8.6 MHz Extended Cavity Cr:ZnS Chirped-pulse Oscillator

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Abstract: We report the first extended cavity Cr:ZnS chirped-pulse oscillator mode-locked by graphene. We demonstrate 415 mW average power at 8.6 MHz repetition rate which results in 48 nJ pulse energy.

 OCIS codes: 140.4050 Modelocked Lasers; 140.3070 Infrared and far-infrared lasers, 140.3580 Lasers, solid-state

1. Introduction

Continuous-wave (CW) and ultrashort-pulsed sources based on Cr^{2+}-doped II-VI crystals are being extensively developed recent years, already entering the real-world applications [1]. In particular the Cr^{2+}:ZnS exhibits robustness, mechanical and optical stability, demonstrates tens of Watts average power in CW regime, up to 24 nJ pulse energy directly from the oscillator [2], and > 90 nJ after the amplifier in femtosecond pulsed regime [2]. Still the pulse energy extracted from the femtosecond oscillator is limited by the soliton breakup due to high n2 of the active medium. Chirped pulse oscillator (CPO) approach has been demonstrated to overcome this problem [3,4], and theoretical modelling shows a great potential for further pulse energy scaling. In this paper we demonstrate the record pulse energy of 45 nJ from the Cr:ZnS laser oscillator through the implementation of the Herriott-type multi-pass cavity (MPC).

2. Experimental setup

Conventional 70-MHz cavity was arranged first. It was a standard delta-cavity with Brewster orientation of the active crystal, astigmatism compensation by incidence angle at mirrors M1 and M2, and additional focusing to saturable absorber using mirror M3. The system was pumped by a 5W linearly polarized Er:fiber laser emitting at 1.61 μm. Graphene-based saturable absorber mirror (single-layer graphene transferred onto the surface of a broadband HR dielectric mirror) served as a saturable absorber. The cavity exhibited normal round-trip GDD caused by 2.5 mm active Cr:ZnS crystal and 1 to 3 mm thickness of YAG crystal adjustable by translation of one of the YAG wedges. Output coupler with 30% transmission was used.

