Yb: CaF2 based 100-fs diode-pumped oscillator

F. Druon, F. Friebel, J. Boudeile, Dimitri Papadopoulos-Orfanos, Marc Hanna, Patrick Georges, P. Camy, V. Petit, J. Doualan, R. Moncorgé, et al.

Yb:CaF$_2$ based 100-fs diode-pumped oscillator

F. Druon, F. Friebel, J. Boudeile, D. N. Papadopoulos, M. Hanna, P. Georges
Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Univ Paris-Sud, RD 128 campus Polytechnique, 91127 Palaiseau, France
frederic.druon@institutoptique.fr

P. Camy, V. Petit, J. L. Doualan, R. Moncorgé
Centre de recherche sur les Ions les Matériaux et la Photonique, Université de Caen, 14050 Caen, France

C. Cassagne, G. Boudebs
Laboratoire Propriétés Optiques des Matériaux et Applications, Université d'Angers, 2 boulevard Lavoisier, 49000 Angers , France

Abstract: We demonstrate 100-fs Yb:CaF$_2$ with an average power of 380 mW for a 13-nm-bandwidth spectrum centered at 1053 nm. The impact of the Kerr and thermal lenses on the short pulse stabilization has been investigated.

OCIS codes: *320.7090 Ultrafast lasers; 140.3615 Lasers, ytterbium;*

1. Introduction

Within the realm of directly-diode-pumped solid-state lasers based on Yb-doped crystals, an intense interest has raised concerning cubic and simple crystals (such as cubic garnets YAG, GGG oxides Sc_2O_3, Y_2O_3, Lu_2O_3 or fluorites CaF_2,SrF_2). In fact, the cubic crystalline structure is interesting at least for two reasons: first because the phonons propagation in these lattices is very good which leads to very good thermal properties (thermal conductivities on the order of 10 W/m/K), second because it may allow the production of ceramic crystals in large dimension. Among the cubic crystals, the fluorite (Yb:CaF$_2$) has risen a great interest for the development of femtosecond lasers [1,2]. For a cubic crystal, fluorite has a very particular broad and smooth emission band. This broadness is explained by the different valence between the dopant (Yb^{3+}) and the substituted (Ca^{2+}) cations inducing clusters during the doping process [3]. In 2004, a high-power diode-pumped Yb^{3+}:CaF$_2$ femtosecond laser with pulse duration of 153 fs was reported. These results were very promising, but one could have expected shorter pulses considering the broadness of the emission spectra of fluorite. The main limitation to reach shorter pulses can be attributed to the strong tendency of Yb:CaF$_2$ to Q-switch due to the very long lifetime (2.4 ms) of the metastable $^2F_{5/2}$ level, and to the difficulty to stabilize a CW modelocked (CW ML) operation for shorter pulses. In this paper we investigate a laser cavity specifically designed to produce shorter pulses, and determine its limitations.

2. Cavity setup

To increase the stability range of CW ML regime, we have developed a cavity involving a stronger Kerr lens. This cavity is presented in figure 1.

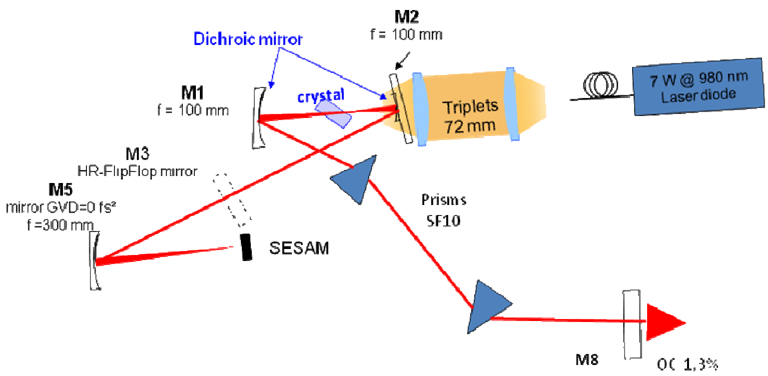

Fig 1. experimental setup.

We use a 6.1-mm-long Yb:CaF_2 crystal doped at 2.6 %. The laser waist in the crystal was reduced (compared to ref. 1) down to 33x46 μm^2. To match the laser and pump beams, a 7-W laser diode coupled to a 50 µm fiber has been used. To initiate the ML regime a SESAM was used, with the following characteristics: 1 % saturable absorption, 70 $\mu J/cm^2$ fluence saturation, and incident laser beam waist of 20x20 μm^2.

