DEVELOPMENT OF A RAMAN FIBER-OPTIC PROBE FOR IN-VIVO DENTAL APPLICATIONS

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INTRODUCTION

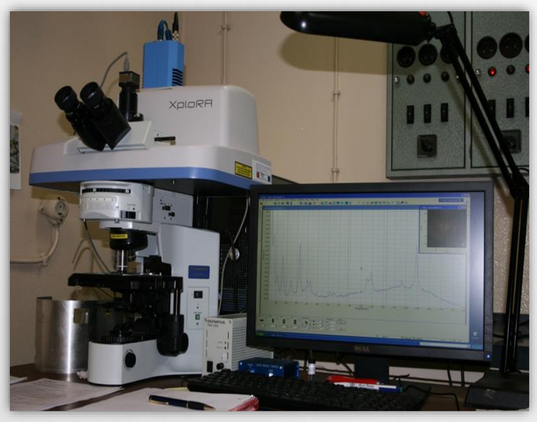
One of the main goals in modern medicine is the early detection and treatment of diseases. Tooth enamel is the most highly mineralized and hardest tissue in the human body, which covers and protects the anatomic crown of the tooth. Despite all research studies dedicated in the past two decades for the development of improved methods for the early detection of dental carious lesions, in clinical practice the caries detection is still mostly limited to conventional visual and visual-tactile techniques such as sharp explorers and dental radiographs [1]. Raman spectroscopy, a form of vibrational spectroscopy, is presently considered a viable optical method for biomedical applications mainly due to its non-destructive modality to analyse molecular composition. This method is becoming progressively important in biomedical research especially for its high biochemical specificity, low water sensitivity and capability to work in the near-infrared (NIR) region with fiber-optics [1, 2]. Raman spectroscopy has shown to be very appropriate for the characterization of dental tissues (Figure 1), from caries detection to the evaluation of demineralization caused by acidic external agents [2, 3]. The sensitivity of this spectroscopic technique for alterations in the symmetric stretching band of phosphate ions in the hydroxyapatite matrix could be used as a powerful tool for early diagnostics, even before signs of demineralization are detected with conventional methods [1-3].

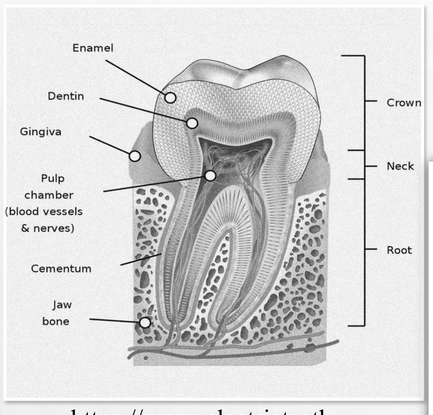
Main advantages of Raman technique are the following: non-destructiveness, non-invasiveness, high-biochemical specificity, no sample preparation, low water sensitivity, flexibility during the spectra acquisition (of different contents, under different angles), simplicity in the sample analysis process, proper for local and quantitative assessment of crystal structures or crystallographic misalignments.

OBJECTIVES AND METHODS

The present doctoral research aims to develop a mobile, highly sensitive Raman system based on dispersion optics and state-of-the-art detector that would provide useful diagnostic information, obtained in-vivo in a clinical setting. Though, the main difficulties rely on: **(1)** tissue fluorescence being several orders of magnitude superior to the Raman signal; **(2)** the Raman signal from tissue being very weak and require prohibitive excitation powers and/or collection times to obtain spectra with acceptable signal-to-noise ratios **(3)** contamination signal from the delivery and collection fiber-optics. The developed Raman device should be able to overwhelm all these mentioned above limitations. The designed Raman remote fiber-optic probe (Figure 2), must contain the following: focussing and collimating lenses, band-pass filter (laser transmitting filter), dichroic mirror (in our case the incident beam and collected signal light share a common path, a dichroic 45° beam splitter transmits the laser light through the optics to the sample while efficiently reflecting the returning Raman-shifted signal light in direction to collection fiber), notch filter (laser blocking filter, mostly used for preventing undesired laser light from reaching the detector and covering entirely the relatively weak Raman signal – 1 in 10 million, and to suppress the Rayleigh scattered radiation) since it is required an excellent filtering, essential for blocking the very intense laser light while still allowing high transmission with enhanced isolation of the slightly wavelength-shifted Raman scattered signal.

