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Generation of Sub-150-fs, 100 nJ Pulses from a Low-cost Cavity-dumped Cr:LiSAF Laser

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Abstract: We report a low-cost, cavity dumped Cr:LiSAF laser, generating 135-fs pulses at 825 nm, with 105 nJ pulse energies and ~0.78 MW of peak power at 10 kHz, using only 600 mW of pump power.

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Several application areas of ultrafast laser technology such as white-light generation, micromachining, and deep multiphoton microscopy imaging, require high peak power laser sources. Compared to multipass cavity lasers or complex amplifying schemes, cavity dumping is a relatively simple technique which can be used to scale up the available peak powers from mode-locked laser oscillators. Cavity dumping has been successfully applied to increase the pulse energies of Ti:Sapphire lasers [1-3], ytterbium-doped lasers [4] and neodymium-doped lasers [4]. However, Ti:Sapphire lasers cannot be directly diode-pumped, which increases the cost and complexity of the system. Also, for the diode-pumped ytterbium-doped and neodymium-doped lasers, the obtainable pulsewidths are limited to hundreds of femtoseconds to picoseconds [4]. As an alternative, Cr\(^{3+}\)-doped colquiriite gain media can be directly diode pumped around 650 nm, and have broad emission bandwidths around 800-850 nm, enabling 10-fs long pulse generation [5]. Moreover, direct-diode pumping of Cr:Colquiriite lasers also allows high electrical-to-optical conversion efficiencies (~10%), compactness, and ease of use [5]. Pumping Cr:Colquiriites with four single-mode diodes, 50-100 fs pulses with 1-2.5 nJ pulse energies and 20 kW peak powers have been generated from standard 100 MHz cavities [5], where the obtained peak powers were limited by the total available pump power (600 mW). Slightly higher peak powers can be obtained with multimode diode pumping (~40 kW) [6], at the expense of increased complexity.

In this work, we report the first cavity-dumping experiments with a simple, low-cost, single-mode diode-pumped Cr:Colquiriite laser. As the gain medium, we have chosen Cr:LiSAF among the Cr:Colquiriite family, since it has a higher emission cross-section. This increases the gain and reduces Q-switching instabilities. The crystal was pumped by four 150-mW single-mode laser diodes at 660 nm, each costing only $150. A semiconductor saturable absorber mirror (SESAM) [7] (also referred as saturable Bragg reflectors (SBR) [8]) was used for initiating and sustaining mode-locking, making stable turn-key mode-locked operation possible. By cavity dumping at 10 kHz repetition rate, the laser generated 135 fs pulses at 825 nm, with 105 nJ of pulse energy and ~0.78 MW of peak power. At higher dumping rates approaching 1 MHz, the pulse energy was reduced to 62 nJ, due to the limitations imposed by Q-switching instabilities. This study demonstrates that low-cost Cr:Colquiriite lasers have the potential to generate MW level peak powers with very modest pump requirements.

Fig. 1 (a) Schematic of the cavity dumped, single-mode diode-pumped Cr:LiSAF laser. PBS: polarizing beam splitting cube. (b) Measured dynamics of intracavity pulse train at a dumping rate of 10 kHz. (c) Contrast ratio between the dumped pulse and neighboring pulses (~20:1).

Fig. 1 shows the schematic of the Cr:LiSAF laser. The 5-mm-long, 1.5% Cr:LiSAF crystal was pumped by four linearly-polarized, AlGalnP single-mode diodes, and up to 600 mW of pump power was incident on the crystal. An astigmatically-compensated, x-folded laser cavity, with curved dichroic mirrors (ROC=75 mm, ROC=radius of curvature) (M1-M2 in Fig. 1(a)) was used in the laser experiments. A second Z-fold focus was created by use of 100 mm ROC mirrors, where we placed the 3-mm thick, fused silica acousto-optic cavity dumper. The cavity dumper (64380-SYN-9.5-2, Neos Technologies, Inc.) had a single-pass diffraction efficiency of ~30%, and was used in double-pass configuration to obtain 50-60% dumping efficiency. The dumped beam was picked up with a small metallic high reflector after its second pass through the dumper. A 250 mm ROC curved mirror was used to focus onto the...
SESAM/SBR, which initiated and sustained mode-locked operation. For soliton pulse shaping, negative dispersion was introduced into the cavity with Gires–Tournois interferometer (GTI) and double-chirped mirrors (DCM). The estimated total round-trip cavity dispersion was \( -2250 \text{ fs}^2 \). We did not use any output coupler in the cavity in order to increase the intracavity pulse energies. At an absorbed pump power of 520 mW, the laser produced 135-fs pulses with an average intracavity power of 15 W at 80 MHz repetition rate (190 nJ intracavity pulse energy).

### Table 1: Summary of the cavity dumping results with the single-mode diode pumped Cr:LiSAF laser.

<table>
<thead>
<tr>
<th>Dumping frequency (kHz)</th>
<th>Pulse energy (nJ)</th>
<th>Pulse width (fs)</th>
<th>Average power (mW)</th>
<th>Peak power (kW)</th>
<th>Dumping efficiency (%)</th>
</tr>
</thead>
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<tr>
<td>10</td>
<td>105</td>
<td>135</td>
<td>1.05</td>
<td>778</td>
<td>55</td>
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<td>62</td>
<td>160</td>
<td>62</td>
<td>354</td>
<td>33</td>
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</tbody>
</table>

Fig. 2. Measured optical spectra and second harmonic autocorrelation traces from the cavity dumped Cr:LiSAF laser at several dumping rates.

Table 1 summarizes the cavity dumping results. For repetition rates up to 100 kHz, dumping efficiencies of 50% and pulse energies of 90-100 nJ could be obtained and the dumping had very little effect on laser dynamics. The contrast ratio between the dumped output pulses and the neighboring pulses was greater than 20:1 (Fig. 1 (c)). The highest pulse energy was 105 nJ, obtained at a repetition rate of 10 kHz. For this case, the pulse duration was 135 fs, corresponding to a peak power of 778 kW. Fig. 1 (b) shows the measured intracavity pulse train dynamics for a dumping rate of 10 kHz, where we first see an overshoot of intracavity pulse energy which then relaxes back to steady state within ~30 s. At 50 kHz dumping rate (and above), the subsequent dumping event occurs even before the transient from the current dumping has relaxed, and this requires the usage of a lower dumping rate (to prevent pulse to pulse instability). Also, for dumping rates above 200 kHz, the pulse duration and spectrum also start to change considerably because the dumping event is frequent enough to significantly change the intracavity laser dynamics (Fig. 2). Moreover, two photon absorption processes in the SESAM/SBR limited the obtainable pulse widths to 135-fs, and caused multiple-pulsing instabilities for shorter pulses. In summary, we have presented what is to our knowledge the first demonstration of cavity dumping of a Cr:Colquiriite laser, demonstrated peak powers approaching MW level, and discussed the limitations imposed by the SESAM/SBR-induced mode-locking dynamics.

### References


