بسم الله الرحمن الرحيم

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College of Graduate Studies

Rust removalby using Pulsed Nd: YAG Laser

إزالة الصدأ بإستخدام ليزر النيوديميوم المطعم بعقيق اليتيريوم والألمونيوم النبضي

Complimentary research for masterdegree

BY: Lubna Ali Jalal Aldeen

Supervisor: Dr. Faiz.M.B. El Shafia

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الآيــــــة

قال تعالى:

﴿قَالُواْ سُبۡحَانَكَ لَا عِلۡمَ لَنَآ إِلَّا مَا عَلَّمۡتَنَآ

إِنَّكَ أَنتَ ٱلۡعَلِيمُ ٱلۡحَكِيمُ﴾

صدق الله العظيم

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Dedication

This humble thesis it dedicated to:

My family, specially my late mother,my father

All my brothers my sisters, and my friends

Acknowledgement

My sincere grateful goes to my greatest God, then to my supervisor D. Faiz M.B. El-Shafia, for his visionary supervision and creative guidance at all stages during the writing of this work.

I'm indebted to my family who has helped me with their encouragement.

Also I thanks teacher Mushier and Mariya who were standing beside me and directed me,To them all myDeepest thanks

Abstract

In this study photo ablation interaction between laser and matter have been used to remove rust from iron surface ,this technique based on absorption of laser beam by thin layer on surface in very short time that lead to heat the surface and remove the rust particles from it, Nd:YAG laser used with energy 400mJ,repitition rate was 8Hz,wavelength 1064 nm and pulse duration10ns,the rust of iron was ablated when it irradiated by laser beam, and we notes that from the results this method is moreaccurate, fast and very effective . So this technique can be used in broadband to clean other metallic materials and others.

المستخلص

في هذه الدراسة أُستُخدمتفاعل النزع الفوتونى بين الليزر والمادةلازالة الصدأ من سطح الحديد ، تعتمد هذه التقنية علي امتصاص شعاع الليزر بواسطة طبقة رقيقة على سطح الحديد في زمن قصير جداً وهذا يؤدي الي تسخين السطح وازالة جزيئات الصدأ منه ، وتم استخدام ليزر الانديالك بطاقة مقدارها400mJ ومعدل تكرار مقداره 8Hz وطول موجي مقداره 1064nm وزمن النبضة 10ns.أُزيل الصدا عندما شُعع سطح الحديد بالليزر من جميع العينات ولُوحِظ من النتائج ان هذه الطريقة دقيقة وسريعة وفعّالة جداً لهذا يمكن ان تستخدم هذه التقنية على نطاق واسع لنظافة المواد المعدنية وغيرها.

CHAPTER ONE

INTRODUCTION

Introduction

1.1 History of laser and its application:

The first theoretical foundation of laser was given by Einstein in 1917 using plank's low of radiation that was based on probability coefficients (Einstein coefficients) for absorption, spontaneous and stimulated emission of electromagnetic radiation [1, 2, 3].

In 1960 Maiman developed ruby laser for the first time, this was followed by much basic development of lasers from 1962 to 1968 almost all important types of lasers including semiconductor lasers, Nd:YAG lasers, Co_2 gas laser, dye lasers and other gas lasers were invented in this era [2].

After 1968 the existing lasers were designed and fabricated with better reliability and durability.

By mid-1970s more reliable lasers were made available for truly practical applications in industrial applications such as cutting, welding and marking. During the 1980s and early 1990s the lasers were explored for surface related applications, such as heat treatment, cladding, alloying, glazing and then film deposition. As a result, laser has wide applications from very mundane (bar code scanner) to must sophisticated (3-dimensional holography), more commercial (audio recording) to purely scientific (optical computer) and lifesaving (surgery) to life threating (weapons) [4, 5, 6].

Laser finds a ubiquitous presence mainly for some unique combination of properties, these important properties that justify the use of laser in such a wide spectrum of applications are:

(a) Spatial and temporal coherence (i.e. phase and amplitude are unique)

(b) Low divergence (parallel to the optical axis)

(d) Monochromaticity [5,7,8].

1.2 Research problem:

The applications of laser in industry, in Sudan are not widely speared, namely the use of laser in removing rust.

1.3 Aim of the work:

The main object of this work is use pulsed Nd:YAG laser to remove rust from iron surfaces at its fundamental wavelength (1064nm).

1.4 Research out lines:

This research consists of four chapters; the first and second chapters are concerned with introduction and laser physics. The third chapter describes laser matter interaction. The final chapter consist experimental results.

CHAPTER TWO

LASER PHYSICS

Laser physics

2.1 Introduction:

Rust is a common name for a very common compound iron oxide, the chemical formula (Fe_2O_3) for iron to become oxide three things are required: iron, water and oxygen, the rust weakness iron and lead to fragility it. There are some equations explain rust producing

$$Fe_{(s)} \longrightarrow Fe^{2+}_{(aq)} + 2e^{-} \quad (2.1)$$

At this equation some of the iron atoms produce iron ions, and undergone oxidation, "oxidation is the loss of electrons by ions".

Then iron ions meet hydroxide ions, it produce iron hydroxide:

$$Fe^{2+}_{(aq)} + 2OH^{-}_{(aq)} \longrightarrow Fe(OH)_{2(S)} \quad (2.2)$$

Dissolved oxygen will then oxidize the iron hydroxide producing the substance called rust [9].

The rust can be removed with traditional mechanical and chemical methods, these methods increase the risk of oxidized which will lead to loss of information about surface details.

So that we can use laser to remove the rust from iron surfaces.

The main advantages of using pulsed lasers for rust removal are specific thickness of material can be removed (controllable), non-contact process, no large volumes of waste products (environmentally preferable), and we can chose the wavelength to removal depending on material properties.

