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GAIN NARROWING FREE OPERATION OF CHIRPED PULSE REGENERATIVE AMPLIFIER BASED ON YB:$LuAlO_3$ CRYSTAL

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1. Introduction

Diode-pumped femtosecond laser sources with pulse repetition rates of hundreds kHz and pulse energies of tens microjoules are of practical importance for high-precision micromachining in industry and biomedicine [1].

These pulse trains can be generated conveniently with RA systems based on bulk regenerative amplifiers. The highest output power reported so far for bulk RAs is 28 W in an Yb:CALGO operating at 500 kHz, with 217 fs pulses [2]. The output power of about 21 W at 200 kHz PRF with 200 fs pulse duration is obtained on Yb:KGW dual crystal system [3]. Femtosecond laser pulses with duration as short as 97 fs with output power of 1.2 W at 50 kHz PRF were obtained with the Yb:CALGO RA system [4] which demonstrates the possibility of sub-100 fs pulses amplification. Generalizing the above data, we can conclude that the search for new laser media with appropriate spectroscopic properties for regenerative amplification of ultrashort laser pulse is still of high interest.

Yb-doped lutecium aluminate laser crystal (Yb:$LuAlO_3$) has attractive spectroscopic properties which makes it promising material for femtosecond laser systems. It has a reasonable large emission cross section (~0.7×10^{-20} cm^2), long upper-level lifetime (475 µs), small quantum defect (<4%), and broadband absorption and emission spectra. In this paper we report the experimental results of an Yb:$LuAlO_3$ chirped pulse RA generating 6 W average power with chirped pulses and 4.4 W output power with a compressed 165 fs pulses for the first time to the best of our knowledge.

2. Experimental layout

The schematic of the system is shown in Fig. 1. As a seed laser diode-pumped Yb:KYW oscillator was used which provides 98 fs pulses [5]. The RA setup chosen for this experiment is quite common, employing a BaB_2O_4 Pockels cell for pulse injection and ejection. Amplifier cavity was formed by two concave folding mirrors (M1, M2) and two flat mirrors (HR1, HR2). 2 mm-long a-cut Yb(2at.%):$LuAlO_3$ crystal was used as a gain medium. The crystal was maintained at 15 °C by means of thermo-electrical cooling elements with water-cooled heatsink.

The main problem for longitudinal pumping of Yb:$LuAlO_3$ crystal is a comparatively low quantum defect (~5%). The strong absorption band of the crystal that can be used for efficient pumping centered at 978.5 nm for π-polarization while the smooth stimulated emission (SE) band is located around 1040 nm.

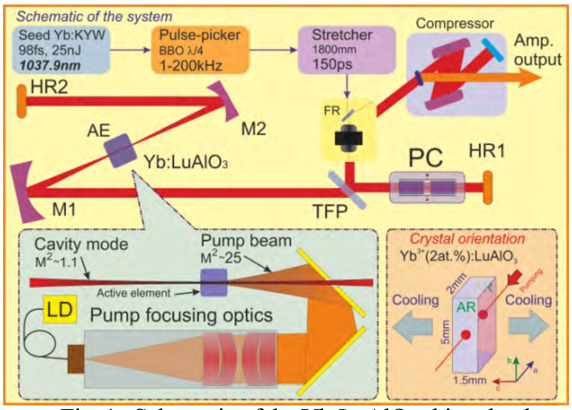

Fig. 1. Schematic of the Yb:$LuAlO_3$ chirped pulse regenerative amplifier

To overcome this spectral features a novel “off-axes” pump layout was developed for longitudinal pumping of the active element (Fig. 1). This pump arrangement was recently successfully tested in the longitudinally pumped passively mode-locked Yb:KGW laser [6]. As a pump source a multiple single emitter InGaAs fiber coupled laser diode (Ø105 µm, NA=0.15) with maximum output power of about 28 W was used. The pump light was formed by set of lenses into the spot with diameter of about 180 µm ($1/e^2$). The losses on transmission of the hole from such "pump" mirror did not exceed 3 % of pump power. Besides that such pumping scheme enable us to tune the wavelength of the laser diode exactly in the absorption band of the material without losses in the short-wave pass filter (input mirror). One of the important things most notably for regenerative amplifiers with longitudinal pumping schemes is that the part of the intracavity pulse energy passes through the input mirror and damages pumping diode. Our pumping scheme is free of these negative issues.

In Fig. 2 the pump beam profiles during the propagation through the gain crystal are depicted. As can be seen the pump beam profile was a circular and homogeneous inside the crystal. The drop in the middle of the pump beam profile appears at the distances >3mm from pump beam waist and therefore do not introduce any negative influence due to the pumping inhomogeneity on the mode-matching and output laser performance.

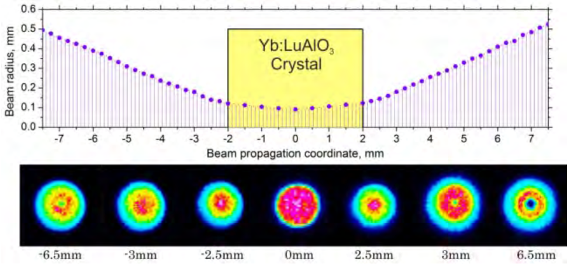

Fig. 2. Beam radius and pump beam profiles during the propagation through the cavity and gain crystal.

