Q-SWITCHED Nd:YAG LASER INDUCED PHOTODISRUPTION IN AN EYE MODEL

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Dedicated to:

My Parent: Wan Majid Wan Idris & Hasimah Awang,

Siblings: Redhuan, Rodzli, Rodhiah, Ridzaudin, Robiatul Adawiyah

Husband and son: Abd Rahman Tamuri and Abdullah Uwais Abd Rahman

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ABSTRACT

This study attempts to characterize the photodisruption in simulated eye model induced by Nd:YAG laser. To simulate the eye environment, saline solution was chosen as vitreous filled pyrex cuvette which acted like eye ball. Polymethylmethacrylate (PMMA) plate later on was placed in the pyrex cuvette to be as an intraocular lens. The laser beam was focused into saline solution using two techniques. The first technique uses single camera lens and the second technique uses combination of negative and positive lenses. Activities at the focal region were visualized by means of CCD video camera and interfaced with image processing system via Matrox Inspector sofware. The pressure wave induced at the focal region was detected using hydrophone and the plasma temperature was measured and estimated using Langmuir probe. The damage induced after exposure of laser on PMMA was observed using optical microscope. By focusing light pulses lasting in nanoseconds to a spot size, this laser can create an optical breakdown associated with plasma formation. Multiple breakdowns were observed when the laser was focused using single lens. A single ellipsoidal plasma configuration was generated with a combination of lenses. A series of acoustic-shockwave signals representing the pressure waves produced at the focal region had also been recorded. From the measurement, a maximum pressure of 0.0254 bar was obtained. The temperature raised at the plasma region was estimated to be 12,064 K or 1.04 eV. The damage threshold was obtained at a fluence of 6.86 x 10^2 Jcm^{-2} on the PMMA with various damage formations. Severe damage was observed as the number of laser pulses increases. In short, all the mechanisms involved have been successfully characterized. These information can be very useful in recognizing the opportunities and limitations of the Nd:YAG laser in medical applications.

ABSTRAK

Kajian ini bertujuan untuk mencirikan fotopenghancuran dalam sampel simulasi mata yang dijana oleh laser Nd:YAG. Untuk menyediakan sampel mata, larutan garam dipilih untuk menggantikan cecair dalam mata yang diisi di dalam bekas *pyrex* yang bertindak sebagai bebola mata. Kepingan perspeks (PMMA) kemudiannya diletakkan sebagai kanta intraokular. Alur laser difokuskan ke dalam larutan garam dengan menggunakan dua teknik. Teknik pertama adalah menggunakan satu kanta kamera dan yang kedua menggunakan kombinasi kanta negatif dan kanta positif. Aktiviti pada kawasan pemfokusan diperhatikan menggunakan kamera video CCD yang diantaramuka dengan sistem pemprosesan imej melalui perisisian Matrox Inspector. Gelombang tekanan yang dijana pada kawasan pemfokusan dikesan menggunakan hidrofon dan suhu plasma diukur dan dianggarkan menggunakan penduga Langmuir. Kerosakan yang dijana selepas dedahan laser ke atas PMMA diperhatikan menggunakan mikroskop optik. Dengan memfokuskan denyut cahaya nanosaat kepada satu saiz titik, laser ini boleh menghasilkan keruntuhan optik diikuti dengan pembentukan plasma. Keruntuhan berganda dapat diperhatikan semasa laser difokuskan menggunakan satu kanta. Satu plasma berbentuk elipsoid dijana dengan kombinasi kanta. Beberapa siri isyarat gelombang akustik-kejutan yang mewakili tekanan gelombang yang dijana pada kawasan pemfokusan juga dirakamkan. Berdasarkan pengukuran, tekanan maksimum sebanyak 0.0254 bar diperolehi. Peningkatan suhu pada kawasan plasma dianggarkan sebanyak 12,064 K atau 1.04 eV. Kerosakan ambang berlaku pada 6.86 x 10^2 Jcm^{-2} di atas permukaan PMMA dengan beberapa bentuk kerosakan. Kerosakan yang berlaku didapati meningkat dengan peningkatan kuantiti denyut laser yang digunakan. Secara ringkas, semua mekanisma ini telah berjaya dicirikan. Semua maklumat ini boleh menjadi sangat berguna dalam mengenalpasti peluang dan had dalam mengaplikasikan laser Nd:YAG dalam perubatan.

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a	-	Radius of the aperture
C_p	-	Specific heat
d,D	-	Distance
E	-	Laser energy
Ea	-	Absorbed laser energy
E_o	-	Electric field strength
f	-	Focal length
I	-	Current
I_s	-	Electron saturation current
L	-	Lens
M	-	Magnification factor
n_e	-	Electron density
P	-	Pressure
P_d	-	Power density
R_b	-	Radius of the optical beam
R_L	-	Resistor
R_t	-	Acoustic source radius
r	-	Radius of the beam spot
T_e	-	Electron temperature
V	-	Voltage amplitude
V	-	Optical absorbed volume
V_f	-	Floating potential
V_s	-	Plasma potential
V_{pp}	-	Probe potential
W	-	Laser power

w	-	Beam radius
w_0	-	Beam waist
z	-	Depth of focus
z_0	-	Focal point
z_R	-	Rayleigh region
α	-	Absorption coefficient of the liquid
β	-	Thermal expansion coefficient
ΔT	-	Temperature rise
λ	-	Wavelength
μ_{eff}	-	Penetration coefficient
v	-	Speed of sound
ρ	-	Density of the liquid

