Sub-50 fs, Kerr-lens mode-locked Yb:CaF 2 laser oscillator delivering up to 2.7 W

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Abstract: By means of a high-brightness optical pumping scheme with a fiber laser, we demonstrate Kerr-lens mode locking (KLM) with an Yb:CaF_2 laser crystal. Stable 48 fs pulses are produced at an average power of 2.7 W.

1. Introduction

Calcium fluoride has raised a great interest in the laser community since its revival in 2004 when it has been doped with ytterbium ions. Indeed, since its first laser operation in 2004 [1,2], Yb:CaF_2 have been among the most studied crystals for the development of high power, short-pulsed solid state lasers. Thanks to its broad emission bandwidth, its good thermal properties and its strong energy-storage ability, Yb:CaF_2 is particularly suitable for high-energy, high-power femtosecond laser systems [2,3]. Nevertheless, development of ultra-short pulsed oscillators with Yb:CaF_2 has revealed certain exertion. In fact, due to the very long lifetime of Yb:CaF_2 (τ =2.4 ms) and its low nonlinear refractive index (1.6 10^{-20} m^2/W), the stable sub-100-fs mode-locking operation (ML) of Yb:CaF_2 remains challenging and very few works have reported operation in this regime [4]. Up to now, the ML of Yb:CaF_2 oscillators has only been achieved using a saturable absorber mirror to produce stable femtosecond pulses. In this paper we report, to the best of our knowledge, on the first demonstration of a high average power sub-50 fs pulses Kerr Lens Modelocked oscillator in Yb:CaF_2 by means of a high-brightness pump source [5].

2. Experimental setup

The laser cavity and pumping geometry is sketched in figure 1. We use a 6-mm-long, 4 x 4 mm² Brewster-angle cut 4.5 at % Yb:CaF_2 crystal mounted in a water-cooled copper holder. The Yb:CaF_2 crystal is positioned between two R = 100 mm spherical mirrors (M_1, M_2) in a standard X-fold cavity configuration. To compensate the astigmatism due to the Brewster-angle incidence, these mirrors are tilted with an angle of 8°. On one side, the cavity is delimited by a high reflection (HR) mirror (M_5) where a pair of SF10 60° prisms (P_1, P_2) is inserted as an intra-cavity dispersion control. The cavity is closed on the other side by a 20% output-coupler (M_4). The mirrors of the cavity are specified to introduce a low group-velocity dispersion (GVD). The cavity is nearly symmetric and its length of 2.05 m corresponds to a repetition rate close to 73 MHz.

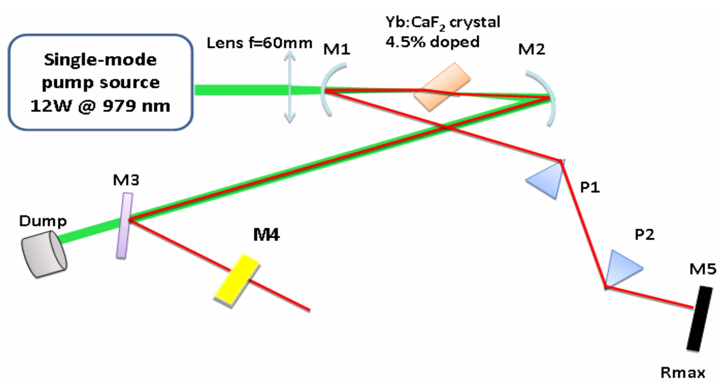

Figure 1 : Experimental setup

The $Yb{:}CaF_2$ crystal is longitudinally pumped by a high-brightness fiber pump source through the M_1 dichroïc mirror (HT for wavelength below 980 nm and HR above 1020 nm). The pump source (ALS-IR 15W model) consists in an Yb-doped fiber laser emitting up to 12 W of linearly polarized radiation at 979 nm with a spectral bandwidth of 200 pm and is characterized by a high spatial quality with a M^2 of 1.1. The pump radiation is focused into the $Yb{:}CaF_2$ crystal by a 60 mm focal-length lens. The high spatial quality of the pump beam allows us to obtain a spot radius at the focal plane of 20 µm (at $1/e^2$) leading to a confocal parameter equal to 2.3 mm and a maximum pump intensity of 1 MW/cm^2. Hence, the absorption of the $Yb{:}CaF_2$ is saturated when the pump focus is positioned in the middle of the crystal leading to an unabsorbed power of 8 W. Under this pump intensity and without lasing effect, the inverted population on-axis is estimated to be 48 %.

3. Results and discussion

At first, we characterize the CW performance of the high-brightness fiber-pumped $Yb{:}CaF_2$ oscillator. At 12 W of incident pump power, a maximum output power of 3.7 W is obtained at the central wavelength of 1046 nm. In this configuration, the unabsorbed pump power measured after the dichroïc mirror M_3 is 4 W leading to an optical-to-optical efficiency of 31 %.The laser threshold has been measured to be 950 mW with a 20% output coupler. It only correponds to the losses introduced by the coupler. Moreover, even if the pump intensity is very strong into the cristal, a weak thermal birefringence has been measured (Prisms losses ~ 100 mW and Brewster $Yb{:}CaF_2$ losses ~ 20 mW). Since the pump source used in this setup is characterized by a low M^2 value, a very good spatial overlap between the laser beam waist and the gain channel is achieved over the 6 mm crystal length and leads to a high optical-to-optical efficiency [6].

