Compact and Highly Efficient Intracavity SHG Green Light Source with Wide Operation Temperature Range Using Periodically Poled Mg:LiNbO3

Toshifumi YOKOYAMA,* Kenji NAKAYAMA, Akira KUROZUKA, Tetsuro MIZUSHIMA, Tatsuo ITOH, Kiminori MIZUUCHI, and Kazuhisa YAMAMOTO

AV Core Technology Development Center, Matsushita Electric Industrial Co., Ltd., Yagumo-nakamachi, Moriguchi, Osaka 570-8501

*E-mail address:yokoyama.toshifumi@jp.panasonic.com

(Received January 29, 2008)

A compact, high power SHG green light source with wide operation temperature range over 30 degrees Celsius has been developed by using a wavelength-locked laser diode and a 0.5mm-long periodically poled Mg:LiNbO3 (PPMgLN). A continuous green light of 1.7W was generated by intracavity frequency doubling of a Nd:YVO4 laser with the PPMgLN. The wall-plug efficiency was as high as 18.9%. The volume of the green light source was 2cc.

Key Words: Solid laser, Intracavity, LiNbO3, Second-harmonic generation (SHG), Laser

1. Introduction

Compact green coherent light sources offer great potential for various applications such as display, measurement, spectroscopy and biomedical-use. Particularly, mobile equipments require a small green laser around multi-watt output power. Intracavity second harmonic generation (SHG) of a laser diode (LD)-pumped solid-state laser (DPSSL) is an attractive method to obtain high power green light 1-3). This method has several advantages such as compactness and high efficiency.

DPSSL with LBO achieved a continuous-wave (CW) output power of 5.1W 4) with optical-optical efficiency of 31%. DPSSL with KTP was also developed and 5.6W (CW) green output with optical-optical efficiency of 25.5% was obtained 5). Second harmonic green light generation using a periodically poled Mg:LiNbO3 (PPMgLN) has been reported with output power of 3.5 mW 6). High power green light source with DPSSL has been studied in many research groups.

However, downsizing of DPSSL with multi-watt class green output is still so difficult because it depends on a thermo-electric cooler (TEC) system. The TEC is important in high power and stable operation of DPSSL, because high power operation needs huge heat transfer from DPSSL and stable operation requires sever temperature control to satisfy a phase-matching condition. The heat generation of DPSSL is enhanced by the TEC operation, because the energy loss of TEC is a few times larger than that of transfer heat. This large power consumption requires big size heat sink and it degrades the compactness so much.

In this paper, we demonstrate a compact and high power DPSSL by utilizing a PPMgLN as a nonlinear material. The PPMgLN is optimized to obtain high efficiency and wide operation temperature range for realizing the TEC-free operation.

2. Nonlinear materials

To achieve the TEC-free operation, further improvements are required in nonlinear material. One is the higher conversion efficiency, which suppress heat generation caused by the low electro-optical efficiency of DPSSL. Another is widening of operation temperature range of nonlinear materials to obtain stable output power without precise temperature control. Table 1 shows the characteristics of nonlinear material used in conventional DPSSL. PPMgLN has large figure of merit over 10 times larger than KTP and 100 times larger than LBO. At the view point of stable operation, KTP has widest operation temperature range. Nonlinear material has trade-off relation between operation temperature range and conversion efficiency. Wide operation temperature range can be obtained in short crystal length, but conversion efficiency becomes low. To compare the total performance of nonlinear materials, we bring a multiple of figure of merit and ΔT, as shown in Table 1. PPMgLN have best performance about 30 times larger than LBO. KTP has similar performance as PPMgLN and is widely used for green source under 100mW. However, KTP has gray track problem and it can’t assure the lifetime in watt class operation 7,8). Therefore, PPMgLN is the best materials for realizing high power, high efficiency, and wide operation temperature range. Based on these comparison, we focused our attention on PPMgLN.

To utilize best potential of PPMgLN, we have developed high-voltage application technique 9). A uniform PPMgLN with 7μm period and high conversion efficiency of 2.8% W/cm

<table>
<thead>
<tr>
<th>Table 1 Comparison of nonlinear crystals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPMgLN</td>
</tr>
<tr>
<td>Figure of merit (d2/ε0n3)</td>
</tr>
<tr>
<td>ΔT (°Ccm)</td>
</tr>
<tr>
<td>Figure of merit * ΔT</td>
</tr>
</tbody>
</table>

The Review of Laser Engineering
Supplemental Volume 2008
which is nearly equal to the theoretical value were achieved over large area of 1-mm thick crystal.