This chapter is concerned with laser properties and generation. It also concerned with the laser types and safety.

2.2 Concepts of Laser:

The word laser originally was the upper-case LASER, it means **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation, wherein light broadly denotes electromagnetic radiation of any frequency and wavelength ranging from ultra-violet to infrared .

Laser is distinguished from other electromagnetic radiation mainly in terms of its coherence, spectral purity and ability to propagate in straight line [1, 2, 3, 4].

2.3. Characteristics of laser light:

Laser radiations characterized by coherence (spatial and temporal), high degree of monochromaticity, directionality, and brightness [4, 8, 10].

These properties were discuses here in details.

2.3.1 Coherence:

It is the one of the unique properties of laser light; it arises from the stimulated emission process, which provides the amplification. Coherence can be termed as the measure of the ability of two photons to interfere or intermix with each other; this coherence is described in terms of spatial and temporal coherence [1, 8, 10].

2.3.2 Monochromaticity:

It refers to the highly purified color produced by the laser.

Laser energy is composed of photos that are all the same color or wavelength.

Practically no source of light including laser is ideally monochromatic, so that monochromaticity is a relative term.

The laser line would be absolutely monochromatic if its oscillating with single frequency (ν), that is width of it is zero ($\Delta\nu=0$).

The single mode laser has the highest degree of mochromaticty

[2, 10].

2.3.3. Directionality:

One of the most striking properties of laser is its directionality that is its output is in the form of an almost parallel beam. Owing to its directional nature it can carry energy and data to very long distances for remote diagnosis and communication purposes.

Beam of an ideal laser is perfectly parallel and its diameter at the exit window should be same to that after travelling very long distances, although in reality it is impossible to achieve.

Deviation in the parallelism of practical laser beam from the ideal is not due to any fault in the laser design, but due to diffraction from the edges of mirrors and windows [2, 11].

2.3.4 Brightness:

Lasers are more intense and brighter sources compared to other conventional sources such as the sun which it emitting radiation isotropically.

Brightness is defined as power emitted per unit area per unit solid angle, For example 1 mW He Ne laser is almost 10^6 times brighter than the sun [2, 5].

2.3.5 Other characteristics are as follow:

Highly energetic radiation: energy of laser photon in term of tera volts.

Size: human hair to very large building

Power rang: from 10^{-9} *to* 10^{20} W

Wavelength: micro wave to soft X- ray.

Frequency: from 10^{11} to 10^{17} HZ.

Energy: to 10^4 J, pulse duration to $6\times10^{-15}S$ [1].

2.4 Generation of laser:

Laser comprises three principal components, namely the gain medium (or resonator), placed between a pair of optically parallel and highly reflecting mirrors with one of them partially transmitting, and energy source to pump active medium to produce population inversion

The laser medium may be a solid (e.g. Nd: YAG or neodymium doped Yttrium – aluminum - garnet), liquid (dye), or gas (e.g. Co_2) [2, 10].

figure (2.1) illustrate components oflaser device consists of three main parts, a gain or laser medium in form of laser rod, and optical resonator or cavity with two mirrors and pumping source that supplies energy to gain medium.

The chemical species in the gain medium determines the wavelength of the optical output. Between two mirrors, one is a fully reflecting and other a partially reflecting [10].

