EXPERIMENTAL LASER-MACHINING OF SILICON WAFER

LAU ZHEN CHYEN

Report submitted in partial fulfilment of the
requirements for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

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 Engineering.

Signature
Name of Supervisor: Dr. DAW THET THET MON
Position: LECTURER OF FACULTY OF MECHANICAL ENGINEERING
Date: 6/12/2010

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: LAU ZHEN CHYEN
ID Number: ME07067
Date: 6/12/2010

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr. DAW THET THET MON for her invaluable guidance, continuous encouragement and constant support in making this thesis possible. I owe my deepest gratitude for her progressive vision in my final year project, her tolerance of my mistakes, and her time spent on my final year project. I also would like to express very special thanks to the panel member who give valuable comment and suggestion during my project presentation.

My sincere thanks go to members of the staffs of the Mechanical Engineering Department, UMP and also staffs from UTHM who helped me in many ways and made the lab work successful.

I remain indebted to my parents, family members for their love, dream and sacrifice throughout my life. This thesis would not have been accomplished without kind support, encouragement and faith from them. . Special thanks should be given to my coursemates. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This thesis deals with laser machining of silicon wafer at various process parameters. The objective of this thesis is to investigate the effect of laser machining parameters on the cut surface quality and determine the feasible laser machining parameters that can machine silicon wafer. The thesis describes how machining parameters and air assist gas affects cut surface quality. The silicon wafer was machined by laser with and without air assists. Principally, two experimental sets with different cutting speed and laser power were designed in statistical software. The kerf widths and quality were observed under microscopes. The results then were analyzed using statistica software. The analysis indicated that cutting speed has significant effect to the kerf width and laser cutting with air assists produced wider kerf. Result obtained also showed that laser cutting without air assists produced better cut surface quality. The feasible machining parameter of silicon is estimated at 1.0-2.0 mm/min for cutting velocity, 0.80-0.94 watt for laser power in laser cutting without air assist and 1.0-4.0 mm/min for cutting velocity, 0.80-0.90 watt for laser power in laser cutting with air assist.

ABSTRAK

Tesis ini membentangkan pemesinan wafer silikon oleh laser dengan parameter yang berbeza. Objectif tesis ini ialah untuk menyiasat kesan parameter pemesinan laser terhadap kualiti permukaan yang terpotong dan juga untuk menentukan parameter yang sesuai bagi pemesinan wafer silikon. Tesis ini menjelaskan bagaimanakah parameter pemesinan laser dan bantuan gas udara memberi kesan kepada kualiti permukaan yang terpotong. Wafer Silikon dimesinkan oleh mesin laser dengan bantuan gas udara dan tanpa bantuan gas udara. Setiap set pemesinannya dipotong dengan kelajuaan pemotongan dan daya laser yang berbeza berdasarkan jadual eksperimen. Lebar dan kualiti garitan diberi pemerhatian dengan menggunakan mikroskop. Selepas itu, keputusannya dianalisa dengan STATISTICA. Analisis menunjukkan bahawa kelajuan permotongan mempunyai kesan yang penting terhadap lebar garitan dan pemesinan laser dengan bantuan gas udara menghasilkan garitan yang lebih lebar. Keputusan eksperimen juga menunjukkan bahawa pemesinan laser tanpa bantuan gas udara menghasilkan kualiti pemotongan yang lebih baik. Parameter yang sesuai bagi pemesinan wafer silion ialah 1.0-2.0 mm/min (kelajuan pemotongan), 0.80-0.94 watt (daya laser) untuk pemesinan laser tanpa bantuan gas udara dan 1.0-4.0 mm/min (kelajuan pemesinan), 0.80-0.90 watt (daya laser) untuk pemesinan laser dengan bantuan gas udara.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

λ	Wavelength
ω	Radius
Θ	Divergence angle
Θ_f	Divergence angle passing the lens
M^2	Beam Quality
δ	Minimum spot diameter
$T_{z,t}$	Temperature at the center of the spot
I_α	Irradiance
α	Thermal diffusivity
E_g	Band gap energy
K	Thermal conductivity
ρ	Density

