

Single-frequency and Kerr-Lens Mode-locked Nd:YLF/ppKTP Ring Laser

F. Camargo², T. Zanon-Willette¹, T. Badr¹, N.U. Wetter² and J.-J. Zondy^{1*}

¹Institut National de Métrologie, Conservatoire National des Arts et Métiers, 61 rue du Landy, F-93210 La Plaine Saint-Denis, France.

²Instituto de Pesquisas Energéticas e Nucleares, Av. Lineu Prestes 2242, CEP 005508-000 São Paulo, Brazil.

*Corresponding author e-mail : jean-jacques.zondy@cnam.fr

Recently, a continuous-wave (cw) diode-pumped intra-cavity frequency-doubled Nd:YLF ring laser oscillating on the σ -polarized transition ($\lambda_0=1314\text{nm}$) and employing a temperature-tuned periodically-poled KTP (ppKTP) nonlinear crystal has been reported to generate up to 0.92W single-frequency red output power [1]. When the ppKTP was strongly phase-mismatched, evidence of passive cascaded Kerr-lens mode locking (KLM) was inferred from a broad phase-coherent spectrum analyzed by a confocal Fabry-Perot interferometer. In this work, we demonstrate indeed that complex cascaded second-order nonlinear processes occurring inside the ppKTP crystal are responsible of the KLM operation of a π -polarized ($\lambda_0=1321\text{nm}$) Nd:YLF/ppKTP ring laser (Fig.1), over the full range of the ppKTP temperature tuning ($15^\circ\text{C}<T<75^\circ\text{C}$). While the ppKTP phase-matching temperature for the gain center wavelength occurs at $T\sim 25\text{-}30^\circ\text{C}$ (with a FWHM temperature bandwidth $\Delta T_{\text{PM}}=10^\circ\text{C}$ and spectral bandwidth $\Delta\lambda_{\text{PM}}=0.8\text{nm}$ for $L=10\text{mm}$), significant broadband ($\Delta\lambda_{2\omega}\leq 1\text{nm}$) red average power ($<100\text{mW}$) is measured from intra-cavity SHG over the above full temperature variation. The preliminary analysis of the laser emission versus the ppKTP temperature or versus the intra-cavity power demonstrates unambiguously the tendency to cascaded KLM effects, which threshold occurs at about 5W of diode pump power. Mid-IR spectra recorded with an optical spectrum analyzer (OSA) reveal emission bandwidths greater than $\text{BW}=3\text{nm}$ (Fig. 2) under the pulsing temporal regime, in correlation with a broadband background transmission from the scanning Fabry-Perot interferometer. Time traces recorded with a 10-GHz bandwidth InGaAs photodetector yield a periodic train of bi-colour sub-300ps pulses (instrumentation-limited) at the laser free-spectral range ($c/L_{\text{cav}}\sim 420\text{MHz}$ or $\tau_{\text{rep}}\sim 2.41\text{ns}$). Further analysis of the pulsing features is under way. While passive KLM mode-locking due to pure cascaded second-order nonlinear effects was first reported in a $\text{GdVO}_4/\text{ppKTP}$ standing-wave cavity operating close to its stability region [2], our unidirectional ring laser operates well within the cavity stability range and is rather designed for cw operation. Such a mode-locked behaviour is never observed with a much broader spectral phase-matching bandwidth SHG crystals such as BiBO ($\Delta\lambda_{\text{PM}}=3.9\text{nm}$) or LBO ($\Delta\lambda_{\text{PM}}=47\text{nm}$).

Tunable cw single-longitudinal mode (SLM) operation can be achieved only with the insertion of a coated thin etalon. While in Ref.[1], a high-reflection coated etalon ($R=0.4$) was used, yielding a relatively easy SLM tuning of the red emission, we used here a lower $R=0.25$ etalon in order to scale up the red SLM power. With the lower spectral selectivity, SLM and tuning operation required a stringent match of the oscillating mode to the narrow spectral bandwidth of the ppKTP in order to quench the parasitic cascaded second-order nonlinear processes responsible of nonlinear self-phase modulation and mode-locked operation, via the intensity-dependent $n_2I\sim(\text{sinc}(\Delta kL)-1)/\Delta kL$ nonlinear index of refraction. But once realized, record 1.3 W of stable SLM red output at 660.5nm and coarse SLM tuning over $\Delta\lambda_{2\omega}\sim 1.5\text{nm}$ can be achieved (Fig.3). This red power level is equivalent to the maximum fundamental SLM power extracted from the laser with an optimal output coupler of $T_{\text{out}}\sim 2\%$, realizing earlier predictions on optimal intra-cavity second-harmonic generation [3].

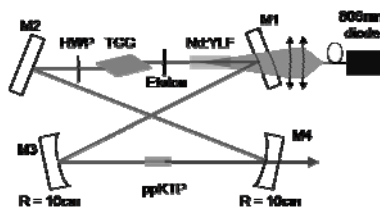


Fig.1: Experimental unidirectional ring laser setup for cw intra-cavity SHG. All mirrors are HR at $1.3\mu\text{m}$ and transmit $\sim 90\%$ of the red power.

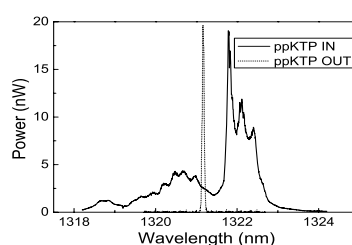


Fig.2: Laser spectra without etalon, at $T_{\text{ppKTP}}=30.5^\circ\text{C}$ and diode pump power ($P_{808\text{nm}}=12\text{W}$): without (dotted) and with ppKTP showing the $\sim 6\text{nm}$ width of the π -transition (full line).

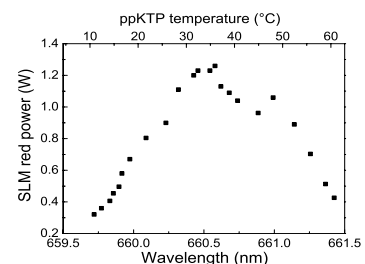


Fig.3: cw SLM red power tuning curve versus ppKTP temperature, when the etalon is inserted and the ppKTP carefully phase-matched.

[1] R. Sarrouf, V. Souza, T. Badr, G. Xu, J.-J. Zondy, "Watt-level single-frequency tunable Nd:YLF/periodically-poled KTiOPO_4 laser", Opt. Lett. **32**, 2732-2734 (2007).

[2] S.J. Holmgren, V. Pasiskevicius, F. Laurell, "Generation of 2.8 ps pulses by mode-locking a Nd:GdVO₄ laser with defocusing cascaded Kerr lensing in periodically-poled KTP", Opt. Express **13**, 5270-5278 (2005).

[3] R. G. Smith, "Theory of intracavity optical second-harmonic generation", IEEE J. Quantum Electron. **6**, 215-223 (1970).