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Mid-infrared frequency-domain optical coherence tomography with undetected photons

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Abstract

Optical coherence tomography (OCT) is a non-destructive testing and imaging technique, giving morphological information about sub-surface structures. We implement mid-infrared frequency-domain optical coherence tomography based on a nonlinear interferometer using correlated photon pairs. This enables high-resolution depth scans of strongly scattering samples with high sensitivity, speed and lateral resolution.

So far, OCT was dominantly implemented in the VIS or near-IR ranges [1]. However, for materials with strong scattering or absorption mid-IR OCT can be advantageous [2; 3], but has so far been hamstrung by the requirement for expensive and complex light sources and suffered from detector arrays with low efficiency and large noise. A novel mid-IR OCT method that only requires cost-efficient near-IR detectors and a VIS cw laser source is based on nonlinear interferometry [4]. It uses spectrally correlated photon pairs to probe a sample with mid-IR idler photons while only detecting their partners, near-IR signal photons. Previously, only time-domain OCT was shown, with relatively low axial resolutions of 500 µm at 1550 nm [5] and 105 µm in the mid-IR [6].

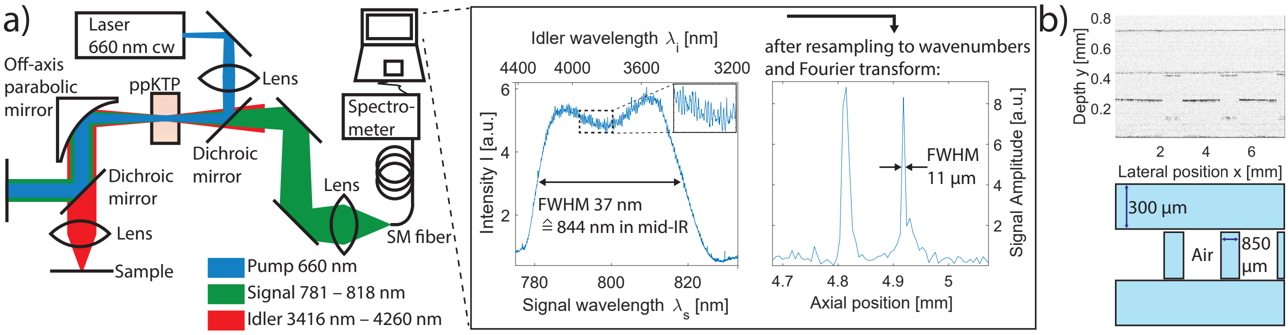

Figure 1: a) Setup. Photon pairs generated in a ppKTP crystal, pumped by a 660 nm laser (500 mW cw), enter a Michelson interferometer. The mid-IR idler photons probe the sample. All light is focused back into the crystal for interference. The near-IR signal photons are coupled into a single-mode fiber and detected by an uncooled grating spectrometer. Inset: Spectrum for a 100 µm thick glass slide. Its Fourier transform reveals the front and back surface. b) Upper panel: OCT scan (8 ms per A-scan) through a 900 µm thick stack of three layers of strongly scattering alumina ceramics. Lower panel: Drawing of the ceramic stack.

Here, we implement for the first time mid-IR frequency-domain OCT with undetected photons. The setup, based on nonlinear interferometry, is depicted in fig. 1. We reach a SNR of 48 dB at 8 ms integration time and demonstrate high axial (11 µm) and lateral resolution (14 µm). Maximum depths and integration times are comparable to – or better than – those of the classical approaches based on upconversion or thermal detectors [2; 3]. Compared to time-domain OCT approaches based on nonlinear interferometery [5; 6] we reach a much faster acquisition, enhanced simplicity and robustness of the setup, with an order of magnitude better axial resolution. To demonstrate the practical usefulness of our technique, we apply it to technologically relevant samples, including ceramics and paints. Our results show its practical relevance for real-world applications.

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