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High efficient CW Nd:MgO:$LiNbO_3$ self-frequency-doubling laser

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Abstract

A new CW self-frequency-doubling laser operating on high-gain polarization of Nd:MgO:$LiNbO_3$ has been demonstrated in a nearly concentric resonator. The maximum second-harmonic output of 4.6 mW and the conversion efficiency up to 11.7% per watt were achieved,

1. Introduction

In 1979, the laser non-linear multifunctional crystal Nd: $LiNbO_3$ was developed and the self-frequency-doubling effect was first obtained with this crystal pumped by a flashlamp[1]. However, development was not pursued because this crystal has a disadvantage of the low photorefractive damage threshold. Several years later, MgO doping of Nd:$LiNbO_3$ was used to increase the distribution coefficvient of Nd ion into $LiNbO_3$ and reduce the photorefractive effect. Nd:MgO:$LiNbO_3$ combines the excellent laser properties of Nd ions with the non-linear properties of $LiNbO_3$ under high enough photo-refractive damage threshold, as well as being suitable for the simplest devices of SHG. Recently, several research groups reported self-frequency-doubling laser in a pulsed mode[2]. The first CW operation of self-frequency-doubling laser was achieved with Nd:MgO:$LiNbO_3$ crystal by T. Y. Fan et al[3]. In all published system, a Brewster angle window had to be inserted in the cavity to force Nd: MgO: $LiNbO_3$ laser to oscillate in σ polarization ($E \perp c$) with low-gain at $\lambda = 1.093$ μm and suppress the high-gain π polarization ($E \parallel c$) at $\lambda = 1.085$ μm to chieve phase-matching condition needed by SHG[2,3]. Beasuse of the low-gain of the fundamental wave the pump power threshold for SHG were quite high.

We designed a new Nd:MgO:$LiNbO_3$ self-frequency-doubling laser which operated on the high-gain laser wavelength at $\lambda = 1.085$ μm. The maximum second-harmonic output and the conversion efficiency were higher than that obtained by T. Y. Fan et al. with low-gain laser wavelength and the phase-matching temperature for SHG were lower. For the first time to our knowledge, our experimental results demostrated the self-frequency-doubling of high-gain polarization of Nd:MgO:$LiNbO_3$ crystal. The crystal used in our experiments was with greater MgO doping, so that the photorefractive damage was not found even at room temperature.

2. Principle of design

To avoid Poynting vector walk-off and obtain a higher conversion efficiency we choose to use a 90^0 phase-matching, the laser oscillation must be in the ordinary polarization (perpendicular to the z-axis of crystal), while the second-harmonic wave has an extraodinary polarization. However, in a y-cut crystal, the laser must preferentially oscillate with the high-gain π polarization. We inserted a quarter wave-plate at $\lambda = 1.085$ μm in the laser resonator to force the π polarization orientation of the high-gain laser to change to σ polarization during a round trip, so that the phase-matching can be achieved. At next trip the σ polarization laser would change to back to π polarization which could not be used to generate the second-harmonic wave, therefore in this system a half of the intracavity intensities of the fundamental wave was available for the self-frequency-doubling. Even so, the effective intracavity intensities for the second-harmonic generation were still much higher than that of low-gain polarization at $\lambda = 1.093$ μm, bexause the effective stimulated-emission cross section at $\lambda = 1.085$ μm was about 4 times of that $\lambda = 1.093$ μm (see Fig. 2 of ref. 2). There-by, the threshold pump power for the second-harmonic generation in the high-gain polarization systems might decrease and the conversion efficiency should increase.

3. Experimental arrangement

The experimental arrangement is illustrated in Fig. 1. A CW Rhodamine 6G ring dye laser pumped by an argon ion laser was tuned to the 598 nm absorption line of the crystal and used as the pump source of the self-frequency-doubling laser.

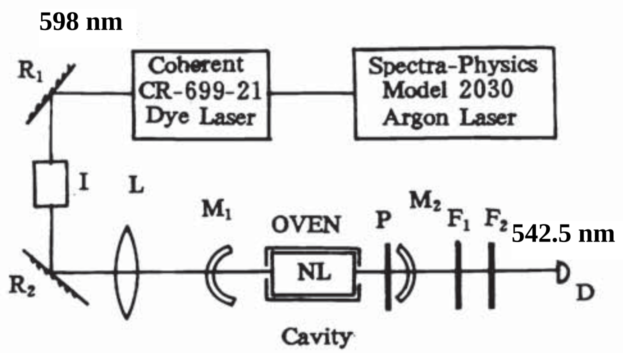

Fig. 1. Experimental arrangement.

