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351 mW of 275 nm continuous wave generation in a Pr:YLF laser pumped by a blue laser diode at 444.2 nm

ZHENG Quan[1,2], XIAO Hui-dong[2], CHEN Xi[2], WANG Yan[2], WANG Yu-ning[2], LIU Hui-zhen[2], TIAN Dong-he[2], WANG Jin-yan[2], YAO Yi[2*]

(1. *Changchun Institute of Optics*, *Fine Mechanics and Physics*, *Chinese Academy of Sciences*, *Changchun* 130033, *China*;

2. *Changchun New Industries Optoelectronics*, *Ltd*, *Changchun* 130012, *China*)

* *Corresponding author*, *E-mail*: *yaoyi@cnilaser.com*

Abstract: This paper describes what is thought to be the first generation of a continuous wave deep ultraviolet laser at 275 nm by efficient frequency doubling of a blue-diode-pumped Pr:YLF laser at 550 nm. A TEM_{00} mode deep UV laser radiation at 275 nm with an output power of 351 mW was obtained through the use of novel methods of coating and LD collimating. The authors could not find any prior reports on a Pr:YLF laser operating at 275 nm and believe this paper is the first.

Key words: CW ultraviolet laser; 275 nm laser; Pr:YLF; frequency doubling

444.2 nm 蓝光半导体泵浦掺镨氟化钇锂晶体连续351 mW 输出 275 nm 紫外激光器

郑　权[1,2], 肖辉东[2], 陈　曦[2], 王　彦[2], 王禹凝[2], 刘会珍[2], 田东贺[2], 王金艳[2], 姚　矣[2*]

（1. 长春光学精密机械与物理研究所, 中国科学院, 长春 130033, 中国;

2. 长春新产业光电技术有限公司, 长春 130012, 中国）

摘要: 本文首次阐述介绍了蓝光半导体泵浦掺镨氟化钇锂晶体产生 550 nm 激光, 并通过高效倍频技术, 获得 275 nm 连续紫外激光输出。通过采用新颖的镀膜技术和半导体准直技术, 获得了 351 mW 的 275 nm 基模深紫外激光输出。目前为止, 这个首次基于掺镨氟化钇锂获得 275 nm 激光的报道。

关　键　词: 连续紫外激光器; 275 nm 激光器; 掺镨氟化钇锂晶体; 倍频技术

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1 Introduction

Many trivalent rare-earth ions (RE^{3+}) exhibit visible radiative transitions, potentially enabling visibly emitting all solid-state lasers[1-2]. So far, various visible lasers based on RE^{3+}-doped crystalline media have been demonstrated. Among them, trivalent praseodymium ion (Pr^{3+}) is recognized as one of the most useful active ions for achieving efficient visible lasers because the visible transitions of Pr^{3+} perform as a four energy level system, and they have larger emission cross sections than other RE^{3+}. Praseodymium trivalent ion (Pr^{3+}) doped materials have been used to realize laser operation in the visible region, such as Pr:YLF at green, orange, and red wavelengths.

An important and successful application of Pr:YLF crystals is the generation of a continuous wave ultraviolet laser with second harmonic generation. This process has high conversion efficiency and high output power, especially in the deep ultraviolet range below 280 nm. Deep ultraviolet (UV) lasers with wavelengths shorter than 280 nm have found many promising applications in sterilization, communication, optical storage, spectral analysis, and biochemical detection. Most papers on ultraviolet radiation concentrate on the third and fourth harmonic generation. There is little research on continuous-wave ultraviolet radiation generated by second harmonic generation.

