UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LASER MACHINING OF WASTE PLASTIC PRODUCTS

This report submitted in accordance with the requirements of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelors of Manufacturing Engineering (Honors) (Manufacturing Process)

by

MOHD SYAZMAN BIN JAAFAR

B051010189

890929045089

Faculty of Manufacturing Engineering

2013

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **LASER MACHINING OF WASTE PLASTIC PRODUCTS**

SESI PENGAJIAN: **2012/13 Semester 2**

Saya **MOHD SYAZMAN BIN JAAFAR**

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 Malaysiasebagaimana 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:

____

(Penulis)

Alamat Tetap:

NO. 13, Jln Biru 6, Tmn Pelangi,

85000 Segamat,

Johor Darul Tak'zim.

Tarikh: ________________________

____

(Penyelia)

Cop Rasmi:

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 “Laser Machining of Waste Plastic Products” is the results of my own research except as cited in reference.

Signature : ________________

Author’s Name : Mohd Syazman bin Jaafar

Date : ________________

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the fulfillment of the requirement for the degree of Bachelor of Manufactuirng Engineering Bachelor Of Manufacturing Engineering (Manufacturing Process) (Hons.). The members of the supervisory committee are as follow:

(Official Stamp of Principal Supervisor)

ABSTRACK

Penggunaan Laser semakin bertambah sebagai satu perkakas pemotongan. Jumlah besar produk plastik terbuang menyumbang sebagai satu daripada sisa utama dalam negara. Kempen diguna semula perlu untuk lebih banyak meningkatkan supaya mencapai matlamat bagi mengurangkan sisa. Sejak bekas minyak “HDPE” ialah satu daripada sisa utama, kajian memotong ia pernah dijalankan oleh bantuan mesin pemotong laser. Pembolehubah terbaik diperlukan untuk mengoptimumkan penggunaan tenaga minimum dan merendahkan kos keseluruhan proses. “Design of Experiment (DOE)” perlu digunakan bagi mendapatkan pembolehubah terbaik semasa kerja eksperimen. Pelbagai keputusan perlu diukur yang mana termasuk jarak pemotongan, kelebaran kerf, ketinggian kekasaran permukaan dan getaran. Akibatnya, kebanyakan daripada jawapan diukur menggunakan mikroskopi pengimejan digital dan kekasaran permukaan mudah alih penguji. Didapati bahawa kuasa laser dan kederasan memotong main satu kesan utama bagi semua empat keputusan. Selain itu , hasil telah diadakan menyepakati betul-betul dari kajian terdahulu pada spesifikasi bahan yang sama. Beberapa contoh penggunaan ada dicadangkan supaya penggunaan bahan plastic terbuang dapat di optimumkan di dalam kehidupan seharian manusia.

ABSTRACT

The laser finds increasing commercial use as a cutting tool. The big numbers of waste plastic products contribute as one of the major waste in the country. Reused campaign needs to be more enhanced in order to achieve the goal of reducing the waste. Since the HDPE oil containers were one of the major waste, the study to cut it been carried out with the help of laser cutting machine. The optimum parameters need to be optimized in order to get the minimum energy consumption and low cost processes. The design of experiment (DOE) been used in order to get the best parameter during experimental work. Various responses been measured which include cutting distance, kerf width, surface roughness and burr height. Consequently, most of the responses were measured using the digital imaging microscopy and portable surface roughness tester. It finds that the laser power and cutting speed play a major effect in all four responses. Besides, the result was being agreed well from the previous study on the same material specification. Several material applications recommended in order to maximize the use of waste plastic products in the human life.

DEDICATION

To my beloved father; Jaafar bin Mat, beloved mother; Olah binti Saad and beloved siblings; Siti Syazana binti Jaafar, Mohd Syazwan bin Jaafar, Siti Syazwani binti Jaafar.

ACKNOWLEDGEMENTS

Bismillahirahmanirahim,

First of all, I would like to thanks Allah for His bless and let my Final Year Project (PSM) II successfully done. Then, I would like to appreciate my parents for their encouragement and support in order to finish my project.

