FEASIBLE LASER PARAMETERS IN FABRICATION OF MEMS STRUCTURES ON SILICON

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG

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I certify that the project entitled "Feasible laser parameters in fabrication of MEMS structures on silicon" is written by Yong Chee Ping. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Examiner: Signature:

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.

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STUDENT'S DECRALARATION

I hereby declare that the work in this project is my own work and has not been accepted for any degree and is not concurrently submitted for award of other degree.

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DEDICATION

` Time and energy have to be sacrificed to finish the project on time. For dedication, family members, supervisor and also stuff whose give their lovely hands to complete the project are the most important.

To my beloved parents who always support me in term of spiritual and also financial.

To my supervisor Dr Daw Thet Thet Mon who always gave me knowledge, information and spiritual to complete my project.

ACKNOWLEDGEMENT

When gone through this final year project, there were many problems in terms of skill wise and knowledge wise and even mentality I had faced. To complete this final year project, there are many people I would like to acknowledge who willing to share their precious experiences with me.

First of all, I am very grateful where the faith let me meet a supervisor Dr. Thet Thet Mon who is lovely and willing to share her precious experiences on conducting my final year project. The ideas and guidance from her are invaluable where money can not buy. When I faced problems, she is the first person who I ever seek because she gave me a very good explanation with her professional minded where can improve and enhance my ideas to complete this high difficulty task. I also very appreciate the tolerance and patient where she always been there to compensate the silly mistakes and the laziness I had made. Due to full commitment of beloved supervisor, I am able to complete the final year project where fulfill all the requirement of this thesis.

Besides, due to facility problems and skill wise, I also very appreciate the professional ideas and guidance when attend special trip to University Technology Malaysia(UTM) from Prof. Dr. Noriah bt. Bidin and Mr. Yusef Alewi. When I reached the lab, they are very friendly and professionally conduct the experiment to give me more experiences on the laser machining.

When we visited University Tun Hussein Onn Malaysia(UTHM), Mr. Zazuli bin Mohid and technician Mr Azmisalleh are very kind to share their experiences with me and give their opinion on certain effect of variables and suggestions.

I am very grateful with the knowledge that they gave me and I will appreciates all the thing had been done and wish all being bless by god.

ABSTRACT

The technique of making MEMS structures are kept improving which from old fashion with high cost machine to very advanced one to save time and labor cost. In this report, laser machining of silicon using ND:YAG is introduced. The main objectives are generating MEMS structures on silicon wafer by using laser micromachining and the effects of parameters of laser micromachining on silicon.STATISTICA is used to design and analyze the experiments. Two experimental sets: (1) laser processing with assist gas and (2)laser processing without assist gas were carried out. Basic feature of MEMS and micro spots were generated. The micro features were investigated under SEM. Experimental results were analyzed in STATISTICA. Analyzed results show that laser power is the most significant effect followed by pulse width and the assist gas on the micro feature size and particularly feature quality. It was found that laser processing without assist gas produce promising results.

ABSTRAK

Teknik untuk memhasilkan MEMS struktur berkembang dengan pesat daripada mesin yang makan masa dan kos kepada kos dan masa yang minima. Dalam laporan ini, ND:YAG laser akan di kemukakan untuk menjalani analisis dan rekaan eksperiment. Objektif yang paling penting adalah menghasilkan struktur MEMS dalam silicon piring dan mengkaji hubung kait parameters.Demi menjalani analisis dan reka experiment, STATISTICA digunakan. Dua set experiment akan dijalani (1) proses dengan bantuan gas (2) proses tanpa bantuan gas. Micro-spot akan dihasilkan dan diperiksa bawah SEM. Keputusan daripada experiment akan dikaji dengan menggunakan STATISTICA. Keputusan analisis yang dikemukakan adalah kuasa yang digunakan membawa hubung kait yang penting dan diikuti oleh kepanjangan pulse dan keggunaan bantuan gas atas kualiti dan size struktur. Keputusanya, laser tanpa bantuan gas menghasilkan keputursan yang baik dalam analisis.

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μ	micron
p	P-value
t	pulse wisth
P	power(watt)

LIST OF ABBREVIATIONS

ANOVA	Analysis of variane
DOE	Design experiment
FYP	Final year project
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.0 PROJECT BACKGROUND

In future, laser machining have better opportunity compared to conventional machining processes as technology become more advanced and always improved. To understand more about laser machining and also background of the title, the history and characteristics of micromachining are studying.