3. CW modelock operation

In this configuration, the laser emits around 400 mW. In order to optimize the CW ML stability using SESAM and KLM, we evaluate the thermal and Kerr lenses in our conditions using the following equations giving the lens dioptric powers D_{th}, D_{Kerr}:

$$D_{th} = \frac{1}{f_{th}} = \frac{\eta_h P_{abs} \chi}{2\pi \omega_p^2 \kappa_c} \quad , \qquad D_{Kerr} = \frac{1}{f_{Kerr}} = \frac{n_2 L P_{intra}}{\pi \omega_l^4 f_R \Delta t} \quad ,$$

Using the parameters defined in ref. 4 for the thermal lens and for the Kerr lens dioptric power, with a nonlinear index value $n_2 \approx 2.10^{-20} m^2/W$ (independently measured with a Z-scan method), a crystal length $L = 6.1mm$, an intracavity power $P_{intra} = 40W$, a repetition rate $f_R = 113MHz$ and a pulse duration of $\Delta t = 100fs$ and including the divergence of the pump and signal beam in the crystal (equivalent $\omega_l = 40\mu m$, $\omega_p = \sqrt{\int_0^L dz/(L\omega_p^2)} = 170\mu m$. The values obtained for the thermal and Kerr lens dioptric powers are $D_{Kerr} = 53m^{-1}$, $D_{th} = -1.6m^{-1}$ clearly indicating the dominance of the positive Kerr lens on the negative thermal lens. Adjusting the cavity taking into account these parameters, we achieved a very stable CW ML regime with 99 fs pulses for a corresponding spectrum of 13.2 nm centred at 1053.4 nm (fig. 2). The time-bandwidth product is 0.39.

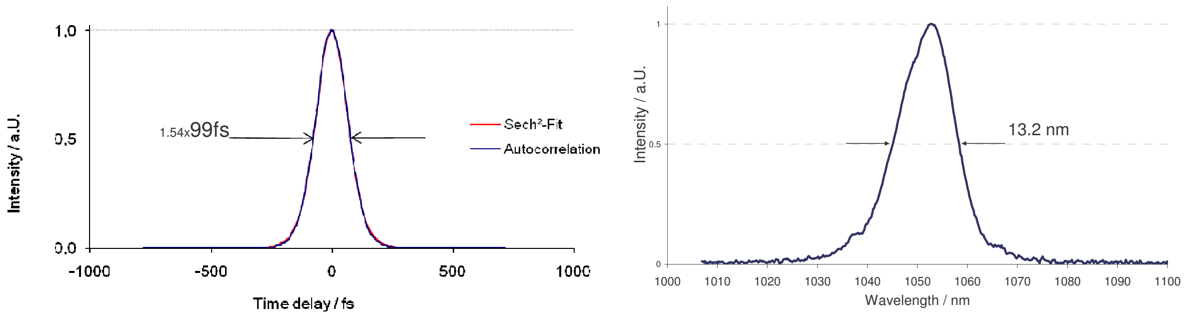

Fig 2. autocorelation (left) and spectrum for the shortest pulses obtained in a stable CW ML regime.

4. Influence of the Kerr lens and the thermal lens on the CW ML stability

First, to validate the fact that generating 100-fs pulse is possible only with a strong Kerr lens, we replaced the 6.1 mm-long crystal by a 1.5 mm-long one. In that case the shortest pulsewidth obtained was 147 fs.

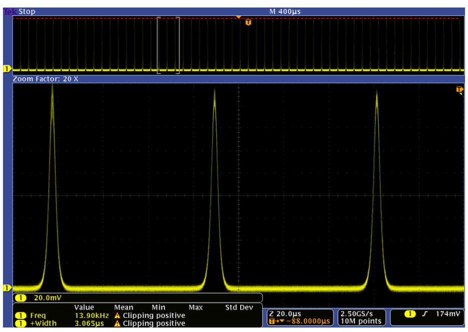

Fig 3. Q-switch operation.

Second, to explore the stability range of the CW ML regime, we tuned the dispersion of the cavity moving the prisms, in order to find other regimes in competition. Tuning the cavity dispesion we obtained a stable CW ML over 400 fs^2 with a pulse duration ranging from 170 fs down to 99 fs. In this range, long term CW ML is observed and the negative thermal lens does not impact the stability. Outside of this range, only Q-switch laser operation is obtained. Typical Q-switch operation at 14 kHz is presented in fig. 3. Experimentally we did not observe other stable regimes such as multi-pulsing or Q-switch ML.

