

Diode-pumped, single-frequency, Cr:LiSAF coupled-cavity microchip laser

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Abstract

A double gain section composite cavity Cr:LiSAF microchip emitting either 670 nm GaInP/AlGaInP diode laser or krytrine ion laser pumping allowed a 20% single longitudinal mode operation with absolute limited fluctuations of less than 20 MHz.

With the recent availability of inexpensive yet powerful and efficient single stripe diode lasers considerable interest has been directed towards microchip lasers (microlasers) [1] as compact, tunable, single-frequency sources. Although diode-pumped, extended-cavity, solid-state lasers can readily reproduce similar characteristics [2] to microchip lasers or separate fibered, ring or prism, etc., the convenience and compactness of microlasers make them attractive for many systems applications. The micro-laser geometry lends itself particularly well to single frequency operation as it can be constructed such that the cavity mode spacing is greater than the gain bandwidth of the solid state laser medium. As a consequence, the majority of microchip lasers reported to date have been principally based on pseudospontaneously doped crystals [1,3,4], although not exclusively [5,6], since the gain bandwidth can be a function of the dielectric mirror coatings on the microchip or high doping levels of the stripe laser can permit very short resonator lengths and allow single frequency operation. The application of these lasers to efficient frequency doubling is also of considerable interest [7-10] and in particular the generation of a compact blue source. This, however, requires an efficient funda-

mental wavelength in the range 800-900 nm. A natural choice is the Cr-doped colquirium [11], i.e. Cr:LiSAF, LiCAF, LiBO₃, etc. These active media present a particularly attractive combination of spectrally broad absorption and emission cross sections and are ideally suited to excitation by high power GaInP/AlGaInP diodes around 670 nm. A notable advantage with these systems is also the ability to increase the active ion concentration (in excess of 20% mol% in Cr:LiCAF) without a significant quenching effect to the excited state lifetimes of the species [12]. In this Letter we report the characterization of a composite Cr:LiSAF microchip using both Er ion and laser diode excitation which permitted stable single frequency operation.

For a 3% doped Cr:LiSAF sample, a 70% absorption can be achieved at 670 nm over a 500 μ m crystal length with the exciting radiation polarized parallel to the *c* axis. It can therefore be seen that the longitudinal mode separation ($\Delta\lambda_m \sim 0.5$ nm) of such a conveniently sized and readily available crystal is considerably less than the gain bandwidth of Cr:LiSAF, which approximately extends from 750 nm to 1000 nm [12]. This is demonstrated in Fig. 1 where the pump power dependent output spectra of

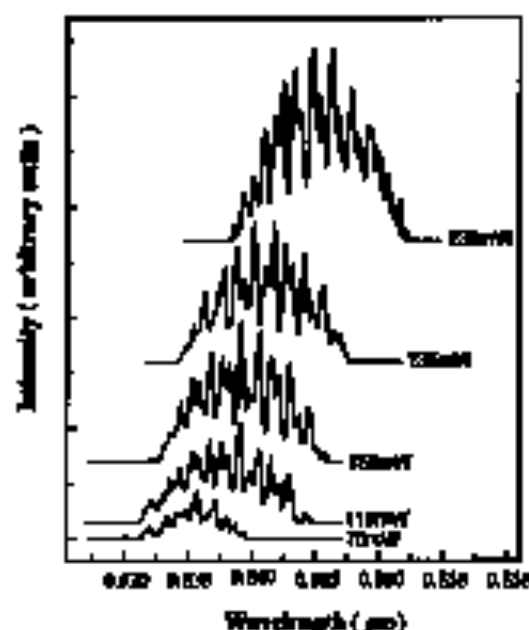


Fig. 1. Absorbed pump power dependent spectral output of a single diode-pumped, 300 μm long, Cr:LiSAF microchip laser.

