Intracavity Frequency Doubled Yb:YAG Miniature Laser

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Abstract

We report our recent results for tunable single axial-mode oscillation of intracavity frequency doubled Yb:YAG miniature lasers. For frequency tuning, an intracavity birefringent filter was used.

Key Words: (190.0190) Nonlinear optics; (140.3570) Lasers, single-mode; (140.3600) Lasers, tunable; (140.7300) Visible lasers.

Introduction

Compact and efficient visible source of stable, single-frequency radiation are of potential interest for many applications such as display, interferometer and holographic systems. However, current argon-ion lasers suffer from low efficiency, short lifetimes and low coherency. Alternatively, as green lasers such as frequency doubled Nd-doped lasers are poor tunability and far from 515 nm.

In other hand, diode-pumped Yb:YAG laser which is promising material as a high power and high efficiency laser also have a potential for a wide tunable and high power mode lock lasers [1-3]. We also have reported a cw single-frequency and wide tunable Yb:YAG miniature laser [5]. Subsequently, frequency doubled Yb:YAG laser is one alternative technique to obtain single-frequency tunable light source around 515 nm region. In this paper, we report our recent results for tunable single axial-mode oscillation of intracavity frequency doubled Yb:YAG miniature lasers. For frequency tuning, an intracavity birefringent filter was used

Modeling

In the intracavity frequency doubled lasers, as shown in Fig. 1, the total cavity loss is given by

$$L = L_i + \delta_s + \eta_s \tag{1}$$

where L_i is the intrinsic cavity loss, δ_S is the reabsorption loss due to the fractional population in the lower laser level, and η_S is the second harmonics generation loss. The reabsorption loss of the quasi-four-lasers will be negligible by highly puming intensity. The reabsorption loss is given by:

$$\delta_s = \frac{\alpha_\ell \ell I_s}{I_\omega} \ln\left(1 + \frac{2 I_\omega}{I_s}\right) \tag{2}$$

where α_ℓ is the absorption coefficient, ℓ is the length of laser medium, I_S is the saturable intensity and I_ω is the fundamental wave intensity.

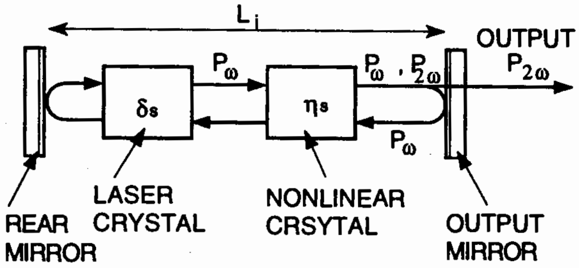

Figure 1. Model of an intracavity frequency doubled laser.

To saturate the lower-laser level absorption, increase the fundamental wave intensity. For it, reduce the SHG coupling coefficent. When the reabsorption loss is negligible, we obtain the optimum coupling coefficient as following

$$\kappa_o = \frac{L_i}{I_s A} \tag{3}$$

where A is the beam area of the laser crystal. This formula is same as the four-level-laser's one. Then, the optimum nonlinear crystal length is given by:

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$$\ell_{s,o} = \sqrt{\frac{n_s^3 c^3 \varepsilon_0 L_l}{2\omega^2 d_{eff}^2 I_s} \cdot \frac{\pi w_s^2}{A}} \qquad (4)$$

were n_S is the refractive index of the nonlinear crystal, w_S is the beam spot size, ω is the angle frequency of fundamental wave and d_{eff} is the nonlinear coefficient. Because the Yb:YAG has 8 times larger saturation intensity compared with the Nd:YAG, the intracavity frequency doubled Yb:YAG lasers are with enough short nonlinear crystal size. This results is good agreement with previous analysis to increase internal fundamental wave intensity.

Experiments

The experimental configuration of the laser is presented in Fig. 2. A miniature laser crystal, consisted of a 400μm YAG crystal doped with 25 at.% Yb (Scientific materials Co.) assembled on a sapphire substrate. The pump side of the crystal had a transmission of >95 % at the pump wavelength and a reflectivity of >99.9 % at the lasing wavelength. The opposite side of the Yb:YAG has reflectivity of ~90 % at the pump wavelength and few percent reflectivity at the lasing wavelength for a coupled-cavity.