To reduce measurement errors owing to feedback, we placed an optial isolator I between the pump source and lens L which focused the pump beam into the centre of Nd:MgO:$LiNbO_3$ crystal. The nearly concentric self-frequency-doubling laser cavity consisted of the input mirror M_1 and output mirror M_2 both with the curbature radius of 20.6 mm. The transmissivities of M_1 and M_2 for the pump laser at $\lambda = 598$

nm, the fundamental wave at $\lambda = 1.085\ \mu m$ and the second-harminic wave at $\lambda = 542.5$ nm were respecticely 89.5%, 0.05%, 51.5% and 91.5%, 0.02%, 99.6%. The *y*-cut crystal with the dimensions 3 mm × 3mm × 10 mm was placed in centre of the cavity. The faces of crystal were coated to minimize the reflection of the fundamental wave. The quarter wave-plate *P* with antireflection films at $\lambda = 1.085\ \mu m$ was placed between the crystal *NL* and M_2 and used to change the polarization direction of the fundamental wave from $E \parallel c$ to $E \perp c$ during a round trip, vice versa. The net second-harmonic output form M_2 were received and measured by detector *D* with the filters F_1 and F_2 which prelented the residual pump beam and fundamental wave from entering into the detector. The crystal was placed in an oven the temperature of which were controlled and stablized by a home-made electronic feedback servo system. The precision of temperature control was ±0.01°C and the response time to the thermal fluctuation was about 5 sec.

4. Experimental results

The curve of net second-harmonic outputs from M_2 versus the absorbed input pump powers and the pump powers incident on the cavity was shown in Fig. 2(a). The crosses in the figure are the experimental measurements. The solid curve is a least-squares fit to a parabola. The second-harmonic outputs leaked out from M_1 were not measured so that the actually generated frequency doubling outputs should be higher that we got. The 90° phase-matching was achieved by temperature tuning the crystal birefringence. During the experiments we found that the external control temperature on the crystal must correspondingly be reduced to maintain the optimum phase-matching when the pump level were raised because the pump irradiance absorbed by the crystal invitable resulted in the temperature raise. The control temperatures were linearly decreased as the pump powers were increased. The relation curve between the external control temperatures and the pump powers is also shown in Fig. 2(b).

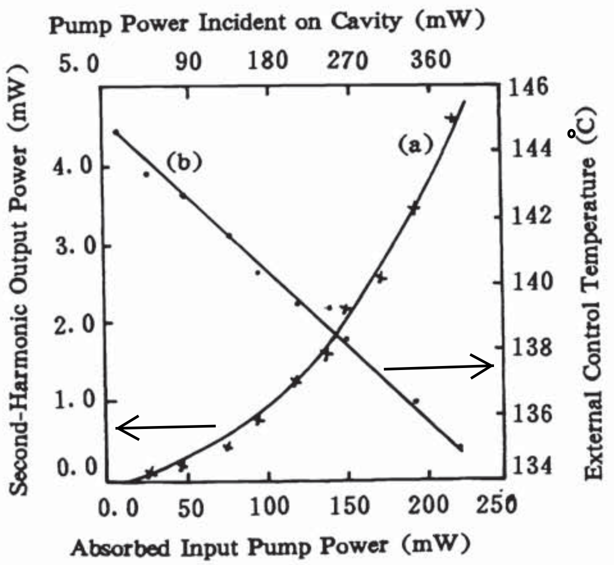

Fig. 2. (a) Single-ended outputs at the second-harmonic versus the absorbed input pump powers and the pump powers incident on cavity curve (b) The relation curve between the external control temperatures and the absorbed power

It should be mentioned that the quarter wave-plate used in our experiments was not exactly made for $\lambda=1.085$ μm wavelength but for $\lambda=1.06$ μm to our available, therefore the intracavity loss of fundamental wave powers was quite high. We estimated that the improvement of the output power by at least 1 order of magnitude should be possible if a better quarter wave-plate was used.

5. Conclusion

We have given the first demonstration of CW self-frequency-doubling with the high-gain polarization laser at $\lambda=1.085$ μm of Nd:MgO:$LiNbO_3$ in a nearly concentric resonator. The maximum second-harmonic **(542.5 nm)** output power from M_2 and the conversion efficiency, defined as the ratio of total second-harmonic output to pump power absorbed above threshold, were 4.6 mW and 11.7% per watt which were higher than that obtained by T. Y. Fan et al. with the low-gain polarization laser at $\lambda=1.093$ μm of Nd:MgO:$LiNbO_3$ (1.1 mW and 7.6% per watt)[3]. The phase-matching temperatures were from 135.16°C to 144.71°C which were lower than the published result (~152°C)[3]. High conversion efficiency, lower pump power threshold (12 mW) and lower the phase-matching temperature in addition to the minimized photo-refractive damage of the crystal offer the simplest and most efficient second-harmonic-generation way.

6. References

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