5-Watt level widely wavelength-tunable UV output from a frequency-doubled Alexandrite laser

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Abstract: We demonstrate a record 5-Watt level, wavelength tunable, continuous-wave UV output based on a diode-pumped Alexandrite laser employing intra-cavity second harmonic generation. A wide wavelength tuning range from 364nm to 402nm was achieved.

1. Introduction

Ultraviolet (UV) light has many significant applications, for example, spectroscopy, atom cooling and trapping, biological auto-fluorescence and virus sterilisation, photochemistry, and photolithography. Most applications have different wavelength requirements so a tunable UV source would be ideal to meet these needs. In this respect, Alexandrite is a particularly attractive laser gain medium because its widely tunable lasing range (~700nm – 858nm) can be simply and directly converted to tunable UV by second harmonic generation SHG (~350 – 426 nm) and tunable deep-UV by higher harmonic generation. Furthermore, due to Alexandrite's excellent thermo-mechanical properties and availability of high-power red diode pumps provides prospect to operate to high UV powers. Prior diode-pumped Alexandrite laser work using intra-cavity SHG for continuous wave (CW) UV output, generated 335mW (in one direction) at 375nm [1], and 2.55W at 378nm [2], but in both cases without wavelength tuning. In the work of this presentation, we demonstrate the highest UV power to date 5.05W from a diode-pumped Alexandrite laser and additionally with wide UV wavelength tuning from 364nm to 402nm. The UV laser design has excellent long-term power stability and record optical-to-optical efficiency 16.2% for a diode-pumped UV Alexandrite system.

2. Experimental setup

Figure 1 shows the schematic diagram of the experimental setup for our diode-pumped Alexandrite laser with intra-cavity SHG. The pumping source was a fibre-coupled red laser diode (LD) at 635nm (core diameter 200µm; NA=0.22). The pump was coupled out of the fibre with a fibre collimator lens ($f_c = 35.4$mm) and focused by a pumping lens ($f_{pump} = 75$mm) into an Alexandrite crystal (4×4×7 mm^3 in dimensions and 0.2 at.% Cr-doping). The pump size at the crystal was $\omega_{pump} = 230$µm. The pump was unpolarized and absorbed in a double-pass configuration. Predominant pump absorption was along the b-axis of the Alexandrite crystal on first pass and the transmitted pump retro-reflected, with a 90-degree polarization flip by double-pass of a quarter-wave plate (QWP), and re-focused by a curved mirror for absorption of the orthogonal pump polarization on second pass.

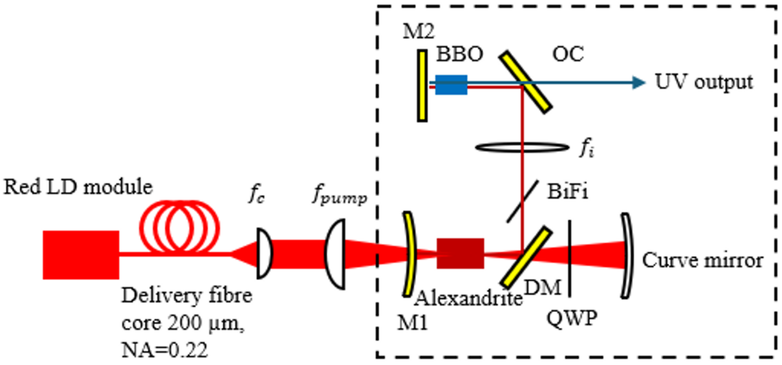

Fig. 1. Schematic diagram of experimental setup of tunable UV Alexandrite laser.

The laser resonator was composed of a convex mirror (M1), a 45-deg dichroic mirror (DM), a 45-deg tuning mirror (OC) and a plane mirror (M2). M1 was a zero-lens mirror with curvature of $R_{M1} = -200$mm HR coated at 760nm and high transmission for pump; DM was HR at 760nm and AR at 635nm; OC was HR at 760nm and AR at 380nm and used as an output coupler for UV. M2 was HR coated for both 760nm and 380nm. A BBO crystal (AR coated) near M2 was used for SHG. An intra-cavity lens ($f_i = 40$mm) was incorporated to form a smaller beam size on BBO and for cavity stability control. The cavity distances were: $L_0 = 9.5$mm between M1 and Alexandrite; $L_1 = 122$mm between Alexandrite and f_i; and $L_2 = 50$mm between f_i and M2, optimized for maximum UV power with best beam quality. A birefringent filter (BiFi) plate (quartz, 0.5mm in thickness) was inserted into the cavity to line-narrow and tune lasing wavelength.

3. Results and analysis

In Fig. 2(a), the blue line shows the UV power curve as a function of absorbed pumping power. Maximum output UV power of 5.05W was achieved at 384nm with absorbed pump power of 31.1W, corresponding to optical-to-optical efficiency, ratio between output UV power and absorbed pump power, of 16.2%, which is the highest efficiency for a CW UV diode-pumped Alexandrite laser with intra-cavity SHG. The threshold was 2.8W. We measured the UV power at maximum output for 1 hour, with a relative RMS 1.03%, which confirms excellent long-term stability of the UV source. The wavelength tuning was realized by rotating the BiFi plate and angle adjustment of BBO crystal for optimum phase matching. In our laser system, wavelength tunable range from 364nm to 402nm was achieved, as shown in Fig. 2(b). The UV spectral bandwidth was measured to have FWHM < 1.5nm (and might be limited by resolution of spectrometer used).

