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A 10 kHz Ce:LiSAF laser pumped by the sum-frequency-mixed output of a copper vapour laser

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Abstract

We report what we believe is the first Ce:LiSAF laser pumped by the 271 nm sum-frequency-mixed output of a copper vapour laser. The 10 kHz pulse-repetition-frequency (PRF) free-lasing Ce:LiSAF laser yielded a maximum output power of 70 mW, with a slope efficiency of 21%. With a single prism tunability from 285–295 nm was achieved, which is believed to be the first report of tunable laser operation from a Ce:LiSAF laser, operating at high (multi-kHz) PRFs. © 2001 Published by Elsevier Science B.V.

Keywords: Solid state lasers; Metal vapour lasers

1. Introduction

During the last 10 years Ce:LiCAF and Ce:LiSAF have emerged as reliable and compact directly tunable UV laser sources [1–3], benefiting from the pre-existing Cr:LiSAF crystal growth procedures. Due to the broad tunability (283–313 nm) [4] and high slope efficiencies (up to 33%) [5] that have been demonstrated from Ce:LiSAF lasers, this laser material has already found application in areas such as atmospheric remote sensing [5]. Additionally, use of charge compensating co-doping together with anti-solarant pumping has been shown to result in significantly enhanced Ce:LiSAF laser performance (slope efficiencies up to 47%) [6].

With the exception of a 20 kHz pulse-repetition-frequency (PRF) Ce:LiSAF laser, pumped by the frequency quadrupled output of a $Nd:YVO_4$ laser [7], all of the other Ce:LiSAF lasers reported to date have been operated at relatively low PRFs (10s of Hz). This 20 kHz Ce:LiSAF laser was found to lase efficiently (28% slope efficiency), with high output power (250 mW), when operated in an un-tuned configuration with a $R = 50\%$ output coupler, yet no tunability of this laser was reported. Studies of cerium laser performance at elevated (multi-kHz) PRFs are important as they provide more stringent tests of the cerium laser material's

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photochemical stability as any induced colour centres have less inter-pulse time to relax within. Additionally, many spectroscopic applications require tunable UV sources that operate at multi-kHz PRFs.

We have recently shown that the frequency-doubled copper vapour laser (UV-CVL), is an excellent multi-kHz PRF pump source for both Ce:LiCAF [8] and Ce:LiLuF [9,10] lasers. This is due to the high average power (1–2 W), short pulse length (∼10 ns) output that the UV-CVL provides (values quoted are for medium-scale e.g. 20 W fundamental power single-unit devices [11]). The UV-CVL can be configured for output at 255, 271 or 289 nm by sum-frequency mixing or frequency doubling the 511 and 578 nm CVL fundamental lines, permitting a single UV-CVL to pump a variety of different cerium doped laser materials. In this paper we augment our previous cerium laser studies by presenting what we believe to be the first report of a Ce:LiSAF laser, pumped by the 271 nm sum-frequency-mixed output of a CVL.

2. Experimental configuration and results

The experimental configuration of the tuned 10 kHz PRF Ce:LiSAF laser is shown in Fig. 1. Details of the construction of the 271 nm UV-CVL pump laser can be found in Ref. [8]. The maximum power available for pumping the cerium laser was 920 mW and the UV pulse length was found to be 8 ns FWHM, which is well matched to the 28 ns excited state lifetime of Ce:LiSAF [3]. The divergence of the 3.75 mm diameter 271 nm beam was 900 μrad, or approximately 11 times diffraction limited.

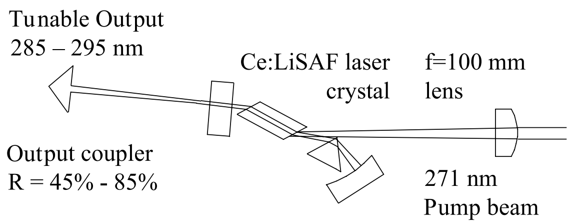

Fig. 1. Experimental layout of the UV-CVL pumped Ce:LiSAF laser, operated in a prism-tuned configuration.