In addition, silicon is one of the most important materials that have been used for many laser micromachining process research. The silicon has high hardness, high Young's modulus, high tensile yield strength and high corrosion resistance. Silicon is most important material for making micro-mechanical part because it has those excellent mechanical properties as well as other merits such as the abundant supply of the inexpensive raw material, and the controllable processing procedure for achieving high level of purity. The emergence of piezo-resistive silicon pressure sensors and acceleration transducers led to a rapid development of silicon micro-machining technology, which in turn caused the further rapid progress in micro- sensors, micro-actuators and MEMS (micro-electromechanical-systems).

The early stage of silicon micro-machining is an extension of traditional integrated circuit (IC) manufacturing technology. Even now IC-based silicon processing is still being extensively used in producing micro-parts or micro-mechanisms for MEMS. These techniques of silicon fabrication are mostly based on the principle of lithography, which features pattern transfer from mask to resist and then to film or substrate. It typically includes photolithography, electron beam (EB) lithography and reactive ion etching .These machining methods involve cumbersome processes such as preparing photo-masks and photosensitive resist, adjusting beam exposure, developing the exposed resin, etching the substrate, and making necessary alignments which definitely restrict the flexibility and efficiency of micromachining.

Direct writing is giving more attention because it can directly writing structures into substrate or base material with focused and precise laser beam, eliminates the participation of masks and resists, and has obvious advantage in fulfilling the tasks when a high flexibility is required. Developing on direct laser direct writing has high level of attraction to make it as a useful and versatile tool for rapid prototyping, small-scale production, or for new product development, such as bio-chip, lab on chip. However, these researches mainly used Ar ion, Nd:YAG or CO2 laser beams rather than excimer laser. Generally, excimer laser has much shorter wavelength, much smaller beam divergence, shorter pulse width, higher capability in initiating photochemical reactions and lower thermal interaction when compared with other lasers. In view of its great potentials and the importance of silicon micro-machining, experimental investigations on the excimer laser direct etching (without the participation of any chemical enchants) technique, so as to provide effective operational procedure and to understand its rudimental mechanisms in fabricating micro-mechanical structure, were performed.

In this project, ND:YAG laser is main laser source that used to performed the laser machining on silicon to investigate the quality of the spot surface and the effect of the power and width of the laser on diameter of the spot. Design of experiment (DOE) is used to carry out the experiment systematically as well as same time. The STATISTICA is used to construct DOE and analyze the results. This provides basic idea to fabrication of MEMS structure on silicon using laser.

1.1 PROBLEM STATEMENT

The traditional technique of making MEMS imposed high cost time consuming and environmental hazardous because the safety factors of the machine is not good enough compare to now a day machines. Heat is one of the source that used to construct laser micromachining which can seriously affect the quality of micromachining. However, laser micromachining is one of the alternative way to performed high technology cutting edge tasks. In contrast , the ultrafast laser techniques have weak points in terms of rather roughened surface and the processing speed, which is much slower than that of the traditional mechanical method. Systematic way of identify laser parameters for laser micromachining on silicon have not been done.

1.2 OBJECTIVES OF THE RESEARCH

i. To generate MEMS structure on silicon wafer using laser micromachining .
ii. To identify the effect of laser parameters on the size and quality of silicon MEMS structure.

1.3 SCOPE OF THE PROJECT

i. MEMS structures considered is basic feature of micro hole and micro cone.
ii. Nd-YAD solid state laser integrated with computerized control are used for laser machining experiments.
iii. The experiments will be designed in STATISCA
iv. Laser parameters considered are width, pulse energy, height of the power.
v. Laser-Generated structure will be observed under optical microscope or scanning electron microscope
vi. Relationship between laser parameters and structural scale and quality will be developed.

1.4 METHODOLOGY

Methodology in this project consists of systematic of laser micromachining experiment, STATISCA analysis of experimental result, the major equipments and tools involved are ND:YAG laser source integrated with CNC controller , high power optical microscope and scanning electron microscope.

1.5 ORGANISATION OF THESIS

This thesis consist of 5 chapters which as below

1.5.1 Chapter 1

In this chapter, the contents that included are project background, problem statements , objectives, scopes of the project and methodology.

1.5.2 Chapter 2

To exposed and understand about the laser micromachining, materials, and MEMS, the literature review is construted.

1.5.3 Chapter 3

The explanation on how the experiment is carry out with using systematic way like using optical microscope, scanning electron microscope(SEM),Design of Experiment(DOE), STATISTICA software and the laser machine.

1.5.4 Chapter 4

The results and discussions of the experiment are discussed in this chapter which are analysis result and recommendations.

1.5.5 Chapter 5

In this chapter, the conclusion and recommendation are discuss in this chapter .

