A pump-probe technique for the monitoring of laser ablation

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Abstract

The use of pulsed lasers in such applications as surgical tissue ablation has motivated investigative works to better understand the laser ablation mechanisms in several tissues types. When a laser pulse with sufficient energy, above some threshold value, hits a material or a biological tissue, a plume consisting of steam, particles and molten ejecta rapidly expands from the target site. Many different methods such as the laser beam deflection technique have been developed in search of a useful tool for studying the ablation process. A novel probe-beam technique can be employed to access the ejected mass in the ablation. In this work, we use a Nd:YAG laser operating at the fundamental 1.06 μm wavelength to generate an ablation plume. The sample used is a biological soft tissue due to its high absorption degree for infrared radiation. A helium-neon laser is used to detect the smoke-like plume that scatters the laser light. This light is collected by a 600 μm optical fiber and sent to a spectrometer. A 256x1024 intensified CCD with 5 ns gating capability is connected to the detector port. The CCD gating and time delay is controlled by a delay generator. After adjusting electronically the desired acquisition time window, the scattered He-Ne laser light were analyzed for several delay times in relation to the ablation pulse. Understanding the mechanisms involved in material ablation allows reduced material damage and better results depending on the goals of the analysis.

Introduction

The use of pulsed lasers in such applications as surgical tissue ablation has motivated investigative works to better understand the laser ablation mechanisms in several tissues types. Understanding the mechanisms involved in tissue ablation allows for a reduced tissue damage and best surgical results when a high energy laser is used.

Most of the mechanisms involved in laser tissue ablation is revealed through the plume formed by the removed tissue. Although the final result of the ablation can be evaluated by observing the tissue directly, under a microscope or at the naked eye, it is through the plume dynamics that most physical processes are brought about. [1- 3]. Many different methods such as the laser beam deflection technique have been developed in search of a useful tool for studying the ablation process [4].

In addition, a novel probe beam geometry is employed to access the ejected mass in the tissue ablation. We use an optical fiber to detect the light that is scattered by the plume from a helium-neon laser beam, instead of detecting the light transmitted through the plume.

Experimental Setup

A 10 mW Helium-Neon laser emitting at 632.8 nm, with a 1.5 mm beam diameter was used as a probe. The probe beam was aligned perpendicularly to the Nd:YAG laser beam and parallel to the ablated surface, as in figure 1.

The He:Ne laser was used to detect the smoke-like steam and debris rising from the impact site. That plume composed of a expanding steam and ejected debris scatters the helium-neon laser light. The scattered light was collected by a 600 µm fused silica fiber, as represented in the diagram shown in figure 2. The collected light was coupled into a ¼ m spectrometer (Oriel Instruments MS257). The wavelength calibration was performed by using a red, a yellow and a green He-Ne lasers operating at 632.8 nm, 594 nm and 543.5 nm, respectively, and an additional 4 mW laser at 532 nm. An intensified CCD (Charge Coupled Device) with 256x1024 pixels was connected at the monocromator detector port. The specified CCD gating capability was 5ns. The CCD gating and time delay was controlled by a model DG535 delay generator, from Stanford Research. After adjusting electronically the desired acquisition time window, the scattered He-Ne laser light was analyzed for several delay times in relation to the ablation pulse.

