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

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Abstract

A double gain section composite cavity Cr:LiSAF microlaser utilising either 670 nm GaInP/AlGaInP diode laser or krypton ion laser pumping allowed tunable, single longitudinal mode operation with detection limited linewidth 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 as regards thresholds, output powers, etc., the convenience and compactness of microlasers make them attractive for many systems applications. The microlaser 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 primarily based on neodymium 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 microlaser or high doping levels of the active ion can permit very short interaction 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 fundamental wavelength in the range 800–900 nm. A natural choice is the Cr-doped colquiriites [11], i.e. Cr:LiSAF, LiCAF, LiSGaF, 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 lifetime of the samples [12]. In this Letter we report the characterisation of a composite Cr:LiSAF microlaser using both Kr 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 µm crystal length with the exciting radiation polarised parallel to the *c* axis. It can therefore be seen that the longitudinal mode separation ($\Delta\lambda_m \sim 0.3$ 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

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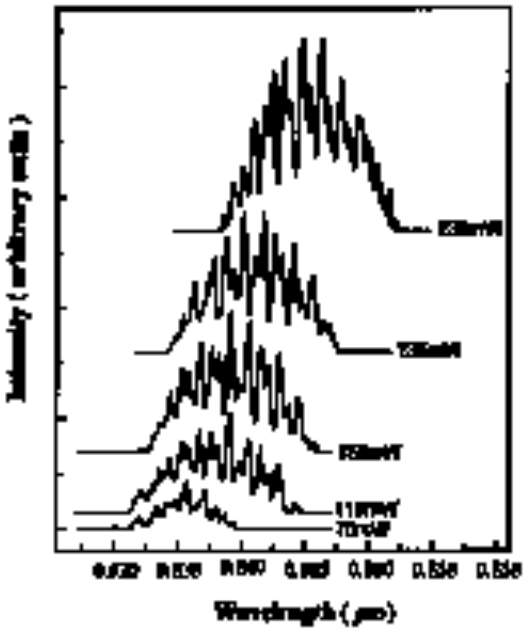

Fig. 1. Absorbed pump power dependent spectral output of a single element, 500 μm long, Cr:LiSAF microchip laser.

a single element Cr:LiSAF microlaser is shown. The laser was a plane parallel 500 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 >99.9% from 780–900 nm and a transmission at 670 nm >90%. The output facet was coated with a 99% reflective coating over the 780–900 nm range. It should be noted that the actual reflectivities chosen were unoptimised for this microlaser application, the purpose of this letter solely to demonstrate the technique. Initially pumped by the focussed output (16 cm focal length lens, 50 μm spot size) of a Kr ion 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 coarse tuning effect on the central lasing wavelength of this single element device, which can be seen in Fig. 1 was due to the increased local 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 no attempt was made to thermally stabilise the microchip laser assembly or to remove the dissipated pump power, the effect of increasing temperature 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 40%. The dashed line shown in Fig. 2 is the 40% slope efficiency. Above approximately 100 mW absorbed power, increased thermal problems gave rise to considerably decreased conversion efficiency. When the pump beam was chopped, even with a mark space ratio as large as 1:1, the output power with input power exhibited a linear increase, indicating that in the unchopped regime the roll off in efficiency was dominated by the thermal degradation. The thermal dissipation problem 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 microlaser cavity was assembled as shown in Fig. 3. This construction utilised vernier type interferometric 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 flash-lamp pumped solid state lasers [15]. The coupled laser configuration reported here also has similarities with the cleaved coupled cavity [16] configuration successfully used to achieve single mode operation with semiconductor lasers. The 500 μm Cr:LiSAF sample as described above was used in conjunction with a nominally 1 mm long piece of identically doped and

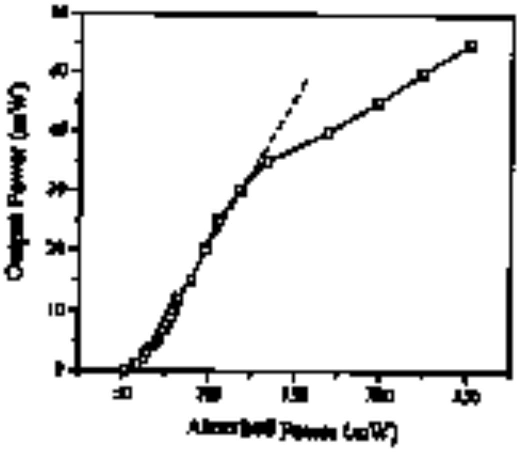

Fig. 2. Variation of the output power with absorbed pump power for a single 500 μm element Cr:LiSAF microlaser.

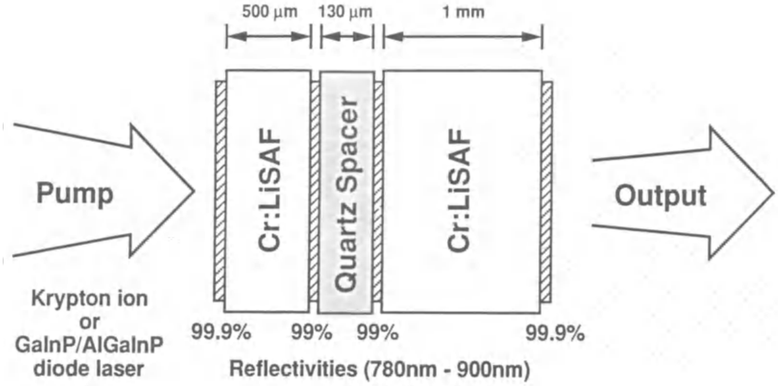

Fig. 3. Schematic of the composite cavity, single frequency Cr:LiSAF microlaser.

