Frequency Comb Self-Referencing using an Intra-Cavity SESAM as Fast Opto-Optical Modulator

Stéphane Schilt, Martin Hoffmann, Thomas Südmeyer

Laboratoire Temps-Fréquence, Université de Neuchâtel, Neuchâtel, Switzerland

Email: stephane.schilt@unine.ch

Diode-pumped solid-state lasers (DPSSLs) have emerged for a few years as a promising alternative technology to Ti:sapphire oscillators and fiber lasers for frequency comb generation. A critical step for the use of a new ultrafast laser technology as a frequency comb is its ability to be self-referenced, i.e., to phase-stabilize the carrier-envelope offset (CEO) frequency f_{CEO}. The standard method for CEO stabilization is by gain modulation, which is conveniently done by directly modulating the pump diode current in fiber lasers and DPSSLs. However, the modulation bandwidth is limited by the upper state lifetime of the gain material, which is in the ms range for common material like Er or Yb. This limits the overall feedback bandwidth achievable for CEO stabilization, and may prevent achieving a tight in the case of a too noisy free-running CEO beat. Recently, a graphene electro-optical modulator (EOM) with MHz modulation bandwidth was used to stabilize f_{CEO} in a Tm-fiber similariton oscillator [1], but intra-cavity graphene EOMs do not appear well-suited for DPSSLs stabilization due to their relatively high non-saturable losses (currently 5%).

We present here a novel method for CEO frequency control that combines high bandwidth with low loss, low nonlinearity, and low dispersion [2]. It makes use of intra-cavity opto-optical modulation (OOM) consisting of a semiconductor saturable absorber mirror (SESAM), which is anyway present in the laser cavity to initiate the modelocking, additionally pumped by a telecom-grade continuous wave laser diode for CEO frequency control. In a proof-of-principle experimental demonstration, we implemented this method in a femtosecond Er:Yb:glass laser oscillator that was previously self-referenced using standard gain modulation with pump current control [3]. We show great improvement with the new SESAM-OOM compared to standard gain modulation in terms of modulation bandwidth (by one order of magnitude), residual integrated phase noise (63 mrad vs 720 mrad at 1 Hz - 100 kHz) and relative frequency stability (by a factor of 4) as shown in Fig. 1.

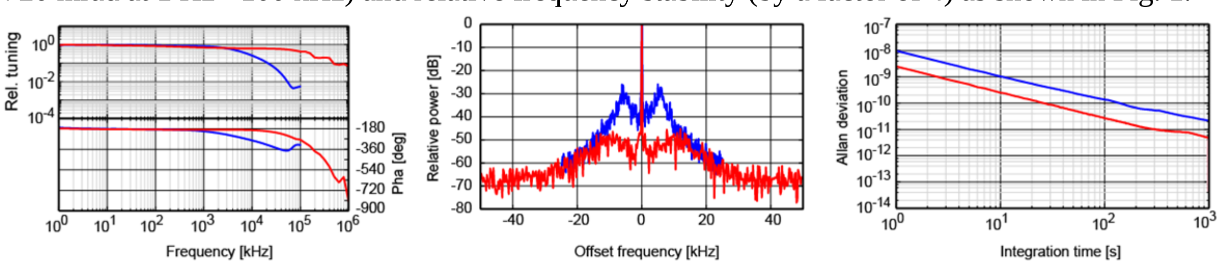

Fig. 1: Comparison of the new SESAM-OOM (red curves) with previous results obtained by pump current feedback (blue curves) for CEO stabilization. (a) f_{CEO} transfer function. (b) CEO RF spectrum. (c) Allan deviation.

These first results show the large potential of optically-pumped SESAMs for frequency comb self-referencing. With the short recombination time of semiconductor absorbers in the ps range, high modulation bandwidths can be achieved with this method. Combined with the low dispersion, thermal lensing, and losses, our technology is expected to contribute to the future CEO stabilization of novel high-power or high repetition rate ultrafast lasers requiring multi-transverse mode pump diodes that induce higher CEO noise, such as high-power thin disk lasers [4] or GHz-lasers.

[1] C.-C. Lee, et al., Opt. Lett. 37, 3084-3086 (2012).
[2] M. Hoffmann, et al., Opt. Express 21, 30054-30064 (2013).
[3] S. Schilt, et al., Opt. Express 19, 24171-24181 (2011).
[4] A. Klenner, et al., Opt. Express 21, 11 (2013).