A single diode-pumped Cr:LiSAF microchip laser is shown. The laser was a phase parallel 300 μm thick piece of initially 6 mm diameter, 5.5% Cr-doped Cr:LiSAF (obtained from Lightning Optical Corporation, Florida). The pumped face had a dielectric coating with a reflectance $> 99.5\%$ from 780–800 nm and a transmission at 670 nm $> 90\%$. The output face was coated with a 99% reflective coating over the 780–900 nm range. It should be noted that the actual reflectivities observed were unoptimized for this microchip laser application; the purpose of this laser solely to demonstrate the technique. Initially pumped by the focused output (16 cm focal length lens, 50 μm spot size) of a Er laser, the multi-longitudinal mode operation of this laser is clearly apparent, with an approximate mode separation of 0.5 nm. For an absorbed pump power of up to 225 mW, the conversion effect on the modal lasing wavelength of this single element device, which can be seen in Fig. 1 was due to the increased laser temperature and the associated increase in the long wavelength tail of the ground state absorption, as has been observed previously with solid state lasers and similarly in dye lasers. As an attempt was made to thermally stabilize the microchip laser assembly or to remove the diode-pumped pump power, the effect of increasing tempera-

ture with increased pump was also clearly in evidence on the variation of output power with absorbed power, see Fig. 2. For an absorbed power of up to approximately 120 mW the output power increased reasonably linearly, with an efficiency approaching 50%. The dashed line shown in Fig. 2 is the 50% slope efficiency. Above approximately 100 mW absorbed power, increased thermal problems gave rise to considerably decreased conversion efficiency. When the pump beam was changed, even with a magnification ratio as large as 1:1, the output power with laser power exhibited a linear increase, indicating that in the unclipped regime the roll off in efficiency was dominated by the thermal degradation. The thermal dissipation problems can clearly be improved by changes in the geometry of the device and the introduction of cooling to the assembly.

In order to achieve single frequency operation, a composite microchip cavity was assembled as shown in Fig. 3. This construction utilized a mirror type heterostatic mode selection which was proposed [13] and successfully demonstrated [14] for extended cavity laser systems. Segmented laser rods have also been used to effect mode selection in diode-pumped solid state lasers [15]. The same laser configuration reported here also has similarities with the observed coupled cavity [16] configuration expected to achieve single mode operation with excimer-pumped lasers. The 300 μm Cr:LiSAF sample as described above was used in conjunction with a specially 1 mm long piece of identically doped and

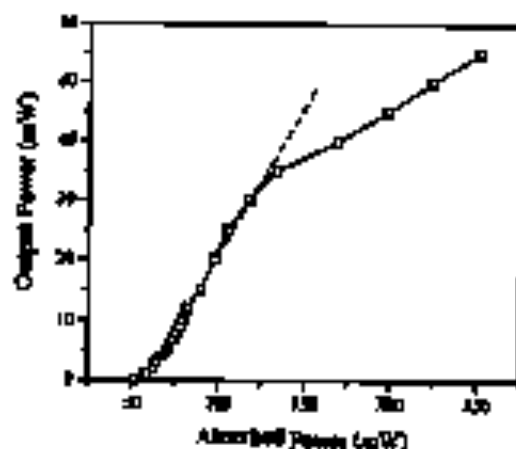


Fig. 2. Variation of the output power with absorbed pump power for a single 300 μm long Cr:LiSAF microchip laser.

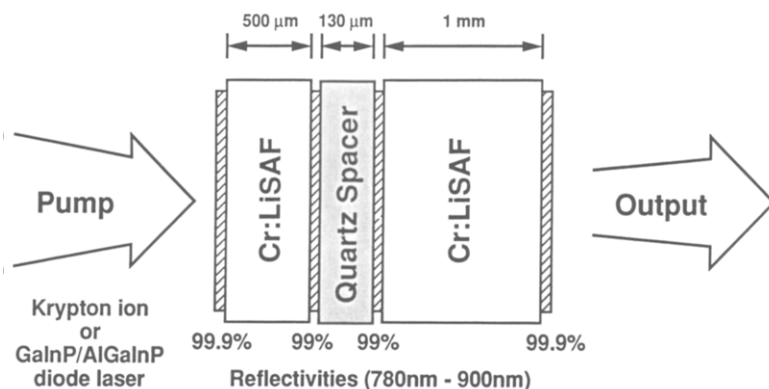


Fig. 3. Schematic of the composite diode, single frequency Cr:LiSAF microcavity.

