Nd:YAG polarized laser with beam quality beyond the birefringence limit and its application in a Singly-Resonant Optical Parametric Oscillator

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Nd:YAG polarized laser with beam quality beyond the birefringence limit and its application in a Singly-Resonant Optical Parametric Oscillator

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1. Abstract

We demonstrate a simple, reliable and cheap high output power, linearly polarized and high-quality beam @1064 nm laser source, based on a previous work [i], where a Nd:YAG Diode-pumped Solid-state Laser (DPSSL) based on standard, commercial laser modules was presented. This kind of laser source is interesting for a large number of applications, such as pump laser for an Optical Parametric Oscillator (OPO) and frequency conversion, maintaining near-diffraction-limited beam quality factor (M^2~1).

2. Resonator Simulation

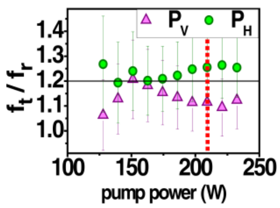
2.1) Laser resonators with thermal lens: 2 stability zones [ii]

2.2) Joined zones: wide dynamic range of operation [iii]

- Large TEM_{00} modes (W_{30}) inside the laser rod
- Necessary for high output powers [iv–vi]

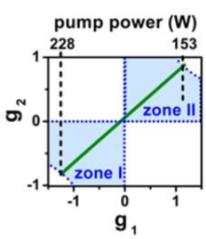
2.3) Difference between radial (f_r) and tangential (f_t) thermal induced lenses: 20% [vii, viii], birefringent beam waist $(W_{BL}^{30})^2$~$3.5\lambda f$ (λ wavelength, f average focal length at maximum pump power).

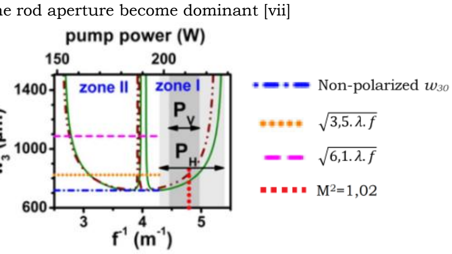
2.4) Measured polarized components (operation range above 190 W): vertical (dioptric power P_V) f_t/f_r~1.11 and horizontal (dioptric power P_H) f_t/f_r~1.25



2.5) Beam quality: vertical, closer values of W_{30} in both directions (f_t~f_r)

- $(W_{BL}^{30})^2$~$6.1\lambda f$, 32% bigger birefringence-limited value
- Diffraction effects at the rod aperture become dominant [vii]





2.6) Polarization

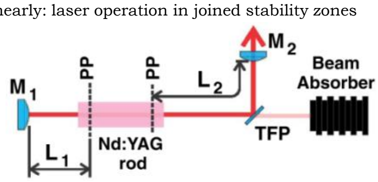
- Horizontal: part of the laser operate outside the stability zone, suffering strong diffraction effects with large beam waist in the vertical direction
- Vertical: contained inside of zone I

2.7) Initial resonator dimension

- Distances mirror-principal plane (PP): L_1=35 cm and L_2=42 cm
- Mirrors r_1=-30 cm (M_1) and r_2=-50 cm (M_2)
- Stability diagram edge: 240 W ⇒ <f>=18.2 cm, W_{BL}^{30}=823 µm (unpolarized laser)

2.8) Resonator shortened linearly: laser operation in joined stability zones

2.9) Final dimensions:
L_1=33.7 cm and L_2=41.6 cm (distance M_2-TFP=10 cm)



3. Nd:YAG laser

3.1) Components:

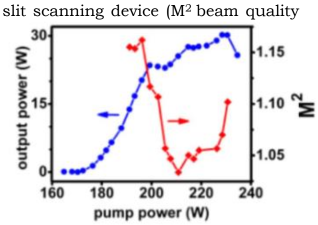
- 78mm long 0.6% Nd-doped YAG rod
- DPSSL module containing 12 @808 nm diode bars
- r_1=−30 cm (input, R_1=99.9%) and r_2=−50 cm (output, R_2=70%) mirrors
- Intracavity Thin-film Polarizer (TFP) designed for R_S(@1064 nm, 45°)>99.8% and R_P(@1064 nm, 45°)<1%

3.2) Output coupling of 30% at 1064 nm

3.3) Measurements: powermeter and slit scanning device (M^2 beam quality factor)

