

DENTIN AND ENAMEL SPECTROSCOPY IN THE ABLATIVE REGIME

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Abstract - In the present study, the dental tissue composition was investigated in vitro during ablation with Nd:YAG Laser (1064 nm), by using luminescence spectroscopy of the ablation plume. The objective was to identify the elemental composition of the caries-free dental tissue and to evaluate the possibility of discriminating the enamel from dentin. EDS was used as a complementary method for the analysis. The atomic elements responsible for the optical emission lines present in the acquired spectrum were identified. The following elements were found in both enamel and dentin: Ca, Sr, K, Mg, Mn, P, Zn, Si, F, Fe and H. Main differences between the studied structures originated from the Mn and Mg emissions.

Introduction

There is a need for precise tissue removal with minimal thermal/mechanical collateral damage in many laser-surgical applications including dentistry.

Such optimization of the laser ablation implies in understanding the physical mechanisms involved in the mass removal process. Published work [1,2] suggests that an ultrashort pulse laser ablation system can meet this need.

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 generated during the laser ablation process 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 [3-5].

A technique called laser induced breakdown spectroscopy (LIBS) can be used for the determination of the relative concentrations of the components of various solid samples, including metallic alloys, insulators, archeological artifacts, and paintings [6]. Differences between several types of biological tissues can also be identified using LIBS [7-10]. The present work reports on the spectroscopic measurement of the ablation plume generated by laser ablation of tooth and the application to the dentin - enamel discrimination during ablation by using the LIBS in caries-free tooth.

Materials e Methods

A Q-switched Nd:YAG laser (Quanta Ray, 1.064 μm , 10 ns pulse duration) has been fired onto teeth sample targets at an incident angle of 90° from the surface. After focusing with a 40 cm focal length lens, the beam diameter at the sample plane was 0.8 mm, resulting in a laser fluence of 40 J/cm².

The plume luminescence was collected by a 600 μm fused silica fiber. The optical emission spectra have been analyzed by means of a 0.5 m spectrograph (Oriel Instruments MS257) furnished with a 300 lines/mm grating blazed at 400 nm which covers the spectral region from 325 nm to 625 nm.

An intensified CCD (Charge Coupled Device) with 256x1024 pixels, with a resolution of about 0.5 nm, was connected at the monochromator detector port. The specified CCD gating capability was 5 ns. The CCD gating and time delay was controlled by a model DG535 delay generator, from Stanford Research.

The wavelength calibration was performed by using lines of a Hg-Cd-Zn calibration lamp (Figure 1). The accuracy of the wavelength calibration is estimated to be 0.5 nm. The fiber was positioned parallel to the sample surface and perpendicularly to the high-energy laser beam, as in Figure 2.

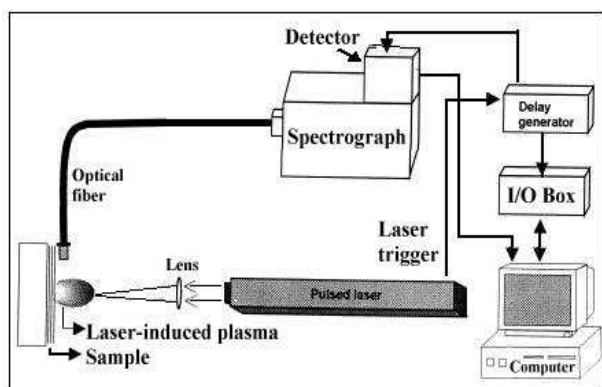


Figure 1: Schematic diagram of the experiment.

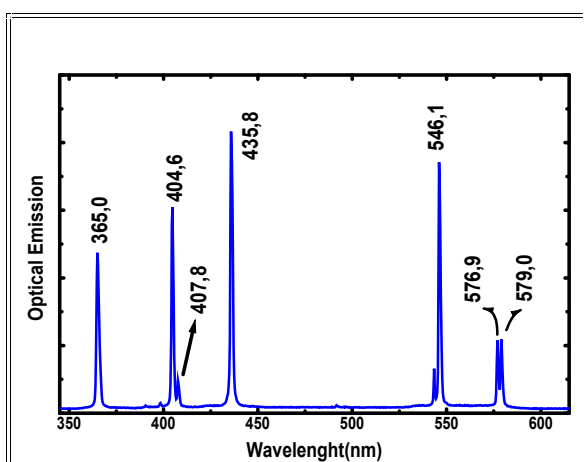


Figure 2: Calibration spectrum from a Hg-Cd-Zn lamp showing lines at: 365,0 nm; 404,6 nm; 407,8 nm; 435,8 nm; 546,1 nm; 576,9 nm; 579,0 nm.