dielectrically coated Cr:LiSAF. A 130 μm thick plane parallel piece of fused quartz was placed between the samples and in close optical contact with the 99% reflective (780–900 nm) coatings of the laser elements. The complete optical assembly was held in a copper jacketed mechanical construction which could be temperature controlled and held the three main optical elements in contact. No index matching liquid was used between the components. Again it should be noted that this is not the optimum geometry and is clearly not the best mirror coatings for energy extraction. Initially krypton ion laser pumping was used and a 10 cm focal length lens focused the pump radiation into the assembly with the shorter Cr:LiSAF sample on the input pump side. Use of the lens enabled examination of the effects of pump beam defocusing and stimulation of diode laser pumping, which was also examined.

The measured spectral output from the composite microcavity is shown in Fig. 4. It can be seen in Fig. 4a that over the spectral range 820 nm to 920 nm only one single spectral component was dominant. The insert in Fig. 4a shows the spectral width of this component to be completely limited by the nominal 0.1 nm resolution of the spectrum analyzer. On a logarithmic scale (Fig. 4b; measured using an Anritsu Model 9701 B), no other modes were detectable to more than 30 dB below the signal peak. The low level noise apparent in Fig. 4b is a result of the pumping by the unstimulated Krypton laser. However, single mode operation was achievable up to the maximum observed pump power of 250 mW.

A dielectric coated spherical mirror Fabry-Pérot

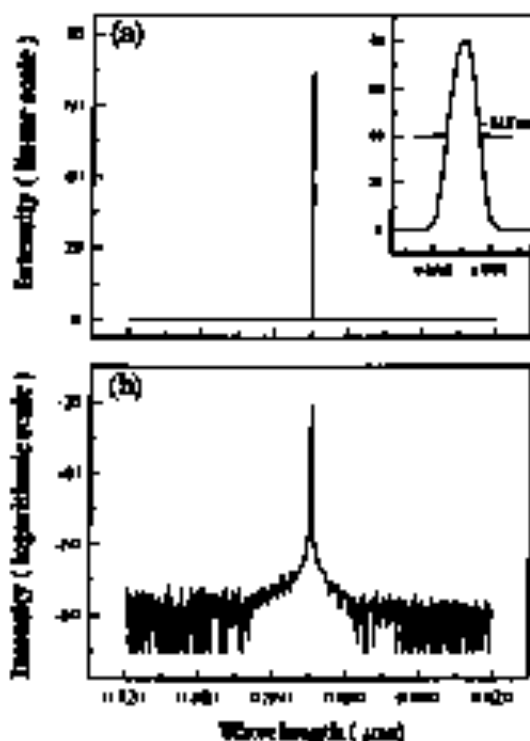


Fig. 4. Measured spectral optical spectrum of the output of the composite diode Cr:LiSAF microcavity (a) linear scale with insert showing spectral resolution of 0.1 nm and (b) logarithmic scale.

spectrum analyzer, with a variable and selected line spectral range of 27.3 GHz was used to determine the microcavity bandwidth. The upper part of Fig. 5 demonstrates fine spectral range and the insertion limited single longitudinal mode operation at 850 nm,

