Simple and Compact Carrier-Envelope-Phase Stabilized Ti:sapphire Laser

Jinghua Sun[1], Derryck T. Reid[1], Lukasz Kornaszewski[2], Bill Miller[2] and Graeme P. A. Malcolm[2]

1. *SUPA, Dept. of Physics, School of Engineering and Physical Sciences, Heriot-Watt University, Riccarton, Edinburgh EH14 4AS, UK*
2. *M Squared Lasers Ltd, 1 Technology Terrace, Todd Campus, West of Scotland Science Park, Maryhill Road, Glasgow, G20 0XA, UK*

Abstract

Many applications exist for simple, compact and portable frequency-combs, potentially benefitting users in high-resolution spectroscopy, astro-photonics, optical frequency metrology, precision distance metrology, coherent spectroscopy, time and frequency transmission, etc [1]. Although combs from fibre oscillators have achieved sub-mHz linewidth [2] – similar to solid-state lasers – their output power, tunability and mode-spacing are still limited. For these reasons, Ti:sapphire combs based on an emerging class of low-noise miniature 532-nm lasers are still competitive in compact frequency comb systems. Here we report a demonstration of an extremely simple carrier-envelope-phase (CEP) and repetition rate stabilized Ti:sapphire laser, which occupies a footprint of only 300 x 550 mm when using just commercially available discrete opto-mechanics, including CEP-stabilization hardware.

Ti:sapphire laser

A very compact green laser, OPUS, from Laser Quantum was used as the pump source for the Ti:sapphire laser. Using 4.3 W cw pump power, the Ti:sapphire laser generated 700 mW modelocked output power with pulse durations of 25fs.

The Ti:sapphire laser (Figure 1.(a)) adopted a ring cavity and mirror-based dispersion compensation scheme, which benefit from high-repetition-rate operation and long term stability. A ring cavity also offers much better immunity to optical feedback, so no optical isolator is needed after the Ti:sapphire laser [3]. A pair of fused-silica wedges was used for carrier-envelope offset adjustment. One slow PZT transducer was mounted at the back of the small chirped mirror for repetition rate locking.

Typically 60% of the Ti:sapphire laser power was coupled into the photonic crystal fibre (PCF) for one-octave super-continuum generation. 40% of the Ti:sapphire power (280 mW) and >100 mW super-continuum power were available for downstream applications. A sufficiently broad supercontinuum was also achievable by using only 50% of the laser output power.

