

MIT Open Access Articles

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.

Citation: Demirbas, U. et al. "Recent advances in Cr: Colquiriite laser technology." LEOS Annual Meeting Conference Proceedings, 2009. LEOS '09. IEEE. 2009. 387-388. © 2009 IEEE

As Published: <http://dx.doi.org/10.1109/LEOS.2009.5343217>

Publisher: Institute of Electrical and Electronics Engineers

Persistent URL: <http://hdl.handle.net/1721.1/54696>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of Use: 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.



Recent advances in Cr:Colquiriite laser technology

Umit Demirbas¹, Sava Sakadžić², Kyung-Han Hong¹, Jonathan R. Birge¹, Duo Li¹, Hyunil Byun¹, Peter Fendel¹, Gale S. Petrich¹, Leslie A. Kolodziejski¹, David A. Boas², Alphan Sennaroglu^{1,3}, Franz X. Kärtner¹ 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, Sariyer, 34450 Istanbul, Turkey

Corresponding authors: umit@mit.edu and jgfujii@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 experiment 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 of 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.

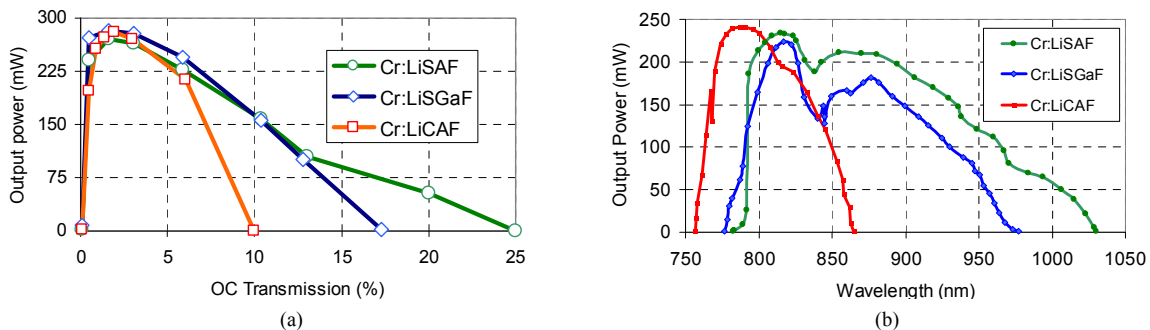


Figure 1: Summary of cw lasing results (a) Variation of cw laser output power with output coupling, (b) cw tuning curves for Cr:LiSAF, Cr:LiSGaF and Cr:LiCAF at room temperature. Both (a) and (b) were taken with about 520 mW of absorbed pump power.

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 ~ 50 fs level. Moreover, saturable absorber mirrors also limited the obtainable tuning range in mode-locked regime to ~ 30 nm level.

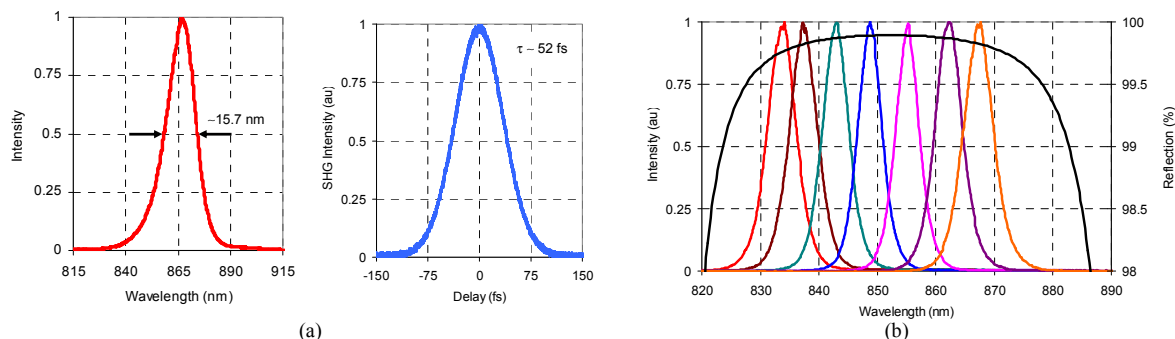


Figure 2: (a) Spectrum and autocorrelation trace for the 52-fs, 2 nJ pulses from the single-mode diode-pumped Cr:LiSGaF laser. (b) Sample spectra from the Cr^{3+} :LiSAF laser, showing tunability of central wavelength of the laser from 832.5 nm to 867.5 nm, for the sub-150-fs pulses. Calculated reflectivity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

