Compact femtosecond laser system with 2 mJ output

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Abstract: 2-mJ, 600-fs, 1047-nm pulses at a 250-Hz rate from a compact, Yb-doped crystal CPA laser system were achieved. We combine a positive-dispersion-regime oscillator, regenerative amplifier and a hybrid stretcher/compressor based on chirped volume Bragg gratings.

OCIS codes: (140.3580) Lasers solid state; (140.4050) Lasers mode-locked (140.7090) Ultrafast lasers (140.4480) Optical Amplifiers

Ultrafast solid state laser systems based on directly diode-pumped, Yb:doped materials provide a compact, low-cost alternative to Ti:sapphire systems when sub-100-fs pulses are not required. Yb:KGW and Yb:KYW crystals provide excellent performance in femtosecond oscillators and high-repetition-rate amplifiers [1]. Yb:CaF_2 provides high-pulse-energy operation due to long fluorescence lifetime of 2 ms [2]. Here we report on the development of compact ultrafast laser system based on a Yb:KGW oscillator, Yb:CaF_2 regenerative amplifier and chirped volume Bragg grating (CVBG) stretcher/compressor.

Yb:KGW PDR femtosecond oscillator

Typical saturable Bragg reflector (SBR), mode-locked Yb-doped oscillators operate in the soliton regime with a small amount of a negative intracavity dispersion and generate 100-200 fs laser pulses. Recently it was shown that operation of a SBR mode-locked laser in the positive dispersion regime (PDR) allows generation of high pulse energy pulses (up to 2 uJ) directly from the oscillator [3]. This regime produces a strongly chirped laser pulse with a duration of a few picoseconds. An external compressor (prism- or grating-based) can compensate the chirp and return the pulse duration to the femtosecond range.

In order to operate our oscillator (Fig. 1) in the PDR regime, to produce high-energy pulses, we used a combination of a negatively chirped mirror and a BK7 Brewster plate to set the net cavity GVD to approximately + 370 fs^2. The SBR had a saturable absorption of 0.7 %, and a saturation fluence of 120 μJ/cm^2 at 1045 nm. Using as 0.6-% output coupler, we obtained 125 mW of average power centered around 1047 nm with 3.5 W of pump power at 980 nm The output pulse of the laser was strongly chirped with a 2.7-ps pulse duration. The output spectrum of the laser was typical for the PDR (see Figure 2, insert) and had the bandwidth of approximately 15 nm. We compensated for the chirp with two 1700 g/mm holographic gratings. The pulse (Fig. 2) after the compression had a 320-fs duration.

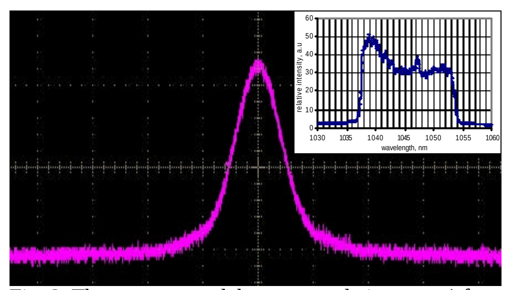

Fig. 2. The spectrum and the autocorrelation trace (after compression) of the Yb:KGW oscillator in PDR regime.

Operation of the laser in the PDR reduced the intracavity peak power and stabilized the operation of the laser significantly compared to the soliton mode-locking regime.

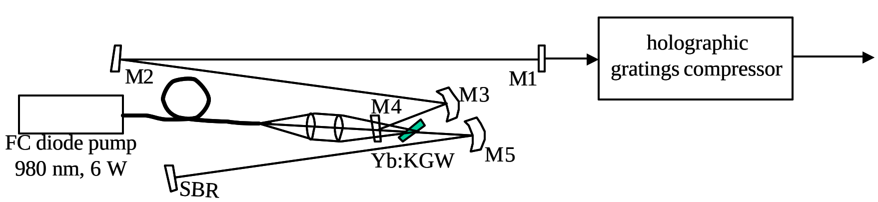

Fig. 1. Schematic of SBR mode-locked Yb:KGW with the pulse compressor: M1 – output coupler; M2 – chirped mirror; M3, 5 – curved mirrors with ROC=200 mm; M4 – dichroic mirror; SBR – saturable bragg reflector; G1-2 – holographic gratings, M – HR at 1050 nm, ?/2 – half waveplate.

