Efficient Femtosecond Laser Stabilization via Stimulated Emission

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A novel scheme for intra-cavity control of the carrier-envelope offset frequency of a 100-MHz mode-locked Er:Yb:glass diode-pumped solid state laser based on the modulation of the laser gain via stimulated emission of the excited Er^{3+} ions is demonstrated. This method makes it possible to bypass the ytterbium-system few-kHz low-pass filter in the f_{CEO} stabilization loop and thus to push the phase lock bandwidth up to a limit close to the frequency of the relaxation oscillations of the erbium system. A phase lock bandwidth above 70 kHz has been achieved with the fully stabilized laser, leading to a low noise stabilized frequency comb.

Optical frequency combs (OFCs) constitute an essential tool for time and frequency metrology and optical spectroscopy applications today.[1] This requires fully stabilized combs, implying that both the repetition rate (f_{rep}) and the Carrier-Envelope-Offset (CEO) frequency (f_{CEO}) are stabilized. f_{rep} stabilization is usually implemented by acting on the laser cavity length via different techniques, enabling large stabilization bandwidths. Feeding back the phase error signal from an *f*-to-2*f* interferometer to the laser pump power is a standard way to stabilize f_{CEO}. However, here the phase lock bandwidth is limited by the stimulated lifetime of the gain medium. Achieving a large phase f_{CEO} lock bandwidth is of high importance for Er:Yb:glass diode-pumped solid state lasers (DPSSLs), since they have demonstrated very low timing jitter figures [2], making them particularly interesting for reference frequency distribution through telecom fibers and ultra-low phase noise microwave generation [3].

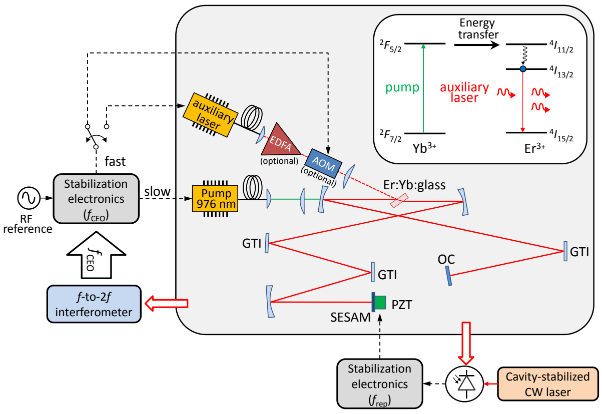

Figure 1: Schematics of the femtosecond DPSSL architecture with the external modulation laser source acting on the laser Er^{3+} transition of the Er:Yb:glass gain medium for stabilization of f_{CEO}. $\lambda_{emission}$ = 1554 nm, f_{rep} = 100.05 MHz, pulse duration: 165 fs (transform-limited). (Inset) Energy diagram of the Er:Yb:glass system with stimulated emission modulation of the gain from the auxiliary laser.

Here,[4] a new approach to intra-cavity CEO stabilization in an Er:Yb:glass DPSSL emitting at telecom wavelength (Figure 1) has been demonstrated. A direct action on the population inversion between the lower and upper states of the Er^{3+} ions (energy diagram in the inset of Figure 1) makes it possible to extend the f_{CEO} feedback bandwidth via a bypass of the few-kHz cut-off frequency low-pass filter induced by the excited Yb^{3+} ion decay rate. This was achieved through stimulated emission induced by an external laser source emitting at a wavelength lying within the transition linewidth in order to depopulate the excited Er^{3+} state.

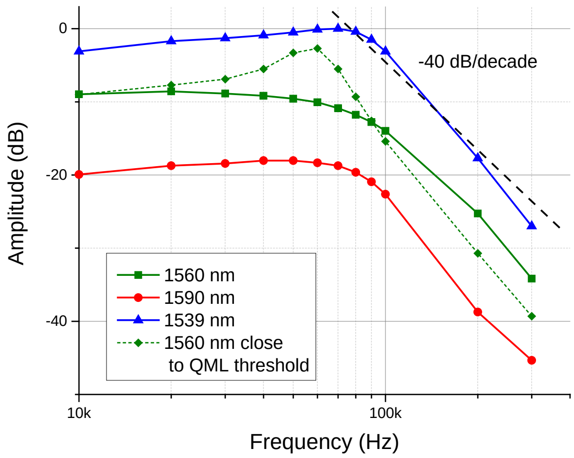

Figure 2: Transfer function of the auxiliary laser power to femtosecond laser output power with 100% modulation depth, rescaled. For 1560 nm, the transfer function (arbitrarily offset) close to the QML threshold shows a typical oscillation relaxation resonance at about 57 kHz.

This gain modulation principle was tested by measuring the transfer function of the auxiliary laser power to the femtosecond laser output power (f_{CEO} is directly linked to intra-cavity power fluctuations). The features of the results displayed in Figure 3 indicate that the energy transfer low pass filter has been suppressed and that the global transfer function is now reduced to a second-order low-pass filter corresponding to the three-level-laser transfer function of the Er^{3+} system.

Using the full stabilization scheme (f_{rep} and f_{CEO}) described in Figure 1 (elements outside the grey rectangle), a phase lock bandwidth above 70 kHz has been demonstrated, leading to a state-of-the-art in-loop integrated phase noise [1 Hz – 1 MHz] of 120 mrad.

[1] N. R. Newbury, "Searching for applications with a fine-tooth comb", Nat. Photonics 5 (2011) 186.

[2] E. Portuondo-Campa, R. Paschotta, S. Lecomte, "Sub-100 attosecond timing jitter from low-noise passively mode-locked solid-state laser at telecom wavelength", Opt. Lett. 38 (2013) 2650.

[3] E. Portuondo-Campa, G. Buchs, S. Kundermann, L. Balet, S. Lecomte, "Ultra-low phase-noise microwave generation using a diode-pumped solid-state laser based frequency comb and a polarization-maintaining pulse interleaver", Opt. Express 23 (2015) 32441.

[4] L. Karlen, G. Buchs, E. Portuondo-Campa, S. Lecomte, "Efficient carrier envelope offset frequency stabilization through gain modulation via stimulated emission", Opt. Lett. 41 (2016) 376.