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CHAPTER 1

INTRODUCTION

1.1 Overview

The remarkable properties of laser radiation make it such a useful tool to be applied for medical applications. The laser beam can be controlled, focused and manipulated to give precise, specific and localized effects in tissues [1]. The applications of lasers and other optical technology in biomedicine is a rapidly growing field. These applications can be classified as diagnostic or therapeutic. In a diagnostic application, the goal is to learn something about the physiology or pathology of the tissue through its interaction with light. On the other hand, for therapeutic use, it is involved with permanent modification of tissue. This can range from simple cutting associated with surgery to the initiation of cytotoxic chemical reactions in photodynamic therapy [2].

The most widespread medical application for laser technology in medicine has occurred in ophthalmology. Ophthalmic laser applications have experienced rapid growth with the use of argon, krypton, argon pumped dye, Nd:YAG and most recently, near-IR diode lasers [3] since the introduction of ruby laser in 1960s.

In 1961, Zaret [4] employed a ruby laser for iris and retinal photocoagulation in rabbits. Delivery systems for retinal photocoagulation employing ruby laser had been developed by Campbell and Koester as well as Zweng and his associates in 1963 [5, 6]. The ruby laser was a valuable tool, but it is quickly supplanted with the introduction of the argon laser photocoagulator. It was because the output of the argon laser was a steady continuous wave instead of a short pulse and it could be moved by existing fiber optic technology into slit lamp. The argon laser is the most widely used to treat extrafoveal chorioretinal diseases such as age-related macular degeneration and diabetic retinophathy, and also been successfully used to treat glaucoma by iridectomy or trabeculoplasty [7].

Ophthalmology offers wide application of lasers since eye is one of the most accessible human organs, and its media (cornea, aqueous humor, lens and vitreous) are transparent to visible light, allowing direct inspection of its internal structures for diagnosis and treatment [3].

1.2 Problem Statement

Photodisruptor laser applications are very useful for cutting, incising or vaporizing intraocular tissue [8]. When laser is deposited on a tissue as thermal energy, there are several mechanisms that may occur such as optical breakdown associated with plasma and acoustic-shockwave generation. Effects generated by this laser-tissue interaction depend on the target material (gas, liquid or solid). Biological tissues are more complex and variable.

In this study, saline solution and polymethylmethacrylate (PMMA) are used to simulate the eye condition. Some experimental work has been setup to observe the photodisruption mechanism induced by Q-switched Nd:YAG laser. The mechanism is studied based on laser parameters (energy, number of pulses and distance of observation). It is very crucial to study plasma formation and acoustic-shockwave generation as they are the main processes of the photodisruption. The investigation on damages induced by photodisruption on the target is crucial as it can be very useful or can be a very destructive. These observations are required to ensure a safety use of laser as a photodisruptor in ophthalmology.

Therefore, the characterization of the photodisruption induced by Q-switched Nd:YAG laser would provide some useful information on how the mechanism of photodisruption depends on the laser parameters. This information also can be very useful indications for clinician and for the system designer to recognize the opportunities and limitations of lasers in applying these devices in medicines.

1.3 Research Objective

The main objective of the research is to characterize the mechanism of photodisruption induced by Q-Switched Nd:YAG laser. This goal can be achieved as the following:

a) Observation of plasma formation in saline water
b) Measurement of plasma temperature using Langmuir probe
c) Measurement of acoustic-shockwave generation in saline water using piezoelectric transducer
d) Investigation of photodisruption effects on transparent material (PMMA) using image analysis.

1.4 Research Scope

In this study, a Q-switched Nd:YAG laser with a fundamental wavelength of 1064 nm and 10 ns pulse duration has been employed as a source to generate photodisruption. The laser beam has been focused using two focusing techniques. One is a single lens technique and the other is combination of two lenses technique. The plasma formation and the generation of acoustic-shockwave were being studied in saline solution. PMMA was utilized as a target material to observe the effects of photodisruption. The dynamic expansion of plasma was observed using CCD camera which was interfaced to a personal computer. The plasma temperature was measured using Langmuir probe. Pressure generated by acoustic-shockwave was detected using piezoelectric transducer which was linked to an oscilloscope. The effects of photodisruption mechanism were then observed using photomicroscope and analyzed using image processing software.

1.5 Thesis Outline

This thesis is divided into eight chapters. Chapter 1 describes the general overview of the research project. The history of laser use in medicine and laser as a photodisruptor are also reviewed. The theory of photodisruption mechanism induced by Q-switched laser will be detailed in Chapter 2. The discussions will include optical focusing technique and laser induced damage on transparent material. The samples, instruments and the experimental setup used to study the photodisruption are presented in Chapter 3. The results and findings of this project are being discussed in Chapter 4 to Chapter 7. The plasma formation and plasma temperature measurement are discussed in Chapter 4 and Chapter 5, respectively while acoustic-shockwave generation is described in Chapter 6. In Chapter 7, damage effects produced by the photodisruption mechanisms on transparent material are discussed.

Finally, Chapter 8 comprises the conclusion of the study and recommendations for future work.