High power supercontinuum generation by high-repetition-rate ultrashort pulse fiber laser for ultrahigh resolution OCT in 1600 nm spectral band

Masahito YAMANAKA[1], Hiroyuki KAWAGOE[1], and Norihiko NISHIZAWA[1]

[1]Dept. Quantum Engineering, Nagoya University, Japan
E-mail: yamanaka@nuee.nagoya-u.ac.jp

Optical coherence tomography is an imaging technique to allow non-invasive cross-sectional observations of micro-scale structures inside sample [1]. Typically, OCT systems are operated at 800-1300 nm spectral window, and the axial resolution is several to 15 µm, which is much higher than that of standard ultrasound imaging techniques. However, the penetration depth is restricted by the attenuation of ballistic light propagation via scattering and absorption by sample itself. For biomedical studies, it is important to improve the imaging depth as well as the spatial resolution, because observation targets are usually thick and it is often required to observe detailed structures below the sample surface to understand the life phenomena. The improvement of the penetration depth of OCT in water-rich biological samples is achieved by using longer wavelength such as 1600-1700 nm, because of the lower scattering coefficient and moderate water absorption loss at the wavelength range [2, 3]. 1550 and 1800 nm spectral bands also offer the comparable penetration depth with that in 1300 nm OCT system [4, 5]. In our group, we recently developed the high power, ultrabroad supercontinuum (SC) source in 1700 nm spectral band, and demonstrated ultrahigh-resolution (UHR) OCT imaging with the improved penetration depth [6, 7]. As described here, 1550-1800 nm spectral band is a good candidate for OCT imaging with high penetration depth.

To obtain high axial resolution in OCT, it is necessary to use light sources with broad spectral bandwidth. In addition, smooth and clean spectral shape is desirable for less artifacts in OCT imaging. In this report, we present the generation of a spectrally-smooth SC for UHR-OCT imaging in 1600 nm spectral band, and UHR-OCT imaging of biological samples with the developed SC.

As the seed pulse to generate a spectrally-smooth SC, we developed a high-repetition-rate, stretched-pulse, passively mode locked Er-doped fiber laser (Fig. 1 a). The stretched-pulse fiber laser scheme is useful for SC generation, because it can provide high-energy ultrashort pulses without additional optical amplifiers. In this experiment, to avoid excessive nonlinear effects inside fiber, the repetition rate was increased up to 182 MHz by shortening the cavity length. The output laser power was 65 mW. The pulse width of ~ 56 fs was achieved by the external chirp compensation using ~ 30 cm single mode fiber. Then, SC was generated by coupling the output pulses into normally dispersive, highly nonlinear fiber (ND-HNLF). The center wavelength of the generated SC was ~ 1578 nm and the spectral width (FWHM) was ~ 172 nm, as shown in Fig .1 b. The output power of the SC was ~ 51 mW. From this result, we confirmed that the SC with smooth spectral shape was successfully generated.

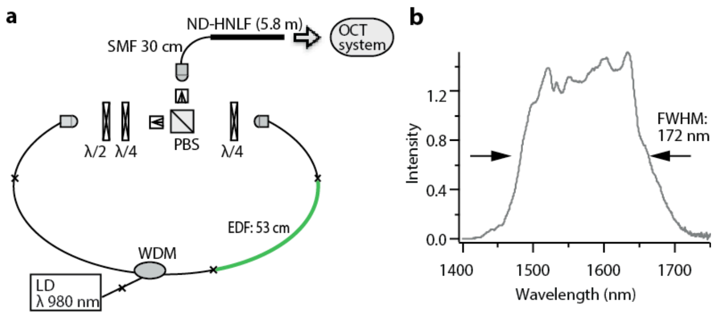

Fig. 1 (a) Experimental setup of the developed SC source and (b) optical spectrum of the SC

By using the developed SC source, we performed UHR-OCT imaging. In this experiment, the sensitivity was ~ 109 dB and the axial resolution was ~ 6.8 µm in air (~ 4.9 µm in tissue (n = 1.38)). Fig. 2 shows the UHR-OCT image of pig thyroid, which was fixed by paraformaldehyde. We confirmed that the detailed structure in pig thyroid is clearly visualized by UHR-OCT with the developed SC.

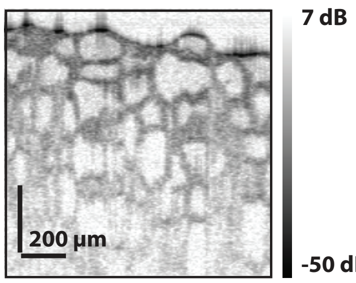

Fig. 2 UHR-OCT imaging of pig thyroid

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