QUALITY INVESTIGATION OF LASER PROCESSED SILICON WAFER

GAN PUOH YOON
B051110163

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
2015

B051110163 BACHELOR OF MANUFACTURING ENGINEERING (MANUFACTURING PROCESS) (HONS.) 2015 UTeM

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

QUALITY INVESTIGATION OF LASER PROCESSED SILICON WAFER

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process)(Hons.)

by

GAN PUOH YOON
B051110163
910915-10-5963

FACULTY OF MANUFACTURING ENGINEERING
2015

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Quality Investigation of Laser Processed Silicon Wafer**

SESI PENGAJIAN: **2014/15 Semester 2**

Saya **GAN PUOH YOON**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ TIDAK TERHAD

Disahkan oleh:

_______________________ _______________________

Alamat Tetap:

NO. 10, JALAN HANG TUAH 5,

TAMAN MUHIBBAH, 86000

KLUANG,JOHOR

Cop Rasmi:

Tarikh: _______________________

Tarikh: _______________________

** Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Quality Investigation of Laser Processed Silicon Wafer” is the results of my own research except as cited in references.

Signature	:	………………………………………….
Author’s Name	:	Gan Puoh Yoon
Date	:	…………………………………………

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) (Hons.). The member of the supervisory is as follow:

………………………………

(Project Supervisor)

ABSTRAK

Pemesinan laser pada wafer silikon digunakan secara meluas di industri kerana menyediakan pelbagai kebaikan berbanding dengan kaedah tradisional yang lain. Dalam projek ini, pemesinan laser digunakan pada wafer silikon jenis P pada suhu bilik dengan laser karbon dioxida pada tahap optimum, iaitu dengan kuasa laser 47.69 W, frekuensi denyut 297.05 Hz dan kitar tugas 60.54% untuk penebukan dan kuasa laser 800 W, kadar pemotongan 2100 mm/min dan frekuensi denyutan 250 Hz untuk pemotongan dalam keadaan stabil. Wafer silikon dibersihkan dengan penggunaan aseton pelarut, dan menjalani proses pengubahsuaian permukaan dengan menggunakan Potasium Hydroxida (KOH) sebelum di mesin oleh laser karbon dioksida. Parameter kajian dalam proses larutan punaran termasuk masa, skala suhu dan kepekatan cecair. Ketebalan wafer silikon sebelum dan selepas larutan punaran, kekasaran permukaan dan keseragaman termasuk dalam kajian, diikuti dengan lebar takuk, kekasaran permukaan pada lubang dan diameter lubang pada wafer silikon selepas pengerudian laser. Penggunaan reka bentuk Box Behnken dalam Response Surface Methodology (RSM) untuk pemodelan dan pengoptimumkan parameter larutan punaran hubungan dengan respons dapatan selepas pemesinan laser. Projek ini bertujuan untuk mendapatkan kekasaran permukaan dalam lubang pada tahap minima dan kualiti lubang yang tinggi. Oleh itu, pengoptimuman larutan punaran ialah 30 minit, 70^{o}C dan konsentrasi 33.64% untuk mendapat respons larutan tahap minima, manakala ketebalan wafer selepas larutan punaran ialah 435.85 µm, kekasaran permukaan selepas larutan punaran ialah 0.16 µm untuk mendapatkan jarak kerf 0.282 mm, lubang diameter 0.39 mm dan kekasaran lubang 1 µm.

ABSTRACT

Laser micromachining on silicon wafers are becoming more widely known in industries as it gives many advantages compared to other traditional methods. In this project, laser micromachining was conducted on the P-type silicon wafer at room temperature with the optimum carbon dioxide, CO_2 laser power of 47.69 W, pulse frequency of 297.05 Hz and duty cycle of 60.54 % for drilling and laser power of 800 W, feed of 2100 mm/min and pulse frequency of 250 Hz for cutting under steady condition. The silicon wafer was cleaned by acetone and undergoes surface modification whereby the wafer is completely immersed and etch in potassium hydroxide (KOH) solution before being machined by CO_2 laser. Parameters involves during etching are time, temperature and concentration. Effect of the thickness of silicon wafer before and after etching, surface roughness and uniformity of the modified wafer are investigated, followed by kerf width, surface roughness of the holes and hole diameter of the wafer after laser drilling. The Box-Behnken design in Response Surface Methodology (RSM) is used to model and optimize the etching parameters with the relation to the output responses obtained after laser machining. This research intends to obtain the minimal surface roughness of the holes and high quality micro holes. Hence, the etching parameters are optimized at 30 minutes, 70^{o}C and 33.14% concentration for minimal etching responses and the wafer thickness after etching is 435.85 µm, surface roughness after etching is 0.16 µm to obtained a kerf width of 0.282 mm, hole diameter of 0.39 mm and roughness of the holes of 1 µm.