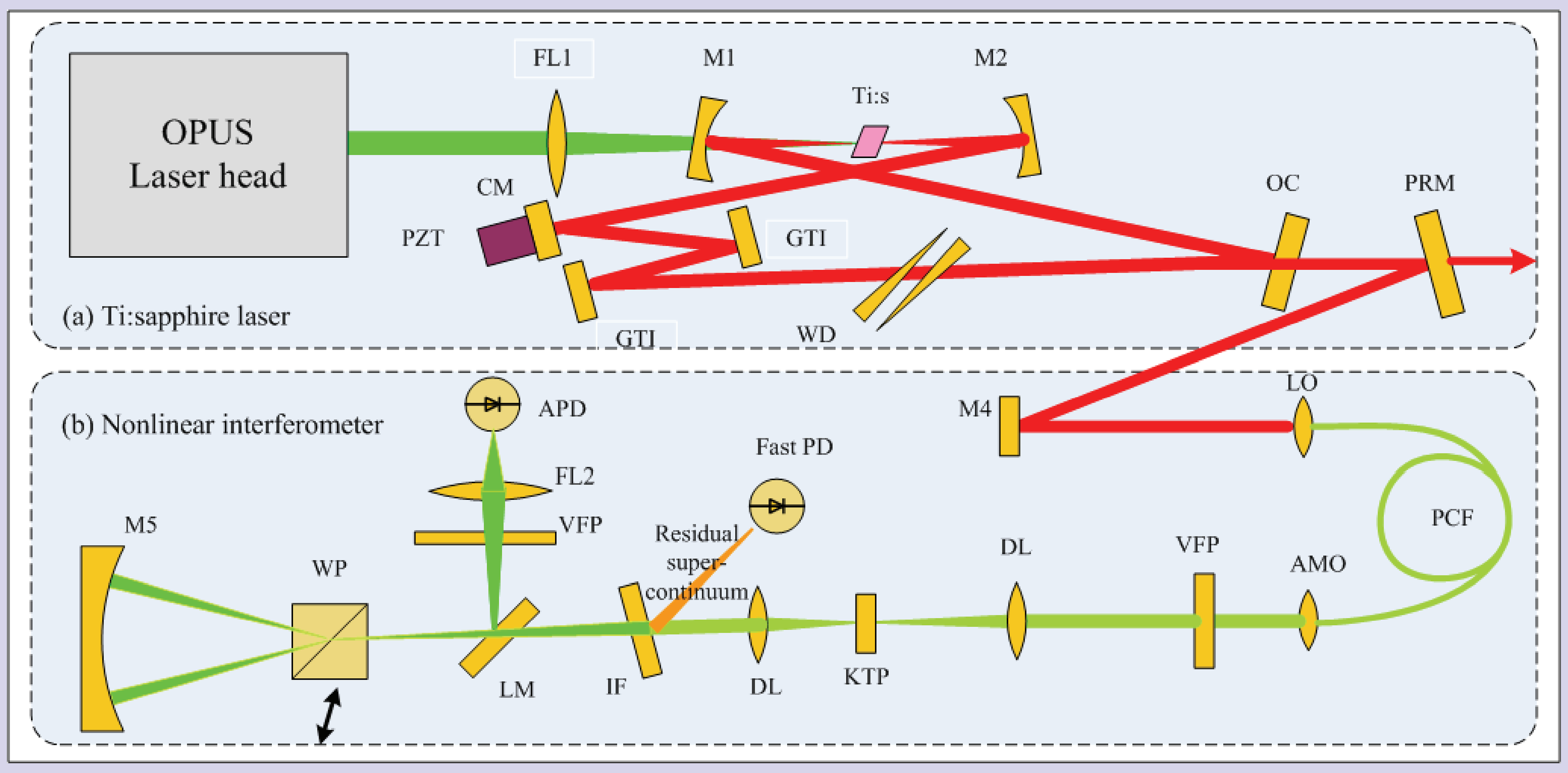

Figure 1: Optical layout of the experiment. CM, chirped mirror; OC, output coupler; LO, laser objective; AMO, achromatic microscope objective, VFP, visible film polarizer; DL, doublet lenses; IF, interference filter; LM, lower mirror; WP, Wollaston prism; APD, avalanche photodiode.

CEP stabilization system

CEP-stabilization was implemented using a common-path Wollaston-prism-based nonlinear interferometer [4] (Figure 1. (b)), which provides an extremely simple, compact and robust means of deriving the carrier-envelope offset (CEO) frequency. The CEO-frequency is mixed with a 10-MHz reference frequency in a digital phase-frequency detector, resulting in an error signal which is used to control the CEO frequency by modulating the power of the Ti:sapphire pump laser. In contrast to other CEP-stabilized Ti:sapphire lasers, we do not use any external modulator (e.g. an acousto-optic, electro-optic modulator or end mirror after prism pair) to control the CEP, but instead we use the error signal to directly modulate the current of the laser diode inside the 532-nm pump laser(Figure 2). This approach achieves a modulation bandwidth of 30 kHz, which is more than enough to ensure CEP-locking.

