Diode-pumped Gigahertz Repetition Rate Femtosecond Cr:LiSAF Laser

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Abstract: We report a low-cost, 1 GHz repetition-rate, diode-pumped, saturable Bragg reflectors mode-locked Cr:LiSAF laser, which generates nearly transform-limited 103-fs long pulses around 866 nm, with a record high peak power of 1.45 kW.

OCIS codes: (140.3460) Lasers; (140.3480) Lasers, diode pumped; (140.4050) Mode-locked lasers

High repetition-rate femtosecond (fs) laser pulses are important in many applications such as optical frequency combs generation [1], low noise microwave source development [2], and high-speed optical sampling [3]. Presently, most of them rely on Ti:Sapphire technology to obtain high peak-power, femtosecond laser pulses with repetition rates in the 1-10 GHz range. Higher repetition rates up to 100 GHz have been recently demonstrated with diode-pumped fundamentally mode-locked Er:Yb:glass lasers [4]. However, most high repetition-rate lasers of this kind can only produce pulses in the picosecond regime with peak powers limited to several watts. In addition, a major drawback of the femtosecond Ti:Sapphire technology is the requirement for frequency-doubled neodymium pump lasers which make the overall system bulky and expensive. In contrast, Cr:Colquiriite gain media such as Cr:LiSAF offer the possibility of direct diode pumping, combined with a broad emission band that can support down to 10-fs pulses [5]. Direct diode pumping facilitates the construction of highly-efficient, compact and low-cost laser systems [5]. Moreover, Cr:Colquiriites can be passively mode-locked with saturable Bragg reflectors (SBR) [6] (also known as semiconductor saturable absorber mirrors (SESAM) [7]), enabling self-starting and robust mode-locked operation. A GHz repetition-rate femtosecond Cr:LiSAF laser was first reported in [8], but had low peak power (~20 W), due to the limited availability of efficient red laser diodes at that time, and limitations in SBR/SESAM design.

In this paper, we present a low-cost, single-mode diode pumped, SBR/SESAM mode-locked, Cr:LiSAF laser at 1 GHz repetition rate. In continuous-wave (cw) mode-locked operation, nearly transform-limited 103-fs long pulses, with 170 pJ of pulse energy and 1.45 kW peak power are obtained around 866 nm. This represents a factor of ~70 increase in attainable peak powers from GHz Cr:Colquiriite lasers [8].

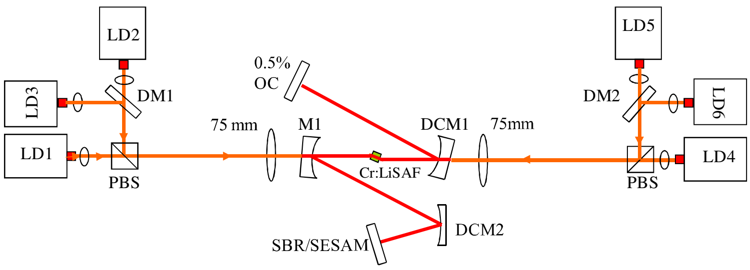

Fig. 1. Schematic of the single-mode diode-pumped femtosecond GHz Cr:LiSAF laser.

Fig. 1. shows the schematic of the experimental setup. The 6-mm long, Brewster-cut, 1.5% Cr-doped Cr:LiSAF gain medium is pumped from both sides in order to balance the thermal load. On one side, LD2 (640 nm) and LD3 (660 nm), both TE polarized, are wavelength-coupled by a dichroic mirror (DM1), and then combined with the TM-polarized LD1 (640 nm) by using a polarizing beam splitter cube (PBS). The other side has an identical pumping configuration. Each of the four 640-nm laser diodes produces about 200 mW output power when driven at 350 mA and TEC-cooled to 15 deg C, while each of the two 660-nm laser diodes produces about 130 mW output power when driven at 220 mA without active cooling. Taking into account the absorption of the crystal (97% for TM polarization and 84% for TE polarization) and the coupling efficiency of the diodes, the total absorbed pump power is 900 mW with all 6 diodes, or 680 mW with only four 640-nm diodes. An aspheric collimating lens of 4.5 mm focal length, in combination with a 75-mm focal-length input lens, focuses each pump beam to the desired beam waist of 70-μm inside the Cr:LiSAF crystal. The laser cavity is a standard four-mirror astigmatically compensated z-shape resonator, constructed using two 50-mm radius of curvature pump mirrors (M1 or DCM1).

