Turnkey 1 GHz Ti:sapphire frequency comb with enhanced off-set locking bandwidth

Laser QUANTUM
INNOVATIVE RELIABLE INTELLIGENT

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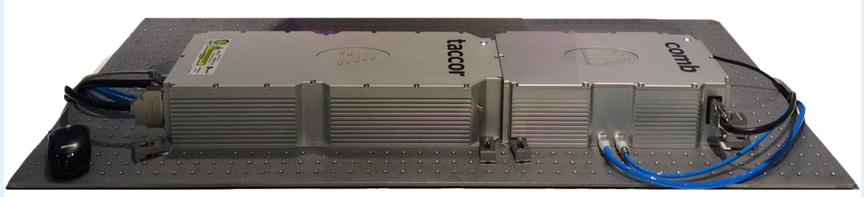
Introduction

In the early days of the frequency comb, mode-locked Ti:sapphire lasers were the dominant light sources serving this ground-breaking technology [1-3]. Amongst them, those with a repetition rate (f_R) around 1 GHz were often favored over systems near 100 MHz due to their larger mode spacing, higher average power coherent supercontinuum output and consequently higher power per mode [2-3]. With maturing fiber laser technology, Ti:sapphire lasers were later rivaled by mode-locked Er or Yb doped fiber lasers offering more user-friendliness with less need for frequent intervention. Although fiber lasers are not generally available at f_R> 250 MHz, more recently their turn-key functionality made them the preferred choice in many applications. To combine the benefits of maintenance free long-term operation with those having a high repetition rate and high power at 800 nm, we have developed a new 1 GHz turn-key Ti:sapphire laser. It is built in a hermetically sealed housing and is capable of continuous operation for many thousands of hours delivering more than 1.8W of average output power. Here we emphasize the application of this laser towards generation and stabilization of frequency combs. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 605057.

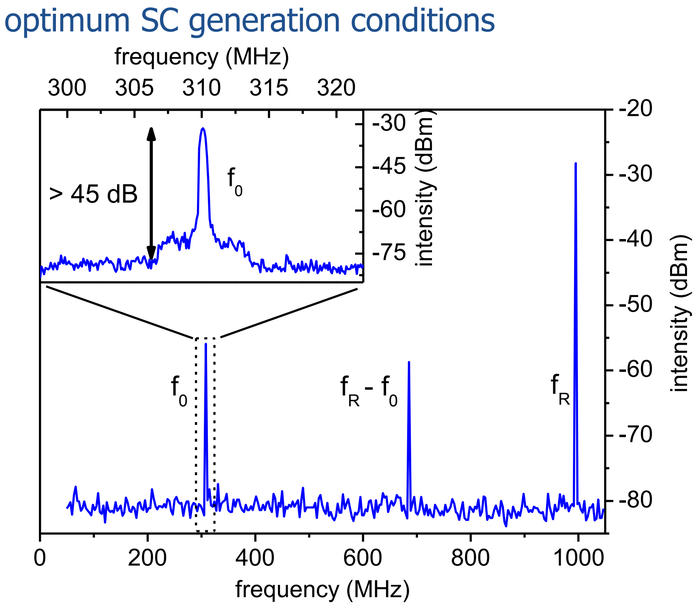
Maintenance free Ti:sapphire laser **taccor**

- True hands-off turn-key laser system at 1 GHz repetition rate f_R
- Self-locking and maintaining, delivering optical pulses down to sub-15 fs
- High stability and continuous operation for many thousands of hours due to hermetically sealed housing
- Integrated pump laser separating the pump diodes from the laser head and thus isolating temperature effects
- Output power up to 1.8W at 800 nm or as a tuneable version with automatic tuning between 740 - 930 nm



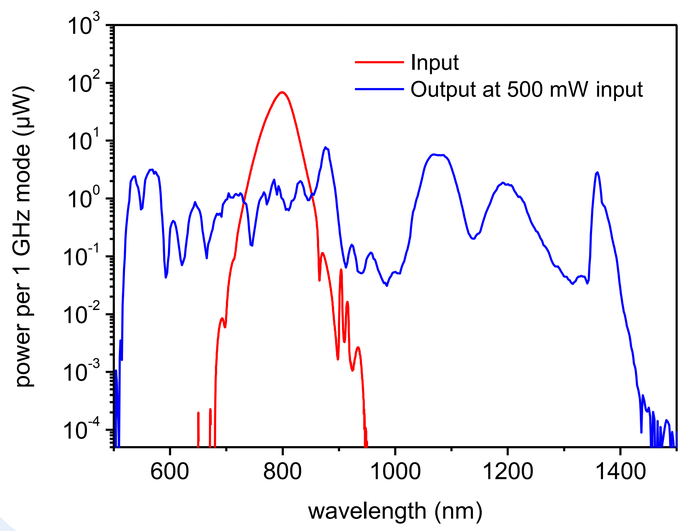
Small footprint f-2f interferometer

- The extension module consists of a matched mirror pair for dispersion compensation, a photonic crystal fiber (PCF) for supercontinuum generation (SC) and a nonlinear f-2f interferometer
- It delivers a long-term stable (>100 hours) RF signal at the carrier-envelope offset frequency f_0 with more than 45 dB signal-to-noise ratio at a 300 kHz resolution bandwidth (RBW)
- For longer operation hours internal piezo mirrors maintain the coupling to the PCF and thus optimum SC generation conditions