DEDICATION

To my beloved parents,

Gan Ghee Whoon

Tan Lay Khim

ACKNOWLEDGEMENT

First of all, I would like to thank everyone around me for guiding me to complete my Projek Sarjana Muda (PSM) successfully. Not to forget, a sincere appreciation to those who be there to guide me either directly or indirectly in completing this PSM report. Sincerely, I would like to thank my supervisor, Professor Madya Ir. Dr. Sivarao Subramonian for providing me extra knowledge and ideas for completing this research. In addition, his guidance, support and advices gives me the opportunity to gain and learn more information throughout the execution of the project. Besides, I would also like to thanks to all the assistant engineers in the Faculty of Manufacturing Engineering (FKP) Lab for their suggestions and information regarding my project. Last but not least, a sincere appreciation to my family members and friends for their support in helping me to complete this project report.

TABLE OF CONTENTS

ABSTRAK	**i**
ABSTRACT	**ii**
DEDICATION	**iii**
ACKNOWLEDGEMENT	**iv**
TABLE OF CONTENTS	**v**
LIST OF FIGURES	**ix**
LIST OF TABLES	**xii**
LIST OF ABBREVIATIONS, SYMBOLS AND SPECIALIZED NOMENCLATURE	**xiv**
CHAPTER 1 : INTRODUCTION	**1**
1.1 Introduction	1
1.2 Background of Study	1
1.3 Problem Statement	3
1.4 Objectives of the research	3
1.5 Scope of Study	4
1.6 Structure of the Report	4
CHAPTER 2 : LITERATURE REVIEW	**5**
2.1 Introduction	5
2.2 Fundamentals of Laser Principle	5
2.3 Carbon Dioxide Laser	7
2.4 Laser Drilling	7

2.4.1 Single Pulse Drilling 8

2.4.2 Percussion Drilling 8

2.4.3 Trepanning Drilling 9

2.5 Laser Micromachining 10

2.6 Laser Cutting 12

2.7 Laser Parameter Selection 14

2.8 Chemical Etching 16

2.8.1 Etching Rate 17

2.8.2 Surface Roughness 18

2.9 Etching Parameters 18

2.9.1 Etching Parameters Selection 25

2.9.2 Etching Concentration 27

2.9.3 Etching Temperature 28

2.9.4 Etching Time 28

2.10 Surface Modification 28

2.11 Silicon Wafer 31

2.12 Silicon Wafer Surface Preparation 32

2.13 Conclusion 33

CHAPTER 3 : METHODOLOGY 34

3.1 Introduction 34

3.2 Research Flow Chart 34

3.3 Design Parameters 36

3.4 Design of Experiment 36

3.4.1 Response Surface Methodology (RSM) 37

3.4.2 Box-Behnken Design 38

3.4.3 RSM Matrix Formation 39
3.5 Material Selection 40
3.5.1 Surface Preparation of Silicon Wafer 41
3.5.2 Chemical Etching of Silicon Wafer 42
3.5.3 Laser Drilling of Silicon Wafer 42
3.6 Experiment Equipments 43
3.6.1 Laser Cutting Machine 43
3.6.2 Scanning Electron Microscopy (SEM) 44
3.6.3 Top Loading Balance 45
3.6.4 Hot Plate 45
3.6.5 Surface Profilometer 46
3.7 Data Collection 46
3.7.1 Depth of Etch 47
3.7.2 Surface Roughness 47
3.7.3 Uniformity 47
3.7.4 Hole diameter 47
3.7.5 Surface Roughness of Holes 48
3.7.6 Kerf Width 48
3.8 Modelling 48

CHAPTER 4 : RESULTS AND DISCUSSIONS 49
4.1 Introduction 49
4.2 Experimental Results for Etching Process 49
4.2.1 Etch rate Analysis 51
4.2.2 Surface Roughness Analysis 55
4.2.3 Uniformity Analysis 59