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
DOE	Design of experiment
DV	Dependent Variable
FS	Femtosecond
FE	Finite Element
HAZ	Heat-affected zone
IC	Integrated circuit
IV	Independent variable
NS	Nanosecond
SEM	Scanning Electron Microscopy
SI	Silicon
YAG	Yttrium Aluminium Garnet

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Silicon wafer is a key component of integrated circuits such as those used to power computers, cell phones, and a wide variety of other devices and therefore it is very demanding in global. With larger wafers, less marginal space remains on the edges as a percentage of total space and can significantly increase the yield per wafer. Although Laser machining can provide high accuracy of cutting geometry, in order to find out the optimum parameter is still an important challenge. Integrated Circuit (IC) fabrication consists of multiple processing steps that add, alter, and remove thin layers in selected regions of silicon wafer to form electronic devices as transistors and diodes which are extremely demanding and part of the long term massive production nowadays (Joseph M.G, 2002). Therefore we need to investigate the effect of laser machining parameters on the surface finish of silicon wafer to obtain the feasible laser machining parameters which reduce the wastage and increase the productivity as a result reduce the production cost at overall. This experiment involves three variables they are cutting velocity, assist gas pressure and laser power thus trial and error is the way to run the experiment in order to obtain the result. However, trial and error is time consuming and a simulation model should be introduced in STATISTICA as an experiment reference to improve the experiment. Based on the result obtained, the effect of laser machining parameter on the surface finish of silicon wafer can be investigated and the chart can be developed as well to explain the smallest feature size generated by laser machining.

1.2 PROJECT BACKGROUND

Silicon wafer is a key component of integrated circuits such as those used to power computers, cellphones, and a wide variety of other devices. A silicon wafer consists of a thin slice of silicon which can be treated in various ways, depending on the type of electronics it is being used in. Silicon is a very high quality semiconductor, making it ideal for the production of such circuits, although other materials have been explored historically.

Components of an integrated circuit can be installed inside a silicon wafer, in addition to install on or around it. The technology behind integrated circuits is constantly evolving, as people push to make smaller and better circuits. Developments in this technology tend to push the limit of laser machining even greater. Therefore, the development of laser machining is improving rapidly in recent year.

The interest in finding optimum laser parameters increased dramatically in recent years. With these optimum parameters, fine and fast production can be achieved to meet the global demand which is getting higher from year to year.

1.3 PROBLEM STATEMENT

In recent year, microengineering processes play an essential role in daily life due to the continuous size reduction in many electronics. In many cases, common mechanical processes like sawing, drilling, or grinding have been adapted to miromechanical demands, but have come to their limits in the course of the progressing miniaturization.

However, current technology making micro feature is time consuming and expensive. Therefore it is essential to study the principle of line focus generation to enhance linear cutting speed. Although lasers are generally able to machine silicon, the major material in many microsystem applications, doing so without influencing the physical properties of the bulk material remains an important challenge. Every material will behave differently from each other when ablated by different laser pulses. Silicon, as the most important material for the semiconductor industry, requires specific parameters to minimize cutting kerf widths, to reduce redeposition on the entrance surface, and to ensure high kerf quality on all sides while retaining high processing speed.

1.4 PROJECT OBJECTIVE

The main aim of this project is to investigate the effect of laser machining parameters on the cut surface quality. The specimen used is mainly based on silicon wafer. As such, the project seeks to fulfill the following objectives:

(i) To investigate the effect of cutting velocity and laser power on the cut surface quality.

(ii) To determine the feasible laser machining parameters that can machine silicon through STATISTICA analysis.

(iii) To develop chart that can relate the surface finish and laser machining parameters.

1.5 SCOPE OF THE PROJECT

The project scopes were identified as well so that the whole project can be done according to the plan and achieve the objectives. This study involved the machining of Silicon wafer by laser. The machining of Silicon wafer will be carried out by Nd-YAG laser integrated with micromotion. The machining parameters considered are laser power and cutting velocity. The experiment will be run twice that is without and with air assist. The machining experiment will be designed using STATISTICA experimental design. The surface quality then will be investigated with Scanning Eletron Mictoscope and Optical Microscope for further analysis. Finally the experiment result will be analyzed in STATISTICA.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There were some preliminary studies related to the laser such as how laser ablation mechanism works, characteristic of laser, and laser types. This information is useful so that appropriate parameters of laser machining can be chosen based on previous research, in order to machine silicon wafer. Moreover, these references were essential when explaining the result obtained from the result. The result obtained from this project was compared to the previous researches to observe the relationship between them.