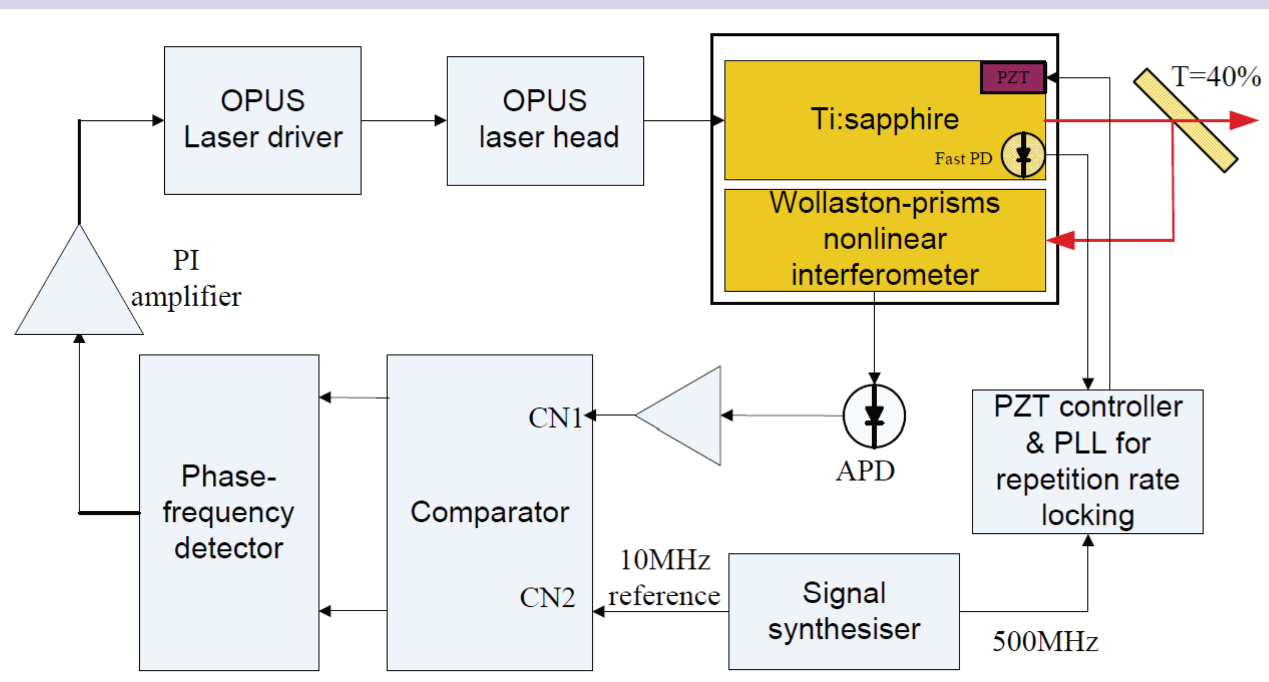

Figure 2: Schematic of the electronic control system for the CEP and repetition rate locking.

Experiment results

Due to the compact ring cavity design, the laser system had very good passive stability. The mode-locked operation was regularly stable for more than 2 hours without an enclosure and in a optics laboratory without clean room. CEP locking was typically stable for 30 minutes without adjustment. With a simple Perspex box covering, the laser system became very quiet, and the free running CEP beat signal measured by the APD had a jitter of less than 100 kHz in 10 seconds, and maintained its absolute frequency within +/- 1 MHz in one hour. With an enclosure, the CEP locking could be maintained for more than one hour.

The repetition rate was locked to an external reference at 500 MHz from a RF signal synthesiser by controlling the PZT in the Ti:sapphire cavity using a slow PLL with 1.5-kHz bandwidth. The CEO frequency was locked to the 10-MHz reference output from the signal synthesiser by controlling the OPUS diode current directly. The CEP locking result had a 12-Hz bandwidth at -3dB when measured with a spectrum analyzer (Rigol DSA1030A) with a 10-Hz RBW (see Figure 3).

The locked signal from the phase-frequency detector was recorded by a 12-bit A/D data acquisition card, and the power spectral density (PSD) analysis of the recorded error signal shows 0.57 rad accumulated phase error in 1 second, integrated up to 2 MHz, which is limited by our A/D card (Figure 4). The trend of the PSD suggests a longer coherent time than 1s. The higher accumulated phase error and the higher high-frequency noise comparing to our previous research [3] may be caused by the pump source we used in this experiment in contrast with the previously used Verdi.

The CEP locking result was recorded at when the repetition rate was not locked, but the slower bandwidth of the repetition frequency lock means that it should not reduce the quality of the CEP locking.

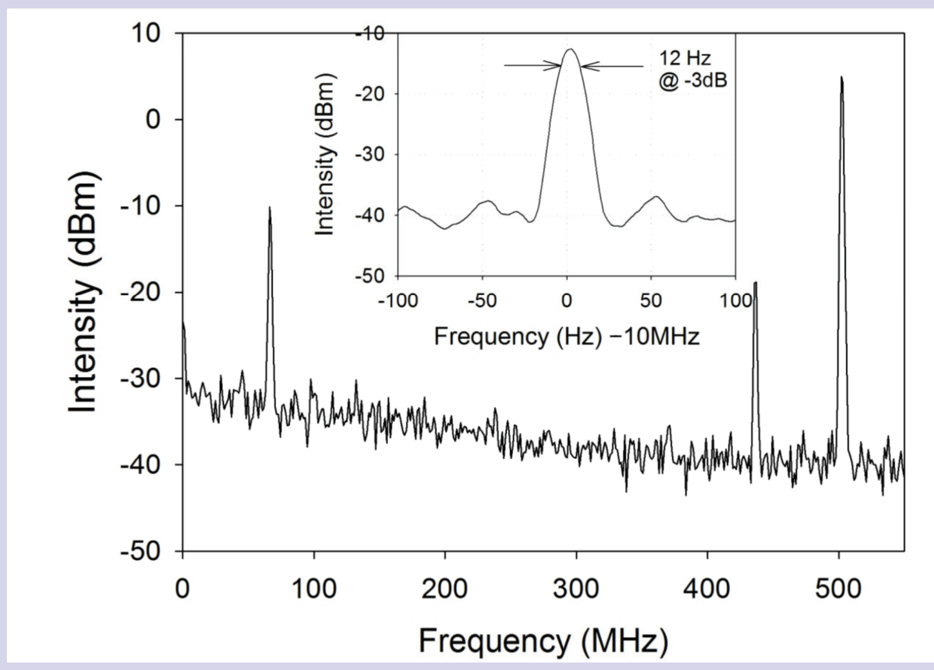

Figure 3: The CEO frequency of the Ti:sapphire laser. The main figure has a RBW of 1MHz and the CEP was not locked and was adjusted far from 10 MHz so that it was clearly visible on a wide span. The inset figure is the locked CEO frequency measured by a RF spectrum analyser with 10-Hz RBW, which shows a 12-Hz bandwidth at the -3dB level.

