LASERLAB-EUROPE

The Integrated Initiative of European Laser Research Infrastructures III

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Work package WP33
“European Research Objectives on Lasers for Industry, Technology and Energy (EURO-LITE)”

Deliverable D33.28
“Demonstration of high single pass gain in Yb doped crystals”

Lead Beneficiary: CNRS-CELIA

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Project webpage: www.laserlab-europe.eu

Deliverable Nature	
R = Report, P = Prototype, D = Demonstrator, O = Other	R
Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

1 Objectives

In WP33, D33.27 we have reported on the development of high brightness laser pump sources. These pumps are based on Yb-doped large mode area fibers and emit at the exotic wavelength of 976 nm (three level transition of Yb). The output power of these near diffraction limited sources range from 15 W with a M^2 of 1.1 to 60 W with a M^2 of 1.8. It has to be compared to fiber coupled diodes emitting at the same wavelength commonly used to optically pump Yb-doped laser crystals. Although efficient and cost effective, their M^2 reaches 80 and consequently their brightness is commonly 2 to 3 times lower compared to the 976 nm fiber lasers. In this deliverable, we propose to take advantage of the diffraction limited fiber sources to pump Yb-doped crystals instead of using the fiber coupled laser diodes. This work is referred to as “high brightness pumping of Yb-doped solid state materials”. We demonstrate here the advantage of the optimal brightness of the pump source for high average power amplification with limited cooling, high gain single pass amplification, ultrashort pulse laser oscillators. In particular, we report here results on single pass amplification in long Yb:CaF_2 crystals with outstanding gain values, an unexpected feature if considering the limited emission cross-section of this material. Also, although not described in the proposal, we report on the measurement of the shortest pulse ever generated with an oscillator based on Yb-doped material thanks to the adoption of high brightness optical pumping.

Pitch: fiber laser; high brightness pumping; illustration with single pass booster; additional results with oscillators

Sources: principle: pampero rationale; single pass booster: high gain paper + ASSL 2015 + SOF2015; oscillator: paper 32 fs

2 Work performed since the start of Laserlab 3 / results / description

2.1 High brightness pumping of Yb-doped laser material: Principle

First of all we recall here the principle of high brightness pumping of Yb materials. Because of the low quantum defect, high quantum yield, suitability for direct diode pumping and a large fractional gain bandwidth, Yb-doped hosts dominate the effort to develop high-repetition-rate, high-average power femtosecond amplifiers for a variety of industrial and research applications. Although Yb crystals generally exhibit very long fluorescence lifetimes, frequently longer than 1 ms, obtaining high gain is very challenging because their emission cross-section is 20 to 30 times lower than that of Nd-doped materials and Ti:sapphire crystals [16]. Very high laser saturation and pump saturation intensities (e.g. for Yb:KGW and Yb:YAG ~10 kW/cm2 and ~30 kW/cm2, respectively) require an exceptionally tight diameter of the pump and cavity modes. Suitably broadband-gain Yb crystalline materials that are most promising for high-energy femtosecond amplification (Yb:CaF2, Yb:KGW/KYW, Yb:GSO/GYSO, Yb:YAP, …) can be pumped into the zero phonon line (ZPL) around 977 nm thus providing the smallest possible generation of parasitic heat for 1.0-1.03-µm amplifier operation. Moreover, to obtained reasonable single pass gain, the crystal should be chosen to be as long as possible. Tight focusing over long distances requires high brightness pump sources as shown in Fig. 1. Therefore we propose to implement the concept of high brightness high power pumping (known and applied for other laser materials) in Yb-doped materials. In this context, the concept is new since no high power high brightness sources exist today. Significant increase of single pass gain is expected in this case by pumping with the specific high brightness diode pumped laser system to be developed in the project. Note here, that there already exist elongated geometries of doped crystals know as “crystal fiber”. The concept underlying these “fibers”

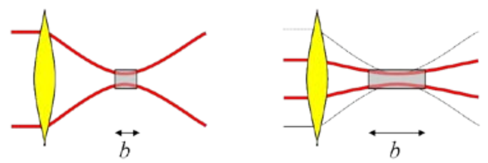

Fig. 1 : Rayleigh range for Optical pumping with low brightness (left) and High brightness (right)

consist of having bulk active media able to propagate a powerful multimode pump beam by internal reflection at the “fiber” boundaries and inject a single mode signal that freely propagate over the crystal length. In our case both the pump and the signal propagates freely as they are both single mode. Moreover their spatial overlap can be finally matched leading to much higher efficiency and much lower thermal issues.

