Real-time high-resolution mid-infrared optical coherence tomography

The potential for improving the penetration depth of optical coherence tomography systems by using light sources with longer wavelengths has been known since the inception of the technique in the early 1990s. Nevertheless, the development of mid-infrared optical coherence tomography has long been challenged by the maturity and fidelity of optical components in this spectral region, resulting in slow acquisition, low sensitivity, and poor axial resolution. In this work, a mid-infrared spectral-domain optical coherence tomography system operating at a central wavelength of 4 µm and an axial resolution of 8.6 µm is demonstrated. The system produces two-dimensional cross-sectional images in real time enabled by a high-brightness 0.9- to 4.7-µm mid-infrared supercontinuum source with a pulse repetition rate of 1 MHz for illumination and broadband upconversion of more than 1-µm bandwidth from 3.58–4.63 µm to 820–865 nm, where a standard 800-nm spectrometer can be used for fast detection. The images produced by the mid-infrared system are compared with those delivered by a state-of-the-art ultra-high-resolution near-infrared optical coherence tomography system operating at 1.3 µm, and the potential applications and samples suited for this technology are discussed. In doing so, the first practical mid-infrared optical coherence tomography system is demonstrated, with immediate applications in real-time non-destructive testing for the inspection of defects and thickness measurements in samples that exhibit strong scattering at shorter wavelengths.

Noise of supercontinuum sources in spectral domain optical coherence tomography

In this paper, we investigate the effect of pulse-to-pulse fluctuations of supercontinuum sources on the noise in spectral domain optical coherence tomography (OCT) images. The commonly quoted theoretical expression for the OCT noise is derived for a thermal light source, which is not suitable if a supercontinuum light source is used. We therefore propose a new, measurement-based OCT noise model that predicts the noise without any assumptions on the type of light source. We show that the predicted noise values are in excellent agreement with the measured values. The spectral correlation evaluated for the photodetected signal when using a supercontinuum determines the shape of the OCT noise floor, which must be taken into account when characterizing the sensitivity roll-off of a supercontinuum-based OCT system.
spectral correlations using both conventional supercontinuum sources and low-noise all-normal dispersion supercontinuum sources are investigated, and the fundamental physical effects that cause these correlations are discussed.

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**All-depth dispersion cancellation in spectral domain optical coherence tomography using numerical intensity correlations**

In ultra-high resolution (UHR-) optical coherence tomography (OCT) group velocity dispersion (GVD) must be corrected for in order to approach the theoretical resolution limit. One approach promises not only compensation, but complete annihilation of even order dispersion effects, and that at all sample depths. This approach has hitherto been demonstrated with an experimentally demanding 'balanced detection' configuration based on using two detectors. We demonstrate intensity correlation (IC) OCT using a conventional spectral domain (SD) UHR-OCT system with a single detector. IC-SD-OCT configurations exhibit cross term ghost images and a reduced axial range, half of that of conventional SD-OCT. We demonstrate that both shortcomings can be removed by applying a generic artefact reduction algorithm and using analytic interferograms. We show the superiority of IC-SD-OCT compared to conventional SD-OCT by showing how IC-SD-OCT is able to image spatial structures behind a strongly dispersive silicon wafer. Finally, we question the resolution enhancement of root 2 that IC-SD-OCT is often believed to have compared to SD-OCT. We show that this is simply the effect of squaring the reflectivity profile as a natural result of processing the product of two intensity spectra instead of a single spectrum.

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Supercontinuum applications in high resolution non invasive optical imaging

Progress will be presented in adapting supercontinuum sources to a variety of applications with emphasis on signal processing procedures. These are customised to alleviate noise and take full advantage of the large bandwidth and large power spectral density of modern supercontinuum sources.

The value of ultrahigh resolution OCT in dermatology - delineating the dermo-epidermal junction, capillaries in the dermal papillae and vellus hairs

Optical coherence tomography (OCT) imaging of the skin is gaining recognition and is increasingly applied to dermatological research. A key dermatological parameter inferred from an OCT image is the epidermal (Ep) thickness as a thickened Ep can be an indicator of a skin disease. Agreement in the literature on the signal characters of Ep and the subjacent skin layer, the dermis (D), is evident. Ambiguities of the OCT signal interpretation in the literature is however seen for the transition region between the Ep and D, which from histology is known as the dermo-epidermal junction (DEJ): a distinct junction comprised of the lower surface of a single cell layer in epidermis (the stratum basale) connected to an even thinner membrane (the basement membrane). The basement membrane is attached to the underlying dermis. In this work, we investigate the impact of an improved axial and lateral resolution on the applicability of OCT for imaging of the skin. To this goal, OCT images are compared produced by a commercial OCT system (Vivosight from Michaelson Diagnostics) and by an in-house built ultrahigh resolution (UHR-) OCT system for dermatology. In 11 healthy volunteers, we investigate the DEJ signal characteristics. We perform a detailed analysis of the dark (low) signal band clearly seen for UHR- OCT in the DEJ region where we, by using a transition function, find the signal transition of axial sub-resolution character, which can be directly attributed to the exact location of DEJ, both in normal (thin/haired) and glabrous (thick) skin. To our knowledge no detailed delineating of the DEJ in the UHR- OCT image has previously been reported, despite many publications within this field. For selected healthy volunteers, we investigate the dermal papillae and the vellus hairs and identify distinct features that only UHR- OCT can resolve. Differences are seen in tracing hairs of diameter below 20 μm, and in imaging the dermal papillae where, when utilising the UHR- OCT, capillary structures are identified in the hand palm, not previously reported in OCT studies and specifically for glabrous skin not reported in any other in vivo optical imaging studies. (c) 2018 Optical Society of America under the terms of the OSA Open Access Publishing Agreement.
Two optical coherence tomography systems detect topical gold nanoshells in hair follicles, sweat ducts and measure epidermis

Optical coherence tomography (OCT) is an optical imaging technology that enables real time, high-resolution, cross-sectional and en face investigation of skin by detecting reflected broad-spectrum near-infrared light from tissue. OCT provides micron-scale spatial resolution and millimeter-scale depth of penetration [1]. Several commercial OCT systems with handheld probes targeted for Dermatology are now available [2].

Dispersion free full range spectral intensity optical coherence tomography

Optical coherence tomography (OCT) is a non-invasive imaging technique with many applications and widespread use in ophthalmology [1]. The axial resolution in OCT is inversely proportional to the bandwidth of the optical source used, but the improved axial resolution comes at the price of more significant effects of dispersion stemming from the imaging system and the imaged medium. In recent years, spectral intensity (SI) OCT has been shown, as a classical realisation of quantum OCT, to remove even orders of dispersion intrinsically [2, 3]. One major drawback of SI OCT is however halving of the imaging range which is crucial in spectrometer based OCT which is limited by the spectral resolution, and hence number of pixels of the spectrometer. In this work we demonstrate SI OCT with the full imaging range.
Phase estimation for global defocus correction in optical coherence tomography

In this work we investigate three techniques for estimation of the non-linear phase present due to defocus in optical coherence tomography, and apply them with the angular spectrum method. The techniques are: Least squares fitting the of unwrapped phase of the angular spectrum, iterative optimization, and sub-aperture correlations. The estimated phase of a single en-face image is used to extrapolate the non-linear phase at all depths, which in the end can be used to correct the entire 3-D tomogram, and any other tomogram from the same system.
Mikkel Jensen (Speaker)
Niels Møller Israelsen (Guest lecturer)
Ole Bang (Guest lecturer)
Adrian Podoleanu (Guest lecturer)

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