Recent advances in Cr: Colquiriite laser technology

The MIT Faculty has made this article openly available. Please share how this access benefits you. Your story matters.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>As Published</td>
<td><a href="http://dx.doi.org/10.1109/LEOS.2009.5343217">http://dx.doi.org/10.1109/LEOS.2009.5343217</a></td>
</tr>
<tr>
<td>Publisher</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>Version</td>
<td>Final published version</td>
</tr>
<tr>
<td>Accessed</td>
<td>Thu Apr 04 02:42:15 EDT 2019</td>
</tr>
<tr>
<td>Citable Link</td>
<td><a href="http://hdl.handle.net/1721.1/54696">http://hdl.handle.net/1721.1/54696</a></td>
</tr>
<tr>
<td>Terms of Use</td>
<td>Article is made available in accordance with the publisher's policy and may be subject to US copyright law. Please refer to the publisher's site for terms of use.</td>
</tr>
<tr>
<td>Detailed Terms</td>
<td></td>
</tr>
</tbody>
</table>
Recent advances in Cr:Colquiriite laser technology

Umit Demirbas1, Sava Sakadžić2, Kyung-Han Hong1, Jonathan R. Birge3, Duo Li1, Hyunil Byun1, Peter Fendel4, Gale S. Petrich1, Leslie A. Kolodziejczyk1, David A. Boas2, Alphan Sennaroğlu1,3, Franz X. Kärntner1 and James G. Fujimoto1

1Department of Electrical Engineering and Computer Science, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
2MGH/MIT/HMS Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Charlestown, Massachusetts 02129, USA
3Laser Research Laboratory, Department of Physics, Koç University, Rumelifeneri, Sarıyer, 34450 Istanbul, Turkey
Corresponding authors: umit@mit.edu and jgfujim@mit.edu

Abstract: We summarize recent progress in low-cost and highly-efficient Cr:Colquiriite laser technology. Pumping with inexpensive single-mode diodes, 270-mW of output power and a total tunability from 754 to 1042 nm were demonstrated in continuous-wave operation. In mode-locked operation, 100-fs pulses with 50-nJ pulse energy were demonstrated.

Currently, the cost and complexity of femtosecond Ti:Sapphire lasers are significant hurdles to their widespread adoption. As promising alternatives, Cr3+-doped colquiriites (Cr3+:LiSAF [1], Cr3+:LiSGaF [2] and Cr3+:LiCAF [3]) also have wide gain bandwidths around 800 nm, enabling broadly tunable laser operation in near infrared spectral region. Attractive properties of Cr:Colquiriite gain media include, (i) low lasing thresholds (~5 mW), (ii) high lasing efficiencies (~50%), and (iii) wide gain bandwidths, which can support down to ~10-fs pulses. Most importantly, Cr3+:Colquiriite gain media can be directly diode pumped by inexpensive ~650 nm diodes. Compared to Ti:Sapphire, which is generally pumped by expensive and bulky frequency-doubled neodymium lasers, direct diode pumping of Cr3+:Colquiriites is highly advantageous in terms of cost, complexity, and efficiency. In this summary, we will review recent progress in the development of Cr3+:Colquiriite laser technology [4-7]. We believe that, Cr3+:Colquiriite lasers have the potential to replace the more expensive Ti:Sapphire lasers in many scientific and technological applications.

In the laser experiments, recently available, ~150mW, ~660±2 nm, AlGaInP single-mode diodes, costing only ~$150 were used as the pump source. Use of this inexpensive pump source enables the reduction of the total material cost of the laser below ~$10k. The gain medium was pumped by four single-mode diodes, giving a total incident pump power of about ~600 mW on the crystals. Astigmatically-compensated, x-folded laser cavities with two curved pump mirrors (R=75 mm), a flat end mirror, and a flat output coupler were used in the cw laser experiments.

Figure 1 summarizes the cw lasing results obtained with Cr:Colquiriites [7]. In cw operation, using ~520 mW of absorbed pump power, up to 257, 269 and 266 mW of output power and slope efficiencies of 53%, 62% and 54% were demonstrated for Cr:LiSAF, Cr:LiSGaF and Cr:LiCAF lasers, respectively. Lasing thresholds as low as ~5 mW and an electrical-to-optical conversion efficiency up to 12% were obtained. These are the highest cw output power levels and slope efficiencies obtained with single-mode diode pumped Cr:Colquiriite lasers to date. By using a fused silica prism or a crystal quartz birefringent filter as a tuning element, record cw tuning ranges from 782 to 1042 nm for Cr:LiSAF, 777 to 977 nm for Cr:LiSGaF, and 754 to 871 nm for Cr:LiCAF were demonstrated.