2.2 Small signal gain increase in Yb-CaF_2

The single-pass gain is measured by implementing the setup depicted in Figure 2. The output of a femtosecond Yb^{3+} fiber oscillator (Menlo Systems) is spectrally filtered by using a pair of diffraction gratings and a slit. The filtered signal is then focused through a dichroic mirror into the crystal by a lens with 150 mm focal length. The seed beam diameter inside the crystal has a diameter of 200 µm. Smaller seed beam as compared to the pump beam guaranties that the gain is measured in the center of the pumped channel. The seed is chopped by an opto-mechanical chopper and the signal after passing the laser crystal is detected by a Si-photodiode. The chopper is synchronized with a Lock-in amplifier (SR810, Stanford Research Systems) which suppress the contribution of ASE, residual pump signal and environmental noises during the gain measurement.

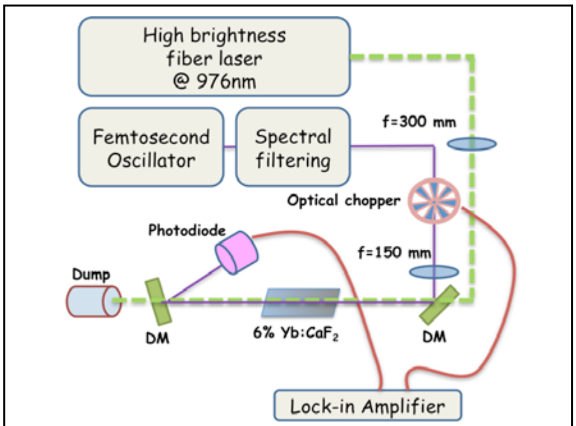

Fig. 2. Experimental setup. DM: Dichroïc mirror 976/1030 nm, The crystal length is either 5 or 10 mm

Figure 2 displays the dependence of the gain on the absorbed pump power for 6%Yb:CaF2 5-mm and 10-mm long crystals. The seed, with a spectral width of 2 nm FWHM is centered

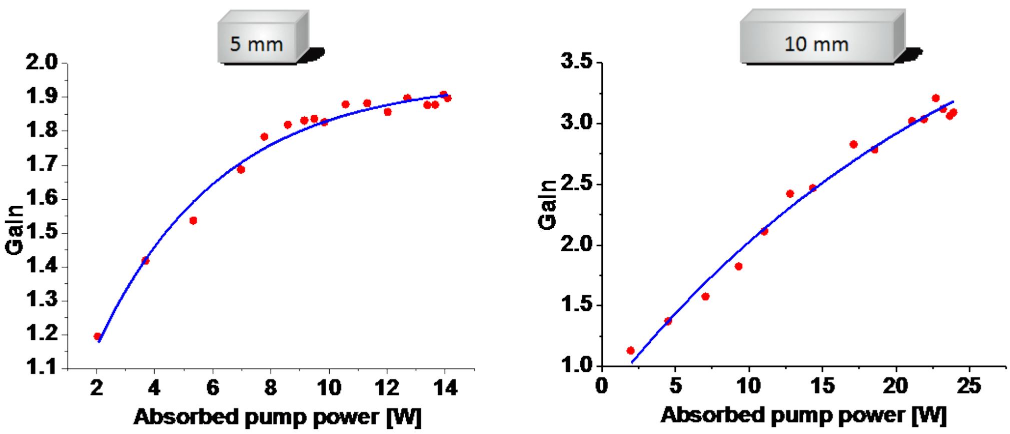

Fig. 3. Small signal gain measurements for 6%Yb:CaF2 5-mm (square) and 10-mm (circle) long as a function of absorbed pump power.