I would like to thanks Prof Madya Dr. Ir. Sivarao in giving me guidance to complete this report and spending a lot of your time for me. Without his guidance, it is difficult and nearly impossible for me to done the project according to the objective been states. The excellent working relationship between my supervisor and me has provided me with bountiful knowledge and experience for the future. The help rendered to me is priceless, be it from the smallest of its kind to the largest.

Last and not least, my highest thankfulness is dedicated to my beloved siblings, housemate, classmate, course mate, frinds and other parties whom have helped me directly or indirectly.

Thanks again to everyone.

TABLE OF CONTENT

Abstrack		i
Abstract		ii
Dedication		iii
Acknowledgement		iv
Table of Content		v
List of Tables		ix
List of Figures		x
List Abbreviations, Symbols and Nomenclatures		xiii
CHAPTER 1: INTRODUCTION		**1**
1.1	Project Background	1
1.2	Problem Statement	2
1.3	Scope of Project	2
1.4	Objectives	3
1.5	Theory	4
	1.5.1 Laser Material Processing	4
	1.5.2 History of Laser	6
	1.5.3 Definition of Laser	10
	1.5.4 The Work Process of Laser	10
	1.5.5 Laser Properties	13
	1.5.6 Types of Lasers	15
	1.5.7 Laser Machining	18

1.5.8 Laser Cutting 23
1.5.9 Types of Parameters 30
1.5.10 Laser Drilling 43
1.5.11 Micromachining 46
1.6 Conclusion 47

CHAPTER 2: LITERATURE REVIEW **48**
2.1 Laser Machining on Metallic Material 48
2.2 Laser Machining on Ceramic Material 52
2.3 Laser Machining on Composite Materials 54
2.4 Laser Machining on Flexible Material 55
2.5 Laser Machining on Wood Material 56
2.6 Laser Machining on Polymer Material 59
2.6.1 Kerf Width 59
2.6.2 Cutting Depth 60
2.6.3 Surface Roughness 61
2.7 Conclusion 62

CHAPTER 3: METHODOLOGY **63**
3.1 Effects of Plastics Waste 64
3.1.1 Solid Waste Definition 65
3.1.2 Solid Waste Regulation 65
3.2 Material Classification 68
3.2.1 Factors to be Consider 68
3.2.2 Material Selection 68

3.2.3 Material Specification 68
3.2.4 Selection Method 69
3.3 Preprocess Parameter 70
3.3.1 Gathering process 71
3.3.2 Selecting and Counting Process 71
3.3.3 Washing Process 71
3.3.4 Sawing Process 72
3.3.5 Final Washing 73
3.4 Experiment Setup 74
3.4.1 Design of Experiment (DOE) 75
3.4.2 Factorial Design 76
3.4.3 Level 76
3.4.4 Variable 77
3.5 Profiling 77
3.6 Design Parameter 79
3.7 Experiment 79
3.7.1 Material Preparation & Profile Drawing 80
3.7.2 Machine Startup & Material Loading 81
3.7.3 Import Program into Control Panel of Machine 82
3.7.4 Dry Run and Actual Run Cutting 82
3.7.5 Responses Measurement 83
3.8 Result and Discussion 84
3.9 Conclusion 84

CHAPTER 4: RESULT AND DISCUSSION **85**

4.1 Data Processing 85

4.2 Cutting Distance 85

4.2.1 Result 85

4.2.2 Effects of Process Parameters 88

4.3 Burr Height 89

4.3.1 Result 89

4.3.2 Effects of Process Parameters 91

4.4 Kerf Width 93

4.4.1 Result 93

4.4.2 Effects of Process Parameters 95

4.5 Surface Roughness 97

4.5.1 Result 97

4.5.2 Effects of Process Parameters 99

4.6 Material Application 101

CHAPTER 5: CONCLUSION AND RECOMMENDATION **102**

REFERENCES **104**

LIST OF TABLES

1.1	Gas Laser Comparisons in the Aspects of Linear Power Density, Maximum Power and Power Efficiency Percent for He-Ne, Argon and CO_2	28
1.2	Types of Assisted Gas Used in CO_2 Laser Cutting	37
1.3	Cylindrical and Conical Nozzle	40
3.1	HDPE resistance and quick facts	69
3.2	Basic Specifications of the LVD Helius Hybrid 2513 Laser Cutting Machine	74
3.3	Cutting parameters need to controlled	75
3.4	DOE Matrix for cutting engine oil container	76
4.1	Cutting distance measurement for all nine cutting lines according to DOE	86
4.2	The details of burr height for all nine cutting lines according to DOE	89
4.3	Details of kerf width and deviation measurement values for all nine Cutting lines according DOE	93
4.4	The details of surface roughness measurement for all nine cutting lines according to DOE	97
4.5	The main parameters for cutting HDPE	101