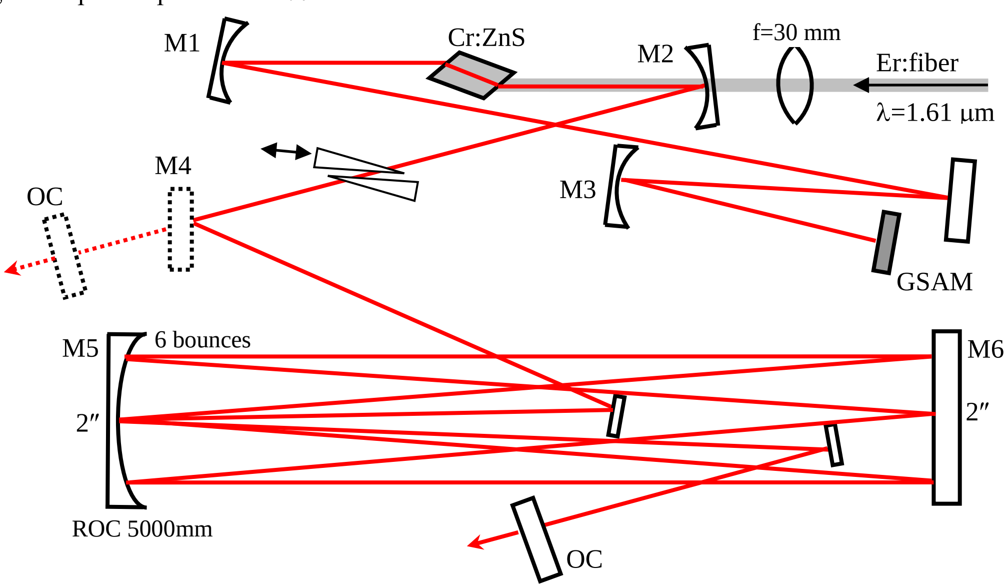

Fig. 1. Experimental setup of extended cavity Cr:ZnS chirped-pulse oscillator

After the mode-locking in a 70 MHz cavity was established, the Herriott-type multi-pass cavity (MPC) was adjusted. One can switch between the normal 70 MHz cavity and the extended cavity using the flipping mirror M4. The MPC consisted of two 2-inch-diameter broadband high-reflecting mirrors M5 and M6. The MPC parameters are chosen to keep the q-parameter of the 70-MHz cavity invariant. This is achieved by proper choice of the radius of curvature of the mirror M5 (5000 mm) and separation between mirrors M5 and M6 (1250 mm). The separation is calculated according to the theory of MPC cavities [5]. For the beam going in one direction there are 6 round-trip passes (n=6) in the MPC, and the beam at the output coupler (20% transmittance) has the same q-parameter as the input beam at mirror M4. The total round-trip length of the extended cavity was equal to 35 m, corresponding to a roundtrip time of 116 ns.

3. Results and discussion

Up to 500 mW of average output power could be extracted from the extended cavity Cr:ZnS laser in CW regime (when GSAM was substituted for a standard HR mirror). Implementation of the GSAM results in a stable mode-locked operation of a laser in the center of the cavity stability zone. Gentle perturbation of the cavity by dragging of GSAM was typically required to initiate the mode-locking. The input-output characteristics of the laser are shown on the Fig. 2.

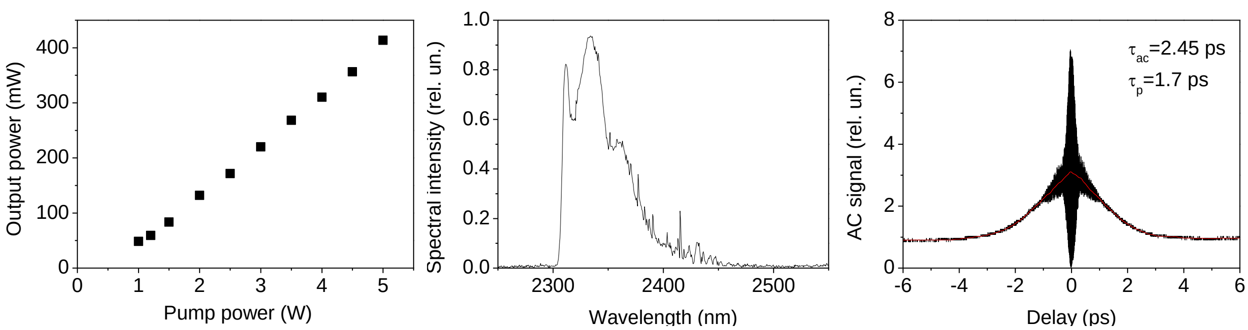

Fig. 2. Input-output characteristic (a), optical spectrum (b), and interferometric autocorrelation trace (c) of the extended cavity 8.6 MHz Cr:ZnS chirped pulse oscillator.

Additional cavity losses caused by GSAM reduced the average output power down to 415 mW. The mode-locking could be established in rather broad range of the output powers. Optical spectrum (Fig. 2b) is typical for the dissipative soliton operation of the mode-locked laser in the case of significant third order dispersion [3], and high-frequency modulation results from the intracavity water vapor absorption [6]. Spectral bandwidth up to 150 nm was demonstrated. Interferometric autocorrelation trace (Fig. 2c) gives the evidence of the strongly chirped pulse with duration around 1.7 ps (assuming gaussian shape). RF spectrum shows clear single peak without any side lobes at fundamental cavity repetition rate of 8.62 MHz, resulting in over 48 nJ pulse duration.

4. Conclusion

Extended cavity Cr:ZnS chirped-pulse oscillator with repetition rate 8.6 MHz was demonstrated for the first time to our knowledge. Record pulse energy of nearly 50 nJ was demonstrated directly from the oscillator. Further decreasing of the cavity repetition rate and optimization of the cavity parameters opens the way to generate over 200 nJ pulse energy without amplification stage.

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