at 1030 nm. Gain saturation at the level of 1.9 is observed for the 6%Yb:CaF2 5-mm long crystal which is due to absorption saturation. In the case of the 10-mm long 6%Yb:CaF2 crystal the small signal gain increases up to 3.2 for 24 W of absorbed pump power without reaching full saturation. Such a high small-signal gain of 3.2 measured at room temperature is 1.8 times higher than previously reported data obtained at cryogenic temperatures[1] despite the fact that emission cross-sections are known to be substantially higher[2,3]. Even more

[1] S. Ricaud, D. Papadopoulos, P. Camy, J.-L. Doualan, R. Moncorgé, A. Courjaud, E. Mottay, P. Georges and F. Druon, “High efficient, high power, broadly tunable, cryogenically cooled and diode-pumped Yb:CaF2 laser,” Opt. Lett. 35, 3757-3759 (2010)

[2] A. Pugžlys, G. Andriukaitis, D. Sidorov, A. Irshad, A. Baltuška, W.J. Lai, P.B. Phua, L. Su, J. Xu, H. Li, R. Li, S. Ališauskas, A.Marcinkevičius, M.E. Fermann, L. Giniūnas, R. Danielius, “Spectroscopy and lasing of cryogenically cooled Yb, Na:CaF_2”, Appl. Phys. B **97,** 339-350 (2009)

important, the energy stored in our long and highly doped $Yb:CaF_2$, corresponds to a value of 131 J/cm^2 while in the cryogenic configuration only 21 J/cm^2 was achieved. These improvements clearly demonstrate the great potential of high brightness pumping of Yb materials by fiber lasers.

Since the present optical pumping by fiber lasers leads to a high density of absorbed pump power, we also have investigated the thermally induced birefringence in the 10-mm long 6%$Yb:CaF_2$ crystal by using a polarized He-Ne laser beam passing through the pumped crystal. The crystal is inserted between two polarizers with transmission axes oriented perpendicular to each other. A fraction of the probe He-Ne laser beam that has been depolarized by the thermally induced birefringence is detected by a Si-photodiode as a function of the absorbed pump power as shown on Figure 4.

Within the first order approximation, depolarization is inversely proportional to the wavelength. Depolarization at 1030 nm is therefore calculated by scaling the measured signal with the ratio $\lambda_{HeNe}/\lambda_{1030}$. A maximum depolarization of 11 % has been obtained for an absorbed pump power of 24 W. The rather low value of 11 % is extremely encouraging if we consider the high doping level of the crystal and the fact that the amplifier was operating at room temperature. Since this study we have determined that although isotropic, Yb:CaF2 crystal have to be cut along the [111] axis to prevent or limit significantly stress induced birefringence.

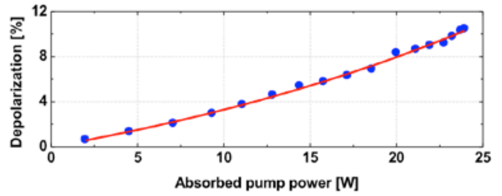

Fig. 4. Thermally induced birefringence at 1030 m as a function of absorbed pump power in the 6%$Yb:CaF_2$ 10-mm long crystal.

These results are reported in “High-gain amplification in Yb:CaF2 crystals pumped by a high-brightness Yb-doped 976 nm fiber laser” by G. Machinet, G. Andriukaitis, P Sévillano, J. Lhermite, D. Descamps, A. Pugžlys, A. Baltuška and E. Cormier, *Appl. Physics B* **111**, 495 (2013)

2.3 High gain fs booster amplifier

Here we demonstrate the efficiency of high brightness pumping of Yb-doped crystal in terms of single pass gain and average power with femtosecond pulses.

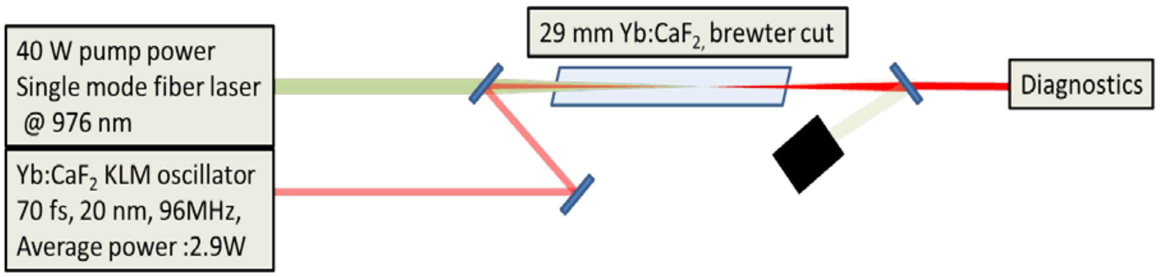

Fig. 5. Experimental setup of the booster amplifier with a 29 mm crystal.