2.2 APPLICATION OF LASER MACHINING

There are wide range of precise machining processes can be done with laser machining such as cutting, drilling, welding, glazing and many more as shown in the Figure 2.1. Laser machining is categorized as precision machining because it able to remove micro-material accurately from micro scale structure. Most of the application of laser micromachining can be found in electronics industry due to very high demands of electronics in electrical appliance such as television, mobile phones, computers and many more.

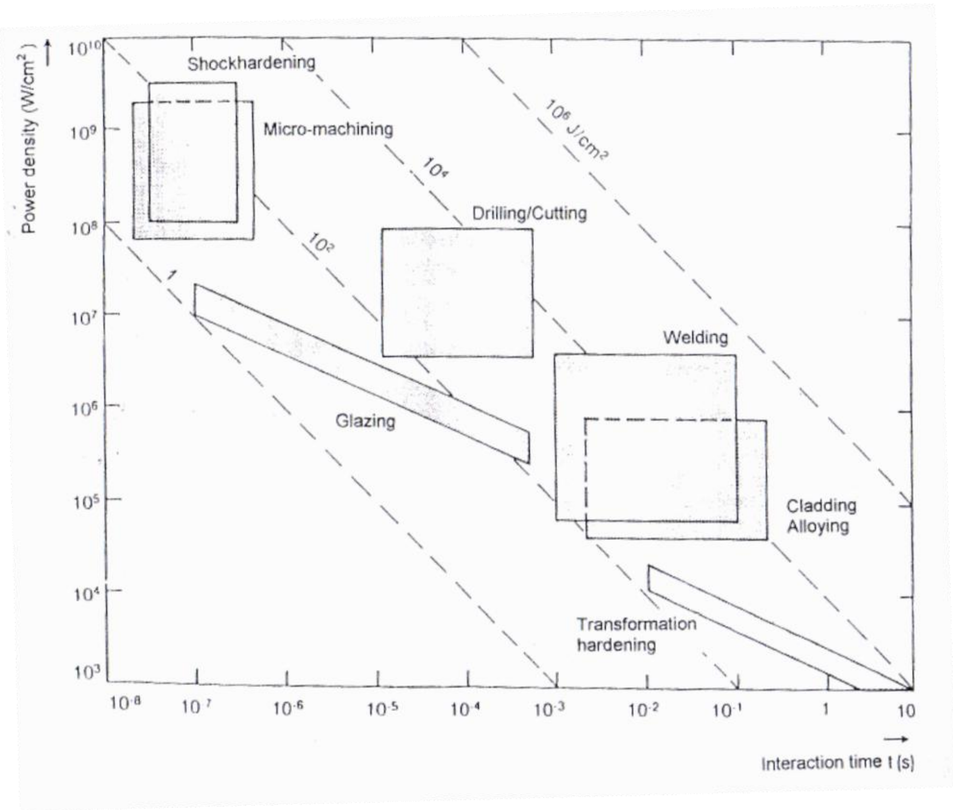

Figure 2.1: Application areas in the I-t diagram

Source: Joseph M.G 2002

The earliest application of laser occurred in 1960s in the cutting of trim grooves on conventional resistors and drilling small holes in diamond. And after that, laser spot welding and micromilling were applied at 1970s and 1980s respectively. In 1990s, laser microadjustment was developed for use in industry to improve the accuracy of micromachining. The development of smaller features is one of the important researches to measure the laser micromachining ability. From the beginning in the 20th century, a reduction in size by a factor of two every seven years in laser technology has been observed (Joseph M.G, 2002).

The cost of production is increasing rapidly too due to complicated optics for micro scale machining that is getting smaller every several years. A set of laser equipment for semiconductor production can cost over a million dollar. Nevertheless the cost of material is being reduced because of extremely high production volume in global (Joseph M.G, 2002).