3. Design of the intracavity

To obtain best performance, we calculated the characteristics of DPSSL based on PPMgLN. Figure 1 shows the calculated result of optical-optical conversion efficiency (ratio of green output power to pump power) of the DPSSL as a function of PPMgLN length under the various pump power. In this calculation, curvature of an output mirror was -20mm, transmittance of the output mirror was 0.027%, length of the intracavity was 8mm, nonlinear coefficient of the PPMgLN was $d_{33} = 16\text{pm/V}$, refractive index of the PPMgLN was 2.2, total internal loss of the intracavity was 0.8%. Figure 1 also shows the dependence of operation temperature range (FWHM of the green output) of the PPMgLN. We designed the PPMgLN length of 0.5mm to obtain operation temperature range over 40 degrees Celsius which can satisfy TEC free operation. At the PPMgLN length of 0.5mm, the optical-optical conversion efficiency exceeds to 45% when the pump power is over 4W. Efficient performance of the PPMgLN can achieve higher conversion efficiency and wide temperature range.

4. Experimental setup

Figure 2 shows the experimental setup of the SHG green light source. The wavelength of a pump LD must be stabilized over wide temperature range within absorption spectrum of the solid laser material. A high-power wavelength-stabilized LD was used as a pumping LD. The wavelength of the LD was locked at 808nm. Maximum output of the LD was 4.34W. The 0.5mm-thick Nd:YVO$_4$ was used as a solid laser material. Because Nd:YVO$_4$ has a high absorption coefficient over a wide pumping wavelength bandwidth. High reflection coat for 1064 nm light was deposited on one side of the Nd:YVO$_4$ and on one side of the output mirror to configure an intracavity. Focused spot size on Nd:YVO$_4$ was around 120 $\mu$m. Anti reflection coated PPMgLN was inserted between output mirror and Nd:YVO$_4$.

5. Results

To confirm the accuracy of our design, we examined the characteristics of DPSSL under the condition of 1W pump power. Figure 3 shows the measured green output power and operation temperature range as a function of the length of a PPMgLN. This result shows that the operation temperature range increases so much under the length of a PPMgLN less than 1mm with suppressing the reduction of the green output power. This suppression may be achieved by the saturation of the conversion efficiency caused by high conversion efficiency of a PPMgLN. These experimental data shows good agreement with calculations. At 0.5-mm PPMgLN, wide operation temperature range over 40 degrees Celsius and high green power of 0.28W was achieved for 1W-pump operation. Based on this experimental results and the design, we demonstrated compact green DPSSL as shown in figure 4.

The configuration of this module was same as shown in Fig.2. The total volume of this DPSSL including optics and pumping laser diode was as compact as 2cc. Green output power of this module was measured as a function of the pump power, as shown in figure 5. Maximum green output power of 1.7W was successfully
obtained with the pump power of 4.34W. High optical to optical conversion efficiency of 39.2% was obtained and the wall-plug efficiency of 18.9% was realized. The operation temperature range of the module was 46 degrees Celsius as shown in figure 6. This operation temperature range was limited by the wavelength-stabilized LD. The degradation or fluctuation of output green can not be observed at the maximum green power of 1.7 W. The potential of PPMgLN can achieve highly-efficient and stable green DPSSL at high power level. This high wall-plug efficiency can make it possible to operate this module without a TEC system. Stable output is also obtained by appending auto power control (APC) system operation temperature range is very wide.

6. Conclusion

A high power and compact SHG green laser module with wide operation temperature range was realized by using a 0.5mm-long PPMgLN and a wavelength-stabilized LD. Green output power of 1.7W was obtained and the volume of the green laser module was 2cc. The wide operation temperature range of over 40 degrees Celsius and high wall-plug efficiency of 18.9% was obtained. Heat generation of this module can be suppressed under 7.3W at maximum green output. This value is low enough to operate this module in mobile or small equipment without a TEC. This module is capable for various applications.

References