Due to its spectroscopic and thermal properties, $Yb:CaF_2$ is one of the most promising crystal for ultra-short pulse amplification at high average power. Since few years, the development of high power Yb-doped fiber laser operating at 976 nm provides high brightness pump source for Yb doped material and makes possible high efficient single-pass Yb amplifier by the use of very long crystal. Recently, using the later high brightness pump source we demonstrated an outstanding small-signal gain in $Yb:CaF_2$ [1]. Here, we report on optical performances of a simple $Yb:CaF_2$ amplifier stage injected by a multi-watts transform limited sub 100 femtosecond (see section 2.4).

[3] M. Siebold, S. Bock, U. Schramm, B. Xu, J.L. Doualan, P. Camy, R. Moncorgé, “$Yb:CaF_2$-a new old laser crystal”, Appl. Phys. B **97,** 327-338 (2009)

The experimental set up is sketched on figure 5. The seed source is based on a Kerr-lens mode-locked Yb:CaF_2 oscillator delivering a 70 fs pulse train at 96 MHz with an average power of 2.9 W [4]. The output pulses have a spectral bandwidth of 20 nm (FWHM) centered at 1048 nm (see figure 2.a).

The single-pass booster amplifier uses a 29 mm length Yb:CaF_2 (doped at 4.5 at. %) cut at Brewster angle mounted on water cooled copper holder. To minimize depolarization effect, [111] crystallographic orientation of the CaF_2 is chosen. The crystal is pumped by a single mode (M^2=1.1) laser pump source delivering up to 40 W at 976 nm in linear polarization. Signal and pump radiations are focused into the Yb:CaF_2 crystal by a 75 mm focal-length lens. The high spatial quality of the pump beam allows us to obtain a spot radius at the focal plane of 50 µm (at $1/e^2$) leading to a confocal parameter of 16 mm and a pump intensity as high as 1 MW/cm^2. The low nonlinear index of Yb:CaF_2 allows us to use a single-pass amplification scheme with tight focus spot without temporal stretching of the femtosecond seed pulse.

When the pump focus is positioned in the middle of the crystal and without signal amplification, the pump absorption saturates leading to an unabsorbed power of 6.5 W. As shown on figure 2.b, the output power of the booster amplifier linearly increases with the pump power with an optical efficiency of 34%. At 40 W of pump power, the average power of the femtosecond pulses reaches 16.5 watts leading to an optical gain of 5.7. The measurement of the femtosecond pulse spectrum before and after the booster amplifier (Fig 2.a) indicates the lack of spectral gain narrowing. At the output of the booster amplifier, 8 bounces on -250 fs^2 chirped mirrors are required to compensate the dispersion of YbCaF_2 crystal and pulse pre-chirp from the oscillator to obtain a final pulse duration close to 70 fs.

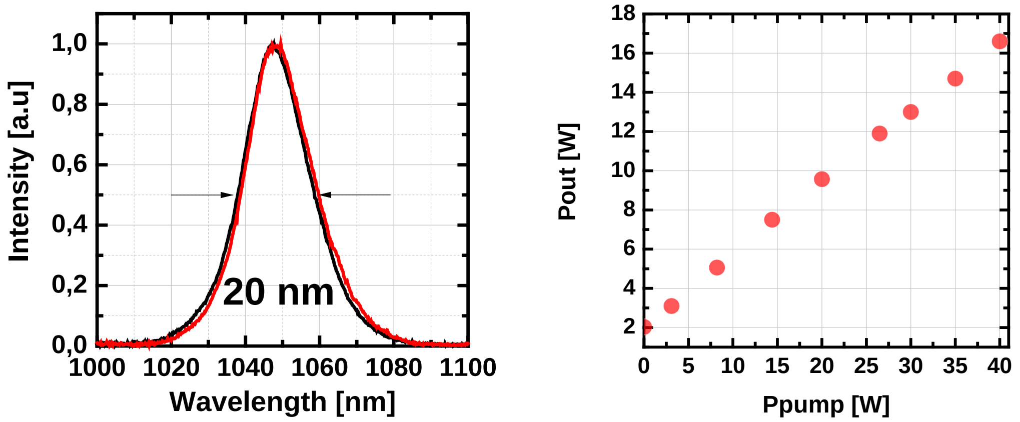

Fig. 6. : a) : Experimental spectrum before (red) and after (black) the booster amplifier at 40 W of pump power. b): Output power versus pump power