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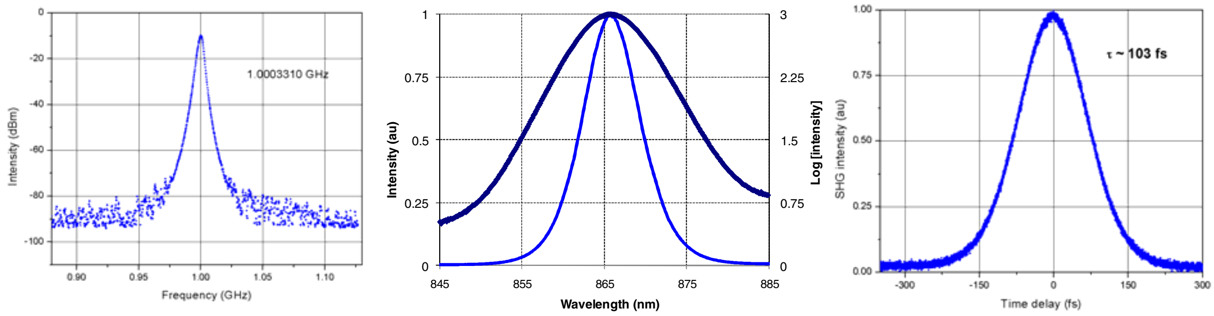
Stable cw mode-locking is obtained with a SBR/SESAM, whose reflectivity is centered around 850 nm and has the same structure as the one described in [5] except for an additional pair of SiO_2-TiO_2 high-reflection (HR) coating on the surface. The HR coating facilitates mode-locking at high-repetition rates in two ways. First of all, tight focusing onto the SBR/SESAM is necessary when pulse energy decreases with increasing repetition rates. In particular, a curved mirror of 25 mm radius of curvature (DCM2 in Fig. 1) is used to obtain a ~30-µm beam waist on the SBR/SESAM. Decreased passive loss level reduces the risk of thermal damage (water cooling of SBR/SESAM at 15 deg C is used). In addition, a HR coating decreases the modulation depth, reducing the critical pulse energy needed to sustain cw modelocking against Q-switching instabilities [9]. In our case, one pair of alternating dielectric layers reduces the SBR/SESAM modulation depth from ~2% to ~0.7%.

In order to provide the required negative dispersion, two dispersion compensating mirrors (DCMs) [10] are used (DCM1 and DCM2 in Fig. 1). The DCMs have a reflectivity of ~ 99.99% around 850 nm and a GDD of -80 fs^2 per bounce. Counting the two bounces on each DCM, as well as the positive GDD from the crystal, air path and output coupler (0.5% OC in Fig. 1), the total round-trip GDD is estimated to be ~ -60 fs^2.



(a) (b) (c)

Fig. 2. Summary of mode-locking results: (a) Measured RF spectrum, showing the laser repetition rate around 1 GHz. (b) Optical spectra in linear and logarithm scales. (c) Autocorrelation trace for the 103-fs long pulses.

The mode-locking results are summarized in Fig. 2. The repetition rate is measured with a photodiode and RF spectrum analyzer and is centered around the ~1-GHz peak, which is 80-dB above background level [Fig. 2(a)]. The optical spectrum has a bandwidth of ~8 nm around 866 nm [Fig. 2(b)]. The autocorrelation has 160 fs FWHM, corresponding to 103-fs pulse width (assuming $sech^2$ pulse shape) [Fig. 2(c)]. The corresponding time-bandwidth product is 0.33, slightly above the transform-limited value of 0.315. When pumped with 6 diodes at full power, the 167-mW average output power results in pulse energy of 170 pJ and peak power of 1.45 kW. CW mode-locking is obtained for absorbed pump powers above 600 mW, and below that the laser operated in pure cw regime (Q-switched mode locking regime is not observed). When pumped by four 640-nm diodes, the laser generates 153-fs pulses with an average power of 146 mW, which corresponds to 150-pJ pulse energy and 0.86 kW peak power.

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