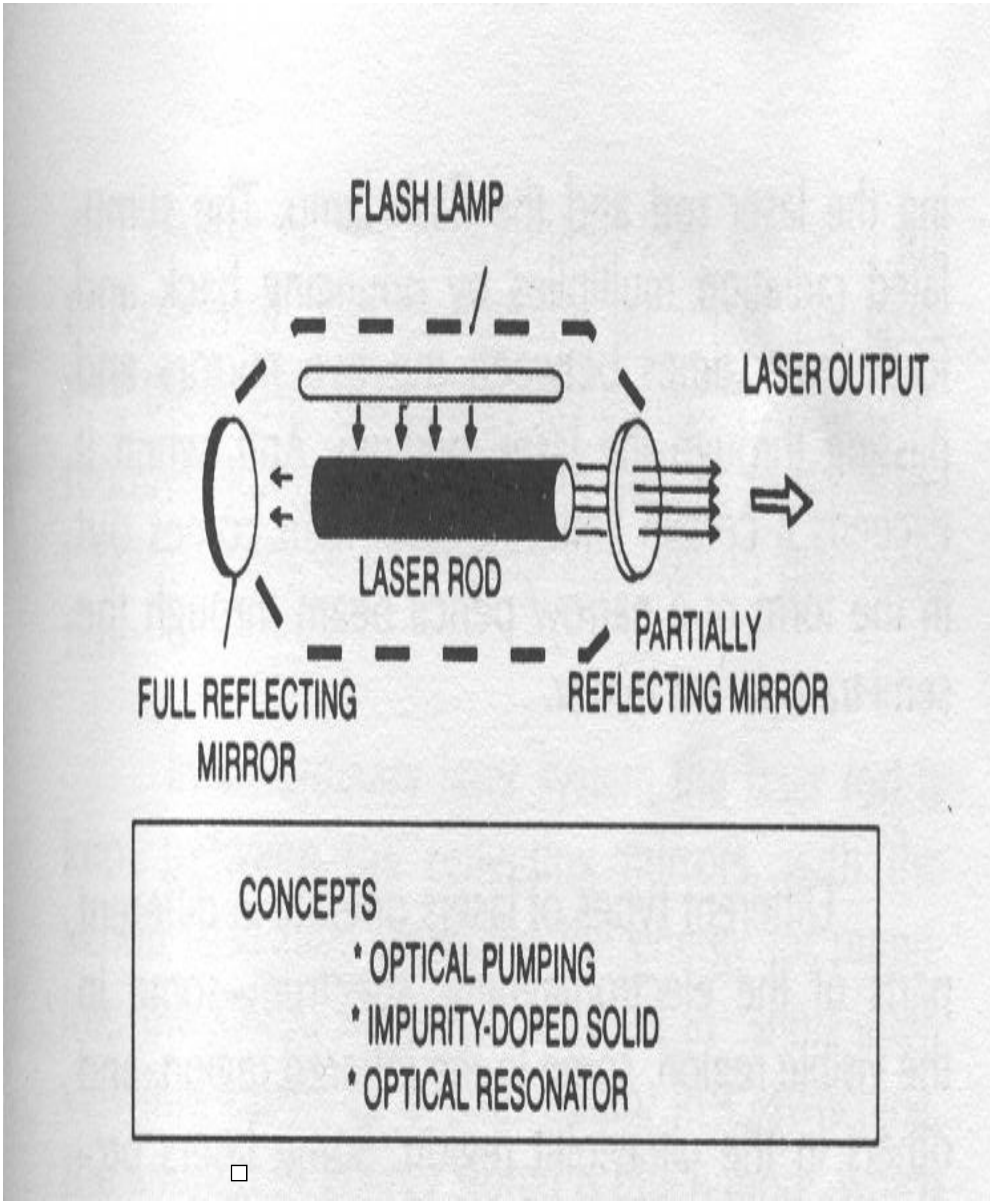

Figure (2.1): components of laser device

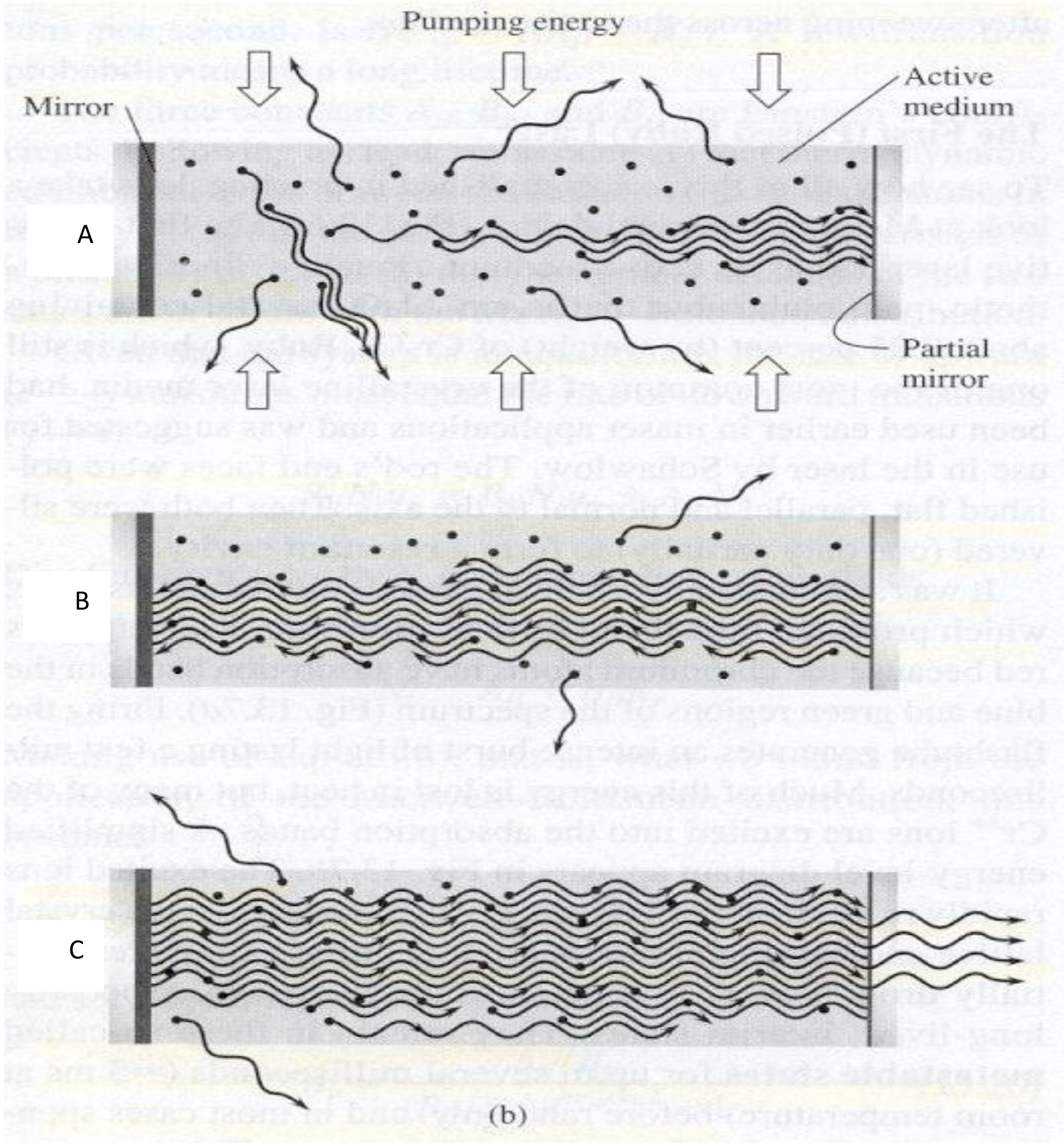

Figure (2.2): Generation of laser

(A): initial stage of energy pumping, excitation and de- excitation of the atoms in the medium leading to emission of laser.

(B): stimulated emission.

(C): formation of laser beam.

A photon interacting with an unexcited atom may get absorbed by it and excite it to higher energy state.