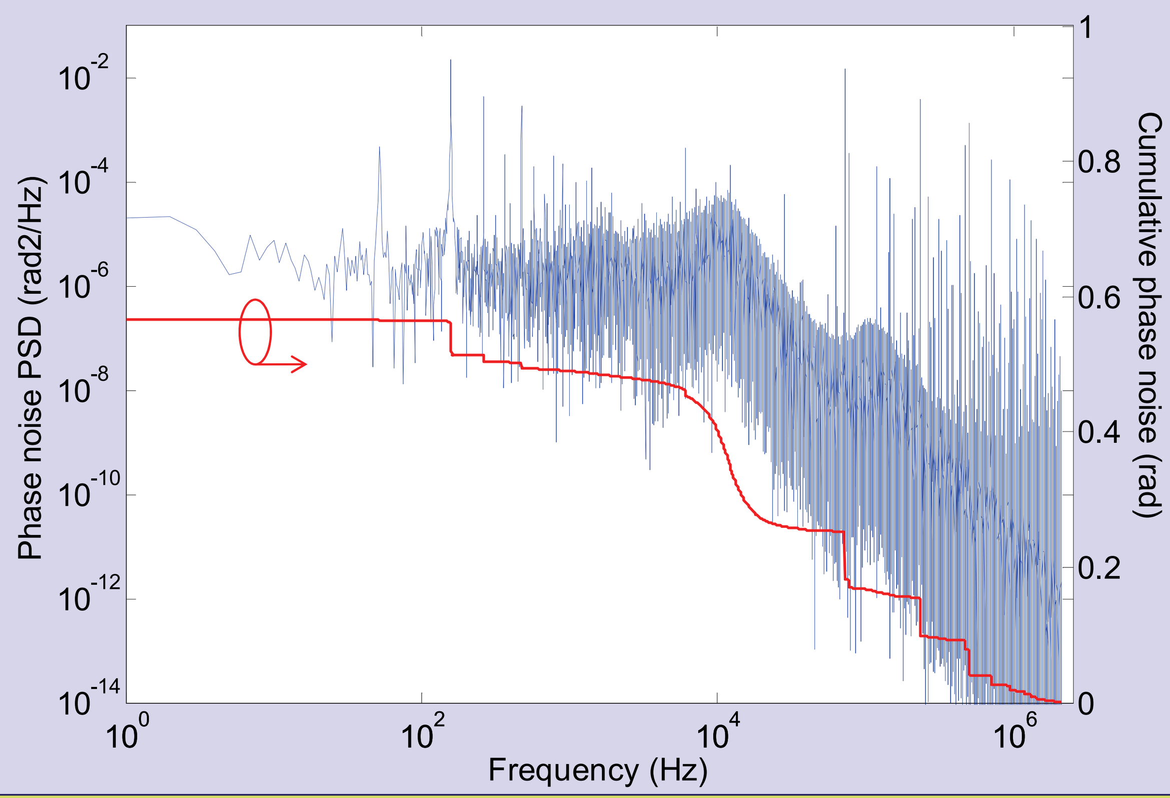

Figure 4: The power spectrum density analysis of the locked signal from the phase-frequency detector. The accumulated phase error in 1s is 0.57 rad.

Conclusion

We have demonstrated a very simple and compact Ti:sapphire-laser-based ultrafast optical frequency comb by using a very compact green pump laser, a ring-cavity design and a common-path Wollaston-prism-based nonlinear interferometer. The system showed long term stability (longer than one hour in prototype), narrow locked bandwidth (12 Hz, which is limited by the measuring instrument) and a long CEP coherence time (more than 1s).

References

[1] J. Ye and S. T. Cundiff, "Femtosecond optical frequency comb: principle, operation and application", Springer, 2005.

[2] T. R. Schibli, I. Hartl, D. C. Yost, et al. Nat. Photonics, **2**, 355 (2008)

[3] T. I. Ferreiro, J. Sun and D. T. Reid, Opt. Letters, **35**, 1668 (2010)

[4] V. Tsatourian, H. S. Margolis, G. Marra, D. T. Reid, and P. Gill, Opt. Lett., **35**, 1209 (2010)