

# Diode-pumped 1123-nm Nd:YAG laser

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We demonstrated a diode-pumped Nd:YAG laser with a plano-concave resonator. When the pump power is 1.57 W, the output power of 1123-nm laser is 132 mW at the temperature of 20 °C, and the power change is less than 2% in an hour. A periodically poled LiNbO<sub>3</sub> (PPLN) was used as outer cavity frequency-doubling crystal and 561-nm laser was observed.

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Nd:YAG lasers that operate at 1064, 1319, and 946 nm have been widely reported<sup>[1-3]</sup>. The 1123-nm line is an important laser line of Nd:YAG, which has potential applications in areas such as differential absorption lidar to allow remote monitoring of atmospheric water-vapor concentration and the second harmonic generation (SHG). The 1123-nm transition of Nd:YAG has the upper and lower laser levels within the same manifolds as the 1064-nm line, as shown in Fig. 1. It must compete with the higher gain 1064 nm because the emission cross section for 1123 nm is only  $3 \times 10^{-20}$  cm<sup>2</sup>, which is approximately 15 times smaller than that for the 1064-nm line<sup>[4]</sup>. Consequently, efficient operation at 1123 nm requires the suppression of parasitic oscillation at 1064 nm, high pump intensity, and optimum resonator with low-loss.

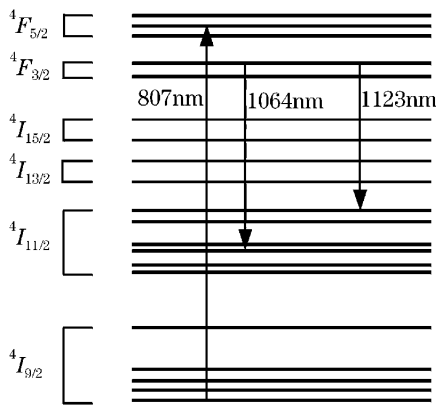


Fig. 1. Energy level scheme for the 1123-nm transition in Nd:YAG.

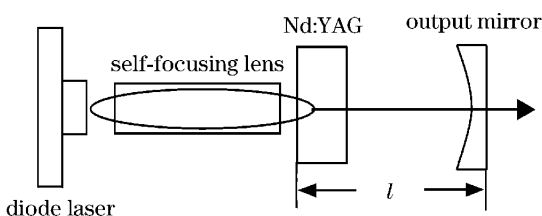


Fig. 2. Diode-pumped Nd:YAG laser of 1123 nm.

A resonator scheme of the 1123-nm laser is shown in Fig. 2. The pump source is an 808-nm laser diode, with the emission area of  $200 \times 1 \mu\text{m}^2$ , which is coupled by an  $f = 1.6$  mm self-focusing lens into the laser crystal. Self-focusing lens is a simple coupling element, through which image is formed by the refracting of alterable refraction material continuously, and which differs from the detached formation of imaging on the edge of symmetrical material of ordinary lens<sup>[5]</sup>. Therefore self-focusing lens can revise image aberration without complicated optical elements or system, and can focus the pump beam only a few microns into Nd:YAG. The transmission for the pump light is about 87%, and the absorption efficiency of laser crystal for pump power is 79.6%. The  $\alpha$ -cut Nd:YAG crystal ( $4 \times 4 \times 3$  mm<sup>3</sup>) with 1.0-at.% Nd doped was mounted in an electricity-cooled copper heat sink which was maintained at the temperature of 20 °C. Many methods can be used to restrain the operation of 1064-nm line, such as inserting etalon or dispersion prism, plating coatings on the resonator mirror to increase the loss of 1064 nm, etc.. In order to reduce the loss of the resonator, we took the method of plating coatings on resonator mirror. The pump surface of Nd:YAG was coated with high-reflection ( $\geq 99.5\%$ ) for operating wavelength (1123 nm) and antireflection ( $T > 85\%$ ) for pump wavelength (808 nm). The output mirror of 1123 nm was coated with high-reflection ( $T = 1.5\%$ ) for 1123-nm wavelength and antireflection ( $T > 85\%$ ) for 1064-nm wavelength.

The 1123-nm wavelength was measured by a spectrometer (SpectraPro-500i, Acton Research Corporation), and the spectrum is shown in Fig. 3. Figure 4 shows the 1123-nm output power as a function of the pump power with different radii of output mirrors ( $R = 50$  mm and  $R = 100$  mm). When the resonator length  $l$  and radius of output mirror are 13 and 100 mm, respectively, the pump threshold is 120 mW, and the maximal output power of 1123 nm is 132 mW when the pump power is 1.57 W. The beam profile was measured along fast-axis and slow-axis of pump light with a beam profiler (Beam-Code, Coherent Instruments Division), as shown in Fig. 5, which shows that the intensity distribution is a perfect Gaussian profile. Figure 6 shows the output power

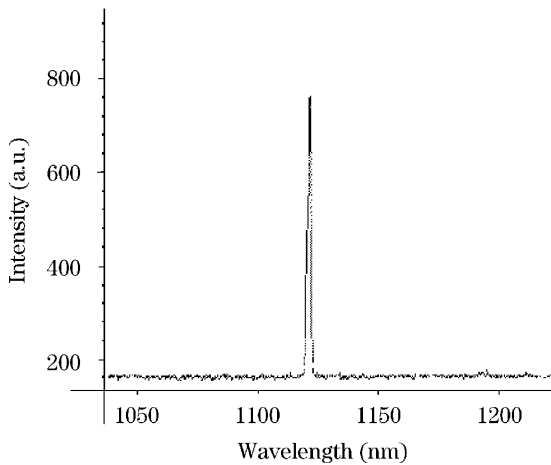


Fig. 3. Spectrum of 1123 nm.

