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Recent advances in Cr:Colquiriite laser technology

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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 8% was demonstrated in cw mode-locked operation.

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 \( \sim 50 \) fs level. Moreover, saturable absorber mirrors also limited the obtainable tuning range in mode-locked regime to \( \sim 30 \) 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 \( \sim 2.5 \) 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 \( \sim 10 \) MHz level. From an extended cavity Cr:LiCAF laser, 98-fs pulses with energies of 9.9 nJ and peak powers of \( \sim 101 \) 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 \( \sim 100 \) 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