Femtosecond pulse generation from a SESAM mode-locked Cr:ZnSe laser

Irina T. Sorokina and Evgeni Sorokin
Institut für Photonik, TU Wien, Gusshausstr. 27/387, A-1040 Vienna, Austria
sorokina@tuwien.ac.at
Timothy J. Carrig
Coherent Technologies, Inc., 135 S. Taylor Avenue, Louisville, CO 80027

Abstract: We report continuous-wave Cr:ZnSe laser, passively mode-locked by an InAs/GaSb SESAM and generating ~100 fs pulses at up to 75 mW power around 2.5 μm wavelength. Routes to shorter pulses are analyzed and compared experimentally.

OCIS codes: (140.4050) Modelocked Lasers; (140.3580) Solid State Lasers; (140.3070) Infrared and far-infrared lasers; (140.5680) Rare-earth and transition-metal solid-state lasers.

An ultrabroadband Cr^{2+}-doped ZnSe laser [1-3] possessing remarkable spectroscopic and mechanical properties and operating between 2 and 3 μm in continuous-wave, Q-switched and mode-locked regimes is highly attractive for such applications as spectroscopy and remote-sensing [4], medicine and technology. So far mode-locking, both active and passive have been achieved in Cr^{2+}:ZnSe [5-7] and Cr^{2+}:ZnS laser [8]. The first works used an acousto-optic modulator to mode-lock the laser with the shortest pulses being 4 ps [5,6] at up to 400 mW [6] output power. Recently, the first semiconductor saturable absorber (SESAM) mode-locked Cr^{2+}:ZnSe laser generating 11 ps pulses at 2.5 μm at 400 mW output power was demonstrated [7]. The pulse duration was presumed to be limited by some intrinsic limitation like an etalon [7]. To overcome a picosecond barrier in Cr^{2+} lasers was therefore although a highly desirable, but also a very challenging task.

This paper reports the first femtosecond pulse generation in a Cr^{2+}:ZnSe laser, passively mode-locked by an InAs/GaSb based multiple quantum well SESAM, generating ~100 fs pulses. We also studied the physical mechanisms, which limited the pulse duration in previous works and constitued a kind of barrier towards femtosecond pulse generation from this material, as well as the operation regimes of the SESAM in terms of parameter ranges for multipulse generation and single pulse operation [9].

The experimental set up is schematically shown in Fig. 1. The X-fold four-mirror cavity configuration was optimized to avoid the possible parasitic étalon effects. The overall cavity length was 75 cm, corresponding to 200 MHz of pulse repetition rate. The dispersion compensation was provided by a single 5 mm sapphire plate, which made the whole laser design quite simple and compact.

The SESAM sample consisted of a saturable absorber based on 50 layers of InAs/GaSb quantum wells, grown on top of a dielectric mirror made from 15 alternating layers of quarter-wave thickness GaSb and $AlAs_{0.08}Sb_{0.92}$ on a GaSb substrate. The SESAM had the small-signal absorption of 12% per bounce, a calculated relaxation time of 200-300 ps, and a saturation fluence of 40 □J/cm^2.

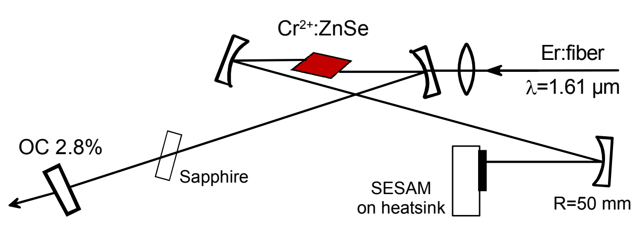

Fig. 1. Schematic of the experimental setup. The pump at 1.61 μm and the output radiation are polarized in the plane of the figure. OC, output coupler with 2% transmission.

The threshold in CW regime was measured to be 200 mW of absorbed power in Cr:ZnSe. The maximum output power in CW regime without SESAM routinely exceeded 1 W level. However, with SESAM installed in the cavity, operation at high power levels caused overheating of the SESAM because

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of its high initial absorption, and we kept the pump power at a relatively low level. In the single pulse regime the optimized laser generated pulses of ~0.97 ps duration at 250 mW of output power without dispersion compensation. Applying the latter led to the significant broadening of the spectra (Fig. 2c) and the corresponding reduction of the pulse duration well into the femtosecond domain.

With sapphire plate for dispersion compensation the laser provided very stable pulses with duration of about 100-110 fs at the output power of 60-75 mW. The autocorrelation trace and the spectrum of a typical pulse are given in Fig. 2. The pulse was measured by the collinear autocorrelator using the two-photon absorption in an InGaAs photodiode, and $sech^2$ shape has been assumed (Fig. 2a). The spectral width of the pulse was 100 cm^{-1} (3 THz), measured by an FTIR spectrometer (Fig. 2b). The spectrum shows some asymmetry, which we attribute to the presence of the strong third-order dispersion in the cavity (Fig. 2c). Nevertheless, the time-bandwidth product of 0.32 is almost ideal for a $sech^2$ pulse. The dispersion was somewhat overcompensated in our cavity (~1800 fs^2 at 2450 nm), and we believe that correct dispersion compensation should allow generation of significantly shorter pulses.

It should also be noted that in its present form the SESAM imposes very relatively high insertion losses. In a plain four-mirror cavity the same laser yielded up to 1.8 W in CW regime. We believe that with a SESAM optimized for minimal losses and one should be able to achieve much higher levels of the output power.

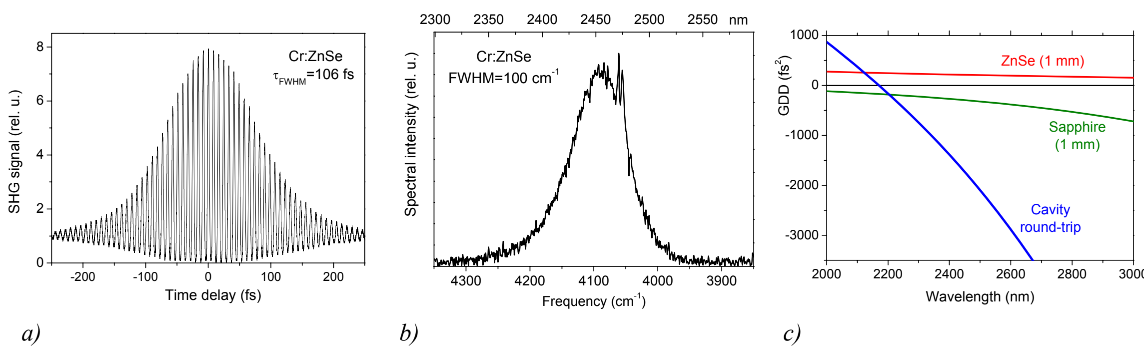

Fig. 2. Autocorrelation trace (a), spectrum (b), and dispersion (c) of the modelocked Cr:ZnSe laser.

Summarizing, we report the first femtosecond pulse generation from the Cr^{2+}:ZnSe laser. The laser was passively mode-locked, using an InAs/GaSb based multiple quantum well SESAM, and generated ~100 fs pulses at 75 mW of output power around 2.45 µm. Those are the shortest pulses generated so far from solid-state lasers in the mid-infrared spectral range. In terms of optical cycles this pulse duration corresponds to about 35-fs pulses in the spectral wavelenth range of Ti:sapphire. The work on further shortening of the pulse duration as well as on diode-pumping should lead to practical and cost-effective femtosecond broadband sources in the very important for applications molecular fingerprint region between 2 and 3 µm.

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