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Yb:CaF₂ based 100-fs diode-pumped oscillator

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Abstract: We demonstrate 100-fs Yb:CaF₂ 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.

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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 Sc₂O₃, Y₂O₃, Lu₂O₃ or fluorites CaF₂, SrF₂). 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:CaF₂) 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 (Yb³⁺) and the substituted (Ca²⁺) cations inducing clusters during the doping process [3]. In 2004, a high-power diode-pumped Yb³⁺:CaF₂ 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:CaF₂ 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.

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 dispersion we obtained a stable CW ML over 400 fs² 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 a unique Q-switch ML pulse always occurring 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-switch 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:CaF₂ 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.

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