2.3 CHARACTERISTIC OF LASER

Laser used for micromachining are characterized by its length of pulse. They are ranging from millisecond to the pico- even femtosecond. Each short pulse length has its own application for example millisecond laser pulse is for microwelding, pico- and nanosecond laser pulse is for ablation of metals.

2.3.1 Laser Wavelengths

The distance of a photon of laser traveled is always measured in light-distance just like for very long-distance we expressed that in light-years. For 100 fs pulse there is only 30 μm of distance amount (Kenneth E. et al., 2007). The wavelength of short pulse laser can be vary from λ = 10.6 μm for the CO_2 laser to 157 nm for a fluorine excimer laser (Joseph M.G, 2002). The range of wavelengths being considered here extends from infrared to ultraviolet is shown in Figure 2.2.

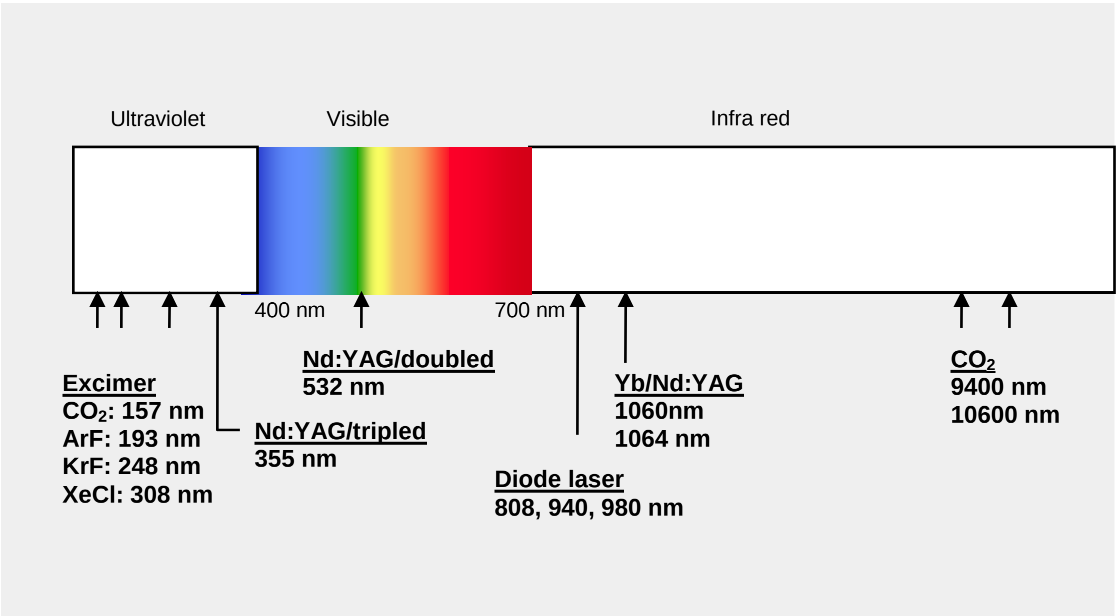

Figure 2.2: Common industrial laser wavelengths

Source: Andrew B.M 2006

Each element or compounds used for laser has its own properties and mechanism to transmit energy. For example, CO_2 laser action takes place between its vibration energy levels whereas Ytterbium (Yb) and Neodymium (Nd) takes place between their electronic energy levels. YAG (Yttrium Aluminium Garnet) and Vanadate or YVO_4 (Yttrium Vanadate) are two commonly-used crystals which act as convenient solid hosts for CO_2 and Yb/Nd.

The laser beam is characterize by the divergence angle Θ, radius ω and the wavelength λ. For an ideal beam trajectory, equation $\Theta \cdot \omega = \lambda/\pi$ is applied. However, in reality, beam quality, M^2 existed in the real beam, which is the ratio between the Θ·ω product for the real beam. For a real beam the product becomes $\Theta \cdot \omega = M^2 \cdot \lambda/\pi$ where $M^2 \geq 1$. With focusing optics the divergence angle after passing the lens becomes $\Theta_f = D/2f$ resulting in a minimum spot diameter δ :

$$\delta = \frac{4}{\pi} \cdot M^2 \frac{f}{D}$$

Small spot can be done by a high beam quality $M^2 \cong 1$ with a short wavelength and a short focal length lens. Some of the common beam properties are listed at below Figure 2.3 (Joseph M.G, 2002).