LIST OF FIGURES

1.1	Classification of Laser Material Processing Flow Chart	5
1.2	The History of Maximum Laser Pulse Intensity throughout the Past 50 Years	9
1.3	Simple Atom Model	15
1.4	Photon Simulation	17
1.5	Photon Amplification; Amplification States (A) Laser Off, (B&C) Initial Random States, (D) Initial Stimulation, (E) Amplification And (F) Coherent Beam	17
1.6	Comparison of Monochromatic Light between Fluorescent Light and Laser	18
1.7	Comparison of Coherency between Normal Light and Laser	18
1.8	Comparison of Radiance of Light Bulb and Laser Beam	19
1.9	Gas Laser Layout	20
1.10	Solid Laser Layout	23
1.11	Schematic of One, Two and Three-Dimensional Laser Machining	23
1.12	Laser through Drilling	26
1.13	Laser through Cutting	27
1.14	Laser through Grooving	28
1.15	Three-dimensional Types of Cutting Methods	29
1.16	Examples of Laser Cutting Process for Various Materials	31
1.17	Laser Cutting Head	33
1.18	Cutting Out an Edge	34
1.19	Part with Oxide-free Cut Edge	35
1.20	Vibrations of CO_2 Molecules	36
1.21	The CO_2 Laser System	37
1.22	Roughness in Relationship to Sheet Thickness	40
1.23	Maximum Cutting Speed with 4000 W Laser Output as	

	Affected by Material Thickness	43
1.24	Maximum Cutting Gas Consumption per Hour in Continuous Cutting for Cutting with Oxygen with Gas Pressure Up to 6 Bars	45
1.25	Maximum Cutting Gas Consumption per Hour in Continuous Cutting with Nitrogen with Gas Pressure Up to 20 Bars	45
1.26	Power versus Time in Continuous Wave	47
1.27	Power versus Time in Gated Pulse	47
1.28	Correlation between Frequency and Surface Roughness	48
1.29	Different Types of Nozzle Design; From Left: Standard Nozzle, Laval Nozzle and Autonomous Nozzle	49
1.30	Focal Position	50
1.31	Standoff Distance	51
1.32	Laser Drilling	56
1.33	Examples of A Trepanned Hole for Different Materials	57
1.34	Example of Percussion Drilled Hole	58
1.35	100µm Holes Drilled in 75mm High-Density Polyethylene with; Left, A Twist Drill Bit and Right, A Kerf Laser	59
3.1	Methodology Flow chart	63
3.2	Type of Municipal Waste Composition 14 SEA and East Asian Countries	66
3.3	Pie Chart of Malaysia Waste Composition in year 2005	67
3.4	Preprocess parameter flow chart	70
3.5	a) Free space between two layers	72
	b) Sawing process	72
	c) Center line of bottle	72
3.6	a) The critical edge during final washing	73
	b) The plastic bag use to kept the clean oil container	73
3.7	The Helius Hybrid 2513 Laser Cutting Machine	74
3.8	The Dimension for the Original Oil Container	77

3.9 a) The Largest Flat Area Oil Container 78
b) Dimension of Flat Area 78
c) The Specimen after Cutting Process 78
3.10 Experimental Flow Chart 79
3.11 Dimension for the DOE Sample 80
3.12 The 2D drawing for the DOE Sample 80
3.13 a) The wood jig clamp on the machine table 81
b) The DOE sample attach on the jig 81
3.14 The Digital Imaging Microscopy (DIM) 83
3.15 The Mitutoyo Portable Surface Roughness Tester SJ 301 83