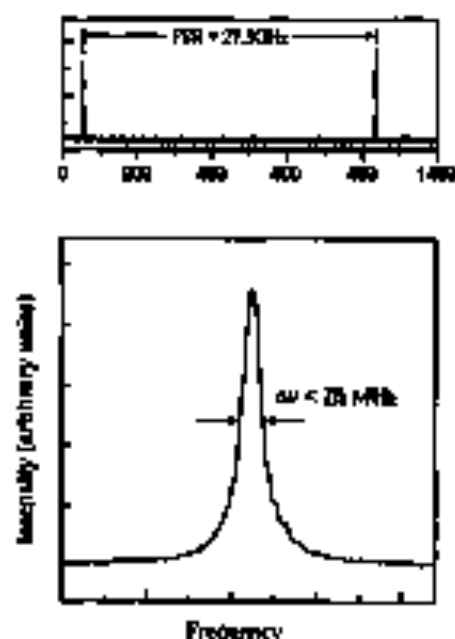


Fig. 5. Optical spectrum of single-mode operation of Cr:LiSAF composite microcavity measured using a scanning Fabry-Pérot. The upper trace of the output from the SA has passed through the filter spectrometer of the detector and the lower trace the resolution limited linewidth of < 20 MHz 200° diode laser pumping. The collimate axis shows an axial collimation.

for the crystal ion pumped system. Resonated with the mechanical mechanism the recorded linewidth was limited by the resolution of the instrument and points to a linewidth of < 20 MHz. Because of the rather poor amplitude stability of the Kr ion pump laser the long term stability of the microcavity linewidth was limited in a few seconds. Spectral integration over longer periods gave rise to measurably poorer linewidths.

Considerable improvement to both the long term stability and reduction of the noise in the system was obtained by substituting the Kr ion laser pumping with a GaInP/AlGaInP laser diode. This 140 μm single stripe width, 1200 μm long diode pumped up to 500 mW around 670 nm. A simple collection/collimation scheme was used to direct the elliptical output beam and a 10 cm focal length lens was used to focus on to the microcavity assembly. Due to losses to collection and beam coupling the maximum absorbed pump power from the diode laser was ~ 300 mW. The focused pump spot was cylindrical with measured diameter of 100 μm by a resolution lim-

ited less than 11 μm . The output from the Cr:LiSAF laser was relatively single mode with instrumented limited linewidths of < 20 MHz being recorded over long integration periods, a representative measured linewidth is shown in the lower of Fig. 5. Laser diode laser pumping the recorded noise level was also considerably reduced. Unfortunately, due to the unspecified reflective coatings used in the microcavity (the actual cavity is terminated by two nominally 100% reflectors) the output power from the diode pumped cavity arrangement was ≤ 1 mW. When the 1 cm long rod was replaced by a single, hemispherical (around 850 nm), nominally 99.9% reflector, single frequency operation was obtainable with output powers approaching 10 mW for 250 mW pump. In this case however, stability was lower and multiple frequency operation frequently observed. As the laser frequency is determined by the cavity mode position within the gain profile, it is possible to obtain wavelength tuning by varying the temperature of the crystal assembly. This was undertaken by varying the pump power or was also achieved by varying the bulk temperature of the laser assembly, and the tuning is restricted by the thermal nature of the coupled devices. Coarse controlled tuning over the spectral range 647–675 nm was obtained. Improved spectral control and stability should be retained through piezoelectric variation of the spacer between the active media.

In conclusion, we have demonstrated reliable, stable, single-longitudinal mode operation of a diode-pumped Cr:LiSAF composite microcavity for the first time. Although the evaluation of output coupling limited the power available, from the measurements taken it is probable that optimization of the reflective coatings should lead to considerably improved output powers in the 10's mW range. This simple laser cavity provides a convenient single frequency seeding signal for high power tunable Ti:Sapphire or Cr:LiSAF amplifiers. It should also be possible with only a slight modification to utilize the technique on semiconductor efficient, single-mode, frequency-doubling to the blue spectral region. In addition, a diode coupled pumping scheme replacing the lens coupling should permit the demonstration of a relatively efficient, compact blue laser source.

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