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter, the overview information about laser machining, MEMs structure and materials are being reviews and extracted to make the title more clear and gain more knowledge.

2.1 HISTORY OF LASER

The mechanism for generating laser pulses lies in the nature of the active laser medium and the corresponding lifetimes of the atomic energy levels. With pulsed lasers much higher peak powers can be reached making these sources attractive for numerous applications in industrial production. By using different pulse generation techniques ,the pulse duration, pulse energy and reproducibility can be modified over wide ranges. There are 3 types of laser generation process as below:

Gain switching

Gain switching can be regarded as the most direct method to generate laser pulses. During gain switching the pumping process is modulated which results in switching the amplification in the laser medium. After the pumping process has been switched on, the population inversion starts to build up. The laser starts to oscillate when the critical inversion is reached, i.e. the gain becomes larger than losses. The oscillation continues until the pumping process is switched off, or until the losses become higher than the amplification. The reproducibility and stability tends to be stochastic, which makes gain switching, in spite of its simplicity, inapplicable for many applications. Pulse duration available from flash lamp pumped solid-state lasers by gain switching can vary between 10 **ps** up to 10 ms.

Q-switching

The output of a gain switched, pulsed solid-state laser is generally a train of irregular pulses ; irregular in peak power, pulse width and repetition frequency. Q-switching can use to remove these irregularities and at the same time greatly increase the peak power. Q-switched lasers normally emit only one giant pulse in an operational cycle and can be applied to continuously pumped lasers in order to produce a train of Q-switched pulses with regular duration, peak power, and repetition rate. The pulse length is typically less than a microsecond down to several nanoseconds and peak powers between 10^6 W and 10^9 W.

Q-switching is a mode of laser operation in which energy is stored in the laser material during pumping in the form of excited atoms and suddenly released in a single, short burst. The quality factor Q is defined as the ratio of the energy stored in the cavity to the energy loss per cycle. During pumping the high reflectivity (HR) mirror is effectively removed from the system, resulting in a low Q factor and preventing the onset of laser emission. After a large amount of energy has been stored in the active medium, the HR mirror is returned to proper alignment and operation, and most of the stored energy emerges in a single, short pulse .

A Q-switch is essentially a shutter placed between the active medium and the HR mirror. With this shutter closed, the HR mirror is blocked preventing oscillation. When the amplifier gain reaches a predetermined value, the shutter is opened to increase the cavity quality. Several techniques can be used for Q-switching of lasers. Mechanical Q-switches can be realized by a light chopper, a spinning disc with a hole, or by a spinning mirror. The chopper is inserted into the optical cavity between the laser rod and the high reflecting mirror. A mechanical chopper is relatively slow. It can switch only afraction of the beam area at a time as it is swept across the aperture. For this reason, mechanical Q-switches are not practical or effective. Spinning reflectors are used quite frequently in Q-switched systems where it is not necessary to closely synchronize the output to some other event.

Usually the high reflecting mirror is rotated **so** that the mirror is tilted out of alignment. The system is Q-switched when the mirror rotates back into alignment (it is in alignment once each revolution). Switching time is typically a few nanoseconds. For electro-optic Q-switching a polarization filter and rotator are placed into the reflecting cavity between the laser rod and the reflecting mirror. Rotating the polarization vector of the laser beam inside the cavity results in low cavity feedback **so** that it cannot pass through the polarization filter. When this polarization rotation is terminated, the cavity reflectivity is high and the system will produce a giant pulse.

Two of the electro optic devices used in this application are Kerr cells and Pockels cells. The Pockels effect is a linear electrooptical effect, i.e. the refraction index change in the parallel and orthogonal direction is proportional to the applied voltage. The Kerr effect is a non-linear electrooptical effect, i.e. the dependency is a square function of the applied voltage. Switching time is fast, typically less than a nanosecond. Within acousto-optic Q-switches a transparent element is placed in the cavity. This transparent device, when excited with intense, standing, acoustic waves by piezoelectric crystals, exhibits a diffraction effect on the intracavity laser beam and diffracts part of the beam out of the cavity alignment. This results in a low feedback. When the acoustic wave is removed, the diffraction effect disappears, the cavity is again aligned, and the system emits a giant pulse. Switching time is slow at 100 ns or greater. Saturable absorbers are available as thin films on glass substrates or as liquids in glass cells.