Freshly extracted, caries-free teeth were used as study samples. LIBS measurements were performed in 30 enamel samples and 30 dentin samples. For the sake of data averaging, to improve the signal to noise ratio, spectra were collected at several different points of the same sample or new sample pieces, were used.

The detector gate width could be measured and adjusted electronically to the desired time window. After adjusting electronically the desired acquisition time window, the laser was fired three times and the accumulated spectra was acquired. The sample was moved to a fresh point for a new acquisition.

The data could than be evaluated for the repeatability and averaged for a better signal to noise ratio.

Results

Various spectra from laser-irradiated teeth were obtained in order to identify the emission lines present in the enamel and dentin. Typical collected spectra are shown in Figure 3.

The majority of the emissions lines in Figure 3 correspond to the Ca. Identified Ca lines are 364.4, 373.6, 393.4, 396.8, 409.8, 445.2, 458.2, 487.8, 526.5, 559.2 and 585.5 nm. Some lines, for example, 518.5 nm e 550.9 nm, are likely to be due to the Mg atom. The lines at 534.4 nm resemble P fluorescence lines. The lines of Mn and Mg are very strong mainly after the ablation of the dentin than in the ablation of the enamel, as seen in Figure 4.

It was found that the emission was dominated by Ca with a contribution from P confirmed by the EDS spectra shown in Figure 5.

Discussions

When the tissue is irradiated with a high-energy laser pulse, the optical breakdown on the teeth surface can lead to plasma formation. It is important to note that plasma luminescence due to optical breakdown often precedes the bulk ejection of ablated material from the tissue or occurs simultaneously with ablation. In the later case, it cannot be separated from ablation product luminescence in a gaseous cloud or the particulate plume. Plasma optical breakdown is complete within a few picoseconds after the end of the incident laser pulse.

A great number of spectral lines was detected. The majority of lines found in the same visible spectral region for both, enamel and dentin, and many of lines exactly fit each other. The composition of the spectra observed is complex: the lines are overlapping and may correspond to various atoms, molecules or radicals.

Therefore precise identification of spectral lines is rather difficult. In this work, the Handbook of Chemistry and Physics [11] used for the identification of the atomic emission lines. EDS was used as a complementary method for the analysis and cross-validation of the results.

The set of spectral lines in plume luminescence signal changes depending upon the chemical composition of the tissue. Time resolved luminescence and probe-beam measurements indicate that the bulk mass ejection process is delayed with respect to the optical emission [12].

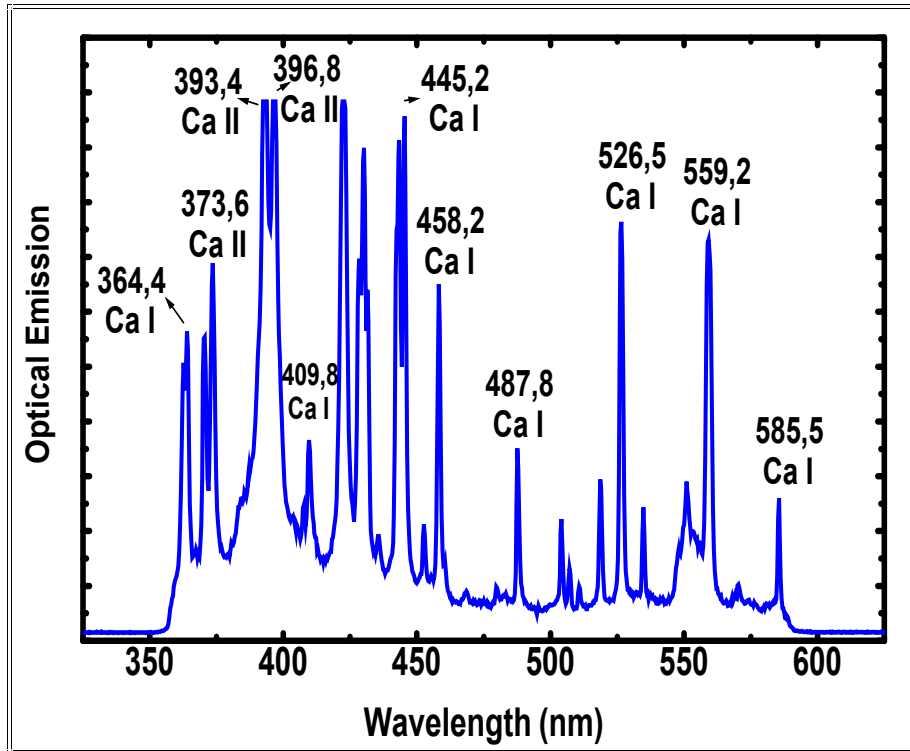


Figure 3: Typical plume luminescence spectra obtained for dentin.