This situation called ‘Population inversion’ is created by the pumping source, the excited atom spontaneously returns to the ground state E1 from the higher energy state E2 by emitting the energy difference as a photon of frequency ν , $\nu = {E_2 - E_1}/{h}$, where (h) is plank’s constant. This phenomenon is known as spontaneous emission (fig 2.2A).

A spontaneously emitted photon may in turn excite another atom and stimulate it to emit photon by de- exciting it to a lower energy level. This process is called stimulated emission of radiation (fig 2.2 B).

The latter is coherent with stimulating radiation so that the phase, wavelength and polarization between the two are identical.

The photons moving along the optic axis interact with a large number of excited atoms , stimulated them and by this process get amplified , they are reflected back and forth by resonator mirror and pass through the excited medium creating more photons.

In each round trip, percentage of these photons exit through the partially transmitting mirror as intense laser beam (fig 2.2C).

Finally , the laser beam is either guided on to work – piece by using reflecting mirrors or delivered at the desired through optical fibers [11].

2.5 Types of lasers:

Lasers can be classified depending on the nature of the active medium to three main categories. Namely, solid, liquid and gas laser. Also lasers can classified according to the excitation mechanism to optically pumped lasers such as solid and liquid lasers, and an electrically pumped laser such as gas and semi conductor lasers.

Depending on the duration of laser output, lasers are classified into two categories, pulsed laser and continuous lasers (CW)

[1, 2]

Here, Classification depending on active medium was discussed.

2.5.1 Gas lasers:

Gas lasers are widely available in almost all power (milliWatts to mega Watts) and wavelengths from ultra-violet to infrared (UV -IR), and be operated in pulsed and continuous modes.

Based on the nature of active media, there are three types of gas lasers; atomic, ionic, and molecular lasers. Most of them are pumped by electrical discharge. Electrons in the discharge tube are accelerated by electric field between the electrodes. These accelerated electrons collide with atoms, ions, or molecules in the active medium and induce transition to higher energy levels to achieve the condition of population inversion and stimulated emission [2].

One of popular type of gas laser contains a mixture of helium (He) and neon (Ne) gases; the gas mixture is contained ata low pressure (about 0.1 torr for neon and 1 torr for helium) with a sealed glass tube called the (plasma tube). The excitation mechanism of it is direct current discharge through the gas. The current pumps the helium atoms to an excited atomic state. The energy of the excited helium atoms is transferred to Neon atoms through collisions, and the neon atoms then undergo a transition to a lower energy state that result in lasing. The feedback mechanism consist of a pair of mirrors selected to the end of the tube, one of these mirrors the output coupler, transmits 1-2 percent of the light to form a continuous (CW) output beam.

Main lasing wavelength of He-Ne is 633nm (red) other wavelengths (543 nm, 1150 nm, 339 nm) are also possible.

He-Ne lasers are low power (~mw) they are used for a ligament purposes, barcodescanners, holography, etc. [1, 2, 7].

2.5.2 Solid state lasers:

Another important family of lasers contains solid crystalline as an active medium, Ruby and neodymium are two common examples of solid state laser with widespread industrial applications, Ruby is crystalline aluminum oxide in which some of the aluminum ions in the crystal lattice have been replaced by chromium ions. These chromium ions are the active elements in the Ruby laser.

In early lasers the ruby was machined into a rod about 4 cm in length and 0.5 cm in diameter. It produces intense of light (λ = 694.3 nm) [12, 13].

A another type of solid state laser is Nd:YAG lasers with chemical formula Nd: $Y_3AL_5O_{12}$ stand for neodymium yttrium aluminum garnet some of the aluminum in the YAG replaced by triply ionized neodymium (Nd^{3+}) a rare earth element, whose electrons goes to excited state and gives emission at 1064nm ,glass is also used as a host for neodymium lasers[1,12].

This system offers the advantage of being a four Level laser, which makes it much easier to achieve population inversion than with the ruby laser. Nd: YAG laser has a very high radiant power output at 1064 nm, which is usually frequency doubled to give an intense line at 532 nm. This radiation is often used for pumping tunable dye lasers. In order to bring 1064nm to visible region the frequency is doubled thus and wavelength becomes half, i.e. 532 nm (in visible region) [1].

Due to the excellent properties of Nd:YAG laser it is extensively used in many industrial applications like drilling in solid objects ,welding and also in medical applications like eye surgery, etc.[4,11].

So that it was used in this research.

2.5.3Liquid (dye) lasers:

Liquid lasers are similar to the solid state laser in that they consist of a host material (in this case a solvent such as alcohol) in which the laser (dye) molecules such as Rhodamines are dissolved at concentration of one part in ten thousand. Dye exhibit a very high degree of fluorescence, i.e., when the dye is exposed to ultra violate light it glows with characteristic color depending on the nature of the material [1, 2].

Different dyes have different emission spectra or colors.as result dye laser cover abroad wavelength range from the ultraviolet at 320nm to the infrared at about 1500nm, a unique property of dye lasers is the broad emission spectrum (typically 30 - 60 nm) Dye lasers are available either in pluses (up to 5- 100 mJ) or as continuous output (up to a few watt) [2,7].

In system that are pumped by either flash lamps or other lasers such as argon ion lasers.

The dye lasers are used mostly for applications were tunability of the laser frequency is required either for selecting a specific frequency is that not a valuable from one of the solid – state lasers, or for studying the properties of a material when the laser frequency is varied over a wide range, therefore the dye laser becomes an important in more a applications such as spectroscopy, photo chemistry, isotope separation, ect.

The dye lasers are less expensive than the solid state lasers and are relatively easy to maintain for regular operation [8].

2.6 Laser safety:

The increasing widespread use of lasers requires more people to become familiar with the potential hazards associated with the valuable new product of modern science.

