Sub 15 ps Self Mode-Locked Nd:YVO$_4$ Laser through Intra-Cavity Sum-Frequency Mixing

Martin Brunzell, Max Widarsson, Fredrik Laurell and Valdas Pasiskevicius
Department of Applied Physics, Royal Institute of Technology, Roslagstullsbacken 21, 106 91 Stockholm, Sweden

Ultrafast lasers have proven to be a great asset in many fields such as biological imaging [1], high-precision machining [2] and nonlinear spectroscopy [3]. This has resulted in a great interest in the further development of passive mode-locked sources. The most common passive mode-locking techniques today rely on semiconductor saturable absorbers (SESAM) [4] or other artificial saturable absorbers, such as Kerr lensing [5]. While these methods are well established, they still have issues with the durability of the SESAM or the need to reach sufficient intensities for reliable operation of the Kerr lens mechanism.

In this work we present a new mechanism for passively mode-locking solid-state lasers using intra-cavity sum-frequency mixing (SFM). The underlying idea is to have two laser cavities with a shared section in which a nonlinear crystal is placed. The nonlinear medium phase-matches the SFM between the two operating wavelengths. By matching the roundtrip time of the two cavities, the same temporal part of the light in the two cavities will always interact. This forces one of the lasers to form a dark pulse and the other a bright pulse. Advantages of this approach is that it works for high repetition rates, can be used for any wavelengths in the transparency window for the nonlinear material and is easy to setup. Moreover, the phase-mismatched frequency doubling in the same crystal might infer cascaded $\chi^{(2)}$:$\chi^{(2)}$ Kerr mechanism which could lead to spectral broadening and solitary mode-locking regime.

The setup is shown in Fig. 1, where two Nd:YVO$_4$ lasers resonate in a folded y-cavity, one operating at 1064 nm and the other at 1342 nm. In the shared section of the cavity a periodically poled nonlinear RKTP crystal is placed which is quasi-phase matched (QPM) for SFM between the two lasing wavelengths.

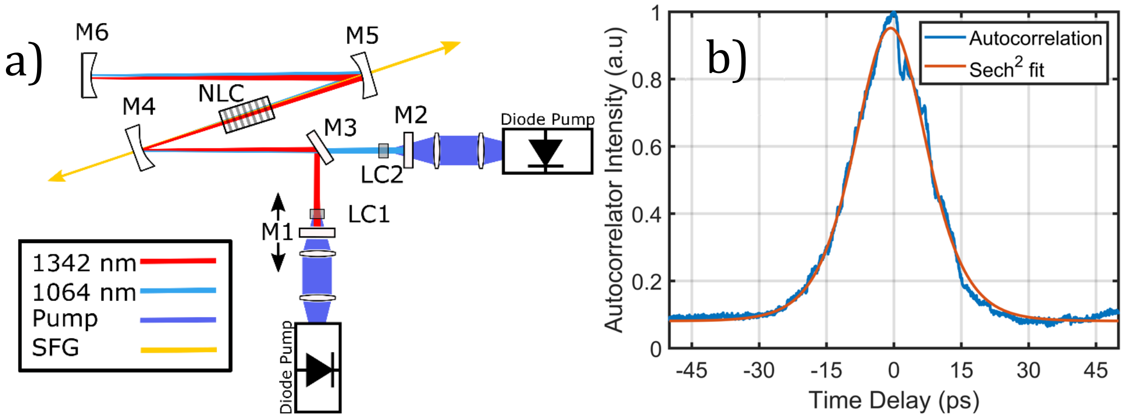

Fig. 1 a) Shows a schematic of the setup used. Where LC1 = Nd:YVO$_4$ with AR coating for 1342 nm, LC2 = Nd:YVO$_4$ with AR coating for 1064 nm, M1-M6 = mirrors for the two laser cavities, and NLC = PPRKTP with a period of 12.65 µm. Both lasers were pumped by an 808 nm laser diode. **b)** Autocorrelation of the 1064 nm pulse train, where the sech^2 fit has a FWHM of ~20 ps corresponding to a pulse width of ~13 ps.

When operating the laser, it was clear that the preferred wavelength for bright pulses was 1064 nm. One possible explanation is that in the 1064 nm laser we expect modulation instability (MI) and possible soliton formation due to action of the negative cascaded Kerr nonlinearity in the normal group velocity dispersion environment. Analysis shows that the effective Kerr nonlinearity is positive at 1342 nm. When using an output coupler of 0.4 % for the 1064 nm cavity and no output coupler for the 1342 nm cavity, a pulse width of ~13 ps was measured, see Fig.1. b. The mode-locked output power at 1064 nm was 102 mW with a repetition rate of 276 MHz.

References

[1] D. Yelin and Y. Silberberg, "Laser scanning third-harmonic-generation microscopy in biology," Opt. Express **5**, 169-175 (1999)
[2] Jian Cheng, Chang-sheng Liu, Shuo Shang, Dun Liu, Walter Perrie, Geoff Dearden, & Ken Watkins, "A review of ultrafast laser materials micromachining," Optics & Laser Technology, **46**, 88-102 (2013).
[3] A. Major, F. Yoshino, J.S. Aitchison, and P.W.E Smith, "Ultrafast nonresonant third-order optical nonlinearities in ZnSe for photonic switching at telecom wavelengths". Applied Physics Letters, **85**(20), 4606-4608 (2004).
[4] U. Keller et al., "Semiconductor saturable absorber mirrors (SESAM's) for femtosecond to nanosecond pulse generation in solid-state lasers," in IEEE Journal of Selected Topics in Quantum Electronics, **2**(3),435-453 (1996).
[5] T. Brabec, Ch. Spielmann, P. F. Curley, and F. Krausz, "Kerr lens mode locking," Opt. Lett. **17**, 1292-1294 (1992)