4.1 The graph Power (W) and Cutting Speed (mm/min) versus Cutting Distance (mm) 87
4.2 The graph Power (W) and Cutting Speed (mm/min) versus Burr Height (mm) 90
4.3 The schematic image of burr height 92
4.4 The graph Power (W) and Cutting Speed (mm/min) versus Kerf Width (mm) 94
4.5 The graph Power (W) and Cutting Speed (mm/min) versus Surface Roughness (μm) 98
4.6 The 3D puzzle from waste plastic product 101

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Ar	-	Argentom gas
CNC	-	computer numerical control
CO	-	Carbon Oxide
DOE	-	Design of Experiment
He	-	Helium gas
Hz	-	Hertz
HAZ	-	Heat affected zone
HDPE	-	High density polyethylene
kg	-	Kilogram
kW	-	kilo Watt
kPa	-	kilo pascal
in.	-	inch
mm	-	millimeter
min	-	minute
Nd:YAG	-	Neodinium, Yttirium-Aluminum-Garnet
N_2	-	nitrogen gas
µm	-	micro meter
O_2	-	oxygen gas
%	-	percentage
PP	-	polypropylene
PC	-	polycarbonate
PMMA	-	polymethyl-methacrylate

CHAPTER 1

INTRODUCTION

Generally, this chapter discussing on the project background, problem statement, scope of the project and objective of the study. All the schematic have been arranged toward a solution for the issue which been raise up.

1.1 Project Background

Based on the project title, “Laser Machining of Waste Plastic Products” is conducted in consequence to study on relevant process parameters which are highly contributing factors to the defects of laser cutting. Plastic products are widely used in human life. It includes the smallest product such as brushing teeth until the biggest product such as a water container tank. From there, the plastics waste also increasing from time to time. The product which been designed only for one specific function been thrown away after that. The technology enhancement makes the manufacturing cost of plastic cheaper than other materials. Besides, recycle process may help to reduce the waste. Since 2000, recycle campaign being promoted widely around the world. After several years, the plastic waste keeps increasing which negating the recycle approach as the best method to reduce waste. Therefore, another approach can be considered is reused method. The source is the waste products, but the process does not mix or melt the original product composition. Only cutting and joining process need to be implemented in order to fulfill the design requirement and new purpose of the waste products. The cutting result needs to be excellent in surface finish to avoid secondary process before getting into joining process. It brings to the advantage of using the non-traditional machining processes such as laser machining. Therefore, this project would be used as guideline to handle the laser cutting process in order to get the excellent surface finish for joining process after that.

1.2 Problem Statement

The plastic material sheet was normally being cut using conventional cutting methods such as scissor, bandsaw, shear machine and blanking machine. The quality and accuracy issue on the cutting geometry being ignored because of the manual process. Human skills and experience became the main criteria in order to be seriously involved in the cutting plastic sheet field. The decreasing of current labor which inversely proportional with the machining cost makes the process of cutting plastic sheet was not a good business in the current situation. Besides, the limitation of machine flexibilities also contributes to the reduction of the method to cut the plastic sheet material.

1.3 Scope of Project

This project aim is to reuse the waste plastic material by implementing laser cutting process. This investigation emphasizes on getting the best geometrical finish after the cutting process without using secondary or finishing processes. Therefore, the largest profiles that can get from one waste material need to be calculated. The minimal expected is to cut into square shape. The thickness of the material is from 1.0 millimeter to 1.5 millimeter. It brings this investigation into the parametric study of the machine parameter. The controllable parameter range needs to be used in order to produce good cutting quality with minimal geometrical errors. Qualifications examinations consider in the aspects of geometrical errors such as elongated taper (kerf width), cutting stability, burr height and surface roughness.

1.4 Objectives

Several objectives are outlined in these investigations which are stated below:

i. To investigate the interaction between laser beam and polyethelene (PE) material;
ii. To identify the suitable parameter processing for polyethelene (PE) material;
iii. To recommend the optimum parameters for cutting the polyethelene (PE) material.

1.5 Theory

All the related fundamental information about the laser machining process are summarized here. There were several types of laser machine, parameters and responses been establish in the current technology field.