4.3 Experimental Results for Laser Process 62

4.3.1 Effect of silicon wafer thickness and surface roughness after etch to the hole diameter and kerf width 63

4.3.2 Effect of silicon wafer thickness and surface roughness after etch to surface roughness of drilled holes 66

4.4 Optimization 67

CHAPTER 5 : CONCLUSION 69

5.1 Conclusion 69

5.2 Future work 70

REFERENCES 71

APPENDICES 82

A Gantt Chart for PSM 82

B Observations 86

LIST OF FIGURES

2.1	Electromagnetic Spectrum	6
2.2	Single Pulsed Drilling Process	8
2.3	Percussion Drilling Process	8
2.4	Trepanning Drilling Process	9
2.5	Laser Cutting Process with Labels	12
2.6	Effect of etching temperature on the depth of etch	19
2.7	Etch rates of KOH and TMAH etchants with and without IPA additives on Si(100)	21
2.8	Etch rate against concentration of KOH	23
2.9	Si etching rate with respect to KOH concentration and temperature for vertical sidewall etching	24
2.10(a)	AFM micrograph images of silicon surface etched with KOH concentration of 20 wt.%	27
2.10(b)	AFM micrograph images of silicon surface etched with KOH concentration of 30 wt.%	27
2.11	AFM topography image of (a) 40%, 60^{o}C KOH etching solution (b) addition of Sb_2O_3 in the solution	29
2.12	SEM image of modified SiNWs (a) with copper (b) with platinum	31
3.1	Overall research flow chart	35

3.2	Points represents the experimental runs of three factor Box-Behnken design	38
3.3	Etching parameters setup	39
3.4	Response to be measure after etching and laser processing	39
3.5	Table of run for etching and laser processing with its responses	40
3.6	Helius 2513 CO_2 Laser Cutting Machine	44
3.7	Scanning electron microscope	45
3.8	Surface profilometer	46
4.1	Experimental and predicted value for etch rate	52
4.2	Effect of etching time to etch rate at temperature 80^{o}C and concentration 40%	53
4.3	Effect of etching concentration to etch rate at temperature 80^{o}C and time 40 minutes	54
4.4	Effect of etching temperature and time to etch rate at concentration 40%	55
4.5	Experimental and predicted value for surface roughness	57
4.6	Effect of etching concentration to surface roughness at temperature 80^{o}C and time 40 minutes	58
4.7	Effect of etching time and concentration to surface roughness at 80^{o}C	59
4.8	SEM image of surface at (a) temperature 70^{o}C and concentration 30%. (b) temperature 80^{o}C and concentration 40%	60
4.9	Effect of silicon wafer thickness and surface roughness after etching to hole diameter and kerf width	63

4.10	SEM image for (a) sample 1 and (b) sample 5	65
4.11	Effect of silicon wafer thickness and surface roughness after etching to surface roughness of drilled holes	66

LIST OF TABLES

2.1	Wavelength associated with the visible spectrum	6
2.2	Cutting condition	13
2.3	List of laser machining parameters	15
2.4	Usage of input parameters and responses	15
2.5	Summary of input parameters and responses	16
2.6	Etching conditions used for different pyramid configuration	24
2.7	Etching input parameters and response	25
2.8	Frequency of input parameters and response	26
2.9	Ranking of etching parameters	26
2.10	Mechanical and Thermal Properties of silicon, Si	32
3.1	Selected etching parameters and their levels	36
3.2	Optimized parameter of laser drilling	36
3.3	SEMI standard for silicon wafer	40
3.4	Specifications of Helius 2513 CO_2 Laser Cutting Machine	43
3.5	Specifications of SEM	44
3.6	Specifications of Mitutoyo SJ 301 surface profilometer	46
4.1	Experiment results for etching responses	50

4.2	ANOVA table for etch rate responses	51
4.3	ANOVA table for surface roughness responses	56
4.4	ANOVA table for uniformity responses	60
4.5	Optimization data for etching responses	61
4.6	Experimental results for laser machining responses	62
4.7	Optimization data for etching	67
4.8	Optimization data for laser machining	68

LIST OF ABBREVIATIONS, SYMBOLS AND SPECIALIZED NOMENCLATURE

CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
MEMS	-	Microelectromechanical System
KOH	-	Potassium Hydroxide
µ	-	Microns
kW	-	Kilowatt
N_2	-	Nitrogen
mm	-	millimeter
ms	-	milliseconds
SEM	-	Scanning Electron Microscope
mm/s	-	millimeter per second
nm	-	nanometer
GPa	-	Giga Pascal
AFM	-	Atomic Force Microscope
Hz	-	Hertz
J	-	Joule
RSM	-	Response Surface Methodology
HAZ	-	Heat Affected Zone
Jcm^{-2}	-	Joule per centimeter square

Si_3N_4	-	Silicon Nitride
%	-	Percentage
Si	-	Silicon
DOE	-	Design of Experiment
^oC	-	Degree Celcius
IPA	-	Isopropyl alcohol
ppm	-	parts per million
ANOVA	-	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 Introduction

Basically, this chapter will explain about the introduction of the project which includes the background of the study, problem statements occurring recently, research objectives, the entire scope of the studies and research organization.