IN CONCLUSION, RAMAN SPECTRAL PARAMETERS, SUCH AS BAND INTENSITY, WIDTH OR PEAK POSITION, BASED ON THE TOOTH MINERAL OVERALL CONDITION AND DISTRIBUTION, CAN BE USED TO SEPARATE THE ENAMEL FROM DENTIN, AS WELL AS NORMAL ENAMEL FROM DECAYED ENAMEL. MORE IMPORTANTLY, THE RAMAN COLLECTED SPECTRA CAN IDENTIFY DENTAL CARIES THAT ARE NOT VISUALLY DETECTABLE. RAMAN SPECTROSCOPY IS A PROMISING TECHNIQUE FOR CARIES DETECTION. APPLIED IN DENTAL CLINICS, COULD YIELD PRECISE, FAST AND REAL-TIME RESULTS.





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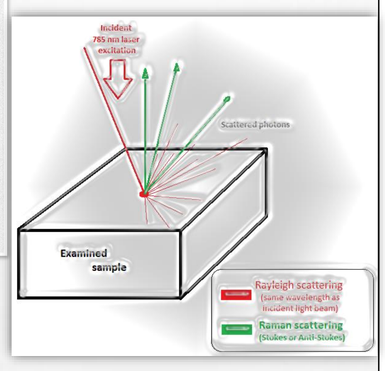


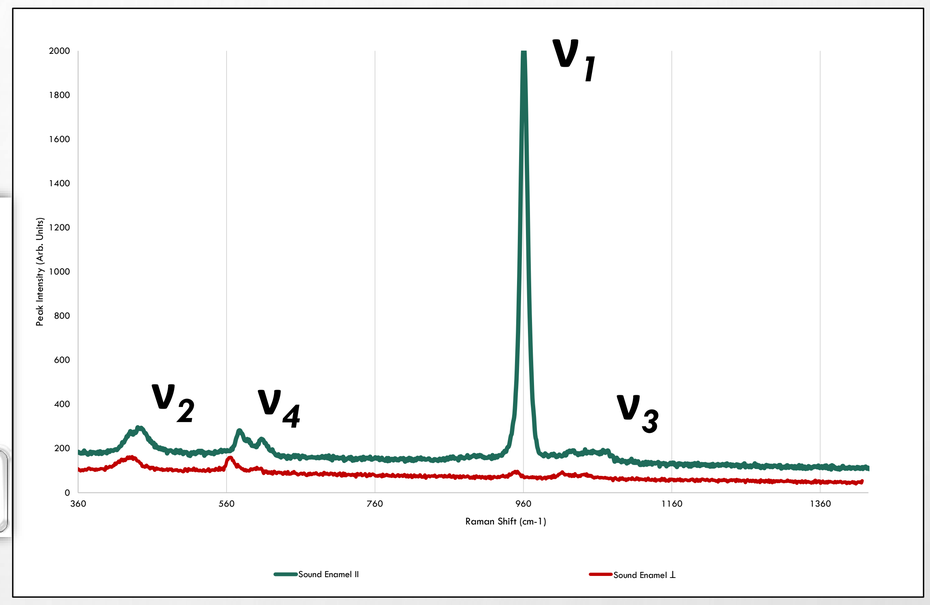
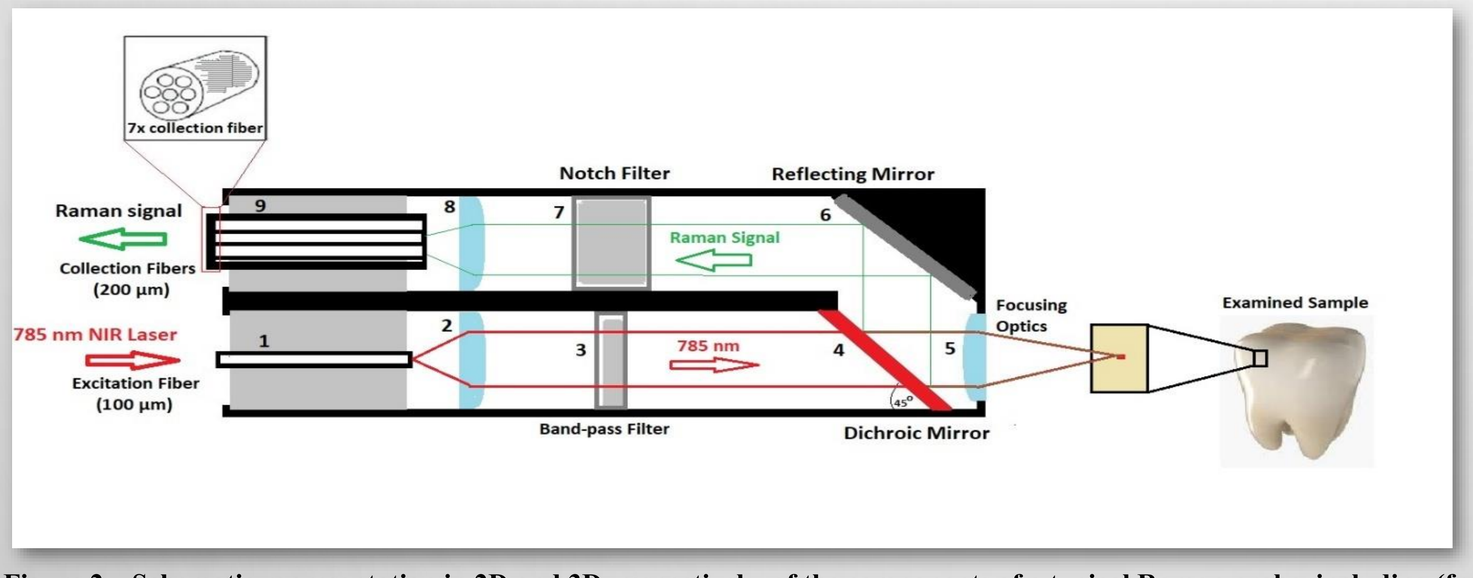