3.4) Results:

- Maximum output power: 30 W
- Best beam quality factor: M^2=1.02(2) at 24.8 W of output power
- Transition between stability zones at 195 W



3.5) M^2<1.16 in the entire range of optical pump power: 165 W ⇒ 235 W

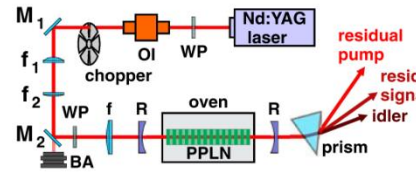
3.6) At 209 W: <W_{30}>=781 µm; f=20.9 cm; beam waist tangential and radial values differing by 7%

3.7) Good spatial beam properties: final laser was used to pump a Singly-resonant OPO (SRO) in Continuous-wave (CW) and pulsed conditions.

4. SRO Experimental setup

4.1) Setup:

- Developed @1064 nm linear-polarized laser
- SRO: 40 mm periodically poled $LiNbO_3$ (PPLN) crystal with four 1 mm² grating regions ranging from 29.52 µm to 31.59 µm; two mirrors with radii r=50 mm and reflectivity R(1064 nm)<2%+R(1.41–1.8 µm)>99.9%+R(3–4 µm)<5%.
- Pump laser beam passes through: Half-wave plate (WP); Optical Isolator (OI); Chopper (500 µs pump pulses, 5% duty cycle); 2:1 expansion telescope (f_1+f_2); plane mirrors M_1 and M_2; f=75 mm lens.



4.2) The lens f focuses the beam in the center of the PPLN crystal: it was adjusted to 55 µm for both pump and resonant beams, resulting in focusing parameters of ξ_{PUMP}=1.1 and ξ_{RES}=1.6 (ξ=L/2.Z_R, L crystal length and Z_R Rayleigh range).

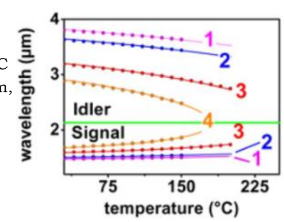
4.3) WP's were used before and after the OI for adjusting power and polarization angle, respectively.

4.4) Mirror M_2 had partial reflection and was chosen to limit the pump power to a maximum of 12 W.

4.5) λ_{PUMP}, λ_{SIGNAL}, λ_{IDLER} and (λ_{SIGNAL}/2) beams were separated by a prism and detected using two spectrometers.

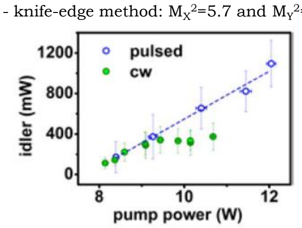
4.6) Results:

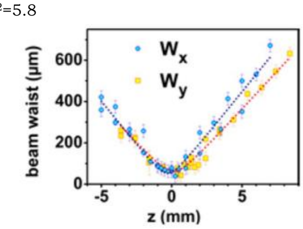
- The PPLN crystal generated wavelengths for temperatures between 30 °C and 150 °C for the gratings Λ_1=29.52 µm, Λ_2=29.98 µm, Λ_3=31.02 µm and Λ_4=31.59 µm
- Pulsed operation (Λ_4 at 150 °C): slope efficiency values of 23.6% (λ_{IDLER}=2.49 µm) and 7.7% (λ_{SIGNAL}=1.86 µm) were obtained for the beams, with 7.7 W of threshold.



4.7) Idler beam: M^2 beam quality factor

- knife-edge method: M_X^2=5.7 and M_Y^2=5.8





4.8) Slightly better power values have been reported ([viii],[ix]): back conversion affecting threshold and beam quality [x].

4.9) The behavior of the output power curve deviated from linear in CW operation, due to thermal effects in the crystal; so it was limited to avoid damage.

5. Conclusions

Beam quality needs not be limited by thermally induced birefringence in dynamical stable resonators, even when using isotropic crystals such as YAG. A beam quality of M^2=1,02 was obtained with a linearly polarized 1064 nm beam, and the output remained stable in power and beam quality for several months without any realignment. The whole pump laser is a small fraction of the cost of an OPO crystal, and a SRO oscillated using it as a pump source, demonstrating its usefulness for this kind of application.

6. Bibliography

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