

СПР биообъектов, в том числе флуоресцентной микроспектрометрии, а также в исследованиях в области фотодинамической терапии.

1. Hagen N., Kudenov M. W. Review of snapshot spectral imaging technologies // *Opt. Engineering*. – 2013. – Vol. 52, № 9. – P. 090901-1–090901-23.
2. Bodkin A. *et al.* Snapshot hyperspectral imaging – the hyperpixel array camera // *Proc. SPIE*. – 2009. – Vol. 7334. – P. 73340H-1–73340H-11.

УДК 621.373.826

Yb:CALYO BASED BROAD-BAND SEEDED CHIRPED PULSE REGENERATIVE AMPLIFIER

Rudnikov A.¹, Kisel V.¹, Yasukevich A.¹,
Hovhannesian² K., Petrosyan A.², Kuleshov N.¹

¹ Center of Optical Materials and Technologies, Belarusian National Technical University, Minsk, Belarus

² Institute of Physical Research, National Academy of Sciences, Ashtarak-2, Armenia

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. One of 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]. 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:CALYO crystal demonstrate promising spectroscopic properties that confirmed by excellent experimental results in mode-locked lasers provided near-transform limited pulses with wide spectra [4]. Despite the availability of femtosecond lasers providing wide spectral width pulses based on Yb-doped crystals seed lasers of large number of RA systems described in the literature have narrower pulse spectral width not over than 15nm. And this also limits the amplified pulse spectral width.

In our paper we present the experimental results of broad-band seeded Yb:CALYO-based chirped pulse regenerative amplifier for the first time to the best of our knowledge.

A conceptual scheme of the system (Fig. 1) consists of Yb:KYW seed laser (100 fs, 10 nJ), fibre-based stretcher, regenerative amplifier and compressor. A 10m-long single mode $\varnothing 9/125 \mu\text{m}$ telecom fibre was used for pulse spectral broadening and temporal stretching ($t_{\text{pulse}}=7.5 \text{ ps}$). The RA setup chosen for this experiment is quite common, employing a 40-mm-long double-BaB₂O₄ Pockels cell for pulse injection and ejection. Pulse repetition frequency (PRF) was chosen to be 200kHz to prevent damage of the optical elements. “Off-axes” pump layout was used for longitudinal pumping of the active element [5–7]. Main advantage of such a pump scheme is that all the cavity mirrors have highly reflecting coating at 900–1100 nm. 2 mm-long a-cut

Yb(3.5 at.%):CaYAIO₄ crystal was used as a gain medium. The last unit of the amplifier system is compressor based on transmission diffraction grating with 1000 grooves per millimetre.

As a pump source a multiple single emitter InGaAs fiber coupled laser diode ($\varnothing 105 \mu\text{m}$, NA=0.15) with maximum output power of about 25 W was used. The pump light was formed by set of lenses into the spot with diameter of about $180 \mu\text{m}$ ($1/e^2$). 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.

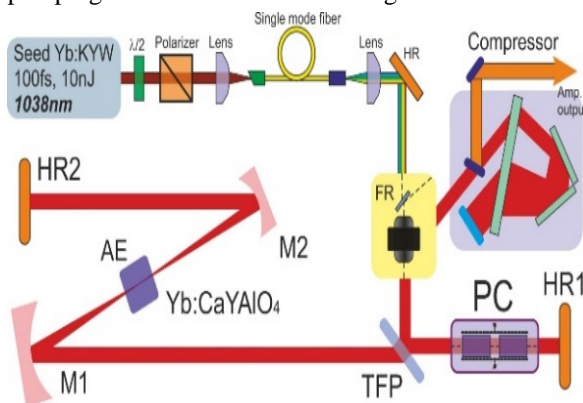


Fig. 1. Schematic of the Yb:CaYAIO₄ chirped pulse regenerative amplifier

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 $>3\text{mm}$ 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.

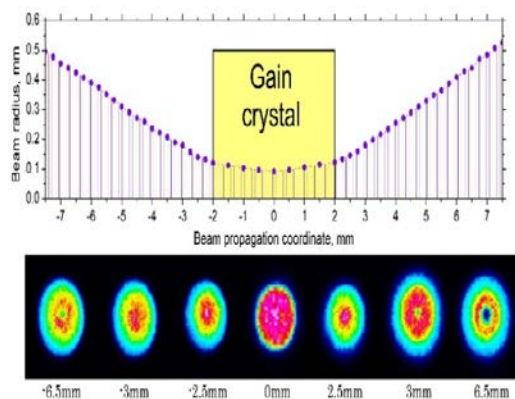


Fig. 2. Beam radius and pump beam profiles during the propagation through the cavity and gain crystal

During the RA experiment we measured the output pulse train parameters for π - and σ -polarized light in the gain medium at 200 kHz PRF. The dependencies of average output power and pulse spectral width on cavity round trip number (c.r.t.) for Yb:CALYO regenerative amplifier system (before compression) are presented in Fig. 3.