Figure 1 – Left: Representation of Horiba XploRA™ Raman confocal microscope, available in the Physics Department, NOVA FCT, used for Raman spectra acquisitions. Middle: Representation of the human tooth structure, revealing the dental enamel and dentin layers, followed by the Raman scattering priciple. Right: Representation of two distinct Raman spectra, obtained with parallel and cross-polarized configurations of the spectrometer, acquired from dental sound enamel. Raman peaks v_2 at approximately 430 cm^{-1}, and v_4 at 590 cm^{-1}, were attributed to PO_4^{-3} groups in symmetric and asymmetric bending vibrations, respectively. Peak v_1 is assigned to symmetric stretching band of phosphate at ~959 cm^{-1}, while v_3 corresponds to a band with two peaks at 1042 and 1070 cm^{-1} which is also attributed to PO_4^{-3} groups in the asymmetric stretching vibration of hydroxyapatite.



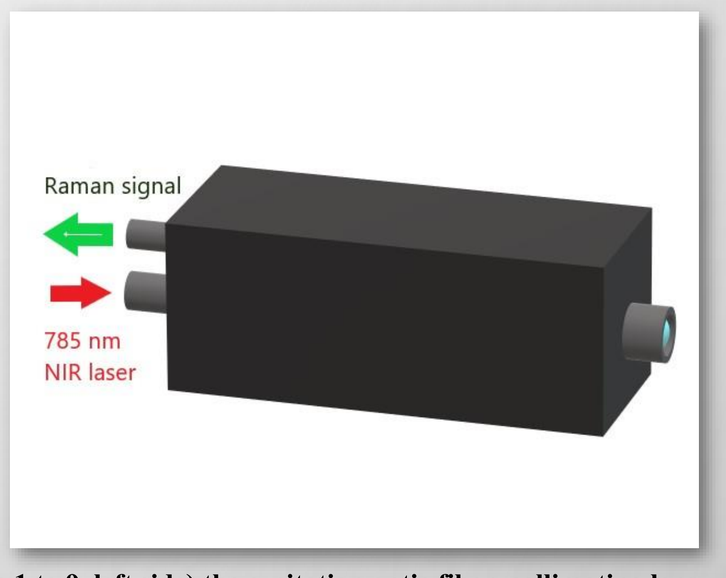


Figure 2 – Schematic representation in 2D and 3D, respectively, of the components of a typical Raman probe, including (from 1 to 9, left side) the excitation optic fiber, collimating lens, band-pass filter, dichroic mirror, focussing lens, reflecting mirror, notch filter, focussing lens and collection fiber bundle.

References

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