In mode-locking experiments, double-chirped mirrors (DCMs) or a fused silica (FS) prism pair were used for dispersion compensation. Saturable absorber mirrors centered around 800 and 850 nm were used to initiate and sustain mode-locked operation. Saturable absorber mirror mode-locked lasers were self-starting, immune to environmental fluctuations and did not require careful cavity alignment, enabling turn-key operation. In mode-locking experiments, ~40-75 fs pulses with 1-2.5 nJ of pulse energies (at ~100 MHz repetition rates) were typically obtained from all of the Cr:Colquiriite lasers. An electrical-to-optical conversion efficiency up to 8% was demonstrated in cw mode-locked operation.

As an example, Figure 2(a) shows the spectrum and the autocorrelation trace for the ~52-fs long pulses obtained from the Cr:LiSGaF laser. The average output power was 172 mW, and the corresponding pulse energy was 2-nJ for the 86 MHz cavity. Figure 2 (b) shows a representative tuning range in cw mode locked operation, where the central wavelength of the pulses was tunable from 832.5 nm to 865.7 nm. The relatively narrow bandwidth of saturable absorber mirrors used in this
study limited the pulsewidths to \( \sim 50 \text{ fs} \) level. Moreover, saturable absorber mirrors also limited the obtainable tuning range in mode-locked regime to \( \sim 30 \text{ nm} \) level.

To scale the laser output energies above \( \sim 2.5 \text{ nJ} \) level, we used two different methods. In the first method, we have built extended cavity \( \text{Cr:Colquiriite} \) lasers, where the pulse repetition rate is reduced to \( \sim 10 \text{ MHz} \) level. From an extended cavity \( \text{Cr:LiCAF} \) laser, 98-fs pulses with energies of 9.9 nJ and peak powers of \( \sim 10^1 \text{ kW} \) were generated. To scale the pulse energies even further, we have used the cavity dumping method. In the initial experiments, a cavity-dumped \( \text{Cr:LiSAF} \) laser produced \( \sim 100\text{-fs} \) level pulses with more than 50-nJ of pulse energy at a repetition rate of 200 kHz.

As an example application area for low-cost \( \text{Cr:Colquiriite} \) laser technology, we have performed multiphoton microscopy (MPM) using a 100 MHz \( \text{Cr:LiCAF} \) laser producing 1.8-nJ pulses around 800 nm (Figure 3). The performance of the \( \text{Cr:LiCAF} \) laser was sufficient to generate a wide range of MPM imaging data without requiring broad excitation wavelength tunability.

To summarize, recent results showed that, single-mode diode-pumped \( \text{Cr}^3+:\text{Colquiriite} \) lasers are becoming attractive, low-cost alternatives to \( \text{Ti:Sapphire} \). Advantages of \( \text{Cr:Colquiriite} \) lasers include (i) low cost, (ii) high efficiency, (iii) compactness, and (iv) ease of use. The main drawback of \( \text{Cr}^3+:\text{Colquiriite} \) laser technology is the limited tuning bandwidth in mode-locked regime, which requires further development. With further progress in obtainable pulsewidths, pulse energies and tuning ranges, \( \text{Cr:Colquiriite} \) lasers have the potential to reach performance levels comparable to more expensive \( \text{Ti:Sapphire} \) lasers. This could enable wide-spread use of low-cost \( \text{Cr:Colquiriite} \) laser technology in many applications like nonlinear optics, pump probe spectroscopy, and amplifier seeding.

References


Figure 2: (a) Spectrum and autocorrelation trace for the 52-fs, 2 nJ pulses from the single-mode diode-pumped \( \text{Cr:LiSGaF} \) laser. (b) Sample spectra from the \( \text{Cr}^3+:\text{LiSAF} \) laser, showing tunability of central wavelength of the laser from 832.5 nm to 867.5 nm, for the sub-150-fs pulses. Calculated reflectivity of the 850 nm SESAM/SBR is also shown.

Figure 3: Multiphoton microscopy images taken with single-mode diode-pumped femtosecond \( \text{Cr:LiCAF} \) laser [6].