Continuous-wave laser operation in the green range at 522 nm and 546 nm has been reported under the application of Pr:YLF. In 2014, P. W. Metz et al. demonstrated the performance of 2ω-OPSL (optically pumped semiconductor laser) Pr:YLF laser with output powers of 2.9 W and 2 W at 522 nm and 546 nm, respectively[3]. High efficiency is achieved by using 2ω-OPSL as a pump source because of the matched absorption wavelength and its perfect beam quality. However, OPSLs operating at blue wavelengths are much more expensive than InGaN-based diode lasers. In 2016, S.Y.Luo et al. reported a blue-InGaN pumped Pr:YLF laser at a wavelength of 522 nm with a maximum output power of 1.6 W[4]. The Pr:YLF-based ultraviolet wavelengths were reported at 261 nm[5], 303 nm[6], and 320 nm[7]. To the best of our knowledge, the corresponding frequency doubled Pr:YLF ultraviolet laser at 275 nm has not been reported.

In this paper, we demonstrate the generation of a compact deep UV laser at 275 nm through efficient frequency doubling of a CW laser diode-pumped Pr:YLF laser at 550 nm. With an incident pump power of 4.82 W, a TEM_{00} mode deep UV laser radiation of 275 nm with an output power of 351 mW was achieved. The novel generated deep UV laser emission of 275 nm has potential applications in optical storage, spectral analysis, and industrial applications. We anticipate that the 275 nm emission in a Pr:YLF crystal will prove to be a promising new UV laser.

2 Experimental Setup

The experimental setup of a frequency doubling of laser-diode pumped Pr:YLF yellow-green laser is shown in Figure 1.

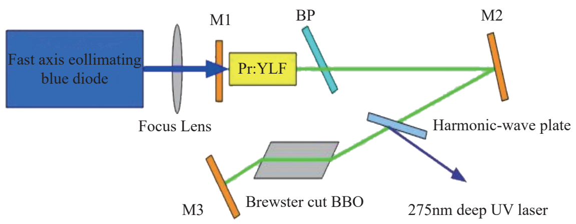

Fig. 1 Schematic of the 275 nm laser

The laser gain medium is an a-cut Pr:YLF crystal with a dopant concentration of 0.5 %, and its dimensions are 4 mm×4 mm×15 mm. Both end faces of the crystal are polished and antireflection (AR) coated from 400 nm to 700 nm. The crystal is wrapped with indium foil and held in a water-cooled copper block to remove the heat. Fig. 2 is the energy level schematics and room temperature polarization-dependent emission Pr:YLF cross-sections in the green spectral region.

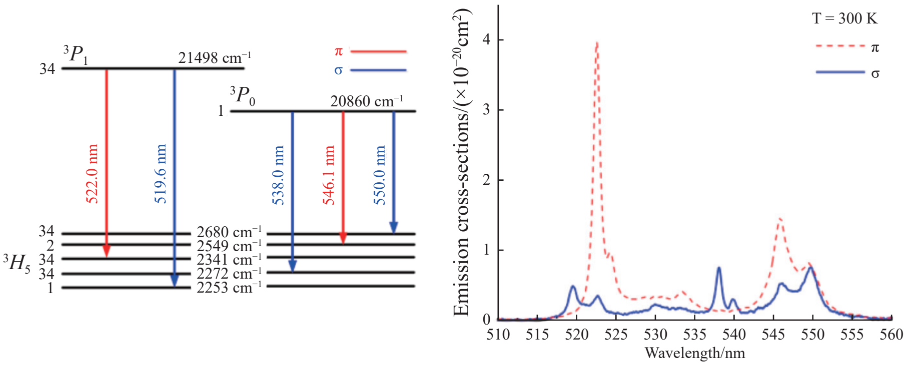

Fig. 2　The energy level and room temperature polarization-dependent emission Pr:YLF cross-sections

The fluorescence spectrum from 500 nm to 570 nm is shown in Fig. 3. A spatially-combined InGaN laser diode module with a maximum output power of 4.82 W was used as the pump source. The pump source emits a blue laser at a peak wavelength of approximately 444.2 nm with a spectral width of about 1.8 nm. The M^2 factors of the pump source are M_x^2=46.91 and M_y^2=15.53 in the horizontal and vertical directions corresponding to the slow and fast axes. This bad beam quality influences the beam quality of the output laser. Usually, a spherical lens is stuck near the LD to compress the divergence angle of the fast axis. With this method, the divergence angles of the two directions differ greatly. The focus spot injected into the crystal has a large ellipticity, which could not satisfy the mode matching condition of DPSSL. In our research, an aspherical lens was fixed between the blue LD and focusing lens. The aspherical lens was adopted to suppress the divergence angle of the fast axis LD singly, and there is no influence on the slow axis. A proper location for the fast axis collimation lens could be found, which gave the pump beam perfect ellipticity. Under this condition, a perfect pump beam spot was obtained, as shown in Fig. 4, which is beneficial for generating a laser with good beam quality.