The basic hazards from laser equipment can be categorized as follows:-

Eye Hazards:radiation which falls on the retina will be focused by the eye´s lens to give an amplification of the power density by a factor of around 10^5 [6].

Corneal and retinal burns (or both) depending upon laser wavelength, are possible from acute exposure. Retinal effects are possible when the laser emission wavelength occurs in the visible and near infrared spectral regions (0.4µ m to1.4µm) can be focused to an extremely small image on the retina. Laser emissions in the ultraviolet and far infrared spectral regions (outside 0.4µm to 1.4µm) Produce ocular effects primarily at the cornea [14].

Skin Hazards:high power lasers can also infect skin burns the problem is less acute than for the eye because that is not the increases in irradiance associated with the focusing action of the eye. High power lasers in industry use are potentially capable of inflicting frightful burn.

The effect of laser irradiation of the skin depends on both, the wavelength and the pigmentation of the skin in the visible, the skins quite reflective in the far infrared, and the skin becomes highly absorbing ,as general rule "never put parts of your body in the path of a laser beam" [6,15].

2.6.1 Laser safety standard and hazard classification:

The basic approach of virtually all laser safety standards has been to classify laser by their hazard potential which is based upon their optical emission

The American National Standard Institute (ANSI) scheme has four hazard classifications, it is used to describe the capability of laser to produce injury to personal, the higher the classification number the grater is potential hazard [14].

Brief description of each laser class is given as follows:-

Class "1":

Denotes laser or laser systems that don't under normal operating conditions, pose a hazard, e.g. CD players, laser printers

Class "2":

Denotes low power visible laser or visible laser systems which, because of the normal human a version response do not normally present a hazard, but may present some potential for hazard if it viewed directly for extended periods time (like many conventional light sources).

Safety glasses are required for prolonged viewed only [6,14].

Class "3a":

Denotes the lowest class of lasers that always require protective eye wear. These laser would not injure the eye if viewed for only momentary periods with the unaided eye , but may present garter hazard if viewed using collecting optics or if viewed without the possibility of a version response (as for UV and IR radiation) [6].

Class "3b":

Denotes laser that can produce a hazard if viewed directly. This includes intrabeam viewing of specular reflections.

Normally, class 3b laser will not produce a hazardous diffuse reflection, protective eyewear is always required.

Class "4":

Denoted high power lasers that produce high risk not only from direct or specular reflections but may also produce hazardous diffuse reflections, such lasers may produce significant skin hazard as well as fire hazards, protective eye wear always required [14 ,15].

CHAPTER THREE

LASER MATTER INTERACTION

Laser matter interaction

3.1 Introduction:

When laser radiation strikes a target surface part of it is absorbed, the energy that is absorbed begging to heat the surface, under some conditions there are important effects due to absorption of energy such as plasma formation, vaporization, ablation, etc. [15, 16].

Whenever the material is irradiated in the laser radiation, the energy will be firstly transformed into electronic excitation energy, and then transformed to lattices of material through collisions between electrons and lattices.

The laser energy converted into mechanical, thermal electronic as well as into anther electromagnetic wave with different configuration.

The deposition of laser energy will produce a series of effects depending on the amount of such as a temperature rise, gasification and ionization, which are depend on the incident radiation and properties of the material [17, 18].

There are two different phenomena result of interaction of laser with matter, pyrolithic and photolithic processes.In both cases short pulses are applied in order to remove material in a controlled way.

Pyrolithic process is based on breaking of chemical bonds by photon energy; there is very little thermal interaction with work piece itself. Photolytic processes are based on a rapid thermal cycle heating, melting and partly evaporation of the heated volume [3].

This chapter will discuss basic phenomena occurring when matter is exposed to light.

3.2 Basic phenomena of laser matter interaction:

In figure (3.1) typical situations shown, where light beam is incident on a slice of matter, there are many principle effects existence as follows:

Reflection, refraction, Absorption, transmition and Scattering

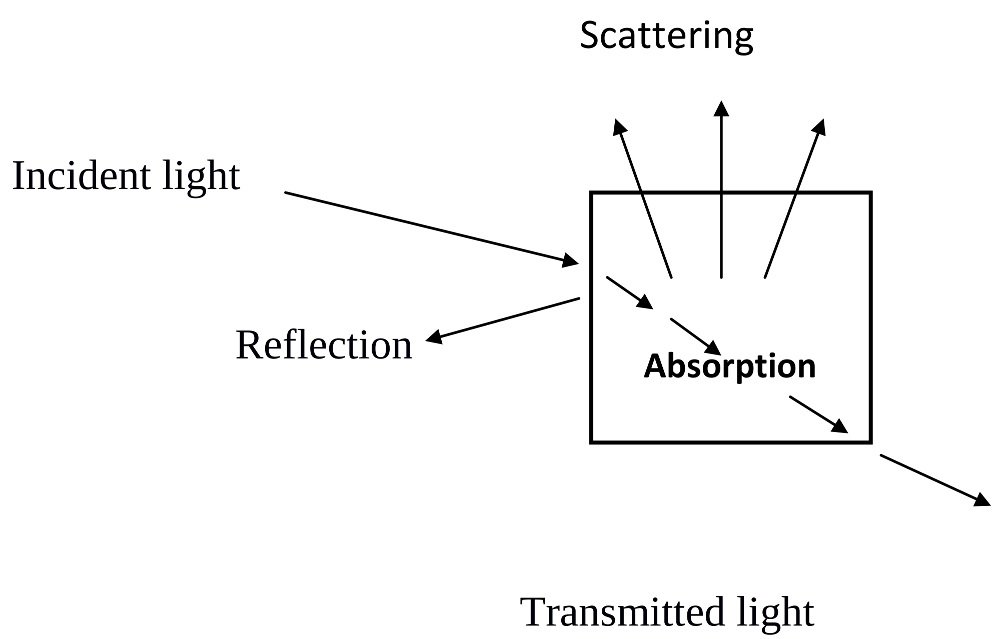

Fig (3.1) Geometric of Reflection, refraction, absorption and scattering.