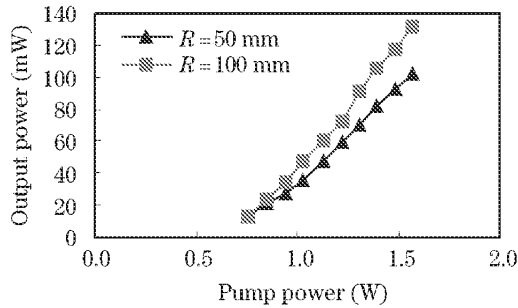


Fig. 4. Output power of 1123-nm laser versus diode pump power.

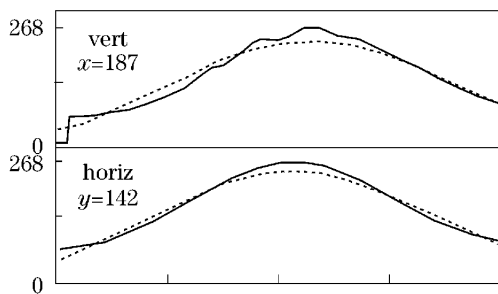
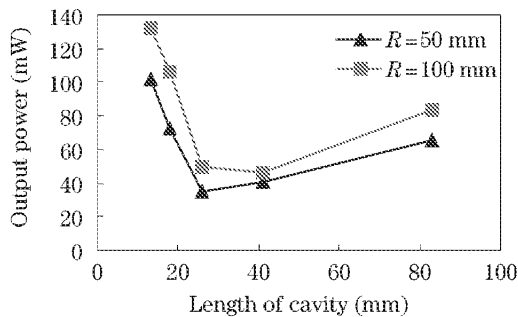

 Fig. 5. Light intensity profile in  $x$ - and  $y$ -axis. Dashed curves: standard Gaussian distribution; solid curves: actual intensity distribution.


Fig. 6. Output power of 1123-nm laser versus length of resonator.

as the function of resonator length for two different output mirrors ( $R = 50$  mm and  $R = 100$  mm). Because of the thermal lens in laser crystal, the stable region of

resonator is enlarged. So the laser resonator with the length of 80 mm is still stable when the radius of output mirror is 50 mm. The laser mode volume is larger when the radius of output mirror is 100 mm than it is 50 mm, so the former ( $R = 100$  mm) makes the resonator output higher laser power, as shown in Figs. 4 and 6.

We conducted the experiment of frequency doubling, and the scheme of the laser resonator is shown in Fig. 7. We employed a lens with the focal length of 8 mm to focus the laser beam into the frequency doubling crystal. The frequency doubling crystal used in the experiment was periodically poled LiNbO<sub>3</sub> (PPLN,  $5 \times 0.5 \times 20$  mm<sup>3</sup>). Because of the obvious variety of LiNbO<sub>3</sub> refractive index with temperature, we modulated the temperature of PPLN by a heat stove to 75 °C, at which the nonlinear coefficient is about 1.0 for the conversion of 1123 to 561 nm. The poled period  $\Lambda$  is about 8.0  $\mu$ m, the tolerant temperature  $\Delta T$  is 1.5 °C, and the tolerant wavelength  $\Delta\lambda$  is 0.13 nm. The two ends of PPLN were coated with dual antireflection coating of 1120 and 560 nm ( $T > 99\%$ ). Basing on the transformation of Gaussian beam through a lens, one can conclude<sup>[6]</sup>

$$l_2 = f + \frac{(l_1 - f) f^2}{(l_1 - f)^2 + (\pi\omega^2/\lambda)^2}, \quad (1)$$

$$\frac{1}{\omega'^2} = \frac{1}{\omega^2} \left(1 - \frac{l_1}{f}\right)^2 + \frac{1}{f^2} \left(\frac{\pi\omega}{\lambda}\right)^2, \quad (2)$$

where  $\omega$  is the waist of Gaussian beam before the lens,  $\omega'$  is the waist of Gaussian beam after the lens,  $l_1$  is the space before the lens,  $l_2$  is the space after the lens, and  $f$  is the focal length of the lens.

In our experiment, the laser waist  $\omega$  on the output mirror is 63.5  $\mu$ m, and the laser waist  $\omega'$  in the PPLN is 26  $\mu$ m. From Eqs. (1) and (2), we calculated that  $l_1$  and  $l_2$  are 27.2 and 10.5 mm, respectively. With these parameter, we obtained 500- $\mu$ W output power of 561-nm laser.

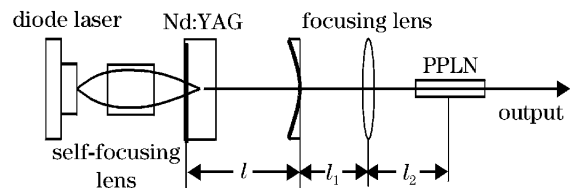


Fig. 7. Scheme of Nd:YAG/PPLN outer cavity frequency doubling.

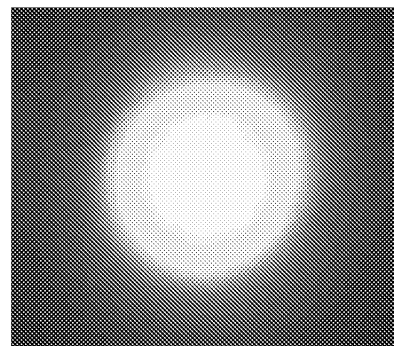


Fig. 8. The beam shape of 561-nm laser.

The beam shape of 561-nm laser is shown as Fig. 8.

In conclusion, we employed a simple plano-concave resonator and obtained 1123-nm laser with 132-mW output power. A PPLN was used as outer cavity frequency doubling crystal and 561-nm laser was observed. Further work includes the power scaling and intracavity frequency doubling.

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