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Yb:CaF$_2$ regenerative amplifier system

For chirped-pulse regenerative amplification the standard stretcher/compressor setup utilizes diffraction gratings that require a substantial amount of space (up to 1-2 m) in order to achieve the necessary dispersion. A significant reduction in a size and weight can be achieved through the use of CVBG [4], but the amount of GVD in the amplified output cannot be adjusted to compensate for the dispersion accumulated in the regenerative amplifier during multiple passes of the laser pulse.

We developed a hybrid CPA setup using a CVBG and an additional compact compressor stage based on transmission holographic gratings. The layout of CPA system is presented in Figure 3. The output from the PDR femtosecond oscillator passes through an isolator and enters an adjustable compressor made of two holographic transmission gratings, then is reflected by the CVBG element. Such a combination serves two purposes: 1) the adjustable grating compressor eliminates the chirp in the oscillator pulse, 2) the CVBG element stretches the pulse to 250 ps. The stretched pulse then entered the regenerative Yb:CaF$_2$ amplifier where it is amplified to the saturation level. After the amplification the laser pulse is reflected by a second identical CVBG element, where it is compressed to the original pulse duration. Adjustment of the distance between two holographic gratings allows fine control over the dispersion compensation and the compressed pulse duration. We chose the two-CVBG-element setup to make system more compact, with a total package size for the laser head of 66 x 21.5 x 40 cm.

In the regenerative amplifier we used a 3.8%-doped, 4-mm-long, Brewster-cut Yb:CaF$_2$ crystal, pumped by a 980-nm, 19-W fiber-coupled diode laser. The amplifier cavity used a X-fold configuration. The system operated at 250 Hz, generating 500 mW of average power. At higher repletion rates we encountered a problem with pulse-to-pulse instabilities due to the long upper state lifetime of Yb:CaF$_2$ [5]. We characterized the output of the laser system with the use of GRENOUILLE (Swamp Optics). Figure 4 represents the autocorrelation trace of the output pulse, which corresponds to the pulse duration 574 fs. The autocorrelation trace indicated the presence of a pedestal which primarily due to a gain narrowing in the regenerative amplifier the limited spectral bandwidth of the CVBG.

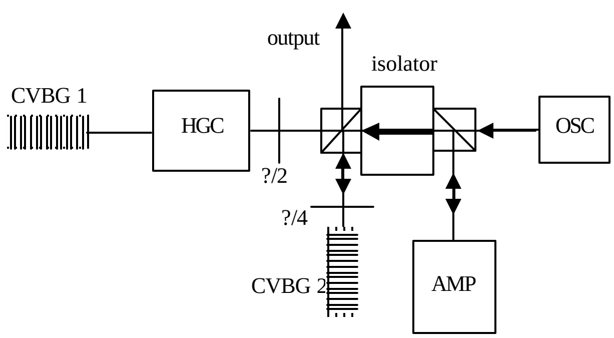

Fig. 3. The configuration of the CPA system with hybrid stretcher/compressor setup: HGC – holographic gratings compressor; CVBG1,2 – chirped volume bragg gratings.

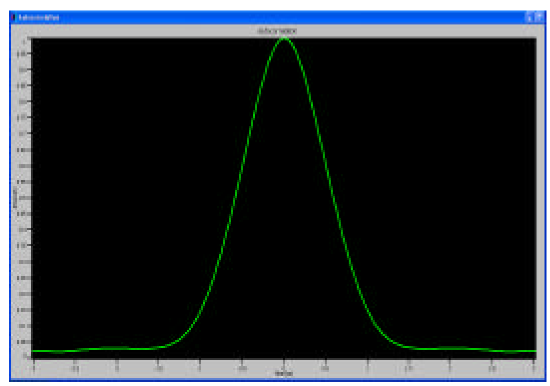

Fig. 4. The autocorrelation trace of the amplified laser pulse.

In conclusion we have developed a compact femtosecond laser system with a 2 mJ, 600 fs output at 1047 nm and a 250-Hz repetition rate. We used a femtosecond oscillator operating in positive dispersion regime as a seed laser and a regenerative chirped-pulse amplifier with a chirped volume Bragg gratings and holographic gratings in a the hybrid stretcher/compressor.

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