Reflection, absorption or scattering are dominated primarily depends on the type of material and the incident wavelength. The wavelength is a very important parameter indeed it determines the index of refraction as well as the absorption and scattering coefficients [14].

3.2.1 Reflection and Refraction:

Reflection is defined as the returning of electromagnetic radiation by surfaces upon which is the physical boundary between two materials of different indexes of refraction such as air and matter.

The simple law of reflection requires the normal of the incident and reflected beams and the normal of the reflecting surface to lie within one plane, called the plane of incidence [14].
The surface itself is assumed to be smooth, with surface irregularities being small compared to the wavelength of radiation.
In contrast, i.e. when the roughness of the reflecting surface is comparable or even large than the wavelength of radiation, diffuse reflection occurs. Then, several beams are Reflected which do not necessarily lie within the plane of incidence. Diffuse reflection is a common phenomenon of must materials because it none provided with highly polished surfaces such as optical mirrors.
Refraction usually occurs when the reflecting surface separated two media of different indices of refraction. It originates from a change in speed of the light wave.

Reflectivity of surface is measure of the a mount of reflectance radiation.Reflectivity and reflectance depend on the angle of incidence, the polarization of radiation, and the indices of reflection of the materials forming the boundary surface [14,16]
Reflection and refraction are use to study of surface properites so that they not nessesary in this research.

3.2.2 Absorption and transmition :

Apsorption is important physical phenomena that occur during the laser-matter interaction.
Absorption due to apartial conversion of light energy into heat motion or certain vibrations of molecules of the absorbing material [16].
Generally, when the laser is fucused on the material surface, it is partialy absorbed the absorptivity depends on the surface strucure, material defects, power density and wavelength of laser light [3].

The absorbed amount of light by the media at certain wavelength is described by the Beer Lambert law equation:

$$I = I_0 \exp(-\alpha z) \qquad (3.1)$$

Where I is the transmitted intensity, I_0 is the incident intensity, α is absorption coeficient of the material and z is thickness of material.

The absorption coeficient (α) depends on the medium, wavelength of radiation , intensity, tempreture, and plsma formation above the target.

This indicated that with increasing depth the absored radiation decreases in correspondese with equation (5) [14,16 21,23].

Substance is said to show general absorption if it reduces the intensity of all wavelength in the considered spectrum by a similar fraction.

Selectave absorption, on the other hand , is the absorption of certain wavelengths in preference to others the existance of colors actually originates from selective absorption .

Usually , body colors and surface colors are distinguished.

Body color is generated by light which pentrates a certain distance into the substance. by backscattering, it is then deviated and escapes backword from surface but only after being partially absorbed at selected wavelength. In other hand, surface color originates from reflection at the surface itself it mainly depends on the reflectance which are reflected to the wavelength of the incident radiation.

The ability of a medium to absorb electromagnetic radiation depends on a number of factors mainly the electronic constitution of its atoms and molecules, the wavelength of radiation,the thickness of the absorbing layer, and internal parameters such as temperature or concentration of absorbing agents[14].

Transparent medium permits the passage of light without any asorption,I.g. the total radiation energy entering into and emerging from such a medium is the same.

In contrast media in which incident radiation is reduced practically to zero

are called opaque.
The terms “transparent“ and “opaque” are relative, since they certanily are wavelength dependant [14].
Only no reflected and non-absorbed or forward scattered photons are transmitted by the slice and contribute to the intensity detected behind the slice. The ratio of transmitted and incident intensities is called transmittance [3].

3.2.3 Scattering:

When elastically bond charged particles are exposed to electromagnetic waves, the particles are set into motion by the electronic field. If the frequency of the wave equal the natural frequency of free vibrations of a particle,resonance occurs being accompined by considerable amount of absorption.

Scattering, on other hand , takes place at frequencies not crrosponding to those natural frequencies of particles[14].
Elestic and inelastic scattering are distingushed, depending on whether part of incident photon energy is converted during the processes of scattering. in the folowing paragraphs, we will first considers elastic scattering, where “incident” and scattered phonon have the same energy a special kind of elastric scattering is “Rayleigh scattering” its only restriction is that the scattering particles be smaller than the wavelength of incident radiation[14].
in particular, we will find a relationship between scattering intensity and index of refraction, and that scattering is inversely proportional to the fourth power of wavelength. the latter statement is also known as rayliegh’s law and it expressed by :

$$I_s = 1/\lambda^4 \qquad (3.2)$$

One important type on inelastic scattering is known as Brillouin scattering it arises from acoustic waves propagating through a medium.
Thereby inducing inhomogeneities of the refraction index.

Brilloun scattering of light higher (or lower) frequencies occurs because scattering particles are moving toward (or away from) the light source [14].

3.3 Interaction mechanisms:

The variety of interaction mechanisms that may occur when applying laser light to materials is manifold.

These types can classify into many categories such as: thermal interaction, photochemical interaction, photo ablation interaction [14, 19].

Each of this types can discus in some detail.

3.3.1 Thermal interaction:

It is effect of deposition of energy into the material, it cause increase in local temperature [14, 19].

Photo thermal explanation of the observations implies that the absorbed photon energy is transferred directly into excitations of lattice vibration; a 'hot spot' is generated, which result in thermally activated fragmentation on the material [21].

Thermal effects can be induced by either CW or pulsed laser radiation [14].