1.5.1 Laser Material Processing

The increasing demand of laser in material processing can be attributed to several unique advantages of laser namely, high productivity, automation worthiness, non-contact processing, elimination of finishing operation, reduced processing cost, improved product quality, greater material utilization and minimum heat affected zone. Figure 1.1 shows a general classification of the laser material processing techniques. In general, application of laser to material processing can be grouped into two major classes:

(a) Applications requiring limited energy/power and causing no significant change of phase or state;

(b) Applications requiring substantial amount of energy to induce the phase transformations.

For the second category, laser power/efficiency and interaction-time is crucial as the processes involve single or multiple phase changes within a very short time. Since of the high-energy requirement, for this class of operations, CO_2 and Nd:YAG lasers are practically the only choice. From the practical application point of view, laser material processing can be broadly divided into four major categories; forming (manufacturing of near net-shape or finished products), joining (welding, brazing, etc.), machining (cutting, drilling, etc.) and surface engineering (processing confined only to the near-surface region).

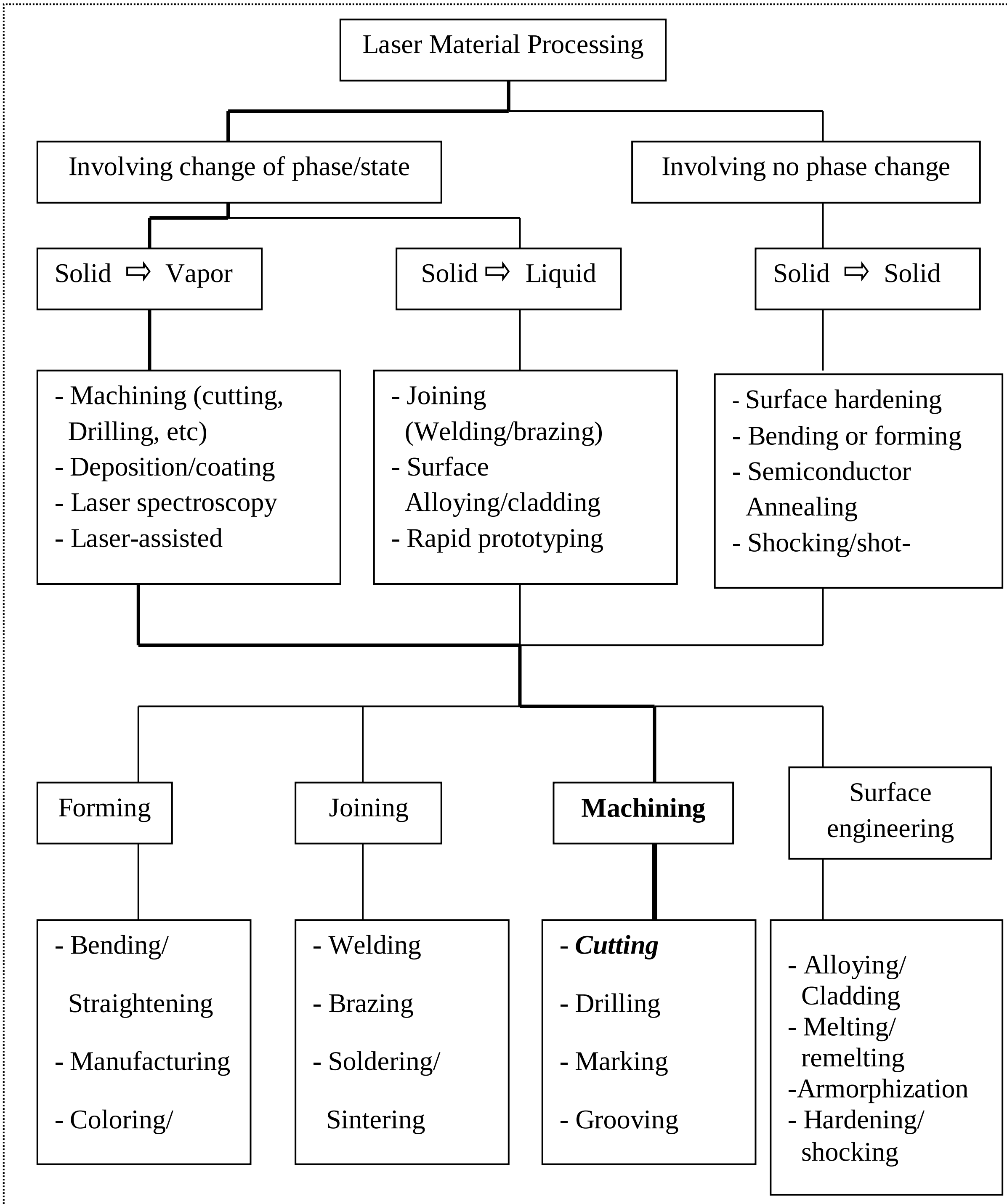

Figure 1.1: Classification of Laser Material Processing Flow Chart.
(Majumdar J. D. and Manna I., 2003)

1.5.2 History of Laser

The principle of the laser was first known in 1917 when German physicist Albert Einstein described the theory of stimulated emission. However, it was not until the late 1940s that engineers began to utilize this principle for practical purposes. At the onset of the 1950's several different engineers were working towards the harnessing of energy using the principal of stimulated emission.

At the University of Columbia was Charles Townes, at the University of Maryland was Joseph Weber and at the Lebedev Laboratories in Moscow were Alexander Prokhorov and Nikolai G. Basov. At this stage the engineers were working towards the creation of what was termed a MASER (Microwave Amplification by the Stimulated Emission of Radiation), a device that amplified microwaves as opposed to light and soon found use in microwave communication systems. Townes and the other engineers believed it to be possible to create an optical maser, a device for creating powerful beams of light using higher frequency energy to stimulate what was to become termed the lasing medium. Despite the pioneering work of Townes and Prokhorov it was left to Theodore H. Maiman in 1960 it invent the first Laser using a lasing medium of ruby that was stimulated using high energy flashes of intense light.