A comparison experiment for the laser output power at fundamental wavelength was conducted. The M2 mirror was replaced by different output couplers with reflectivity 97%, 98% and 99%, respectively, at 760nm. The pump threshold was measured as 9.4W, 7.5W and 3.6W, respectively, and from a Findlay-Clay analysis, the total round-trip intracavity loss was calculated as 0.66%. The highest fundamental output power was obtained with the 98% output coupler, and the red line in Fig 2(a) shows the fundamental power curve. The threshold was 7.48W and the slope efficiency was 29.2%. The fundamental beam quality was $\mathrm{M_x^2} = 7.33$ and $\mathrm{M_y^2} = 5.91$, and beam size was $\omega_{\mathrm{x,IR}} = 125\mu\mathrm{m}$ and $\omega_{\mathrm{y,IR}} = 110\mu\mathrm{m}$ near mirror M2 (spatial image shown in input of Fig. 2 (a)). The spatial image of UV output at the mirror M2 is also shown in Fig 2(a). The beam was asymmetric with beam quality of $\mathrm{M_x^2} = 3.1$ and $\mathrm{M_y^2} = 5.5$, and beam size of $\omega_{\mathrm{x,UV}} = 276\mu\mathrm{m}$ and $\omega_{\mathrm{y,UV}} = 105\mu\mathrm{m}$. The elliptical beam shape is assumed due to the beam walk-off effect in BBO along horizontal direction (extraordinary axis).

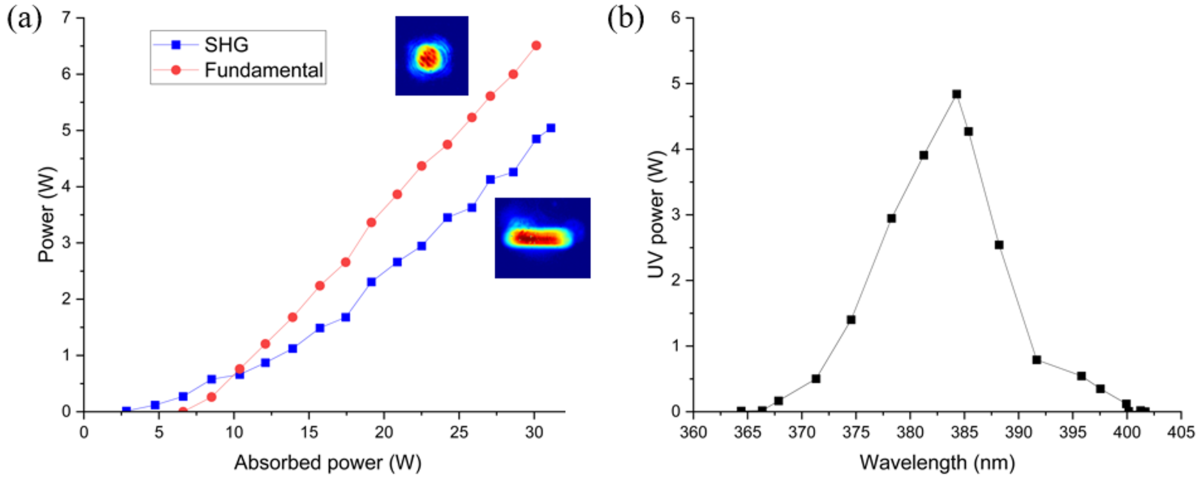

Fig. 2. (a) Laser power curves of UV output at 384.3nm (blue) compared with fundamental output with a 98% output coupler without BBO crystal (red). Insets are spatial beam profiles. (b) UV output power as a function of output wavelength.

4. Conclusions

We have demonstrated the first >5W CW UV output from a diode-pumped Alexandrite laser with intra-cavity SHG. The lasing wavelength was widely tunable in the UV from 364nm to 402nm with a linewidth < 1.5nm. The UV laser displayed excellent long-term power stability and record optical-to-optical efficiency 16.2% for a diode-pumped UV Alexandrite system. We believe that our work provides an excellent reference for high-power, widely-tunable UV lasers based on diode-pumped Alexandrite, and with scope for further optimisation with better optical coatings across spectral tuning band and higher pumping power, and prospects for extension to tunable deep-UV regime with THG (~240nm - 285nm) and FHG (~170nm – 210nm).

References

[1] X. Peng et al, "*Watt-level red and UV output froma CW diode array-pumped tunable alexandrite laser*", CLEO Technical Digest, paper CMAA5 (2005)

[2] Y. Song et al, "*2.55W continuous-wave 378nm laser by intracavity frequency doubling of a diode-pumped Alexandrite laser*", Applied Optics, 60, 5900 (2021)