Depending on the duration and peak value of the matter temperature achieved, different effects like coagulation, vaporization, carbonization, and melting may be distinguished [14].

If sufficient energy is absorbed then the vibration of molecules becomes so intense and the molecular bonding is stretched so far that it is no longer capable of exhibiting mechanical strength and the material is said to have melted on further heating the bonding is further loosened due to the strong molecular vibrations and the material is said to have evaporated.

The vapor is still capable of absorbing the radiation but only slightly since it will only have bound electrons.

The exception occurs if the gas is sufficiently hot so that electrons are shaken free and that gas is then said to be plasma [3].

The vaporization process can be described by the heat flow theory where the surface temperature of the target at the end of the laser pulse is determined by the light absorption and thermal diffusivity [22].

3.3.2 Photochemical interaction:

During photochemical interaction, light induce chemical effects and react within macromolecules or tissues,It can occur at very low power densities approximately about (1w/cm2) and long exposure times ranging from seconds to continuous wave [14].

In this case photons interaction with bound and free electrons in the material structure, which raises them to the higher energy levels.

Energy conversion takes place through various collision process involving electrons, lattice phonons ionized impurities and defects structures [3].

Thermal energy has been used, the rate of chemical reaction increase with heating in metals, the laser energy absorbed by free electrons, these electrons vibrate and react without disturbing, the solid atomic structure as electromagnetic wave-front arrives at surface of the matter

Then all of the free electrons in the surface vibrate in the phase with incoming beam creating (electron gas), this electron gas within the metal structure means that the radiation is unable to penetrate metals to any significant depth, only one or two atomic diameters. Thus metals are opaque and they appear shiny [3].

When the excitation time is shorter than the thermalization time in the material, non-thermal photomechanical ablation mechanisms can occur. for example, with ultra-fast pulsed , direct ionization and the formation of dense electron –hole plasmas can lead to a thermal phase transformations, direct bond- breaking ,and explosive disintegration of the lattice through electronic repulsion [20].

3.3.3 Photo ablation interaction:

Laser ablation is a removable of material from a substrate by direct absorption of laser energy.

Laser ablation methods have the huge advantage of being "self-developing", there for no wet chemistry is necessary in order to removes the irradiated material so that it was used in this research [22].

So that it was used in this research.

In the type of reaction we can use pulsed or CW laser [20].

The ablation process depending on the absorption properties of the target material. The presence of defects. And on laser parameters such as wavelength, pulse duration [20,22,23].

When a photon interacts with matter, the photon energy is coupled to the lattice through electronic processes. The photon absorption by a material occurs in general over an optical depth of several nanometers, where energy in metals is transferred to the electronic system directly and in nonmetallic system typically to the lattice [22].

Many types of pulsed lasers have been used for the ablation of solid materials, and ruby lasers were among the first to be applied. At present, laser ablation systems are equipped with either Nd: YAG or excimer lasers.

Solid state Nd:YAG systems are employed because they are relatively inexpensive, require little maintenance, there is hardly any divergence of the laser beam, and they can be easily incorporate into small commercial ablation systems [22].

In all cases, material removal is accompanied by highly directed plume ejected from the irradiated zone. The dense vapor plume may contain solid and liquid clusters of material. At high intensities, a significant fraction of the species may become ionized, producing plasma [20, 24].

The laser‘s temporal pulse length can have a significant effect on the dynamics of the ablation process. In general, as the pulse length is shortened, energy is more rapidly deposited into the material leading to more raped material ejection the volume of material that is directly excited by laser has less time to transfer energy to the surrounding material before being ejected. Therefore the ablation volume becomes more precisely

defined by the laser's spatial profile and optical penetration depth and the remaining material has less residual energy which reduces the hazard [20].
The laser wavelength is an important parameter for the ablation process in general, with decreasing laser wavelength an increase in the ablation rate is expected for Nd:YAG lasers, the fundamental wavelength is in the near infrared at 1064nm.
A shorter wavelength offers a higher photon energy which is more suitable for an efficient vaporization and ionization of the solid sample. The absorption properties of the target material will finely decide which laser frequency can be employed [22].

3.4 Background on the mechanisms oflaser cleaning:

In 2003 K.G Watkins, Carmel Curran and John.Myung Lee published research paper at Journal of cultural heritage by address ((Two new mechanisms for laser cleaning using Nd:YAG sources)). The first method called ((Angular laser cleaning)). It shows that by controlling the angle of maidens of the cleaning laser.

Significant improvement in the efficiency of cleaning can be achieved when compared with conventional cleaning with a normal angle of incidence. The other method called ((Laser shock cleaning)) in this method the laser beam a lighting to be horizontal to the surface to be cleaned but close to it and selecting operating those parameters, object to be cleaned. They found this method was very much effective than conventional normal incidence cleaning in removing surface pollutants because the laser does not come into contact with the substrate, so that it significantly minimizes the potential for substrate damage they used Q. Switched Nd: YAG laser operating in its fundamental wavelength (1064 nm) to remove encrustations from marble.

The power density were used around10^{12} W. cm^{-2} , five single pulses were used with repetition rate of 0.63 HZ. The laser energy per pulse used for complete removal of pollution layer in both cases was roughly the same (I J).They observed the angular technique cleans was cleaned large area about (8 cm^2) compared with (1 cm^2) for the conventional case.

By 2004 James Ross Coverhill had successful method to remove ink from the papers.

He used Q. switched Nd.YAG laser it was operated at 1064 nm, pulse duration 87 ns, and using a nominal flounce of 41 $\pm$12 Jcm^{-2}.

By shortening the pulse length (63 and 26 ns) using glanTompson prism. The ink removal threshold was reduced to24$\pm$7 and 20$\pm$6Jcm^{-2} respectively. He used different kind of papers and inks.