1.2 Background of Study

Currently, there is a huge demand in micromachining of components for the use of electronic and mechanical devices. The highly demand of micro-components has given the needs to employ alternative manufacturing methods for a wider range of materials such as titanium, metals, semiconductors, ceramics or composites to be used in micro-structures (Jackson and Neil, 2003). As electronic devices are developed and becoming smaller, lighter and thinner throughout the coming years, the tendency towards miniaturization is increasing (Tan, 2006). The development of laser machining is the most widely used technique in micro-machining of engineering components which improves the cutting and drilling quality (Dubey and Yadava, 2008). Laser machining is widely used in industries as a non contact cutting tool that gives several advantages such as lesser reacting force between cutting tool and work piece, greater flexibility, narrower heat affected zone (HAZ), good surface finish and able to machine difficult-to-machine materials.

There are various types of lasers used in modern industries such as CO_2, CO, Nd:YAG lamp pumped, Nd:YAG diode punped, Nd:glass, Yb fibre, Er fibre and Excimer Krf (Lawrence et al., 2010). However, CO_2 and Nd:YAG lasers are the two most broadly used laser beam applications in industries. CO_2 lasers have high average beam power, better efficiency and good beam quality which are suitable for machining thin sheet metal where as Nd:YAG lasers have lower beam power and are able to machine thicker materials. Recently, laser machining has been used in various types of applications such as automobile sectors, aircraft industry, electronics industry and house appliances due to its advantages (Dubey and Yadava, 2008).

Microelectromechanical systems (MEMS) has grown tremendously in the past few years and are important in current technologies. MEMS is produce by the combination of mechanical and electrical function in devices at a small scale. In addition, anisotropic etching of single silicon has been used to fabricate diverse MEMS devices (Yang et al., 2005). MEMS can be divided into 4 types of components includes sensors, actuators, micro structures and micro electronics which can be merged onto the silicon substrate along with integrated circuits.

Chemical etching is a non-traditional machining process which involves the chemical dissolution of work piece in either acid or alkaline solution. This process is also widely used in semiconductor industries and MEMS industries for producing micro-components and micro-chips. Chemical etching can be considered as the oldest non-traditional techniques to machine micro-components compared to laser. Due to several disadvantages of chemical etching such as difficult to produce sharp corners, difficult to machine thick material and poor dimensional accuracy, thus, laser machining is a more suitable method to machine micro-components (Cakir et al., 2007). However, chemical etching on silicon wafer is a pre-processing method before laser machining can be done on the silicon wafer.

1.3 Problem Statement

Conventional micro-electronic components are insufficient to satisfy customer needs due to its growing demands for higher performance. Hence, micromachining of silicon wafer by laser is essential for the miniaturized device manufacture (Lawrence et al., 2010).

Laser micromachining are not realistic for practical mass production due to being unstable and high cost but are reported viable alternative to conventional micromachining because of its advantages over traditional methods (Danny, 2006). Recently, CO_2 and Nd:YAG lasers were tried out for micromachining of metals and glass and gained success to certain extend (Chung and Lin, 2010). CO_2 lasers high wavelength of 10.6 μm which permits it to machine high refractive materials such as silicon wafer (Dubey and Yadava, 2008). CO_2 energy concentration beam is not enough, leading to rough surface on the machined part and will results in thermal interaction that leads to cracking and serious melting to the wafer surface. The coating of silicon wafer did not make any contribution on improving the cutting quality (Lawrence et al., 2010).

Therefore, this project is intended to carry out silicon micromachining with CO_2 laser to investigate the significant effect of surface modification in obtaining high quality micro holes.

1.4 Objectives of the research

The objectives of this research are to :

i. Investigate the effect of etching parameters on the surface modification for laser processed silicon wafer.
ii. Establish model for the etching processes.
iii. Optimization of the etching processes.