Laser	Wavelength λ (μm)	Power P (W)	w·θ (mm·mrad)	Beam quality M^2 (−)	Spot diameter with f/4 lens δ (μm)
HeNe	0.63	0.002	0.2	0.98	3
Nd:YAG[a]	1.06	100	6	10	50
Nd:YAG[b]		1000	25	80	500
Q-Switched		10	2	3	15
Nd:YAG	1.06	100	6	10	50
		1000	25	80	500
CO_2	10.6	1000	10	1.5	80
Copper vapor	0.51	20	0.5	3	8
Ti:Sapphire	0.78	1			
Excimer	0.193–0.351	100	20	200	—

[a] Fine drilling or cutting mode.
[b] Normal industrial laser.

Figure 2.3: Example of Beam Properties

Source: Joseph M.G 2002

2.3.2 Types of Laser

There are many thousands of kinds of laser are known nowadays such as chemical laser, solid state laser, gas laser, dye laser, metal vapor laser and many more. However, the industrial lasers available today mostly are either based upon gas or solid state technology.

The most important industrial gas lasers are CO_2 and Excimer lasers and these lasers occupied wide range of wavelength. CO_2 laser were the first laser to be applied to commercial industrial application. The laser output is commonly continuous, but can be pulsed as well. The wavelength of CO_2 is about 10 μm and average power is usually excess of 10kW for commercial application. Excimer lasers use halogen dimer or rare gas halides as the laser medium. The output wavelength is usually lied between 157 nm and 351 nm. The laser are pulsed unlike CO_2 laser and has pulse duration around 10 ns (Andrew B.M., 2006)

Solid-state laser materials are made by doping a crystalline solid host with ions that provide the required energy states. Solid state lasers are common based around the rare earth element, such as Neodymium (Nd) which is doped with YAG and YVO_4 as common hosts. The majority of solid state lasers supplied today are rod-based. For industrial purposes these can be classified as cw, pulsed and Q-switched. Of these the highest average power is available from cw (Nd:YAG) solid state rod lasers. However, rod based laser do have a drawback. The quality of the laser beam generated can be compromised by the inherent difficulty of extracting the heat produced during operation. Fibre and disc based solid state laser are easier to cool therefore recent years industrial lasers based on these two geometries have begun to reach the market. A summary of pulse durations from several solid state laser technologies is shown in Figure 2.4.

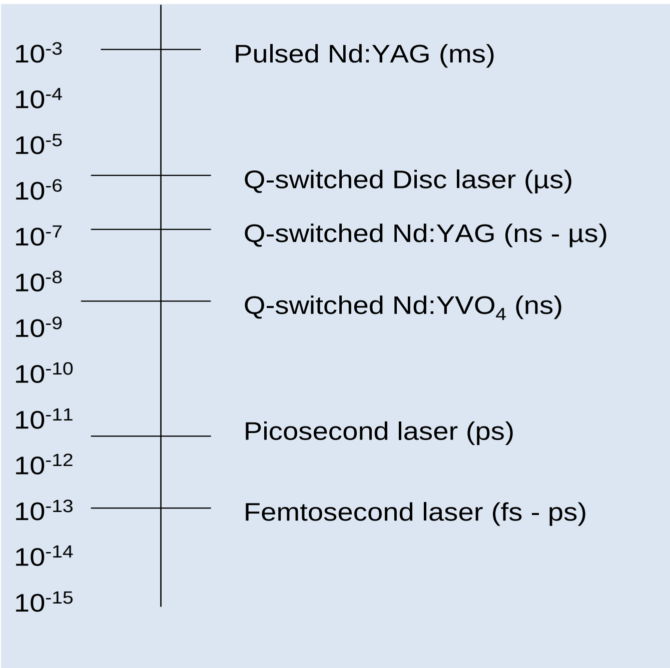

Figure 2.4: Pulse widths from various solid state lasers

Source: Andrew B.M 2006

2.4 MECHANISM OF LASER MATERIAL REMOVAL

Laser micromachining is based on the interaction of laser light with solid matter. As a result of a complex process, small amounts of material can be removed from the surface of the solid. Laser micromachining can be categorized into two processes, they are pyrolithic and photolithic processes. In both cases short to ultrashort laser pulses are applied in order to rermove small amounts of material in a controlled way.

