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Supercontinuum applications in high resolution non invasive optical imaging

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Abstract: 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.

OCIS codes: (060.3510) Lasers, fiber; (170.4500) Optical coherence tomography

1. A diversity of applications

1. Due to large bandwidth[1] that can lead to optical coherence tomography (OCT) operation with microns axial resolution at long wavelengths and submicron axial resolution for short wavelengths, exquisite high resolution images of tissue and phantoms will be presented. As reported recently[2], the unprecedented high axial resolution allows delineation of dermo-epidermal junction, capillaries in the dermal papillae and the vellus hairs. Also, the high resolution achievable opens new avenues in non destructive testing, such as testing the quality of printouts produced by a 3D printer[3]. Comparison of resolution and noise achievable with a SC source and with a widely used Titanium–Sapphire laser (TiSaL) has demonstrated that SC can achieve similar performance with the TiSaL[4]. The main impediment in performing OCT using a SC source has been noise but here we demonstrate that shot noise limited performance can also be achieved with SC sources. Two avenues have been considered, increasing the pulsation frequency in the pump and increasing the averaging time in the detection.

1.1. Low noise SC using a high repetition pump, as implemented in the NKT EXR-9, using 320 MHz[5].

1.2. Low noise OCT using integration on the spectrometer[6]. While using a commercially available, Q-switched SC source (SuperK Compact, NKT Photonics), operating at a low repetition rate of 22 kHz, S/N was improved by acquiring many camera scans, as reproduced in Fig. 1. Such a SC source is of lower cost than the customary mode locked versions.

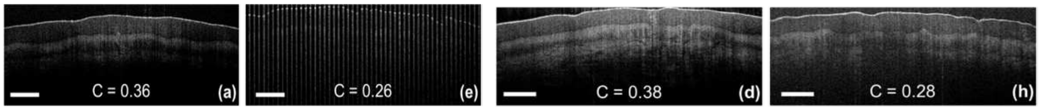

Fig. 1. Example B-scans[6] from a healthy volunteer hand palm skin of 1.6 mm x 4 mm, obtained using (a,d): the NKT EXR-9 (mode Locked-SC) and using (e, h): SuperK Compact, NKT Photonics (Q-Switched-SC). Exposure time in (e) was 20 μs and in (h) 150 μs (scale bar 450 μm). Due to the low repetition rate of the pump in (e), the image is fragmented. This is corrected in (h) by enlarging the integration time.

2. Spectroscopic analysis. Spectral split detection allows spectroscopic OCT imaging, conditioned by a suitably chosen trade-off between the number of spectral windows and axial resolution[7].
3. Compatibility with the other OCT modality, based on sweeping a narrow band, selected by a tunable filter. This allows not only OCT imaging by sweeping[8] but also spectroscopic analysis.
4. Photoacoustic operation[9] is allowed by using a long, ns pulse, delivered by a SC source with sufficient spectral energy density. In this way, a single SC source[10] can be used to perform multimodal imaging. The 2-octave bandwidth (475-2300 nm) makes the SC source suitable for optical OCT as well as for multispectral photoacoustic microscopy (MPAM). The IR band centered at 1310 nm may be chosen for OCT to penetrate deeper into tissue while the 500-840 nm band can be allocated for MPAM. The source is equipped with the ability to select the central wavelength as well as the spectral bandwidth. An energy of more than 35 nJ within a less than 50 nm

bandwidth is achieved on the sample for wavelengths longer than 500 nm. *In-vitro* mouse ear B-scan images are presented together with PAM are images in Fig. 2.

5. Dispersion measurement. The large bandwidth allows via a time domain OCT principle and an acousto-optic tunable filter (AOTF) to evaluate spatial difference between the position of coherence gate peaks at extreme wavelengths within the spectrum generated. This measurement leads directly to group velocity dispersion[11].
6. Time stretch capabilities. A SC operating at tens of MHz can act as an ultra fast swept source for OCT if equipped with a wavelength dependent delay element. It is known that SC pulse trains exhibit a large shot-to-shot fluctuation and poor temporal coherence[12] and this requires more studies for reducing the noise. Several principles have been reported recently for pulsed broadband lasers such as the breathing laser inertia free swept source (BLISS) at 1.06 µm, 28 MHz[13] and compact fibre lasers producing ultrashort pulses using semiconductor saturable absorber mirrors (SESAM)[14] for 2 µm emission at 50 MHz.

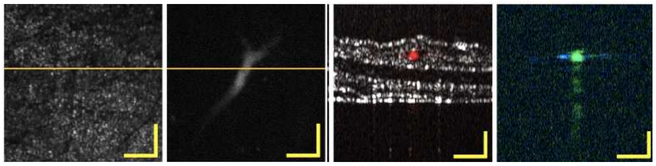
(a) (b) (c) (d)

Fig. 2. *In vitro* mouse ear (a) OCT summed voxel projection along axial direction for 2 mm in air, (b) PAM maximum amplitude projection at 550 nm with 50 nm bandwidth, (c) OCT B-scan, (c) superposition of OCT B-scan (grey) and PAM B-scan at 550 nm with 50 nm bandwidth (red), (d) superposition of PAM B-scans for bandwidths covering 500-600 nm and 600-840 nm (green and blue, respectively). Scale bar: 0.5 mm

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