Time dynamics of the ablation plume induced by a near infrared laser

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Abstract

This work reports the time resolved measurement performed with the goal of studying the dynamics of the ablation plume generated by a Q-switched Nd:YAG laser (Quanta Ray) emitting at 1.06 μm with a 10 ns pulse duration. The selected output energy was 210 mJ. The ablation plume is composed by an expanding steam and ejected debris from the ablated material. It is used a 10 mW helium-neon laser emitting at 632.8 nm as a probe beam, aligned perpendicularly to the Nd:YAG laser beam and parallel to the ablated surface. The probe light is collected by an optical fiber and sent to a spectrophotometer (Oriel Instruments) for analysis. A CCD (Charge Coupled Device) detector was connected to the spectrometer. The technique reveals the differences in the plume behavior. Our results show that the plume is formed with some delay time with respect to the high energy laser pulse. It was also observed that when the Q-switched laser pulse is applied the plume shows up after the optical pulse has already gone. The experimental results show that at early times only light components like some atoms and molecules are ejected from the material, conclusion drawn from the presence of only atomic emissions and the absence of scattered probe beam for times shorter than 50 μs. Only after a certain time delay of the probe beam in relation to the ablation laser pulse the heavier components of the plume are ejected like particulate materials capable of scattering the probe beam. If a long laser pulse is used for the ablative process, the plume once formed interacts with the incident optical beam (the pump beam) through scattering and absorption, reducing the efficiency of the process.

Introduction

Pulsed laser ablation is currently part of many surgical procedures requiring high level of precision. Laser ablation finds widespread use for the correction of common eye disorders like astigmatism and near sighted vision, cataract surgery and cosmetic surgery. Many efforts have been made to associate the laser technology to arthroscopic and endoscopic surgery for many spine disorders, aiming a minimally invasive procedure.

Optimization of laser procedures in biological tissues implies in minimizing thermal damage in the surroundings of the irradiation site as well as minimizing the mechanical damage that could be promoted by shock waves generated by the rapidly expanding vaporized tissue. Such optimization of the laser ablation implies in understanding the physical mechanisms involved in the mass removal process. Optical spectroscopy stands as a powerful tool to gather information on the physical phenomena involved in the ablation process. In addition, real time collection of the plasma luminescence can be used as a sophisticated feedback system to guide laser-assisted surgical procedures, as the spectral signatures can be used to discriminate the type of tissue being hit by the laser. [1-4]

This work reports on the time resolved spectroscopic measurements of the plume generated by a pulsed Nd:YAG laser in chicken heart tissue.

Experimental Setup

A Q-switched Nd:YAG laser (Quanta Ray) emitting at 1,064 μm, with 9 nanoseconds pulse duration was used for the tissue ablation. The selected output energy was 210 mJ, and the beam was focused to a 0,8 mm spot size by using a 40 cm focal length lens and an estimated energy density of 42 J/cm^2.

A He:Ne laser emitting at 632.8 nm, with 10 mW and a 1.5 mm beam diameter was used to detect the smoke-like steam and debris rising from the impact site. It was aligned perpendicularly to the Nd:YAG laser beam and parallel to the ablated surface.

That plume composed by an expanding steam and ejected debris scatters the helium-neon laser light. The scattered light was collected by a 600 μm fused silica fiber. The collected light was coupled into a ¼ m spectrometer (Oriel Instruments MS257). 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, several delay times of the probe beam in relation to the ablation pulse were studied.

Results and Discussions

Considering all the spectral lines observed during the experiments for many different times of evolution of the ablation plume (an example can be seen in figure 1), the presence of an emission line with great intensity in 589 nm has to be noticed. Figure 2 presents a spectrum captured in the visible region with a delay time of 60 µs and a time window of 10 µs.

The use of a diffraction grate with 600 lines/mm and a 400 nm blaze allowed us to identify with more precision this intense line that in fact was related to the sodium doublet with wavelengths of 589.0 nm and 589.6 nm. This sodium emission was identified before using similar methods.

In figure 3 the results for the sodium emission are presented altogether with the probe beam scattering as a function of the time delay. If a long laser pulse is used for the ablative process, the plume, once formed, interacts with the incident optical beam through scattering and absorption, reducing the efficiency of the process. On the other hand, the present results suggests that, for a Q-switched laser, the time between consecutive pulses should be greater than 150 µs, to avoid interaction of one laser pulse with the plume produced by the previous one.

