



# Kent Academic Repository

Klufts, M., Lotz, S., Bashir, M. A., Pfeiffer, T., Mlynek, A., Wieser, W., Chamorovskiy, A., Shidlovski, V., Podoleanu, Adrian G.H. and Huber, R. (2023) *Dual Amplification 850 nm FDML Laser*. In: *2023 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC)*. . IEEE

## Downloaded from

<https://kar.kent.ac.uk/102766/> The University of Kent's Academic Repository KAR

## The version of record is available from

<https://doi.org/10.1109/cleo/europe-eqec57999.2023.10232019>

## This document version

Author's Accepted Manuscript

## DOI for this version

## Licence for this version

UNSPECIFIED

## Additional information

© 2023 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

## Versions of research works

### Versions of Record

If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

### Author Accepted Manuscripts

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) 'Title of article'. To be published in **Title of Journal**, Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

## Enquiries

If you have questions about this document contact [ResearchSupport@kent.ac.uk](mailto:ResearchSupport@kent.ac.uk). Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our [Take Down policy](https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies) (available from <https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies>).

# Dual Amplification 850 nm FDML Laser

M. Klufits<sup>a</sup>, S. Lotz<sup>a</sup>, M. A. Bashir<sup>a</sup>, T. Pfeiffer<sup>b</sup>, A. Mlynek<sup>b</sup>, W. Wieser<sup>b</sup>, A. Chamorovskiy<sup>c</sup>, V. Shidlovski<sup>c</sup>, A. Podoleanu<sup>d</sup> and R. Huber<sup>a</sup>

<sup>a</sup>Institute of Biomedical Optics, University of Lübeck, 23562 Lübeck, Germany

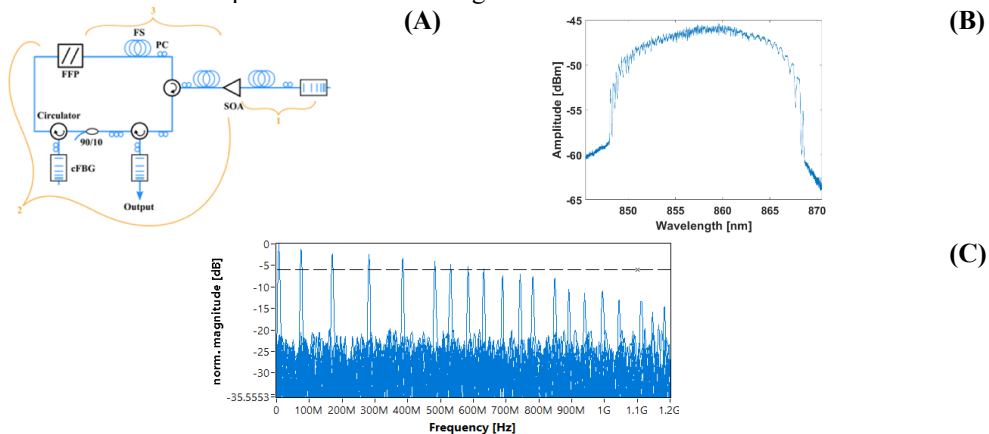
<sup>b</sup>Optores GmbH, 80339 Munich, Germany

<sup>c</sup>Superlum Diodes Ltd., Carrigtwohill, Cork T45 FC93, Ireland

<sup>d</sup>School of Physical Sciences, University of Kent, Canterbury, CT2 7NH, United Kingdom

Fourier domain mode locked (FDML) lasers have been widely used in optical coherence tomography (OCT) for many years at 1550 nm, 1310 nm and 1064 nm [1-4]. Developing a shorter wavelength FDML laser is interesting for eye imaging for instance, due to less water absorption and increased scattering which can improve the contrast of low scattering features.

In this work, we present an 850 nm FDML laser with a new cavity design enabling dual amplification of each sweep in a single round trip. Working at 850 nm becomes a challenge because of, for instance, high chromatic dispersion. In 780HP fiber at 850 nm the chromatic dispersion is three times larger than at 1064 nm, therefore for a dispersion compensation over 72 nm, several chirped Fiber Bragg Grating (cFBG) are necessary, together with the same number of circulators that leads to high losses. To compensate for the losses, a new design of an FDML laser was developed with the aim of performing dual amplification. In such a case the gain is higher, therefore it is expected that the relative intensity noise would improve to approach the value attainable by 1300 nm sources. In this new design the SOA is modulated in such a way that when the sweep from the inside ring is sent to the cFBG (on the right of the scheme, part 1 in Fig. 1 (A)), the SOA is switched on for initial amplification. Then the second amplification happens when the sweep is reflected back by the cFBG, the SOA is on again. Inversely, it is switched off when the sweep is circulating in the ring to prevent any parasitic lasing. The laser is sweeping over only 20 nm to avoid catastrophic optical damage (COD) threshold of the SOA as shown in Fig. 1 (B), we had to reduce the SOA current from 200 mA to 95 mA. Indeed, only one filter is present in the laser which imply that during the second amplification, not only the sweep is amplify but also the ASE which makes the inside power increasing near the COD. We will present different strategies to overcome this limitation.



**Fig. 1** Set-up (A) and spectrum (B) of the dual-pass SS FDML laser sweeping over 20 nm. (C) Sensitivity roll-off of more than 1.2 cm at -6 dB. SOA: semiconductor optical amplifier, PC: polarization controller, cFBG: chirped Fiber Bragg Grating, FFP: fiber Fabry-Pérot filter.

The remaining chromatic dispersion in the laser introduces noise in the laser which degrades its dynamic range to about 25 dB to 35 dB as shown in Figure 1 (C). Despite this, the dual-pass SOA FDML laser exhibits a 6 dB sensitivity roll-off of more than 1.2 cm delay, which is promising for current development steps. The roll-off was acquired using an Optilab 20 GHz balanced photodiode. In addition, based on the modulation of the SOA, with the FFP driven at 409 kHz, a sweep repetition rate of  $\sim 1.6$  MHz is possible by applying optical buffering. We acknowledge the Innovative Training Networks NExt generation of Tunable LASer for OCT (ITN-NETLAS) program of the Marie Skłodowska-Curie actions (H2020- EU.1.3.1., grant agreement no. 860807).

## References

- [1] R. Huber, D. C. Adler, V. J. Srinivasan, and J. G. Fujimoto, "Fourier domain mode locking at 1050 nm for ultra-high-speed optical coherence tomography of the human retina at 236,000 axial scans per second," *Opt Lett*, 32(14), 2049-51 (2007).
- [2] R. Huber, M. Wojtkowski, and J. G. Fujimoto, "Fourier Domain Mode Locking (FDML): A new laser operating regime and applications for optical coherence tomography," *Opt Express*, 14(8), 3225-37 (2006).
- [3] T. Klein, W. Wieser, C. M. Eigenwillig, B. R. Biedermann, and R. Huber, "Megahertz OCT for ultrawide-field retinal imaging with a 1050 nm Fourier domain mode-locked laser," *Opt Express*, 19(4), 3044-62 (2011).
- [4] J. P. Kolb, T. Klein, C. L. Kufner, W. Wieser, A. S. Neubauer, and R. Huber, "Ultra-widefield retinal MHz-OCT imaging with up to 100 degrees viewing angle," *Biomed Opt Express*, 6(5), 1534-52 (2015).