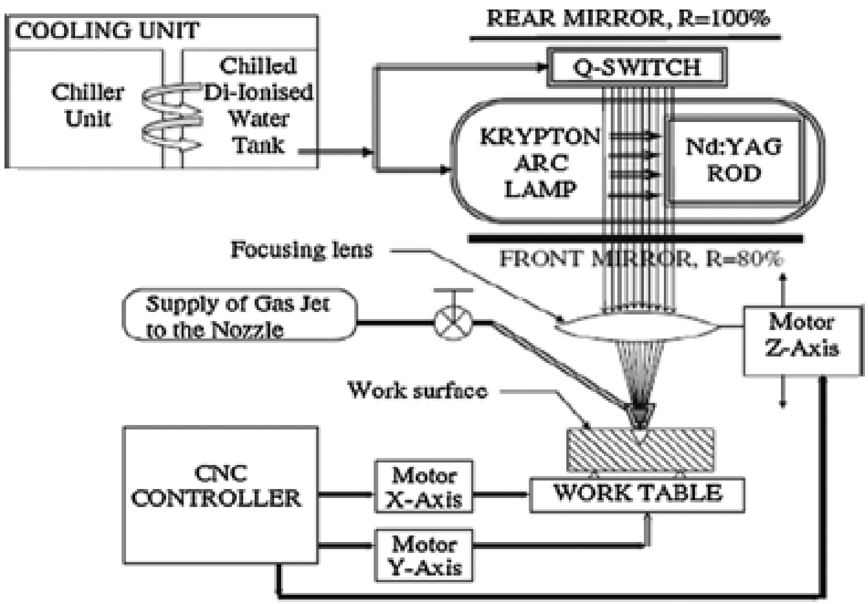


**Figure 2.3:** Laser direct write system to fabricate MEMS component

Source: Dubey (2007)

## 2.3 LASER MICROMACHINING

Laser micromachining is based on the local support of energy to materials at the surface where the laser light is transformed into heat (Meijer, 2001). During laser machining processes, there is no surface contact involved as the laser beam is sprayed from the nozzle directly to the material. Therefore, with a motion controller, there is almost no limit to the cutting path as the cutting point can move in any direction. With laser micromachining, complex designs can easily be performed without expensive tooling costs or long lead times (Duflou et al., 2007).

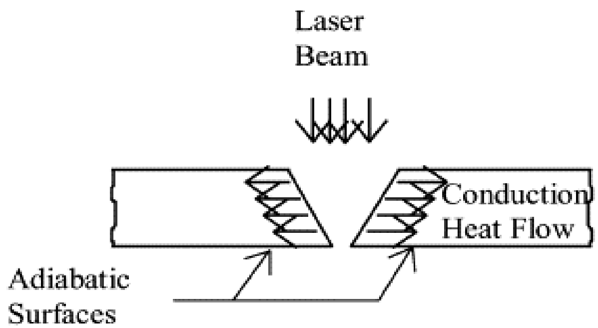


**Figure 2.4:** Laser beam interaction

### 2.3.1 Fundamental of Laser

The word "laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. Laser is limited to electromagnetic radiation emitting devices using light amplification by stimulated emission of radiation at wavelengths from 180 nanometers to 1 millimeter (refer Figure 2.5). The electromagnetic spectrum includes energy ranging from gamma rays to electricity (Aldrich, 2003).