Our results also reveal that for times lower than 40 µs just light components are ejected from the tissue, such as ionized atoms and molecules with low molecular weight, as concluded from the presence of atomic emission and the absence of the scattered light from the probe beam.

The observed delay in the plume formation results from the time it takes for the volume of material, which is vaporized in a confinement regime, to expand. It takes some time for the breaking of the integrity of the matrix tissue and also it takes some time for the material in process of ejection to accelerate off the ablation surface. It is expected that this confinement time is dependent, to some extent, on the thermal and mechanical properties of the target tissue. Such a delay in the plume ejection might affect directly the amount of residual damage in the ablated tissue, as the heated material can transfer some energy to the surroundings before leaving.

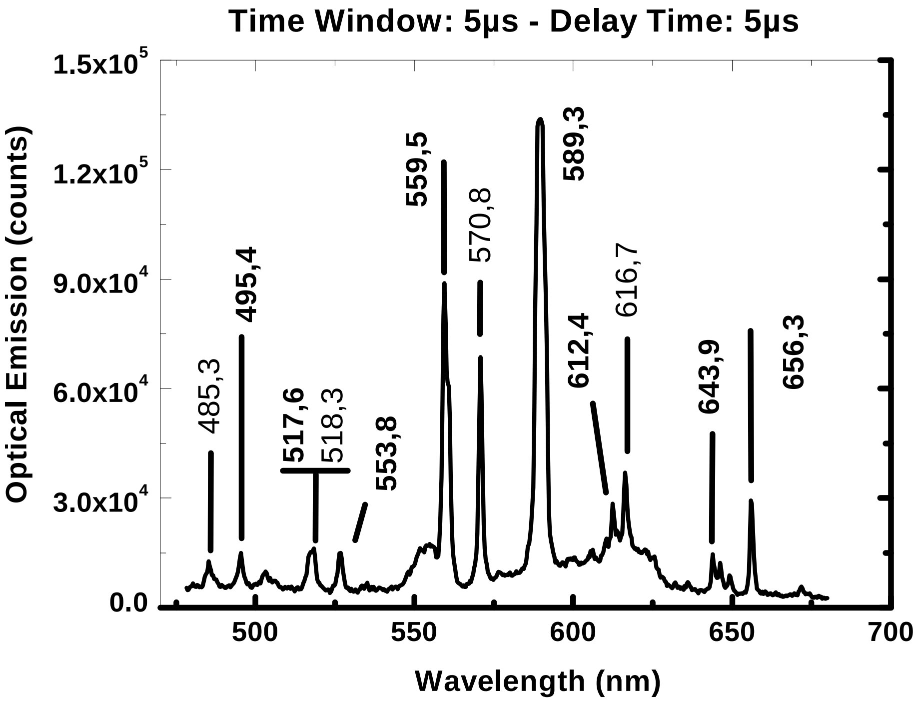

Figure 1: Optical emission spectrum collected presenting many identified emission lines.