At 40 W of pump power, a depolarization under 1 % is measured and no deleterious thermal effects on beam quality have been observed. These performances are in good agreement with our simulations. The latter reveals very encouraging power and energy scaling.

2.4 Ultrashort pulse generation

In this section we demonstrate the benefit of using diffraction limited pump beams at 976 nm (our fiber lasers) to generate ultrashort pulses (sub 50 fs) with unprecedented average power (several W).

The experimental setup of the laser cavity and pumping geometry is sketched on figure 7. We use a 5-mm-long, 2 x 4 mm² Brewster-angle cut, doped at 5 at % Yb:CALGO crystal mounted in a water-cooled copper holder. We have chosen the a-cut orientation to avoid the anisotropy of temperature-dependent refractive index which could appear at high average power and to eliminate the polarization state sensitivity in cross-section emission (see above). The Yb:CALGO crystal is positioned between two R = 100 mm spherical mirrors (M_1, M_2) in a standard X-fold cavity configuration. To compensate 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 and closed on the other side by a 35% output-coupler (OC). A pair of SF10 prisms separated by a distance of 450 mm is used for fine intra-cavity dispersion control. The net intracavity group delay dispersion (GDD) is calculated to be close to -2200 fs² per round trip. All the mirrors used are specified with low group delay dispersion. The cavity is asymmetric with a short arm of 600 mm and a long one of 900 mm.

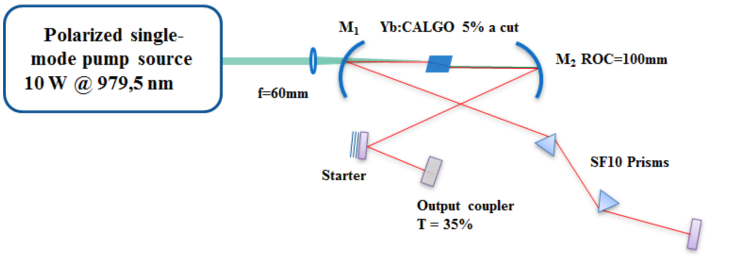

Fig. 7 : KLM Yb:CALGO oscillator experimental setup

The Yb:CALGO crystal is longitudinally pumped by the high-brightness fiber pump through the M_1 dichroic mirror (HT for a wavelength below 980 nm and HR above 1020 nm). We use a commercially available diffraction limited polarized pump source (M^2=1.1) emitting 10 Watts at 979.5 nm (Azur Light System). The pump radiation is focused into the Yb:CALGO crystal by a 60 mm focal-length lens to reach a pump intensity of 1 MW/cm^2.

OC [%]	P_{pump} [W]	P_{out} [mW]	λ_c [nm]	$\Delta\lambda$ [nm]	$\Delta\tau$ [fs]
3	3,6	90	1063	51	32
10	4,3	280	1056	41	35
20	6,3	640	1052	37	37
35	8,9	1100	1045	34	40

Tab. 1 : Spectral and temporal characterization as a function of OC transmission

Typical performances with various output couplers are summarized in table 1. Average power varies from 90 mW to 1.1 W while duration decreases from 40 fs down to the record breaking value of 32 fs. Pulses are retrieved from a SHG-FROG measurement after external compression (around -1000 fs²). In the best case, we have recorded a Fourier transform limited pulse duration of 32 fs and a time bandwidth product of 0.433 (see figure 7) Experimental and retrieved spectra are superimposed with an excellent agreement. This is the shortest pulse duration ever obtained with Yb-doped laser materials.

