

Ceramic Cr:ZnS Laser Mode-Locked by Graphene

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Abstract: We report a high-power graphene mode-locked ceramic Cr:ZnS-laser, producing 3.9 nJ, 140 fs pulses with 45 nm spectral bandwidth at 270 MHz repetition rate, at output power for the first time exceeding 1 W level.

©2014 Optical Society of America **OCIS codes:** 140.4050 Modelocked Lasers; 140.3070 Infrared and far-infrared lasers, 140.3580 Lasers, solid-state

1. Introduction

Femtosecond Cr:ZnS lasers made a great progress in the last few years. The realization of different mode-locking mechanisms, such as SESAM [1,2], Kerr-lens [3,4], and, recently, graphene [5,6] and carbon nanotubes [7] resulted in a wide range of the implementations and output parameters, reaching 44 fs pulse duration [5] and 1W average output power [6]. These remarkable results have been mostly achieved using the monocrystalline Cr:ZnS, which is not easy to produce. At the same time the more technological polycrystalline Cr:ZnS was reported to show a very good performance in the continuous-wave regime [8]. In this paper we report the first realization of a graphene-modelocked femtosecond Cr:ZnS ceramic laser with excellent characteristics, made possible by the simultaneous implementation of the purposely designed chirped- and graphene mirrors.

2. Experimental setup

The experimental setup is shown in Fig. 1. The pump beam of the Er-fiber laser at 1.61 μm was focused by the 40-mm AR-coated lens to a 60x130- μm spot on the crystal. The X-folded near-symmetrical astigmatically compensated four-mirror cavity had a round-trip length of about 1.1 m. Active element (2-mm-thick diffusion-doped Cr:ZnS ceramics) was positioned at Brewster angle between the concave mirrors having 50 mm ROCs. The crystal absorbed about 85% of the pump emission. Graphene saturable absorber was deposited on the surface of the flat high-reflector mirror thus forming graphene-based saturable absorber mirror. The cavity mode was additionally focused to graphene saturable absorber by ROC=100 mm concave chirped mirror. No active cooling was necessary at this power level. We used an output coupler with 18% transmittance. The compensation of the group-delay dispersion (GDD) was achieved by the single chirped mirror (CM) in a double-bounce configuration.

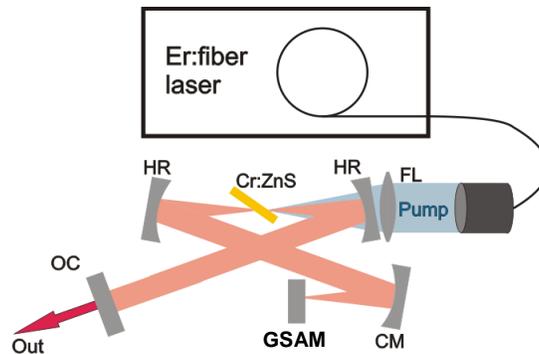


Figure 1. Experimental setup of the graphene-mode-locked ceramic Cr:ZnS laser. FL-focusing lens, HR – high reflector mirror, CM – chirped mirror, GSAM – graphene-based saturable absorber mirror, OC – output coupler.

3. Results and discussion

The laser was self-starting and was operated in the anomalous dispersion regime (also called “negative dispersion regime” or “soliton regime”) with dispersion around -500 fs² per cavity roundtrip. The laser produced up to 1.05 W of average output power on the cavity fundamental frequency of 270 MHz, providing the maximum pulse energy of

3.9 nJ. The pulse energy was limited by the pump power available, but according to our previous results with single-crystalline Cr:ZnS [3], we are quite close to the pulse breakup limit due to third-order optical nonlinearity of the active crystal. The pulse duration shortened with the increase of the pump power, reaching the shortest duration of 140 fs at the maximal output power. The laser spectrum centered at 2.35 μm had a bandwidth of 45 nm FWHM. The pulses were close to the transform-limited with time-bandwidth product of 0.336. The dispersion curve, laser spectrum and autocorrelation function are plotted in Fig. 2.

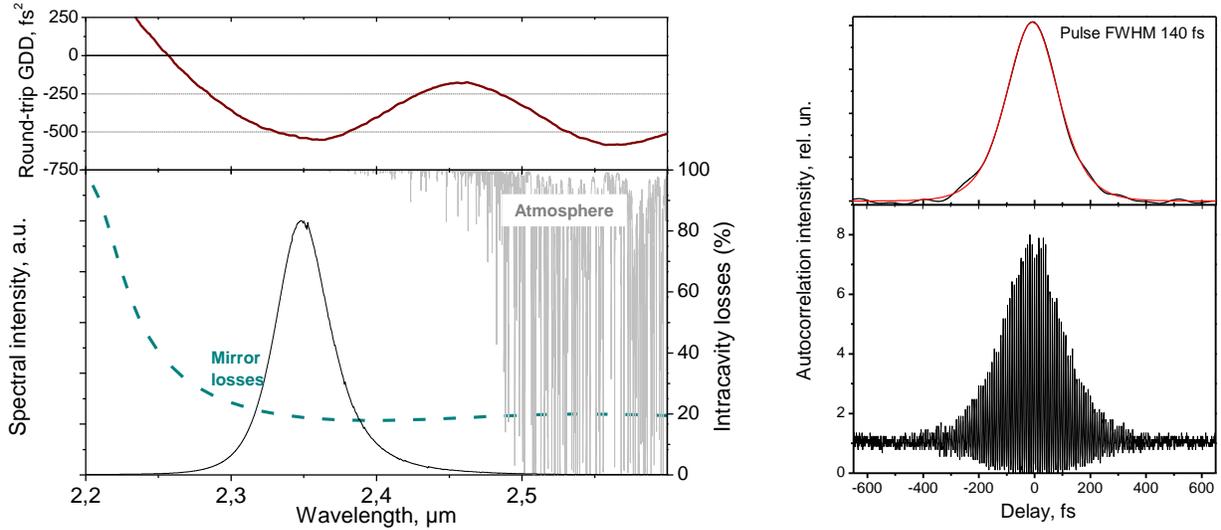


Fig. 2. The intracavity dispersion and laser spectrum of the graphene-mode-locked ceramic Cr:ZnS laser, as well as OC losses and atmosphere absorption (left); interferometric autocorrelation trace and FT-filtered intensity autocorrelation trace with sech² fitting (right).

We have reported the KLM Watt-level femtosecond Cr:ZnS laser recently [4]. This configuration of the laser has a number of advantages. The implementation of the ceramic active element allows to eliminate crystal growth difficulties of monocrystalline Cr:ZnS. Mode-locking by graphene-based saturable absorber mirror results in a reliable self-starting and simplified cavity adjustments. Shortening the cavity and increasing the pump absorption efficiency allow reaching high output power in a reliable single-pulse regime with a controllable pulse repetition rate. We have not observed any damage of either active element or passive shutter during the experiments. Further shortening the pulse duration requires optimization of the mirror designs for fine-tuning the intracavity GDD.

To conclude, we have demonstrated for the first time ceramic Cr:ZnS laser mode-locked by graphene-based saturable absorber mirror. The laser provided average output power over 1W with pulse duration of 140 fs and repetition frequency of 270 MHz. The laser spectrum reached 45 nm bandwidth and was centered at 2.35 μm . We have demonstrated a simple and feasible approach for reliable femtosecond laser in the mid-IR, which should be interesting for a number of applications.

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