For Q-switching, a dye cell is placed in the laser cavity. The dye absorbs the laser wavelength at high rates at low light intensities, presenting a very high cavity loss to the laser, and preventing lasing until the amplifier has been pumped to a high gain state. When the irradiance from the active medium becomes intense enough, the energy that is absorbed by the dye optically pumps the dye material, causing it to be transparent at the laser wavelength. The dye cell is bleached and causes no longer high cavity losses, i.e. the quality of the resonator increases. The absorption change of the dye is the equivalent of Q-switching in the laser, and it can occur in less than a nanosecond. Their switching time is fast.

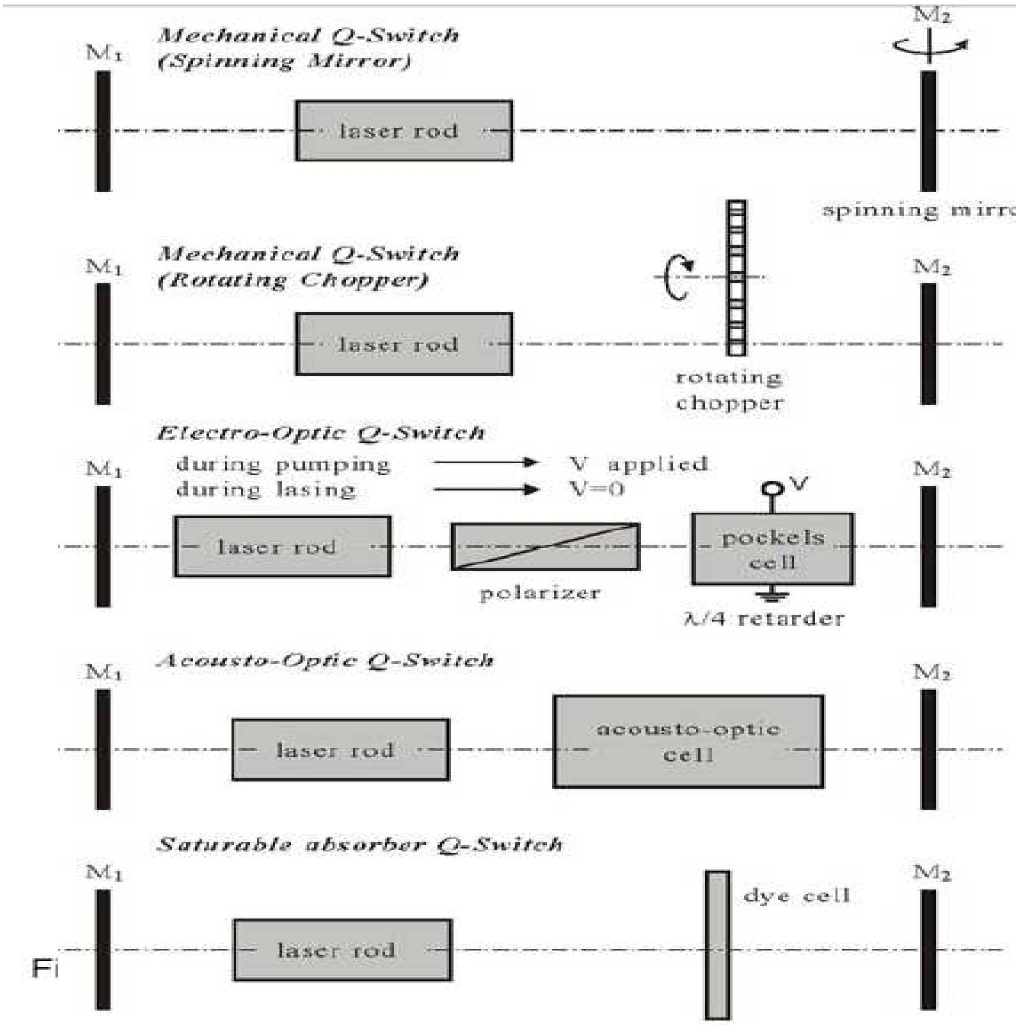

Figure 2.1.1 The mechanism of the laser

Mode-locking

While Q-switching can be used to generate pulses with high intensities in the ns-range, mode locking is used to generate ultrashort laser pulses with pulse duration in the ps- to fs-range. Pulses in the ps-range were generated for the first time by passive mode locking of a ruby laser shortly after its discovery by Mocker in the mid 60s . Mode locking can be used very effectively for lasers with a relatively broad laser transition bandwidth, and thus for lasers with a broad amplification profile, in which numerous longitudinal modes can oscillate simultaneously.

Assuming that 2N+1 modes oscillate with the same amplitude E_0 and a constant phase relation between the modes, the resultant field amplitude E_{tot} can be expressed as a function of the time t. The superposition of the single modes with a constant phase