The pump beam was focused into the laser crystal with a plane-convex lens with a 90 % transmission rate of the pump laser and a 15 mm focal length. The absorption efficiency of the Pr:YLF crystal for the pump beam was about 75 %. The folded V-type cavity consisted of one plane input mirror (M1) and two curved mirrors (M_2 and M_3) with radii of curvature of 200 mm. The input coupler M_1 was AR coated at 444.2 nm and high-reflection (HR) coated from 500 nm to 750 nm. The input mirror could be used to research all Pr:YLF wavelengths.

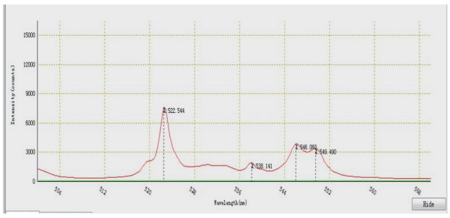

Fig. 3　Pr:YLF fluorescence spectrum from 500 nm to 570 nm

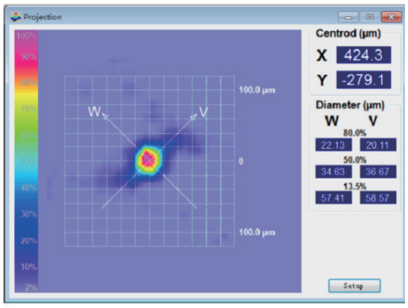

Fig. 4　Focusing shape and size of pump beam spot with a fast-axis collimating blue diode

Establishing the 550 nm laser oscillation without the influence of other wavelengths was difficult. For Pr:YLF crystals, 519 nm, 538 nm, and 550 nm could establish the laser oscillation in the sigma-direction and 522 nm in the pi-direction as well as 546 nm. A Brewster plate (BP) was inserted into the cavity in the sigma-direction at a 56 degree incident angle to suppress the 522 nm and 546 nm in the pi-direction. Due to the thermal depolarization effect, BP could not thoroughly suppress the laser line at 522 nm and 546 nm. On the other hand, the lasers at 639 nm, 607 nm, and 720 nm were found to have larger emission cross sections than 5XX nm in Pr:YLF. A novel coating method was adopted to obtain the single fundamental laser line. The two curved mirrors, M_2 and M_3, were coated as short-wave-pass and long-wave-pass. The coating curves of M2 and M3 are shown in Fig. 5 and Fig. 6, respectively.

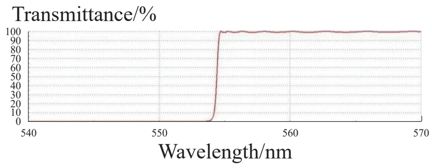

Fig. 5 M_2 coating curve (short-wave-pass)

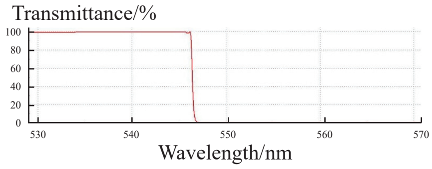

Fig. 6 M_3 coating curve (long-wave-pass)

M_2 was coated simultaneously at high-transmissive below 550nm and high-reflection above 550 nm. M_2 could suppress the oscillation at 546 nm, 538 nm, 522 nm, and 519 nm. However, M_2 is insufficient to suppress the other main laser lines at 607 nm, 639 nm, and 720 nm. M_3 was coated at high-transmissive above 550 nm and anti-transmission below 550 nm simultaneously, which could suppress the 607 nm, 639 nm, and 720 nm in the cavity.