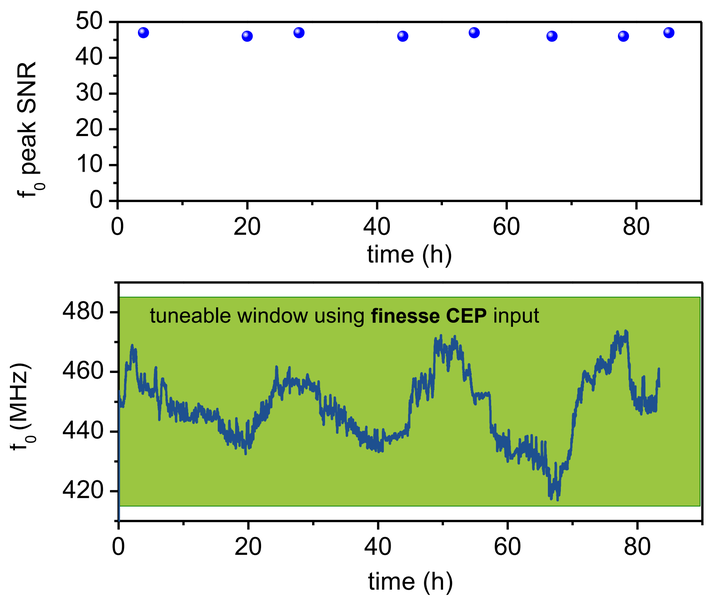


Advantages of the high repetition rate at 1 GHz

- Superior power per mode
- Coherence of a frequency comb broadened using PCFs limited to a few 100 pJ [4], resulting in a 100 fold advantage compared to conventional 100 MHz systems
- Easy identification of the mode number due to large spacing of adjacent comb modes
- Small dead-time in dual comb FTIR, CARS or similar applications due to shorter pulse-to-pulse separation



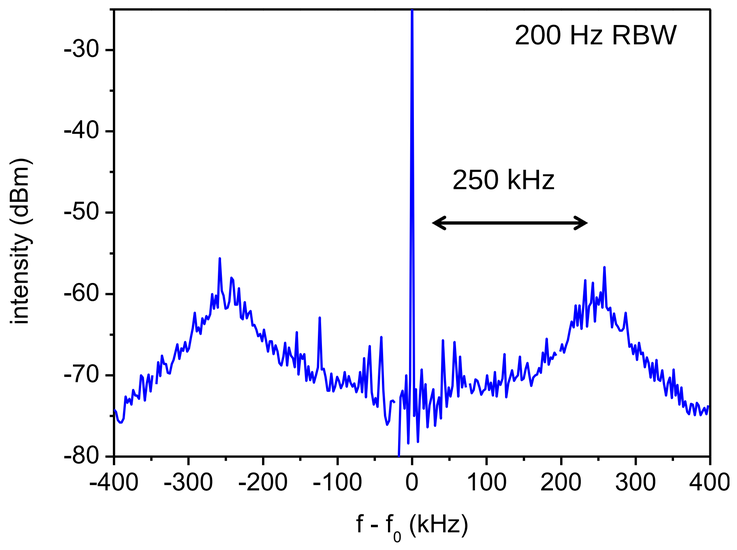
f_0 long term evolution of an unstabilized **taccor**



Indefinite working hours due to long term stability without realignment and tuneability of f_0 with

- 14 MHz/K in the range 22-28°C of the **taccor** housing temperature
- 10 MHz/100mW of the **finesse** 532 nm pump power

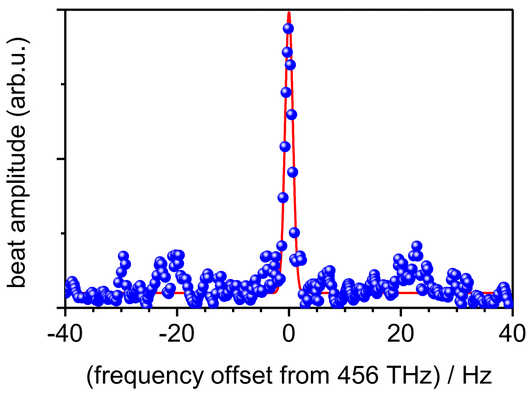
Stabilized **taccor** showing the large bandwidth



- Phase locking achieved by directly feeding back to the current for the pump diodes of the 532 nm solid-state pump laser **finesse**
- The **finesse CEP** input enables a high modulation bandwidth of 250 kHz, a factor of 3-5 higher compared to using e.g. an AOM
- The bandwidth can be pushed further and is limited to below 700 kHz where the phase response exceeds 90°

Laser mode linewidth measurements

- Optical frequency measurements down to 10^{-19} accuracy with stability at the 10^{-17} level in 1s of averaging time and mode linewidths below 1 Hz [5,6]



- Heterodyne beat between two ultrastable cw lasers at 532 THz and at 456 Thz via a Laser Quantum 1 GHz Ti:sapphire laser (graph recorded at NIST [6])

References

[1] T. Udem *et al.*: „Absolute frequency measurements of the Cesium D_1 line with a mode-locked laser", Phys. Rev. Lett. **82**, 3568 (1999).
[2] S. Diddams *et al.*: „An optical clock based on a single trapped $199Hg^+$ ion", Science **293**, 825 (2001).
[3] R. Holzwarth *et al.*: „Optical frequency synthesizer for precision spectroscopy", Phys. Rev. Lett **85**, 2264 (2000).
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[5] L.-S. Ma *et al.*: „Optical Frequency synthesis and comparison with unvertainty at the 10-19 level", Science **303**, 1843 (2004).
[6] A. Bartels *et al.*: „Stabilitsation of femtosecond laser frequency combs with subhertz residual linewidths", Opt. Lett. **29**, 1081 (2004).