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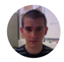

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620 mW Single-Frequency $Nd:YVO_4/BiB_3O_6$ Red Laser

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Abstract: Using a type-I critically phase-matched bismuth borate crystal, a record 620 mW single-frequency red laser at 671 nm is achieved from intra-cavity SHG of a π-polarized single-end pumped $Nd:YVO_4$ ring laser oscillating on the λ~1342nm transition.

OCIS codes: (140.3570) Lasers, single-mode; (190.2620) Frequency conversion

1. Introduction

All solid-state continuous-wave (cw) narrow-linewidth tunable red lasers are convenient alternative sources to bulky and expensive dye-lasers for high-precision laser spectroscopy. In order to efficiently laser cool Lithium atoms (Li) on the $^2S_{1/2}$– $^2P_{1/2}$ dipolar transition (as a preliminary step toward Bose-Einstein Condensation), watt-level single-frequency (i.e. single-longitudinal mode or SLM) laser source at 671nm is required. This wavelength can be synthesized from a frequency-doubled diode-pumped $Nd^{3+}:YVO_4$ laser operating on the π-polarized $^4F_{3/2}$ - $^4I_{13/2}$ transition (λ=1342nm). Such a single-longitudinal mode (SLM) red laser can be conveniently achieved using a unidirectional ring cavity containing a suitable nonlinear crystal for second-harmonic generation (intra-cavity SHG). There has been a number of works devoted to the cw SHG of either 1064nm or 1342nm $Nd:YVO_4$ lasers, but most of these works used standing-wave resonators and were targeted to red power scaling rather than spectral purity (SLM) or tunable operation. In order to avoid spatial hole-burning modes, SLM lasers are most conveniently implemented using a unidirectional ring cavity configuration containing spectrally selective elements such as Lyot filters or solid etalons for fine wavelength tuning. The largest SLM red power using an intracavity SHG of a 1.34µm $Nd:YVO_4$ laser yielded a maximum 370 mW at 671nm [1]. As in most setups, in the latter work non-critically phase-matched lithium triborate (LiB_3O_6 or LBO) was employed as the nonlinear crystal in a folded standing-wave resonator where the type-II cut LBO served as the birefringent filter. In Ref.[1] single-frequency operation could be obtained only with a reduced pump power to avoid the spatial hole-burning effect. In this work, we employ a single-end longitudinally pumped, unidirectional bow-tie ring resonator containing the newly available BiB_3O_6 (BiBO) nonlinear crystal (d_{eff}~2.45pm/V) [2] to synthesize as much as 620 mW of SLM red output at 671nm, which is – to the best of our knowledge – the highest cw SLM red output performance obtained from such a $Nd:YVO_4$ laser. Recently, Dou *et al* reported on a cw (multimode) high-power (1.22 W at 671nm) single-end pumped $Nd:YVO_4$/BiBO laser in a folded standing-wave resonator, with a red optical-to-optical slope efficiency of η=4.9%, limited by thermal effects in the vanadate crystal [3]. In the present work, the 620 mW cw SLM power corresponds to an optical-to-optical efficiency η=6% at P_{abs}=10W of absorbed diode pump power (at λ_p=808nm). Power scaling is limited by thermal lensing effects in the low-doped (0.15 at.%) 3x3x10 mm^3 $Nd:YVO_4$ sample.

2. Experimental setup and laser parameters

The experimental unidirectional ring laser geometry is similar to those used for the intra-cavity frequency-doubled 1.32 µm Nd:YLF lasers employing either LBO, BiBO or ppKTP [2]. Because all cavity mirrors are broadband HR-coated dichroic mirrors (R>99.8% in the range 1300-1350nm, with T~90% in the 650-810nm range), one of the cavities was used for the $Nd:YVO_4$ laser. A Low-doped yttrium vanadate crystal with 10mm-length was preferred to, e.g., a 5-mm long one doped at 0.5 at.% as in Ref.[1] to minimize the longitudinal temperature gradient arising from the single-end pumping scheme (average pump absorption was ~90% at 808nm). The Faraday optical diode consists of a TGG rod (providing θ~8° E-field polarization rotation) with an AR-coated zero-order half-wave plate at 1342nm. Wavelength tuning within the ~3nm bandwidth of the gain curve is achieved with a thin fused silica etalon with partially reflective facets (R~40%). The same BiBO sample used for the Nd:YLF/BiBO laser, cut for type-I (ooe) critical phase-matching at (θ, φ)=(8.6°,0°), could be used for 1342nm SHG (θ=9.0°) although with a higher residual dual-band AR coating performance at 1342 nm (R~1%). The BiBO spectral phase-matching bandwidth is $\Delta\lambda_{CPM}$=3.9nm FWHM, equivalent to the laser gain bandwidth. Because the cavity mirrors have also slightly lower reflectivity at 1342nm, the estimated total fundamental-harmonic (FH) round-trip passive loss is ~2.2%. The lasing efficiency (threshold and output power) of $Nd:YVO_4$ was found roughly similar to that of Nd:YLF, because both laser materials exhibits the

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same saturation intensity $I_{sat}=h\nu/\sigma\tau_f$ (although the emission cross-section σ is ~5 times larger in Nd:YVO_4, the upper excited state lifetime is also ~5 times shorter).