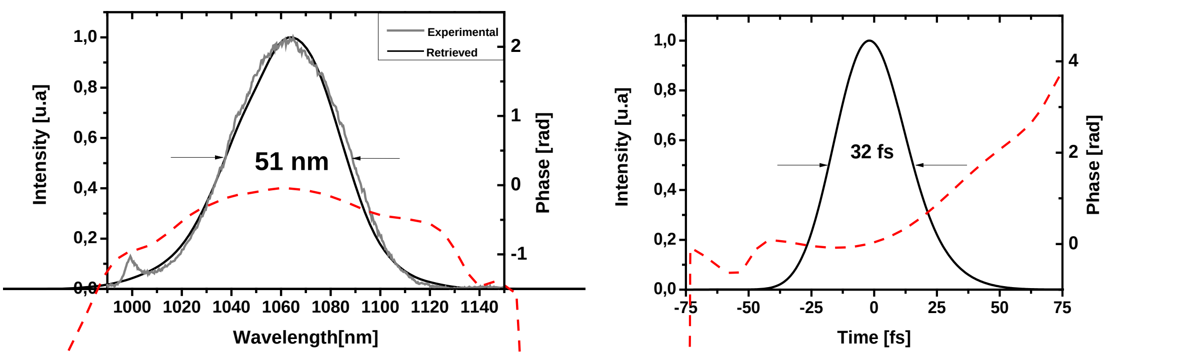

Fig. 8 **:** Experimental spectrum and retrieved FROG-SHG spectrum and spectral phase (left). Retrieved intensity profile and temporal phase of the output pulses (right)

The performances of Yb oscillators achieved implementing the high brightness pumping technique are summarized in figure 9 and compared to other techniques such as diode pumped solid state lasers mode locked with SESAMs or with Kerr lensing. The graph clearly shows that our technology is the only one allowing the production of fs pulses shorter than 50 fs with more than 1 W average power.

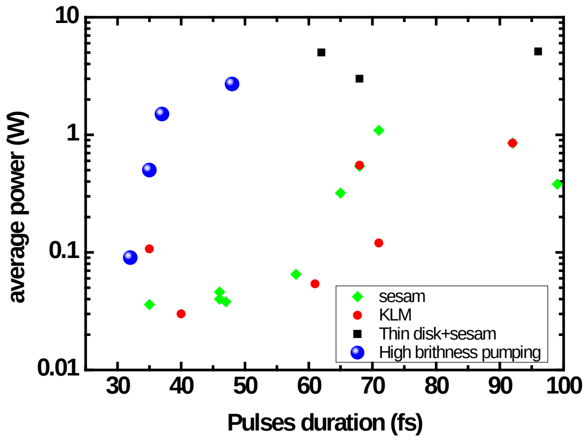

Fig. 9 : Comparison of fiber laser pumped oscillators with other conventional technologies (KLM: Kerr-Lens Mode-locking)

3 Conclusions

The present work package was aiming at demonstrating the great advantage of using diffraction limited fiber pump lasers emitting at 976 nm to pump Yb-doped laser materials. State of the art of such pump sources provide high brightness beams with average powers ranging from 15 W to 60 W. We have used this pump in a booster amplifier architecture and demonstrated single pass gain of up to 5.7 in a long Yb:CaF_2 crystal with a train of sub 70 fs pulses reaching the average power of 16.5 W. Although, not described in the workpackage proposal, we also report on exceptional performances of a Kerr-lens mode-lock fs oscillator. In fact, thanks to the high brightness longitudinal pumping, transform-limited pulses of 32 fs have been recorded which sets a new record for Yb-doped fs oscillators. Moreover, this technology allows to generate sub 50 fs with several W average power.

4 References/Publications

(Publications resulting from the JRA need to indicate DOI and whether open access will be/is granted (yes/no). Please, remember the Laserlab acknowledgement.is mandatory)

Peer reviewed publications

(1) **"High-gain amplification in Yb:CaF2 crystals pumped by a high-brightness Yb-doped 976 nm fiber laser"**
G. Machinet, G. Andriukaitis, P Sévillano, J. Lhermite, D. Descamps, A. Pugžlys, A. Baltuška and E. Cormier
Appl. Physics B **111**, 495 (2013)
DOI 10.1007/s00340-013-5363-z - no open access