The end of fifties saw the race for the "optical maser" (as the laser was still called then) hotting up. In 1958, Schawlow and Townes had theoretically demonstrated the possibility to create an amplifier for radiation in the visible and infrared spectral range, similar to the ones that had already been suggested in 1951 and built in 1954 for microwaves. As early as 1959, Gould G. outlined the design principle for such a device, had the sketches recorded by a notary and later applied for a patent for his ideas. He also coined the phrase "Light Amplifier by Stimulated Emission of Radiation", i.e. LASER. He is therefore regarded by some as the "inventor of the laser".

1960 is generally seen as the birth year of the laser. Maiman T. H. pumped a ruby bar, whose two parallel faces served as a resonator, with a pulsed flashbulb, thereby realizing for the first time a coherent radiation source emitting in the visible spectral range. Maiman's work marked a turning point in quantum electronics: on the one hand, it brought many years of theoretical and practical effort to create such a light source to fruition, on the other hand it initiated a phase of rapid scientific-technical development that still continues today.

Yet like so often in scientific endeavor, one man had the ingenious intuition and the necessary portion of luck, compared with his predecessors and competitors; who is by the name of Maiman. He used ruby which due to its allegedly low radiation efficiency was seen as showing little promise as an active medium for a laser and succeeded. In the race for the first laser, with a relatively modest budget from Hughes Research, beat all the research groups which formed the "Scientific Community" in this field at the time: Lincoln Labs, IBM, Siemens, RCA Labs, GE, Bell Labs, TRG and many others. His results where, however, so surprisingly unusual, that their publication in the prestigious "Physical Review Letters" was refused. Maiman therefore took a route that was rather unusual for an American and published his results in the English magazine "Nature". On 7 July 1960, Hughes Research held a press conference announcing the invention of the laser. With his results, Maiman initiated hitherto scarcely imaginable developments in applied physics. Laser technology began its triumphant progress.

But here too, like so often in science, Maiman missed out on the biggest scientific recognition of them all, the Nobel Prize. His predecessors Basov, Prokhorov and Townes received the prize in 1964 for their "fundamental work in quantum electronics that lead to the construction of oscillators and amplifiers based on the maser-laser principle". Schwalow received the prize in 1981 for his contributions to laser spectroscopy. Maiman was left empty-handed, despite the fact that few other inventions came so close to Nobel's original intentions as the laser. Ingeniously simple, practically oriented constructions, especially if they come from an outsider, are sometimes seen in