A grating compressor was employed at the RA output in order to compress the chirped femtosecond pulse. Compressor with transmission of about 76 % consisted of two reflection Au-coated grating with period of 1800 mm^{-1}, the same as in stretcher.

3. Chirped pulse regenerative amplifier performance

During the RA experiment we measured the output pulse train parameters for E//b and E//c-polarized light in the gain medium at different PRF in the range 1-200kHz. Maximum output power before compression of 6.7W with opt.-to-opt. efficiency of 25% at 75-200kHz PRF was obtained for E//c-polarized light. For E//b-polarization maximum output power before compression of 6W with opt.-to-opt. efficiency about 22% at the same PRF was achieved. During the RA experiment with the highest output power 14.9nm wide (FWHM) pulses were obtained for E//b-polarized light with compressed pulse duration of 165fs. Laser pulses with 2.7nm spectral width were obtained for E//c-polarized light with pulse duration of about 565fs.

The dependency of average output power and pulse energy on the pulse repetition frequency are shown in Fig. 3.

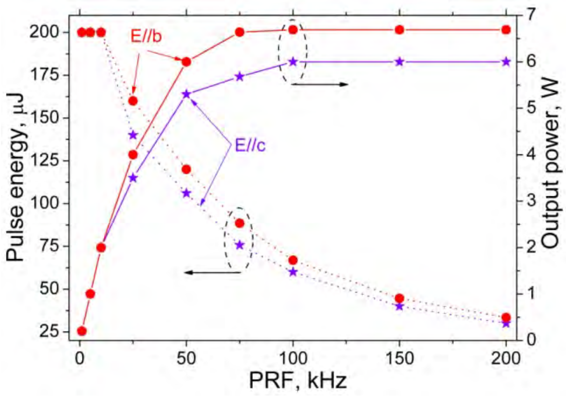

Fig. 3. Average output power and pulse energy versus PRF

$Yb:LuAlO_3$ based RA with E//b-polarized output demonstrated extremely stable broadband output spectrum with 13-15nm spectral bandwidth (FWHM) at different cavity round trip numbers from 63 to 122 and different PRF of 10, 50 and 200kHz without any nonlinear regime of amplification. The output spectra for different polarizations at the highest output power are shown in Fig. 4. In the case of E//b-polarized output spectral width of 14.9nm was wider than seed pulse spectral width of 11.7nm. Moreover, the spectral width of about 14.9nm was almost unchangeable for seed pulses with spectral width in the range 11-15nm (FWHM).

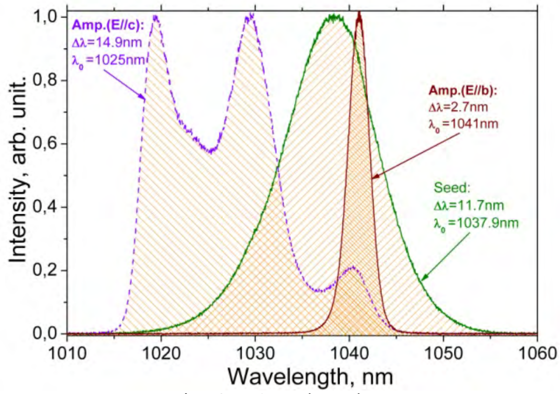

Fig. 4. RA and seed spectra

In conclusion, we have demonstrated, to the best of our knowledge, the first chirped pulse regenerative amplifier based on $Yb:LuAlO_3$ crystal. Gain properties of the crystal for E//b- and E//c-orientations were studied in the RA experiments. Operation without gain narrowing effect was demonstrated for E//b-polarized output while strong gain narrowing was observed for E//c-polarization.

4. References

1. D. Breitling, C. Föhl, F. Dausinger, T. Kononenko, and V. Konov, in Femtosecond Technology for Technical and Medical Applications, F. Dausinger, F. Lichtner and H. Lubatschowski, eds. (Springer, Berlin, 2004).

2. E. Caraccioloet.al., "28-W, 217 fs solid-state $Yb:CAlGdO_4$ regenerative amplifiers," Opt. Lett. 38, 4131-4133 (2013).

3. G.H. Kimet.al., “A high brightness Q-switched oscillator and regenerative amplifier based on a dual-crystal Yb:KGW laser,” Laser Phys. Lett. 10 (2013) 125004 (5pp).

4. Julien Pouysegur et. al., "Sub-100-fs Yb:CALGO nonlinear regenerative amplifier," Opt. Lett. 38, 5180-5183 (2013).

5. A.A. Kovalyov, V.V. Preobrazhenskii, M.A. Putyato, N.N. Rubtsova, B.R. Semyagin, V.E. Kisel, A.S. Rudenkov, N.V. Kuleshov and A.A. Pavlyuk, “Efficient high-power femtosecond $Yb^{3+}:KY(WO_4)_2$ laser,” Laser Phys. Lett. 12, 075801 (2015).

6. V.E. Kisel, A.S. Rudenkov, A.A. Pavlyuk, A.A. Kovalyov, V.V. Preobrazhenskii, M.A. Putyato, N.N. Rubtsova, B.R. Semyagin, and N.V. Kuleshov, "High-power, efficient, semiconductor saturable absorber mode-locked Yb:KGW bulk laser," Opt. Lett. 40, 2707-2710 (2015).