The CW 275 nm output laser did not transmit through the M2 mirror. The UV laser strongly damaged the coating material. A 1.5 mm thick Brewster plate was used to couple out the UV radiation. The plate was made of fused silica. One side is uncoated, and the other is HR coated for 275 nm and AR coated for 550 nm. This type of Brewster plate was proven to be a reliable UV output coupler with a long lifetime and small insertion losses for 550 nm.

For intracavity frequency doubling of 550 nm, a 7 mm long Brewster/Brewster-cut BBO crystal was used with uncoated facets. The nonlinear crystal was mounted on TEC for temperature control. The BBO crystal was designed for critical type I phase matching ($\theta = 45.5°$, $\Phi = 0°$).

3 Results and Discussion

Although the emission at about 522 nm has a 4.3 times higher emission cross-section than that of 550 nm, no lasing at other green lasers was observed in this experiment thanks to the novel coating conditions. The output characteristic of the CW intracavity frequency-doubled Pr:YLF laser in the deep UV spectral region at 275 nm is shown in Fig. 7.

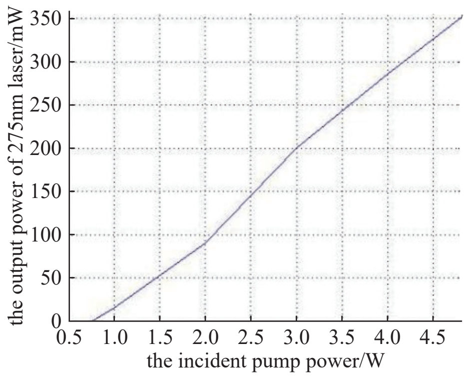

Fig. 7 The output power of 275 nm versus the incident pump power

The laser oscillation threshold was found to be about 750 mW of the incident pump power. The maximum output power is 351 mW with an incident pump power of 4.82 W. The optical-to-optical slope efficiency is about 7.3%. The deep UV laser output power increases with the incident pump power, and no sign of saturation is observed, which suggests a potential to obtain higher deep UV power by increasing the power of the incident laser. Stable laser oscillation is always important for various applications. The spectrum of the 275 nm laser is registered in Fig.8 with a wavelength meter (High Finesse model LSA).

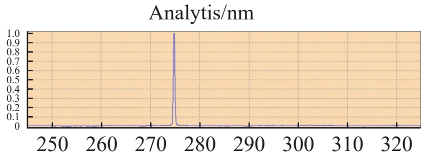

Fig. 8 275 nm laser spectrum

The central wavelength of a deep UV laser is 274.840 nm. To characterize the beam quality of the 275 nm deep UV laser beam, the beam profile and M square factor were measured in the x and y directions under maximum output power, which is shown in Fig. 9. The beam profile testing result shows that the 275 nm laser operates in TEM_{00} mode with a Gaussian far-field intensity distribution. Stable laser output is always desirable for various applications. The stability of the 275 nm laser is about 0.2 % (RMS, root-mean-square), as shown in Fig. 10. The stability demonstrates that there is no wavelength competition in the resonator, and this novel coating method could be adopted in the generation of other weak laser lines.