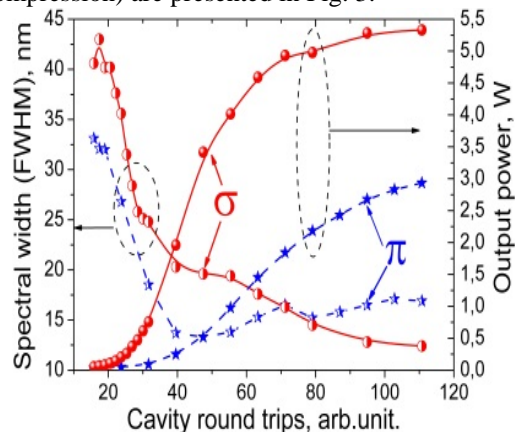


Fig. 3. Dependencies of average output power and pulse spectral width on cavity round trip number

The maximum average output power of 4.2 W was obtained for π -polarized light. On increasing the cavity round trips number from 63 to 126 pulse spectral width decreases slightly from 19.2 nm to 18.2 nm. The widest amplified pulse spectrum of 42.5 nm (FWHM) was obtained for σ -polarized light after 16 c.r.t. On increasing c.r.t. number from 16 to 126 output power has risen from 11 mW to 4 W. Amplified pulse spectrum evolution under its round trip through the amplifier for σ -polarization is shown in Fig. 4.

As one can see from the Fig. 3 π -polarization demonstrates weak dependence of the amplified pulse spectral width on the c.r.t. number. Autocorrelation trace of the amplified pulses for π -polarized light at the highest output power is shown in Fig. 5. Measured pulse duration was about 120 fs assuming Lorentzian pulse shape.

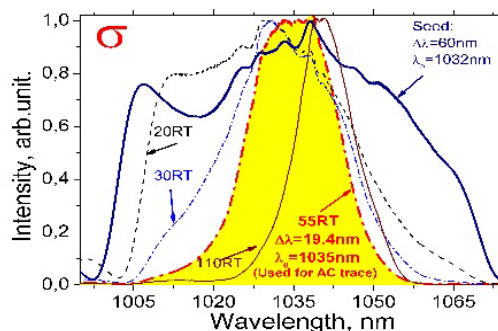


Fig. 4. Pulse spectrum evolution under its round trip (RT) through the amplifier for σ -polarization

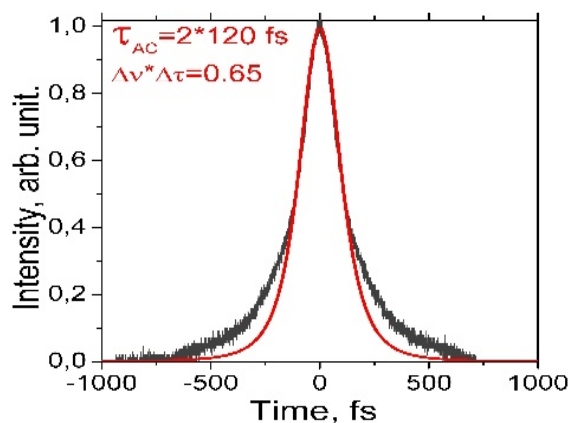


Fig. 5. Autocorrelation trace of the amplified pulses for π -polarization at the highest output power

In conclusion, the results of experimental investigation of broad-band seeded Yb:CALYO-based chirped pulse RA are reported for the first time to our knowledge. It generates as high as 3 W of average output power with 120 fs (19.4nm FWHM) compressed pulses at 200 kHz repetition rate.

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. Caracciolo et al., "28-W, 217 fs solid-state Yb:CaIGdO₄ regenerative amplifiers," *Opt. Lett.* 38, 4131-4133 (2013).
3. G.H. Kim et 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. P. Sévillano et al., "32-fs Kerr-lens mode-locked Yb:CaGdAlO₄ oscillator optically pumped by a bright fiber laser," *Opt. Lett.* 39, 6001-6004 (2014).
6. V. E. Kisel et al., "High-power, efficient, semiconductor saturable absorber mode-locked Yb:KGW bulk laser," *Opt. Lett.* 40, 2707-2710 (2015).
7. A. Rudenkov, V. Kisel, A. Yasukevich, K. Hovhannesian, A. Petrosyan, and N. Kuleshov, "Yb³⁺:CaYAlO₄-based chirped pulse regenerative amplifier," *Opt. Lett.* 41, 2249-2252 (2016).
8. A. Rudenkov, V. Kisel, V. Matrosov, and N. Kuleshov, "200 kHz 5.5 W Yb³⁺:YVO₄-based chirped-pulse regenerative amplifier," *Opt. Lett.* 40, 3352-3355 (2015).