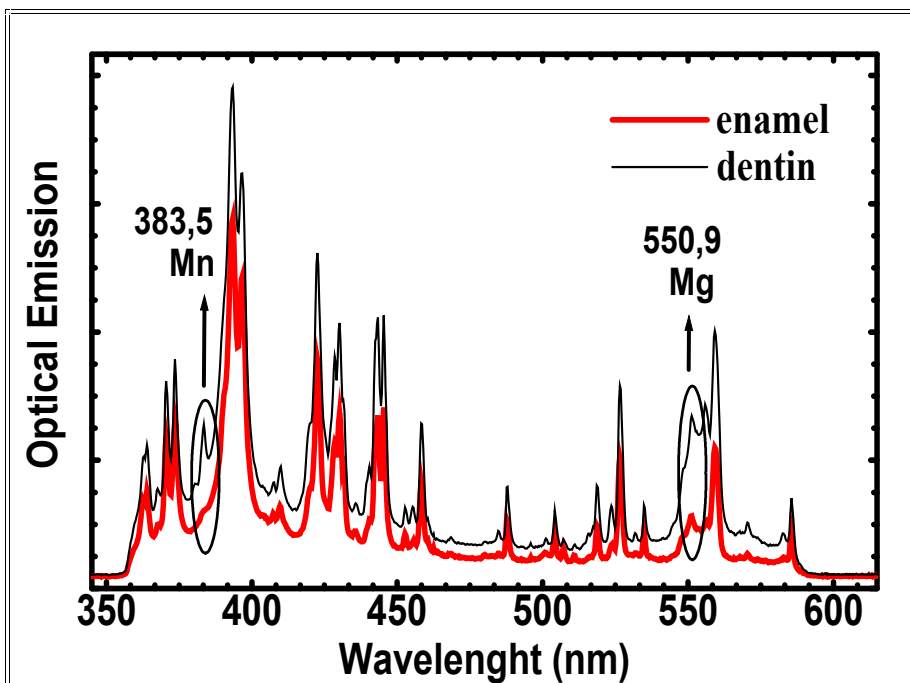


Figure 4: Spectra obtained by LIBS for dentin and enamel. Main differences between the studied structures arise from the Mn (383.5 nm) and Mg (550.9 nm) emissions.

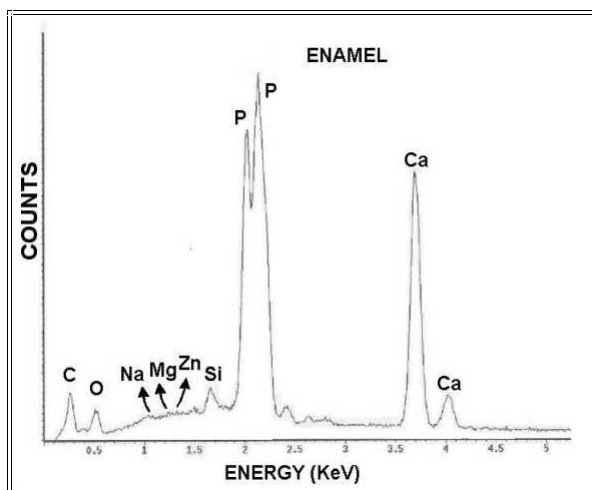


Figure 5: Representative EDS spectrum for enamel.

Conclusion

In conclusion, the atomic elements responsible for the optical emission lines present in the spectra acquired from luminescent plasma generated by laser ablation in enamel and dentin were identified.

The following elements were found in both dental structures: Calcium (Ca), Strontium (Sr), Potassium (K), Magnesium (Mg), Manganese (Mn) Phosphorus (P), Zinc (Zn), Silicon (Si), Fluor (F), Iron (Fe), Sodium and Hydrogen (H). Main differences between the studied structures originated from the Mn (383.5 nm) and Mg (550.9 nm) emissions.

Calcium (Ca) was the element that presented the larger number of emission lines in the studied wavelength range (325 to 625 nm).

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