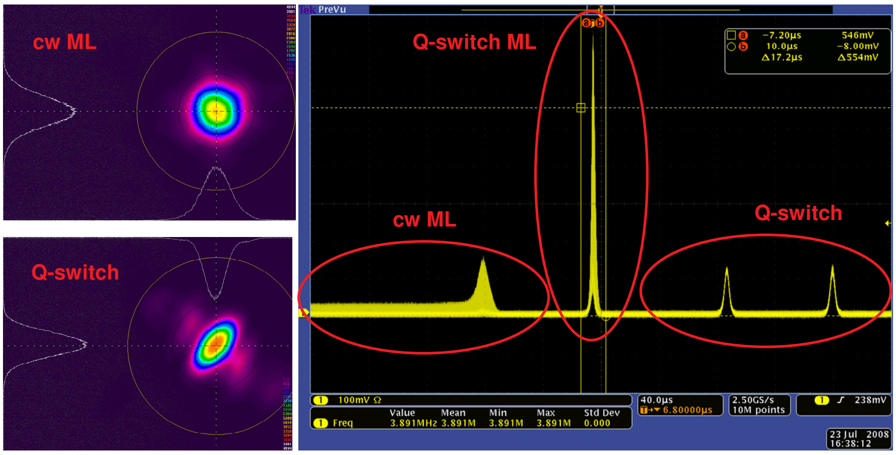

Fig 4. Transition between CW ML and Q-switch operation in the metastable regime.

However, a metastable regime has been observed, in a small dispersion range located at the transition between short-pulse CW ML and Q-switch. In this domain, we observed a slowly (~1 Hz) switching regime alternating between ML and Q-switch. This alternating regime could oscillate from ML to Q-switch for hours without stabilizing to one or the other regime. When operating on one regime, it remained stable for ~1 s and switched back to the other. No other different phases were observed except for an unique Q-switch ML pulse always occuring at the transition from CW-ML to Q-switch (fig. 4). In this metastable regime the CW ML pulses have a duration of ~97 fs. We explain this metastable regime by a small thermal oscillation due to a variation of pump absorption (measured around 100 mW). In fact due to saturation absorption of the pump, the variation of average laser power between Q-swicth and cw ML (380 mW for ML and 350 mW for Q-switch) creates additional negative lens during the CW ML. This negative thermal lens is often too small to counteract the positive Kerr lens except at the transition between the two regimes.

2. Conclusion

We have demonstrated the generation of 99 fs pulses with a diode-pumped $Yb:CaF_2$ oscillator, which is, to our best knowledge, the shortest ever produced with this cubic crystal. The corresponding average power was 380 mW and the spectrum was centered at 1053 nm with a bandwidth of 13.2 nm. According to us, the stable short pulse regime was possible by taking advantage of a stronger Kerr lens compared to the one in the previous laser cavities made with fluorite. The limitation to obtain shorter pulses seems to be a not strong enough Kerr lens to balance the negative thermal lens.

4. References

[1] A. Lucca, G. Debourg, M. Jacquemet, F. Druon, F. Balembois, P. Georges, P. Camy, J. L. Doualan, and R. Moncorgé, "High-power diode-pumped Yb3+:CaF2 femtosecond laser," Opt. Lett. 29, 2767-2769 (2004)

[2] M. Siebold, M. Hornung, S. Bock, J. Hein, M.C. Kaluza, J. Wemans and R. Uecker, "Broad-band regenerative laser amplification in ytterbium-doped calcium fluoride (Yb:CaF2)," Appl. Phys. B 89, 543-547 (2007).

[3] V. Petit, P. Camy, J-L. Doualan, X. Portier, and R. Moncorgé "Spectroscopy of Yb^{3+}:CaF_{2} : From isolated centers to clusters", Phys Rev B, Vol. 78, Iss. 8, pg. 085131 (2008).

[4] J. Boudeile, J. Didierjean, P. Camy, J. L. Doualan, A. Benayad, V. Ménard, R. Moncorgé, F. Druon, F. Balembois, and P. Georges, "Thermal behaviour of ytterbium-doped fluorite crystals under high power pumping," Opt. Express 16, 10098-10109 (2008)