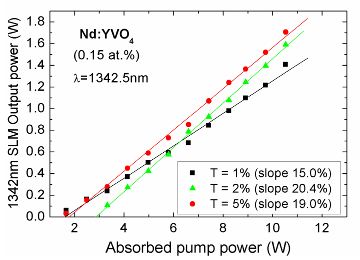

Fig.1: IR power versus pump power for different output couplers.

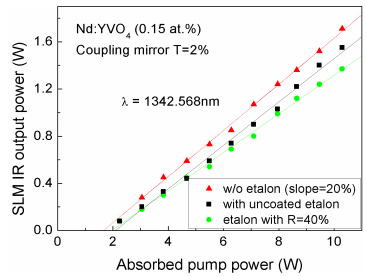

Fig.2: IR power at maximum gain, showing etalon loss.

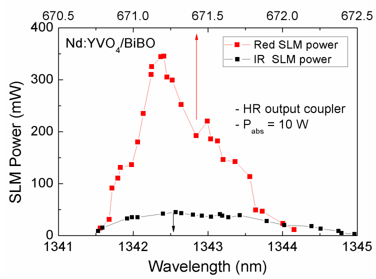

Fig.3 : Single-frequency red and IR output powers versus wavelength, taken at P_{abs}=10W with the R=40% etalon.

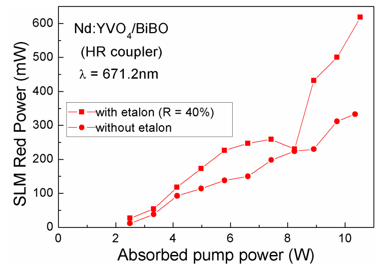

Fig.4: Single-frequency red power versus pump power. Without etalon, SLM operation is characterized by frequent mode-hops.

3. Experimental results

We have first characterized the FH performance of the Nd:YVO_4 unidirectional ring laser (without intra-cavity etalon) as a function of the output coupler transmission *T*, and found an optimal FH output power P_{1342nm}=1.7 W for T=2%, with a pump threshold as low as P_{abs}=1.5W (Fig. 1). Without the etalon, mode competition occurs between typically two to three longitudinal modes at maximum power. When an etalon is inserted in the vicinity of the laser crystal (either uncoated or with R=40%), single-frequency oscillation is obtained at the expense of a slightly reduced slope efficiency (Fig. 2). However, the partially coated etalon was preferred because of much fewer mode hop events: the laser can then passively oscillate on the same longitudinal mode during more than 20 minutes if the setup is shielded from air fluctuations.

When an HR output coupler is used, about 110mW of FH power is leaking through the coupler (twice the power measured with an Nd:YLF crystal at 1321nm), due to the proximity of the mirror coatings band edge. This power is reduced to ~25mW under large SH conversion. Once the BiBO crystal is inserted, the laser can spontaneously oscillate on a single longitudinal mode (at gain center wavelength), owing to the higher loss experienced by sum-frequency processes between longitudinal modes. However smooth and extended SLM wavelength tuning requires the insertion of the R=40% etalon. Unlike for a Nd:YLF/ppKTP laser reported elsewhere (for which the ppKTP spectral QPM bandwidth is $\Delta\lambda_{QPM}$~0.9nm), no second-order cascading effects leading to spectral broadening of the emission are observed in this laser, because the BiBO spectral phase-matching bandwidth is much larger than the laser gain bandwidth [4]. Fig. 3 displays the FH and SH wavelength tuning curves of the laser. Tuning over $\Delta\lambda_{IR}$~3 nm and $\Delta\lambda_{red}$ ~1.25nm can be achieved. Furthermore, because one facet of the BiBO is wedged with an angle ~0.2°, fine continuous tuning over 0.020nm around a given wavelength can be achieved by lateral translation of the wedged crystal, allowing e.g. to address the narrow atomic resonance. Finally, Fig. 4 displays the maximum red power characteristics, with and without the etalon. In conclusion up to 620 mW single-frequency and up to 350 mW SLM tunable red output have been obtained.

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