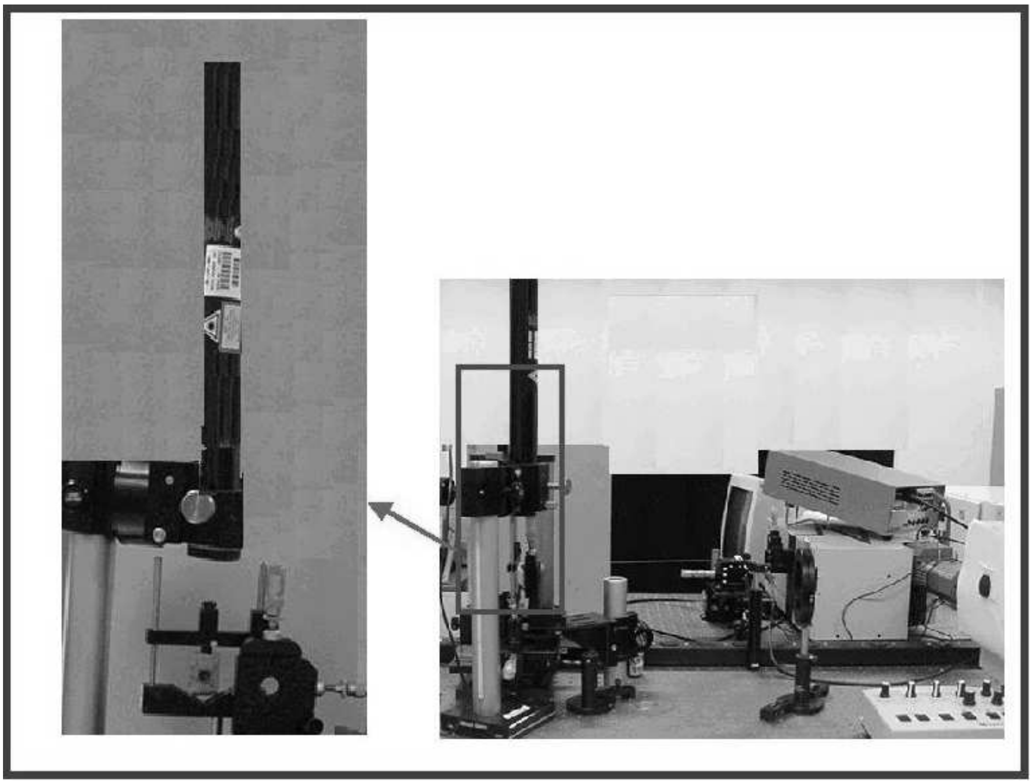

Figure 1: Experimental setup photograph with the He:Ne laser detailed.

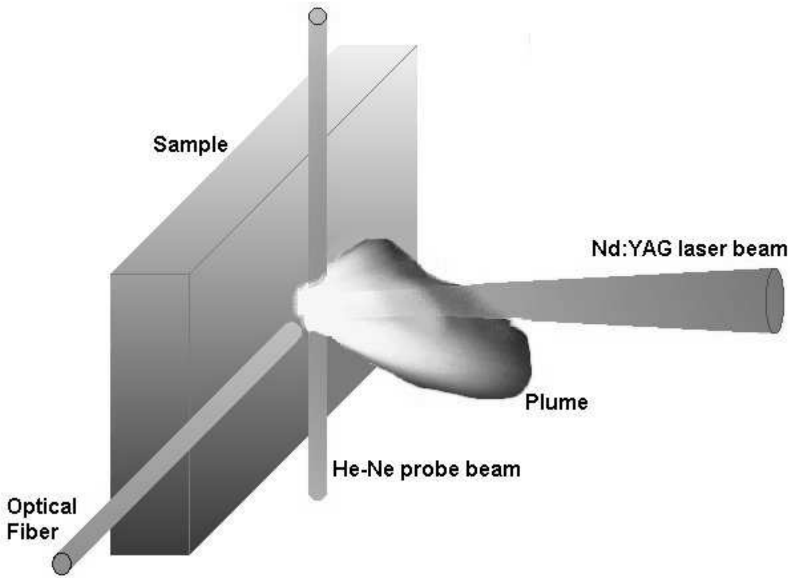

Figure 2: Diagram representing the interaction of the lasers beams with the sample and the optical fiber.

Results and Discussions

One of the spectra collected by the optical fiber is exposed in figure 3. Many emission lines were identified, including the He:Ne laser line (632.8 nm) that was used as the probe beam and was scattered by the components of the ablation plume. It was assured that the probe beam never touched the samples otherwise it could be introducing a spurious signal to the measurements.

Figure 4 shows the signal collected from the ablation plume, at several delay times following the ablation pulse. The plume dynamics after the Q-switch pulse from the Nd:YAG laser is presented in figure 5, as revealed by the light scattered from the probe beam. The plot indicates that the ejected material starts to cross the acceptance cone of the collection fiber at about 40 μs after the ablation pulse has been fired. The signal shows a fast rise to a maximum value and a slower decay. The fast rise can be attributed to the arrival of the high speed components of the plume, formed by the steam and ejected particles. The decrease of the signal at a lower rate comes from slow components of the plume, possibly heavier debris, as well as from the smoke and the particle fragments that remain in the path of the probe beam and takes a little longer to dissipate.

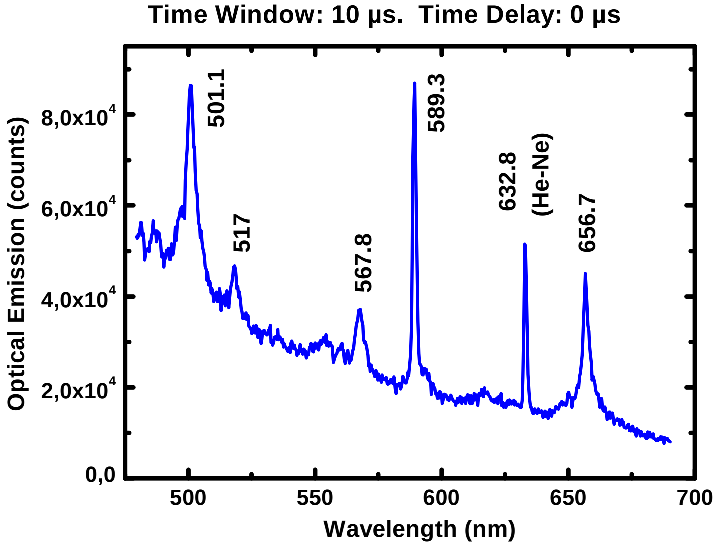

Figure 3: Collected spectrum with the Helium-neon laser line and other emission peaks identified.