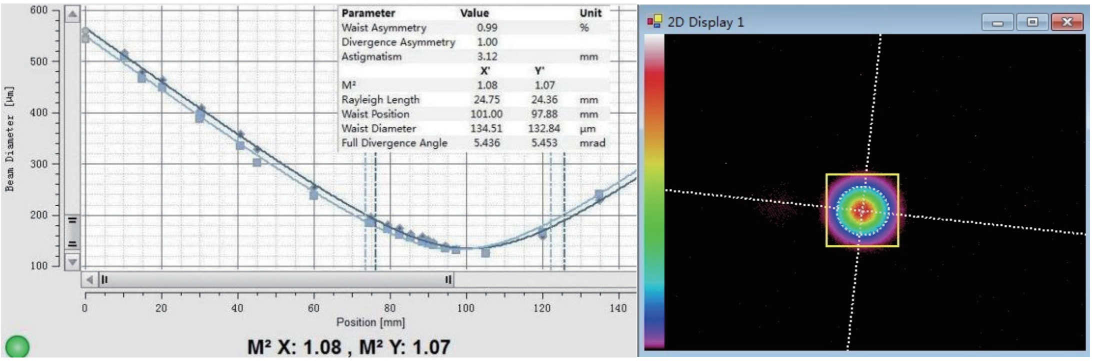

Fig. 9 The beam spot and M-square of the 275 nm laser

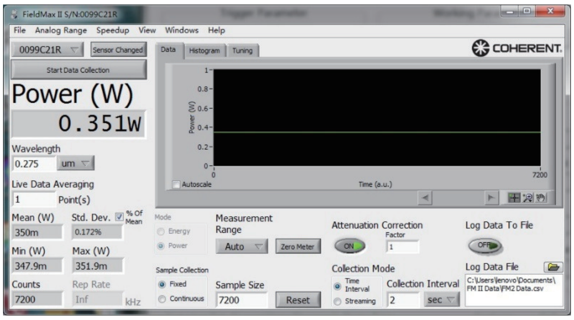

Fig. 10 275 nm laser power stability

4 Conclusion

This paper demonstrated the generation of a compact deep UV laser at 275 nm by efficient frequency doubling of a CW laser diode-pumped Pr:YLF laser at 550 nm. With an incident pump power of 4.82 W, a TEM_{00} mode deep UV laser radiation at 275 nm with an output power of 351mW was obtained. The novel generated deep UV laser emission at 275 nm has the highest conversion efficiency and novel CW deep UV laser wavelength.

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References:

[1] DIEKE G H, CROSSWHITE H M. The spectra of the doubly and triply ionized rare earths[J]. *Applied Optics*, 1963, 2(7): 675-686.

[2] KRÄNKEL C, MARZAHL D T, MOGLIA F, *et al.*. Out of the blue: semiconductor laser pumped visible rare-earth doped lasers[J]. *Laser & Photonics Reviews*, 2016, 10(4): 548-568.

[3] METZ P W, REICHERT F, MOGLIA F, *et al.*. High-power red, orange, and green Pr^{3+}: $LiYF_4$ lasers[J]. *Optics Letters*, 2014, 39(11): 3193-3196.

[4] LUO S Y, YAN X G, CUI Q, *et al*.. Power scaling of blue-diode-pumped Pr: YLF lasers at 523.0, 604.1, 606.9, 639.4, 697.8 and 720.9nm[J]. *Optics Communications*, 2016, 380: 357-360.

[5] FENG K, WANG D, ZHU Y ZH, *et al*.. Simple and compact high-power continuous-wave deep ultraviolet source at 261 nm based on diode-pumped intra-cavity frequency doubled Pr: $LiYF_4$ green laser[J]. *Optics Express*, 2023, 31(12): 18799-18806.

[6] ZHU P F, ZHANG CH M, ZHU K, *et al*.. 303 nm continuous wave ultraviolet laser generated by intracavity frequency-doubling of diode-pumped Pr^{3+}: $LiYF^4$ laser[J]. *Optics & Laser Technology*, 2018, 100: 75-78.

[7] HAN Y, GUO K, ZHAO Y Q, *et al*.. Compact high-power 320-nm continuous-wave single-frequency laser based on power scaling of a diode-pumped Pr: $LiYF_4$ ring laser at red[J]. *Optics Letters*, 2024, 49(14): 3854-3857.

Author Biographics：

ZHENG Quan (1973 —), doctor, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences. His research interests are DSPPL and its application. E-mail: zhengquan@cnilaser.com

YAO Yi (1983 —), master, Changchun New Industries Optoelectronics, Ltd. His research interest is DPSSL. E-mail: yaoyi@cnilaser.com