From his trials he concluded that the switched Nd:YAG laser (1064nm) does offer a practical alternative to the current methods of ink removal from artworks on a paper as the level of damage was reduced and less spread.He observed the fluence required for the removal depended on the paper type, the ink type, and color of ink.

The results of his studies show that the physical and chemical damage to the papers was observed and found to be less destructive to the surface fibers than contemporary mechanical methods of the removal; also he proved efficiency of the laser as a tool for the removal ink from papers. And he determined threshold levels for ink removal and visible damage to paper samples.

The laser spot diameter was 1.5 mm, the maximum pulse energy was 300 mJ and average pulse power was 3 W.

An area of 30x15mm of each sample was cleaned for nearly 120 seconds.

The repetition rate of this experiment was 2.5 Hz**.**

In 2005Y.S.Koh, J. Powell, and A.F.H.Kaplan were Published research paper by address “The removal of layers of corrosion from steel surface : A comparison of laser methods and mechanical techniques”

They used eight methods for removal rust from steel, three of them were mechanical and the other was laser dependent.

They found micro blasting techniques more effectively than laser methods, and TEA CO_2 laser was less effective than the Nd:YAG laser in removing oxide layers.

CHAPTER FOUR

EXPERIMENTAL PART

Experimental part

4.1 Introduction:

The rust can be removed from iron surfaces by using mechanical and chemical methods but removal by laser is very effective because it controlled method and there is no contact between surface and tool of removal.This chapter will explain the method of experiment by presentingdevice, samples whichused, result and discussion.

4.2 Device:

The laser was used Q-switched Nd: YAG laser as shown in figure (4.1) with specifications as follow:

- **Company**: Shanghai Apolo medical technology CO, Ltd, china
- **Model name**: HS-220
- **Power supply**: ~230V,50/60Hz
- **Wavelength**: 1064, 532nm

Figure(4.1) : Nd:YAG laser Instrument

4.3 Samples:

The samples have been used in this study were four iron pieces covered with rust as shown in figure(4.2), they chosen randomly from deferent places.

The rust on these samples was not prepared, it was naturally produced.

Figure (4.2) : show the samples before irradiated by laser

4.4 Experimental set up:

The experiment was used in this research was shown in this figure

Figure (4.3) shown experimental set up

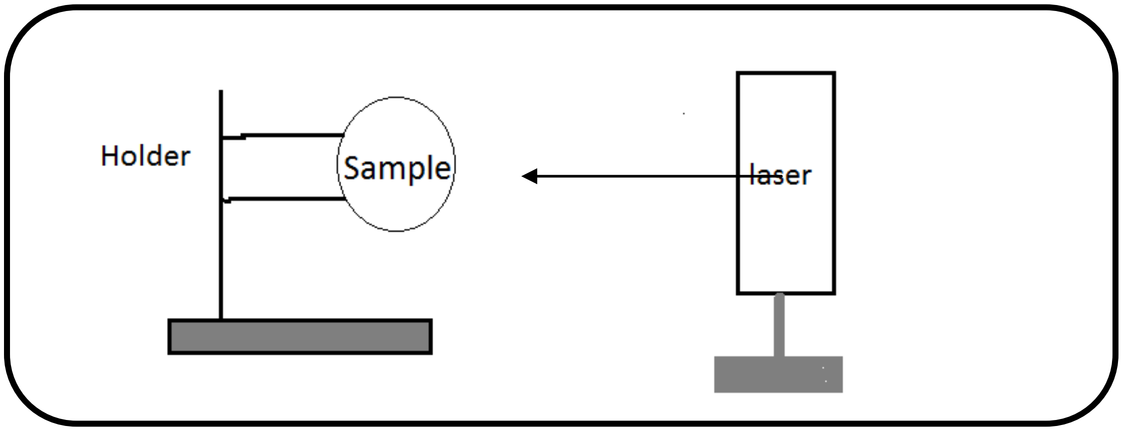

Figure (4.4) shown diagram of experimental set up

4.5 Methodology:

The set up was arranged as shown in figure (4.4)

The laser was irradiated the samples surface with following parameters: pulse energy 400mJ, wavelength was 1064nm, repetition rate 8Hz, and pulse duration 10ns

This method was repeated for all samples

Figure (4.5) : show the samples after irradiated by laser

4.6 Result and discussion:

When the sample irradiated by Q-switched Nd:YAG laser of power 400 mJ at 1064 nm the rust was completely removed from all samples as can seen in figure (4.5) after laser exposure .

Due to the vaporization of the surface contamination,an audidle (click) can be heard when the laser stricke the surface,the character of this sound varies with laser parameters and is also affected by plasma formation.

An experiencal operator will (hear) when the removing process is most effective.

The surfaces charactrastics of the meterial to be cleaned by the laser are important to acheve a good result . one of this charactaristics its absorptivity witch affected by , for example , surface roughness , rough surface absorb more strongly than smooth once . very rouh surface with cavities and other “hidden” areas are difficultt to chean .

Many factors affect the quality of any removing process .

4.7 Conclusion:

Rust removing by using laser is an effective technique since it provieds a high degree of control deuring removing allowing fragile objects or items with aconsidrable amount of surface detail to be effectively removed .

The technique must be used with care since process parametares must be set so as to prevent many other factors influence the result of laser removing and even same laser gives different results depending on the character of the substrate. the colour , prosty and surface structureal affect the process ,change in the thickness of the rust also require changes to operating parameters.

4.8 Recommendations:

I recommended doing the following in the future:

- Study of gaseous emissions during lasercleaning.
- Using another type of laser such as CO2 laser, to compare it with Nd:YAG laser.

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