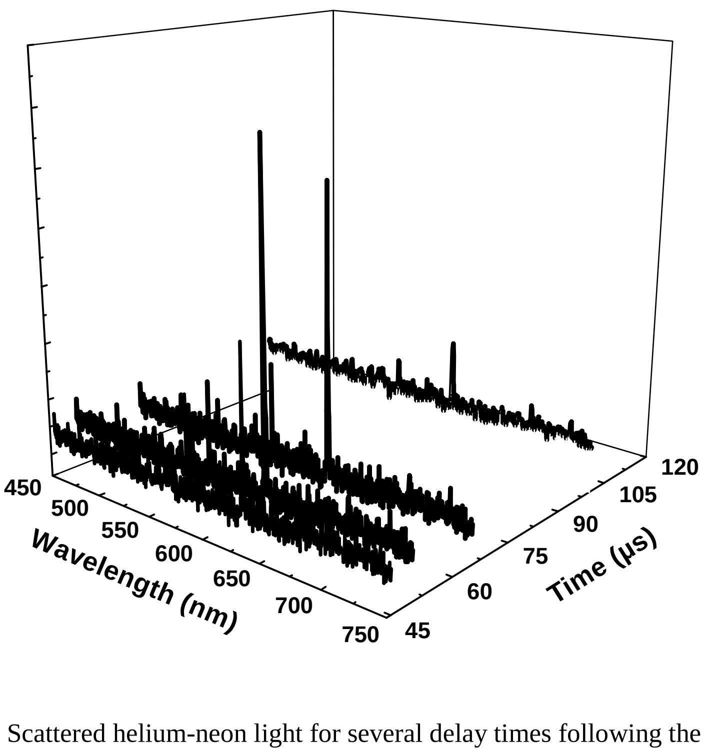

Figure 4: Scattered helium-neon light for several delay times following the ablation pulse.

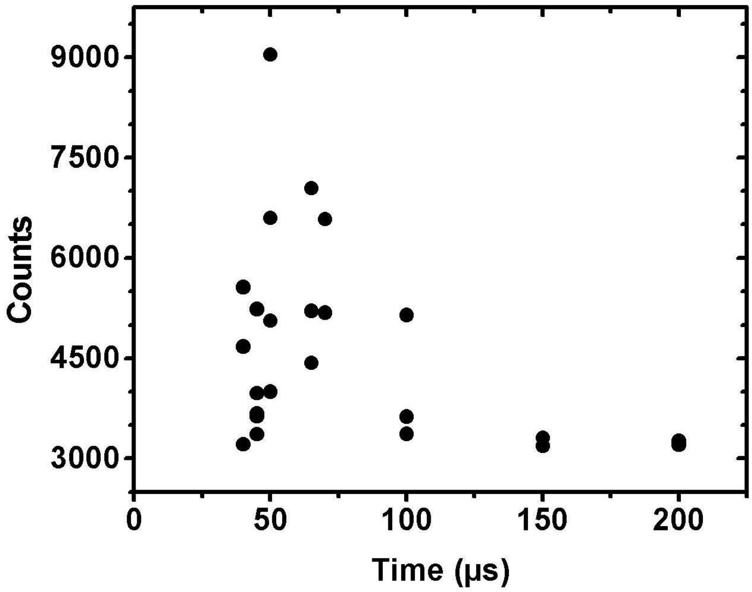

Figure 5: Time evolution of the helium-neon laser light scattered by the ablation plume.

Conclusions

Our results shows that the plume is formed with some delay time with respect to the high energy laser pulse. We observed that, when a Q-switch laser pulse is applied, the plume shows up after the optical pulse has already gone. The ejected material starts to be registered by the spectrometer at about 40 μs after the ablation pulse has been fired.

The intensity of the signal, related to the scattering of the probe beam, presents initially a fast rise and then it decreases at a lower rate. Possibly, the high speed components of the plume, formed by the steam and ejected particles, are registered first while the slow components, represented by the particle fragments and others that remain in the path of the probe beam, take a little longer to dissipate and are measured later.

Acknowledgements

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