In order to discriminate the CW and ML regimes in the oscillator, we adjust the M_2 curved mirror position a configuration where the CW regime is less stable. The CW output power drops down to 2.2 W. Then a stable Kerr-lens mode-locking is initiated by simply translating the prism P_2. In a daily operation, when the KLM starts, a small fraction of the power remains in the CW regime however suppressed with a small displacement of the prism P_1. In an optimal configuration (3 mm of P_2 is inserted in the beam path), the oscillator delivers 60 fs (FWHM) at the 73 MHz repetition rate with an average power of 2.73 W. We estimate the GDD introduced by the prisms to be -2600 fs^2. The spectrum of the femtosecond pulses is centered at 1046 nm with a 28 nm bandwidth (see figure 2.a) and corresponds to a Fourier-Transform limited duration of 47 fs (FWHM). Indeed, the temporal pulse profile from the oscillator has been characterized through a SHG-FROG device and a quadratic phase has been measured and compensated by an external compressor requiring 6 bounces on -100 fs^2 chirped mirror (global transmission of 99.2%). Figure 2.b shows the retrieved pulse characteristics at the external compressor output from SHG FROG measurement. A 48 fs pulse duration (FWHM) has been retrieved in close agreement with the independently measured autocorrelation width of 73 fs. At the external compressor output, the time-bandwidth product of the pulses reaches 0.36. These parameters correspond to a peak power of 770 kW.

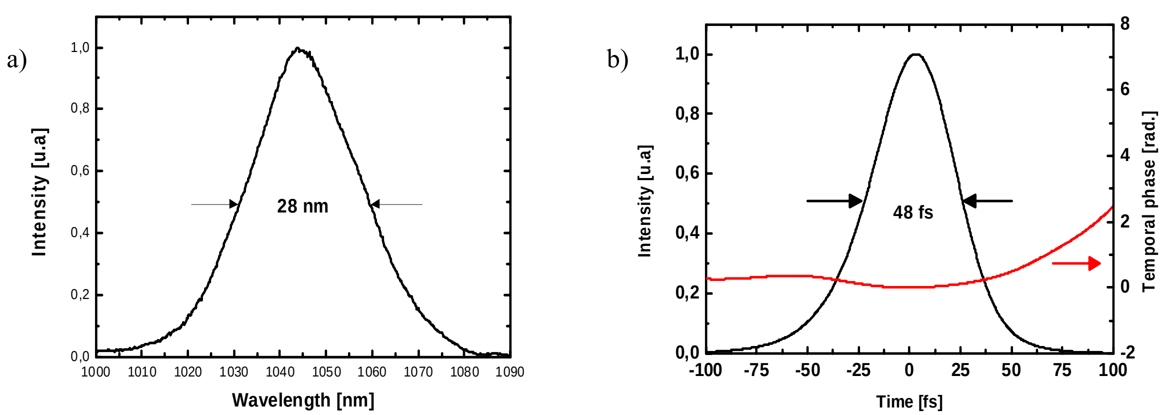

Figure 2 : a) Experimental spectrum, b) SHG FROG retrieved temporal pulse profile

In addition, we have investigated the influence of the pump power level on the stability of the KLM regime. We have recorded the output power and the compressed pulse duration at different pump powers. Results are displayed in figure 3. The best performances (pulse duration and output power) are obtained for the maximal pump power of 12 W but the KLM regime persists with a pump power down to 7 W. As pump power decreases, the spectral broadening from self-phase modulation in Yb:CaF_2 becomes less efficient and leads to longer pulse durations. However the Kerr-lens effect is efficient enough to discriminate ML and CW until 7 W of pump power. In this pumping condition, the oscillator delivers at least 1.6 W of average power with 65 fs pulse duration. Below 7 W of pump power, a continuous peak appears in the spectrum of the output pulses.

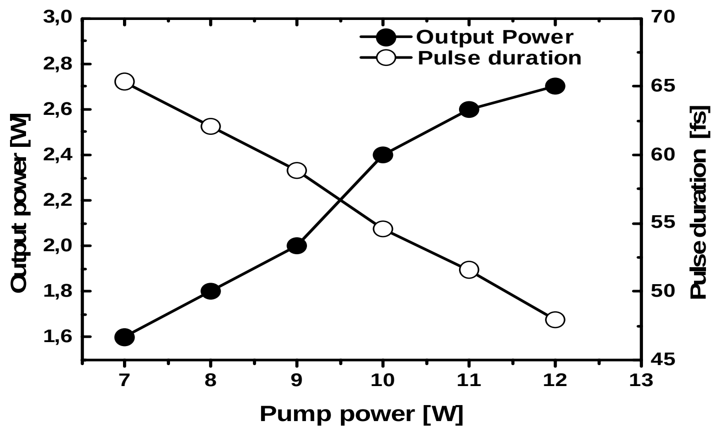

Figure 3 : Performances of the ML Yb:CaF_2 oscillator as a function of the pump power.

In conclusion, we have presented the first experimental demonstration of a high-average power pure KLM femtosecond oscillator based on an Yb:CaF_2 crystal optically pumped by a very high-brightness fiber pump laser. The oscillator delivers, at 73 MHz repetition rate, pulses of 48 fs duration which is the shortest pulse duration ever obtained in Yb doped material at 2.7 W average power level.

4. Aknowledgement

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