The coupled mirror, with 50mm radius of curvature, had a reflectivity of 99.9% at lasing wavelength and a transmission of 90% at SH wavelength. The position of this external mirror was separated by 50 mm from the crystal. For a tuning experiment, a 1 mm thickness quartz plate was inserted into the laser cavity. The Yb:YAG crystal was longitudinally pumped by the beam from the fiber bundled diode-laser (OPC-C005-FC), which was collimated by use of a 12.5 mm focal-length lens. Then a 2.6 mm focal-length lens was used to focus the pump beam to a radius of 68 μm in the laser crystal. A 5mm and 2 mm long KTP crystal was also cut for type II second-harmonic (SH) phase matching (θ= 90°, ϕ= 50°) and antireflection coated for the fundamental and the SH wavelength. The temperature of the Yb:YAG and KTP holder were held at 20 °C and 37°C, respectively.

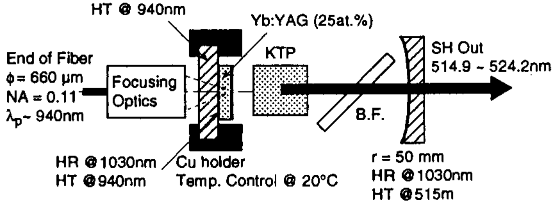

Figure 2. Schematic of the intracavity frequency doubled Yb:YAG laser. For frequency tuning a 1mm thickness quartz birefringence filter was used.

The Yb:YAG output power as a function of absorbed pump power is presented in Fig. 3. A maximum SH output power in a single-longitudinal mode of 150mW cw was achieved at 516 nm with 5mm KTP crystal, corresponding to an intracavity circulating SH power of nearly 300 mW because the Yb:YAG crystal has not high reflectivity at SH wavelength. With 2mm KTP crystal maximum SH output power of 112 mW was observed.

Fig. 4 shows the optical spectra (monitored with a optical spectrum analyzer, Advantest-TQ8345) of the intracavity frequency doubled Yb:YAG laser at 130mW of extract power. The output power stability was ±1.7% during 15 minute, measured by a power mater (Gentic, PS-S10V2), and ±0.42% during 100 ns, measured with a photo diode (Hamamatsu, S1722-01).

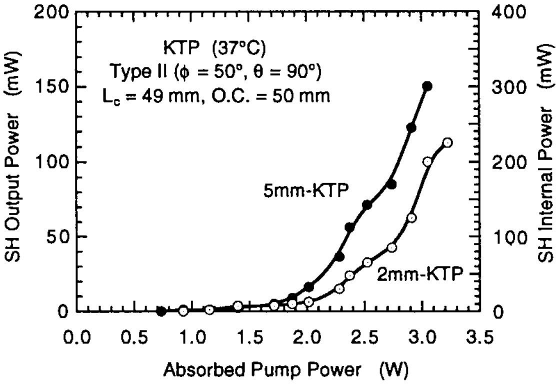

Figure 3. Input-output characteristics of an intracavity frequency doubled Yb:YAG lasers.

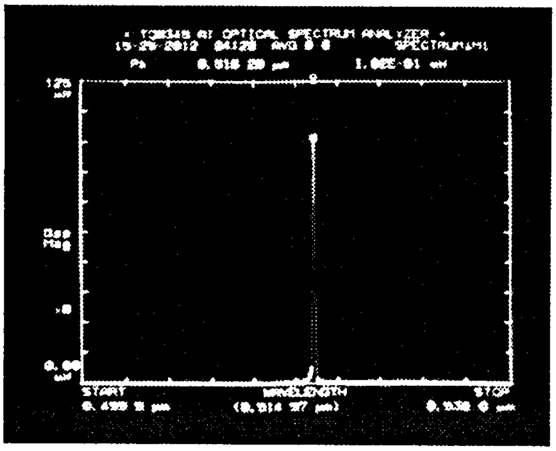

Figure 4. Optical spectra of the intracavity frequency doubled Yb:YAG laser with 130-mW of extract power. The peak wavelength was 516.3nm.

These results indicate that the green problem was suppressed by single-axial-mode oscillation due to the coupled cavity effects [4, 5].

Compared with previous experiments [5], the maximum single-frequency output power of 500 mW at fundamental wavelength, the effective conversion efficiency was reached to 60 %. The tuning width was $\Delta\lambda$~2.2 nm (2.4 THz) around 516 nm with $\delta\lambda$~0.31nm (350 GHz) with 5-mm long KTP crystal. Although the Yb:YAG has a wide gain width of 29 nm the width of SH region was limited to 2.2 nm. This is the reason why the gain of ~1030 nm region was too high to tune with one birefrigent filter. Finally, we obtain 10.9 nm (12.4 THz) tunability by using 2-mm KTP crystal.

Summary

In conclusion, a diode-pumped single polarization and single frequency source in the green region that delivers 150 mW of cw power by intracavity frequency doubled Yb:YAG miniature laser has been demonstrated. Using one birefringent filter frequency tuning over as much as 12.4 THz. This laser system is an interesting light source for various applications, such as high resolution spectroscopic system and holography applications.

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