2.4.1 Laser material removal processes

Pyrolithic processes are based on a rapid thermal cycle, heating, melting, and evaporation of the heated volume. Absorptivity of laser energy is very important in mechanism of laser material removal. Laser energy is focused on the material surface and partly absorbed. The absorptivity depends on the material, the surface structure, the power density, and the wavelength. With a CO_2 laser about 20% is absorbed with laser micromachining while with shorter wavelengths 40 to 80% is absorbed. The remaining part is reflected. Absorption occurs in a very thin surface layer, where the optical energy is converted into heat. The optical penetration depth is defined as the depth for which the power density is reduced to 1/e of the initial density. The absorbed energy diffuses into bulk material by conduction. For short pulse, the heat flow is approximately one-dimensional. The temperature at the center of the spot can be derived from the equation below,

$$T_{z,t} = \frac{I_a \delta}{\lambda} ierfc\left(\frac{z}{\delta}\right)$$

Where $\delta = \sqrt{4\alpha t}$ is a measure for the thermal penetration depth during the pulse time *t*. At this depth the temperature is 9% of the surface temperature. For steel, $I_\alpha = 10^9$ W/cm^2, the melting point can be reached in about 300 ns. The high vaporization rate causes a shock wave and a high vapor pressure at the liquid surface considerably increases the boiling temperature. Finally the material is removed as a vapor by the expulsion of melt, as a result of the high pressure and by an explosive-like boiling of the superheated liquid after the end of the laser pulse. However, the process is quite different for plastic material because the material is removed by breaking the chemical bonds of the macromolecules, and is dispersed as gas or small particles. Therefore no melt is found. Figure 2.5 shows the mechanism of laser material removal.

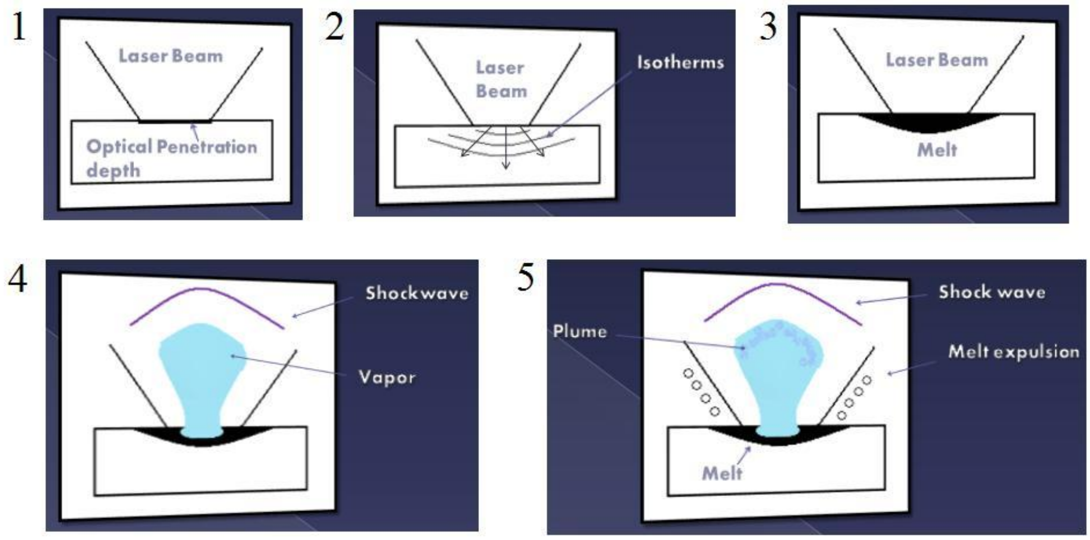

Figure 2.5: Mechanism of Laser Material Removal