(2) **"High-brightness fiber laser pumped 68 fs-2.3 W Kerr-lens mode-locked Yb:CaF_2 oscillator"**
G. Machinet, P. Sevillano, F. Guichard, R. Dubrasquet, P. Camy, J.-L. Doualan, R. Moncorgé, P. Georges, F. Druon, D. Descamps and E. Cormier
Optics letters **38,** 4008 (2013)
http://dx.doi.org/10.1364/OL.38.004008 - no open access

(3) **“32-fs Kerr-lens mode-locked Yb:CaGdAlO4 oscillator optically pumped by a bright fiber laser”**
Sevillano P., Georges, P., Druon F., Descamps D. and Cormier, E
Optics letters **39,** 6001 (2014)
http://dx.doi.org/10.1364/OL.39.006001 - no open access

Invited talks

(1) **“High power operation of Yb-doped fiber laser at 976 nm : present status and applications”**
E. Cormier
SPIE Defense, Security, and Sensing, SPIE DSS 2015, [**9466-9**], 20-24 April 2015, Baltimore (USA)
SPIE Conference proceeding

(2) **“Pompage haute brillance des matériaux lasers dopés Yb : fort gain et impulsions sub 100 fs dans l’Yb:CaF_2”**
G. Machinet, P. Sévillano, R. Dubrasquet, J. Lhermite, G. Andriukaitis, A. Pugzlys, A. Baltuska, P. Camy, JL. Doualan, R. Moncorgé, P. Georges, F. Druon, D. Descamps, E. Cormier
Journées Nationales des Cristaux pour l’Optique, JNCO2013, Cherbourg (France) (2013)

(3) **“Fiber laser pumping of Yb-doped materials : a road to high power sub 50 fs oscillators and high-gain amplifiers”**
P. Sevillano, G. Machinet, R. Dubrasquet, P. Camy, JL. Doualan, R. Moncorgé, P. Georges, F. Druon, D. Descamps, E. Cormier
16th Photonics North Conference, 28-30 May 2014, Montréal (Canada)

(4) **“Yb:CaF2 crystals for short pulse lasers and amplifiers”**
P. Camy, J.L. Doualan, W. Bolaños, A. Braud, R. Moncorgé, B. Lacroix, P. Ruterana, F. Friebel, F. Druon, P. Georges, P. Sevillano, D. Descamps, E. Cormier
Photoluminescence in Rare Earths, PRE'14, Mai 13-16 2014, San Sebastian

(5) **“Pumping Yb-doped bulk materials with 976 nm fiber lasers”**
P. Sévillano, R. Dubrasquet, J. Lhermite, A. Pugžlys, A. Baltuška, P. Camy, R. Moncorgé, P. Georges, F. Druon, D. Descamps and E. Cormier
Advanced Solid State Laser, ASSL2014, 16-21 Novembre 2014 Shanghai (Chine)

(6) **“L’Yb pour la génération d’impulsions ultra-courtes”**
E. Cormier
Optique Bretagne 2015, 6-9 juillet 2015 Rennes

(7) **“High power operation of Yb-doped fiber laser at 976 nm : present status and applications”**
E. Cormier
SPIE Defense, Security, and Sensing, SPIE DSS 2015, 20-24 April 2015, Baltimore (USA)

Communications in international conferences

(1) **"Kerr lens mode-locking of Yb:CaF2"**
G. Machinet, F. Guichard, R. Dubrasquet, J. Boullet, P. Camy, J.L. Doualan, R. Moncorgé, S. Ricaud, F. Druon, P. Georges, D. Descamps, E. Cormier
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(2) **"High power, linearly polarized, continuously tunable ytterbium-doped rod-type photonic crystal fiber laser"**
R. Royon, J. Lhermite, L. Sarger, E. Cormier
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(3) **"Single frequency, ultra-low noise, CW, 4W 488nm fiber laser"**
R. Dubrasquet, J. Boullet, S. Lugan, G. Mery, N. Traynor, E. Cormier,
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(4) **"Sub-70 fs Kerr-lens mode-locked Yb:CaF2 laser os- cillator delivering up to 2.3 W"**
P. Sévillano, G. Machinet, F. Guichard, R. Dubrasquet, P. Camy, J.L. Doualan, R. Moncorgé, P. Georges, F. Druon, D. Descamps, and E. Cormier
Conference on Lasers and Electro-Optics Europe (CLEO-EQEC)[**CA-6.4 TUE**], 12-16 May, 2013, Munich (Germany)