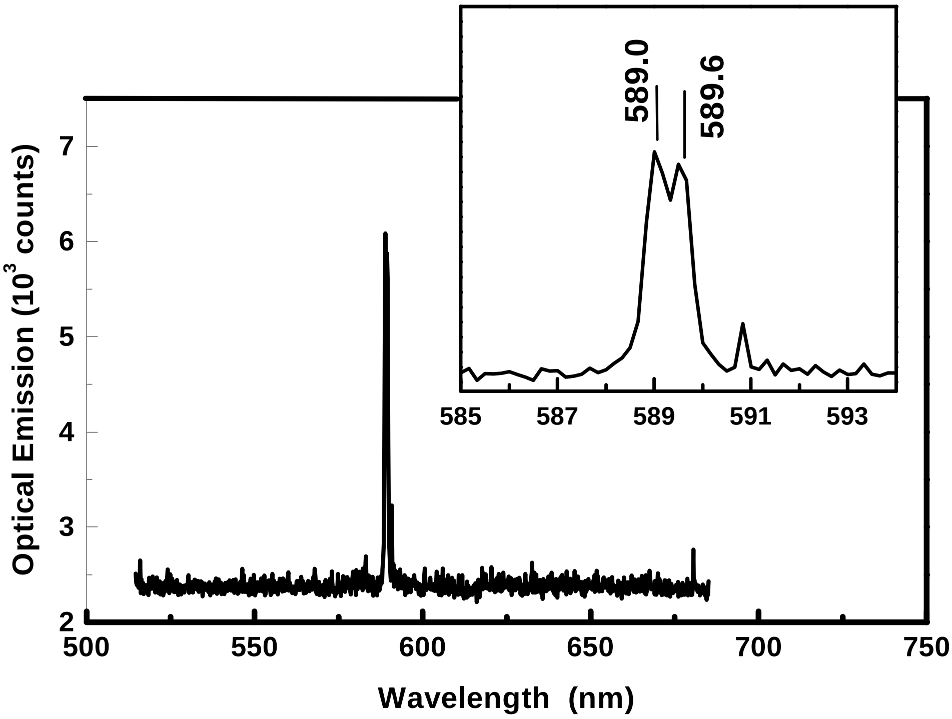

Figure 2: Sodium emission doublet.

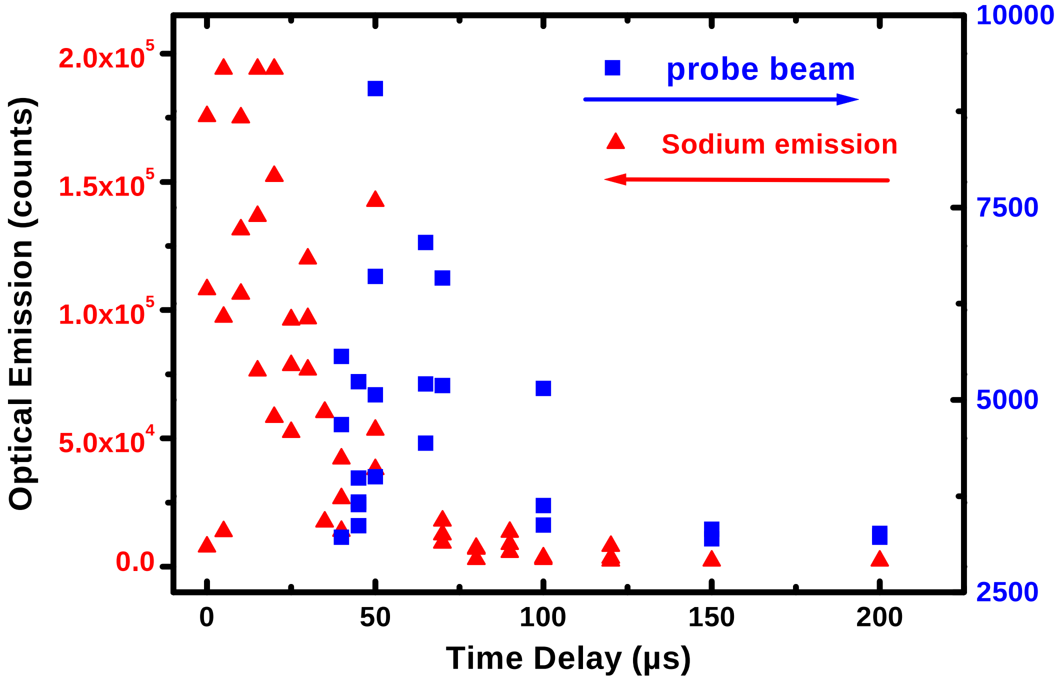

Figure 3: Sodium emission and probe beam scattering as a function of the chosen time delay.

Conclusions

The possibility of measuring the relative atomic composition of a material through the analysis of the ablation process using short laser pulses and scattered laser light as a probe beam was confirmed. This experimental setup as described here can result in a new diagnosis technique which can establishes the differences between healthy and diseased tissues due to chemical alterations.

When a laser pulse reaches a material with more energy than a threshold value an ablation plume constituted by vapor, particles and debris expands rapidly from the target area. A chicken myocardium was used as the sample to this study. Our results show the constitution of the plume for different moments in time. The luminescence spectra in the first moments reveal the presence of sodium, magnesium, calcium and hydrogen in the chicken myocardium.

The results obtained also reveal that for times lower than 40 µs just light components are ejected from the tissue while the heavier components of the plume takes much more time to be ejected and later to dissipate from the path of the probe beam.

Acknowledgements

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