The Ce:LiSAF crystal (VLOC) was 10 mm long with a 0.17 at.% cerium-doping level, providing 60% pump absorption. This crystal was also co-doped with 0.17 at.% Na. A brass mount provided conductive cooling of the crystal. The crystal ends were Brewster cut to favour π polarised lasing, and the polarisation of the pump beam was aligned parallel to the crystallographic *c*-axis, to minimise excited-state-absorption and solarisation effects, which are more deleterious to laser performance in the σ polarisation than in the π polarisation [3].

The un-tuned cerium laser cavity consisted of a flat output coupler and a curved high reflector (ROC = 250 mm). Output couplers of reflectivity, $R = 45\%$, 70% and 85% at the free-lasing wavelengths were used. The 271-nm pump was focused past the high reflector into the laser crystal by an $f = 100$ mm lens, forming a focus in the crystal with a diameter of approximately 90 μm, which was well matched to the cavity mode diameter of 100 μm. A quasi-longitudinal pumping geometry was adopted due to the difficulty of manufacturing a dichroic mirror of high transmission at 271 nm and high reflectivity at the Ce:LiSAF laser wavelengths, with a sufficiently high damage threshold. We kept the cavity length short (50 mm) to reduce the pulse build-up time, given the relatively short Ce:LiSAF excited state lifetime.

The output power characteristics of the free-lasing Ce:LiSAF laser are shown in Fig. 2. Note that all pump powers quoted subsequently refer to absorbed pump power in the Ce:LiSAF crystal. When the cerium laser was pumped with 0.55 W it was found that the highest laser output power of 70 mW, at the free lasing wavelength of 289 nm, was obtained by using the $R = 85\%$ output coupler. In this cavity configuration the slope efficiency was 21% and the lasing threshold was 0.19 W. The output power was limited only by the absorbed pump power available at the time of the experiment, and no temporal deterioration in output power was observed. The pulse length was just 3.5 ns FWHM when this laser was pumped with 0.55 W, corresponding to as much as 2 kW of peak power. When the $R = 45\%$ and $R = 70\%$ output couplers were used, 10 and 35 mW

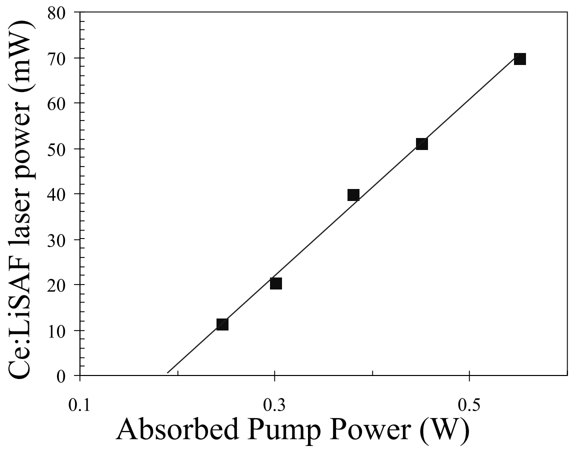

Fig. 2. Cerium laser output power versus absorbed 271 nm UV-CVL pump power, when operated in an un-tuned configuration with the $R = 85\%$ output coupler.

(respectively) of output power were obtained from 0.55 W of pump power.

Tunable laser operation was achieved by placing a fused silica Brewster prism in the cavity and rotating the high reflector to obtain wavelength selectivity. In this case the cavity length was increased slightly to 65 mm to accommodate the prism. The broadest tunability of 285–295 nm (for 0.55 W of absorbed pump power) was attained by using the $R = 85\%$ output coupler, as shown in Fig. 3. In this arrangement 60 mW of output power was derived from the cerium laser at the peak tuning wavelength of 289 nm, and the slope