To scale the laser output energies above ~ 2.5 nJ level, we used two different methods. In the first method, we have built extended cavity Cr:Colquiriite lasers, where the pulse repetition rate is reduced to ~ 10 MHz level. From an extended cavity Cr:LiCAF laser, 98-fs pulses with energies of 9.9 nJ and peak powers of ~ 101 kW were generated. To scale the pulse energies even further, we have used the cavity dumping method. In the initial experiments, a cavity-dumped Cr:LiSAF laser produced ~ 100 -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 Cr:Colquiriite laser technology, we have performed multiphoton microscopy (MPM) using a 100 MHz Cr:LiCAF laser producing 1.8-nJ pulses around 800 nm (Figure 3). The performance of the Cr:LiCAF laser was sufficient to generate a wide range of MPM imaging data without requiring broad excitation wavelength tunability.

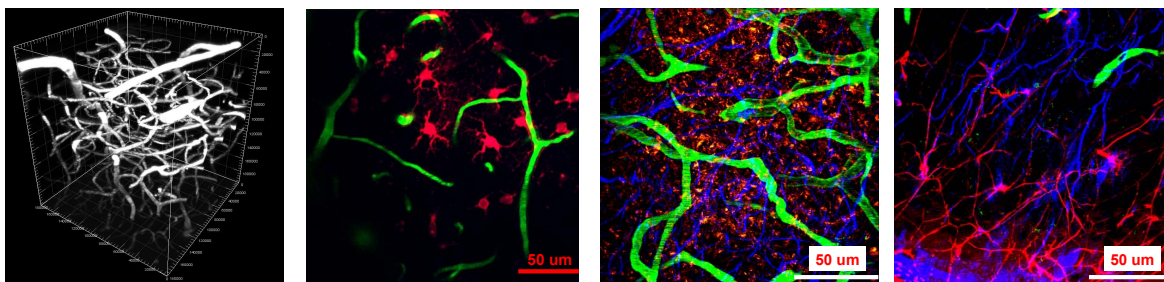


Figure 3: Multiphoton microscopy images taken with single-mode diode-pumped femtosecond Cr:LiCAF laser [6].

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

References

- [1] S. A. Payne, L. L. Chase, L. K. Smith, W. L. Kway, and H. W. Newkirk, "Laser performance of $\text{LiSAIF}_6:\text{Cr}^{3+}$," *Journal of Applied Physics*, vol. 66, pp. 1051-1056, 1989.
- [2] L. K. Smith, S. A. Payne, W. L. Kway, L. L. Chase, and B. H. T. Chai, "Investigation of the laser properties of Cr^{3+} :LiSrGaF₆," *IEEE J. Quantum Electron.*, vol. 28, pp. 2612-2618, 1992.
- [3] S. A. Payne, L. L. Chase, H. W. Newkirk, L. K. Smith, and W. F. Krupke, "LiCaAlF₆:Cr³⁺ a promising new solid-state laser material," *IEEE Journal of Quantum Electronics*, vol. 24, pp. 2243-2252, Nov 1988.
- [4] U. Demirbas, A. Sennaroglu, F. X. Kärtner, and J. G. Fujimoto, "Highly efficient, low-cost femtosecond Cr^{3+} :LiCAF laser pumped by single-mode diodes," *Optics Letters*, vol. 33, pp. 590-592, 2008.
- [5] U. Demirbas, A. Sennaroglu, F. X. Kärtner, and J. G. Fujimoto, "Generation of 15 nJ pulses from a highly efficient, low-cost multipass-cavity Cr^{3+} :LiCAF laser," *Optics Letters*, vol. 34, pp. 497-499, 2009.
- [6] S. Sakadžić, U. Demirbas, T. R. Mempel, A. Moore, S. Ruvinskaya, D. A. Boas, A. Sennaroglu, F. X. Kärtner, and J. G. Fujimoto, "Multi-photon microscopy with a low-cost and highly efficient Cr:LiCAF laser," *Optics Express*, vol. 16, pp. 20848-20863, 2008.
- [7] U. Demirbas, D. Li, J. R. Birge, A. Sennaroglu, G. S. Petrich, L. A. Kolodziejski, F. X. Kaertner, and J. G. Fujimoto, "Low-cost, single-mode diode-pumped Cr:Colquiriite lasers," *Optics Express*, 2009, in review.