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Design and Implementation of a Fiber-Based Endoscope for Fluorescence Lifetime Imaging in Cancer Diagnostics

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Accurate identification of surgical margins remains a critical challenge in head and neck cancer surgery, contributing to high rates of positive margins and subsequent patient relapse. Fluorescence Lifetime Imaging Microscopy (FLIM) offers a promising label-free optical contrast mechanism, leveraging differences in fluorescence decay dynamics to distinguish malignant from healthy tissue in real time. In this project, we present the design and implementation of a fiber-based endoscopic FLIM system aimed at intraoperative cancer diagnostics. The system employs frequency-domain FLIM, using a 405 nm continuous-wave excitation source sinusoidally modulated at 80 MHz, enabling robust lifetime extraction through phase shift measurements while avoiding the pulse broadening limitations associated with time-domain methods in multimode fibers. Spatially-resolved imaging is achieved via wavefront shaping through a multimode fiber (MMF) using a digital micromirror device (DMD) and measured transmission matrix control, generating diffraction-limited focal spots that can be scanned electronically without mechanical actuation. Fluorescence is collected back through the same MMF and detected using a photomultiplier tube, with signal recovery performed using a custom lock-in amplifier to extract in-phase and quadrature components for phase and lifetime estimation. Additionally, cylindrical mode effects observed during calibration are analyzed, explaining the appearance of donut-like output patterns as a consequence of excitation of higher-order LP mode families. Finally, key future directions are discussed, focusing on improving transmission matrix stability, mechanical robustness to bending, and adaptive excitation strategies for reliable clinical integration.

Field of Research/Work

Atomic, Molecular, and Optical Physics

Author: SILVA, Filipe