(5) **"fs mode-locked fiber laser continuously tunable from 976 nm to 1070 nm"**
R. Royon, J. Lhermite, L. Sarger, and E. Cormier
Conference on Lasers and Electro-Optics Europe (CLEO-EQEC)[**CJ-6.1 WED**], 12-16 May, 2013, Munich (Germany)

(6) **"Kerr-lens mode-locked Yb:CaF2 laser oscillator delivering sub-70 fs pulses with 2.3 W average power"**
P. Sévillano, G. Machinet, F. Guichard, R. Dubrasquet, P. Camy, J.L. Doualan, R. Moncorgé, P. Georges, F. Druon, D. Descamps, and E. Cormier
Int'l Conference on Coherent and Nonlinear Optics (ICONO'LAT 2013) [**53806**], 18-22 Juin 2013, Moscow (Russie)

(7) **"Frequency-doubled Yb-doped fiber laser to produce picosecond pulses with 20 W average-power at 489 nm "**
J. Lhermite, R. Royon and E. Cormier
Int'l Conference on Coherent and Nonlinear Optics (ICONO'LAT 2013) [**53832**], 18-22 Juin 2013, Moscow (Russie)

(8) **"Frequency-doubled Yb-doped fiber laser to produce picosecond pulses with 20 W average-power at 489 nm "**
J. Lhermite, R. Royon and E. Cormier
Int'l Conference on Coherent and Nonlinear Optics (ICONO'LAT 2013) [**53832**], 18-22 Juin 2013, Moscow (Russie)

(9) **"220 nJ mode-locked fs fiber laser tunable from 976 nm to 1070 nm "**
R. Royon, J. Lhermite, L. Sarger, and E. Cormier
Int'l Conference on Coherent and Nonlinear Optics (ICONO'LAT 2013) [], 18-22 Juin 2013, Moscow (Russie)

(10) **"Sub-50 fs, Kerr-lens Mode-locked Yb:CaF2 Laser Oscillator Delivering up to 2.7 W"**
Pierre Sevillano, Guillaume Machinet, Romain Dubrasquet, Patrice Camy, Jean-Louis Doualan, Richard Moncorge, Patrick Georges, Frederic P. Druon, Dominique Descamps, Eric Cormier
Advanced Solid State Lasers (ASSL))[**AF3A.6**], 27 October-1 November 2013, Paris (France)

(11) **"High-power sub-50 fs, Kerr-lens mode-locked Yb:CaF_2 oscillator pumped by high-brightness fiber- laser"**
Sevillano, pierre; Machinet, Guillaume; Dubrasquet, Romain; Camy, Patrice; Doualan, Jean Louis; Moncorgé, Richard; Georges, Patrick; Druon, Frederic; Descamps, Dominique; Cormier, Eric
Conference on Lasers and Electro-Optics (CLEO)[**JW2A.41**], 8-13 June, 2014, San Jose CA (USA)

(12) **"37 fs - 1.5 W Kerr-lens mode-locked Yb:CALGO laser oscillator"**
sevillano, pierre; Dubrasquet, Romain; Druon, Frederic; Georges, Patrick; Descamps, Dominique; Cormier, Eric
Conference on Lasers and Electro-Optics (CLEO)[**Stu2E.1**], 8-13 June, 2014, San Jose CA (USA)

(13) **"Chirped Pulse Yb:CALGO Oscillator delivering Sub-100 fs - 4 Watts pulses"**
P. Sévillano, J.C. Delagnes, F. Druon, D. Descamps, and E. Cormier

Conference on Lasers and Electro-Optics Europe (CLEO-EQEC)[**CA-2.3 SUN**], 26-29 June, 2015, Munich (Germany)

(14) "Sub-100 fs - 4 Watts Yb:CALGO chirped pulse oscillator
P. Sévillano, J.C. Delagnes, F. Druon, D. Descamps and E. Cormier
Ultrafast Optics 2015, UFO 2015 [**8984-49**], 16-21 August 2015, Beijing (China)