7a) and a sliding average over 10 B-scans (Fig. 7b) reveals. This shows the potential of speckle and background noise reduction while imaging at high speed. For the scale bar we assumed a refractive index of 1.33 in axial direction. The skin images were recorded at the finger tip (Fig. 8a) and the nail fold (Fig. 8b). A sliding average over 3 frames resulted in a good reduction of background noise. We rescaled the images assuming a refractive index of 1.4. Clearly visible features are the border between the thick stratum corneum at the finger tip and the lower parts of the epidermis, as well as the cross-section through the nail-plate and the epidermis structure in the cuticle region.

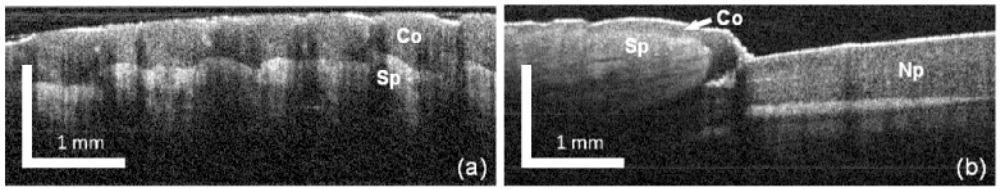

Fig. 8. OCT images of human skin in vivo. (a) Skin at the finger tip with a thick stratum corneum (Co) and a clearly visible border to the stratum spinosum (Sp). (b) Nail fold with a cross-section through the nail-plate (Np) and the epidermis structure in the cuticle region. The images are averaged over 3 frames.

4. Conclusion

We constructed an FDML swept source with a tapered amplifier as gain medium, sweeping bi-directionally at a repetition rate of 116 kHz with an average output power of more than 30 mW during the forward sweep. With a total sweep bandwidth of 70 nm, we achieved an axial resolution of 15 µm in air (11 µm in tissue). As the measured values for sensitivity (110 dB) and signal roll-off (3.4 dB/mm) indicate, the light source is suitable for OCT imaging, which we confirmed by acquiring a number of images.

We compared the light source performance using a standard single-mode fiber and a low-dispersion photonic crystal fiber as delay line. Although the effects of dispersion were clearly reduced with the PCF delay line, it did not improve the performance because of its high insertion loss. With the high gain of an auxiliary SOA, on the other hand, we exploited the full gain bandwidth of the tapered amplifier even with the dispersive standard fiber delay line.

These results bring two important insights for future swept source development. (1) Tapered amplifiers are suitable gain media, when high output power is required. (2) High gain counteracts the effects of dispersion in an FDML system and can help to maintain a high sweep bandwidth.

5. Future light source development

There are a number of possibilities both to improve our current swept source further and to continue research based on our results.

Due to the strong asymmetry of the output power between the two sweep directions, we used so far only the forward sweep for imaging. In other words, we operated with a 50% duty cycle. However, it would be straight forward to discard the backward sweep and to buffer the output in order to increase the A-scan to 233 kHz. Both outputs of the buffering stage would have sufficient power for OCT imaging (>7mW) without post-amplification.

One could also achieve a 100% duty cycle with full output power by using a tunable filter sweeping uni-directionally from low to high wavelengths. However, the fastest reported uni-directional sweep rate without buffering is 115 kHz [29]. In our case, we could therefore not increase the A-scan rate, only the exposure time. This could improve the imaging sensitivity, but at the same time, fringe wash-out effects due to sample motion might become stronger.

Even though the current configuration exploits the gain spectrum of the tapered amplifier very well, the sweep range can likely be broadened further by an adequate modulation of the

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SOA drive current. The tapered amplifier we used is among those with the broadest gain bandwidth currently available. However, tapered amplifiers with even broader bandwidth are likely to be developed, and better OCT depth resolution may thus become possible.

By improving the feedback to the tapered amplifier, one can achieve higher output power, and one may expect reduced intensity noise and higher sensitivity. One could, for example, use an SOA with higher saturation power or optimize the fiber-coupling. The integration of a tapered amplifier into a fiber-pigtailed package, as demonstrated by Haverkamp *et al.* [28], could make the setup very stable and compact. As confirmed by preliminary tests, higher output power is also possible by increasing the tapered amplifier drive current. However, the fiber-coupling efficiency for higher currents must be investigated, and care has to be taken that none of the components in the resonator takes damage.

Although the low-dispersion fiber did not lead to superior performance in this light source embodiment, it still remains of interest for future swept source development. It might become useful for FDML lasers with higher sweep range, which are more severely affected by dispersion. Further studies are necessary to determine how large an amount of dispersion can be tolerated with sufficient gain, before actual dispersion-compensation becomes necessary. It is also possible to use the PCF in a light source with higher sweep frequency, since a shorter delay line has lower insertion loss.

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