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 jacket 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 focussed 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 defocussing and simulation of diode laser pumping which was also examined.

The measured spectral output from the composite microlaser 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 inset in Fig. 4a shows the spectral width of this component to be completely limited by the nominal 0.1 nm resolution of the spectrum analyser. 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 unstabilised Kr ion laser. However, single mode operation was achievable up to the maximum absorbed pump power of 250 mW.

A mode matched spherical mirror Fabry–Perot spectrum analyser, with a variable and selected free spectral range of 27.3 GHz was used to determine the microlaser linewidth. The upper trace of Fig. 5 demonstrates free spectral range and the instrument limited single longitudinal mode operation at 850 nm,

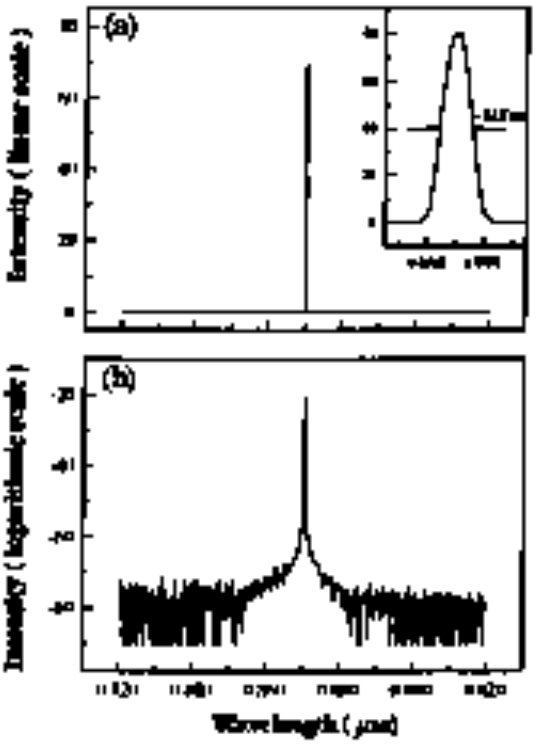

Fig. 4. Instrument limited optical spectrum of the output of the composite cavity Cr:LiSAF microlaser (a) linear scale with inset showing resolution limited bandwidth of 0.12 nm and (b) logarithmic scale.

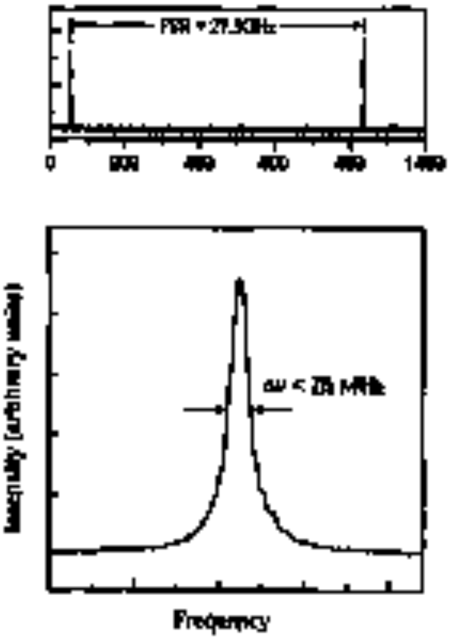

Fig. 5. Optical spectrum of single-mode operation of Cr:LiSAF composite cavity microlaser measured using a scanning Fabry-Perot. The upper trace of the output from the Kr ion pumped system shows the free-spectral-range of the detector and the lower trace the resolution limited linewidth of <20 MHz under diode laser pumping. The ordinate scale shown was an aid to calibration.

for the krypton ion pumped system. Examined with the maximum resolution 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 microlaser linewidth was limited to a few seconds. Spectral integration over longer periods gave rise to measurably broader 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 device is rated up to 500 mW around 670 nm. A simple collection/collimation scheme was used to circularize the elliptical output beam and a 10 mm focal length lens was used to focus on to the microlaser assembly. Due to losses in collection and beam shaping the maximum obtained pump power from the diode laser was ~300 mW. The focused pump spot was asymmetric with measured dimensions of 100 μm by a resolution limited less than 11 μm. The output from the Cr:LiSAF laser was robustly single mode with instrumental limited linewidths of <20 MHz being recorded over long integration periods, a representative measured linewidth is shown in the lower of Fig. 5. Under diode laser pumping the recorded noise level was also considerably reduced. Unfortunately, due to the unoptimised reflective coatings used in the microlaser (the actual cavity is terminated by two nominally 100% reflectors) the output power from the composite cavity arrangement was ≤1 mW. When the 1 mm long rod was replaced by a single, broadband (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 occurred. 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 can also be tuned by varying the bulk temperature of the laser assembly, and the tuning is enhanced by the vernier nature of the coupled cavities. Coarse, controlled tuning over the spectral range 847–875 nm was obtained. Improved spectral control and sensitivity should be obtained through piezoelectric variation of the spacer between the active media.

In conclusion, we have demonstrated tunable, stable, single-longitudinal mode operation of a diode-pumped Cr:LiSAF composite microlaser for the first time. Although the restriction of output coupling limited the powers available, from the measurements taken it is probable that optimisation of the reflective coatings should lead to considerably improved output powers in the 10's mW range. This simple laser could provide 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 utilise the technique to demonstrate efficient, single-mode, frequency-doubling to the blue spectral region. In addition, a close coupled pumping scheme replacing the lens coupling should permit the demonstration of a relatively efficient, compact blue laser source.

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