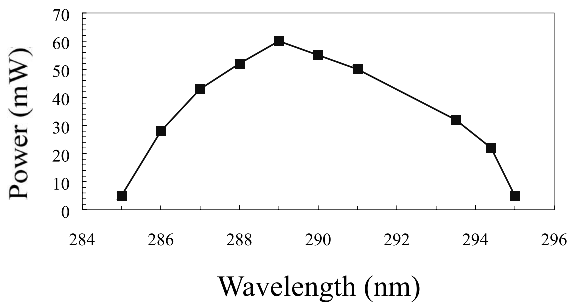

Fig. 3. Ce:LiSAF laser output power versus wavelength for the prism-tuned cavity with the $R = 85\%$ output coupler, when pumped with 0.55 W of absorbed power from the UV-CVL.

efficiency of the Ce:LiSAF laser at this wavelength was 20%. Whilst no line width measurements were performed during these investigations, it is likely that the line widths of the free-lasing and prism-tuned Ce:LiSAF lasers reported here are of the same orders of magnitude as the line widths found (2.4 nm, 0.3 nm, respectively) during our previous Ce:LiCAF study [8].

3. Discussion and conclusion

The 10 kHz PRF Ce:LiSAF laser reported here behaved similarly to the Ce:LiSAF lasers reported elsewhere, which operated at PRFs ranging from 10 Hz to 20 kHz [4–7]. This observation is very encouraging, further confirming that if there is a restriction imposed on the efficiency of Ce:LiSAF lasers with increasing PRF, due to the lifetime of transient colour centres that this lifetime must be less than the inter-pulse period of the highest PRF (20 kHz) Ce:LiSAF laser reported to date [7]. It is possible that such a PRF limitation might correspond to the 100 ns lifetime colour centres (PRF of 10 MHz) that Pinto et al. [4] have observed in Ce:LiSAF.

Whilst the tunability (285–295 nm) and output powers (up to 70 mW) reported here were less than those obtained from other Ce:LiSAF lasers (283–313 nm) [4], (250 mW) [7], it is considered that this was simply due to the limited absorbed pump power in our laser, because of the low absorption (60%) of the Ce:LiSAF crystal. For instance, our tuning data was obtained when pumping at only one and a half times over threshold, whilst that obtained in Ref. [4] was recorded whilst pumping four times over threshold. Given that no saturation in output power was observed with increased pump power, in the investigations reported here, it is expected that use of a more highly doped laser crystal, would result in higher output powers and broadened tunability. As medium scale UV-CVLs are scaleable in output to almost 5 W, via the kinetic enhancement technique [12], it is reasonable to suppose that this Ce:LiSAF laser could be further scaled in output power to beyond the 1 W level, provided that any thermal effects could be suitably managed. Additionally, anti-solarant pumping of the Ce:LiSAF laser with the residual green and yellow CVL output from the non-linear crystal, may also result in enhanced laser performance, given that anti-solarant pumping of a Ce:LiSAF laser (operated with a Na co-doped crystal) was found to increase the laser slope efficiency from 33% to 47%.

By comparing the performance of the Ce:LiSAF laser reported here, with that of the UV-CVL pumped Ce:LiCAF laser that we reported earlier [8] it is found that the latter laser operated more efficiently (23% vs. 20% slope efficiencies, for identical prism-tuned cavities with the $R = 85\%$ output coupler). This result is in accord with other inter-comparative studies [2,4,7] which indicate that Ce:LiCAF is the slightly more efficient of the two laser materials.

In conclusion, we have demonstrated for the first time operation of a Ce:LiSAF laser, pumped by the sum-frequency-mixed output of a CVL. When this 10 kHz PRF laser was operated in an un-tuned configuration up to 70 mW of output was produced at 289 nm with a slope efficiency of 21%. Tunability was obtained from 285 to 295 nm using a single Brewster cut prism, constituting the first report of a tunable Ce:LiSAF laser, operating at a PRF of higher than a few tens of Hz. This demonstration of high PRF tunability extends the current applicability of Ce:LiSAF lasers into areas such as laser induced fluorescence monitoring of tropospheric OH concentrations [13], where multi-kHz PRF tunable UV sources operating in the 300 nm spectral region are required.

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