

20.3: A Bright and Efficient Mobile Projector Using a Compact Green Laser

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Abstract

We have developed an ideal W-class compact green laser for mobile projectors. The wall-plug efficiency of the laser was higher than 15% over wide temperature range. By using RGB lasers and small LCOS projection optics, a mobile projector with high brightness (100 lm) and excellent efficiency (20 lm/W) was demonstrated.

1. Introduction

According to the progress and the spread of mobile devices, we can watch various contents such as web-browsing, video and games, anywhere and anytime. However, the size of the displays of the mobile devices limits the full utilization and enjoyment of these contents. The one way for access to large-screen visual contents via small mobile devices is to cast large-diagonal, high resolution images from a miniaturized projector. With the rapid progress of light sources such as lasers and LEDs, and small spatial light modulators (SLMs) [1], mobile projectors called such as "Pico-" and "Pocket-" projectors attract the market.

Size, brightness, and power consumption limited by a battery are important factors in mobile projectors. To improve these factors, projector throughput or "lm/W", which is the ratio of the luminous output to the power consumption is the key performance parameter [2]. If the projector throughput is high, the projector can manage both large image and low power consumption. Low projector throughput increases waste heat and hinders smaller size and simple device design.

High-wall-plug-efficiency light sources and high-light-use-efficiency projection optics are essential for raising projector throughput. Moreover, high power light sources are necessary to get the high brightness needed for large images. Lasers can provide high light use efficiency due to their small etendue [3] and high output power from their compact size. Red and blue diode lasers with W-class power and high wall-plug efficiency have been developed [4]. However, to the best of our knowledge, there is no compact green laser with W-class power and high efficiency over wide operation temperature range.

We have developed a green laser suitable for mobile projectors and demonstrated a mobile laser projector with extremely high projector throughput.

2. W-class Compact Green Laser

As there are no green diode lasers, the second harmonic generation (SHG) of infra-red laser light is the only technique for obtaining high-power green laser light. To realize highly efficient and compact green lasers, we have been developing intra-cavity SHG of diode laser pumped solid state laser (DPSS) [5,6]. Figure 1 shows a schematic diagram of the intra-cavity SHG green laser. Nd:YVO₄ was used as a solid state laser material for generating

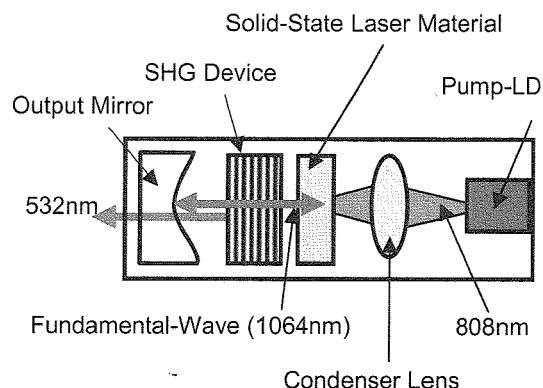


Figure 1. Schematic diagram of the intra-cavity SHG green laser.

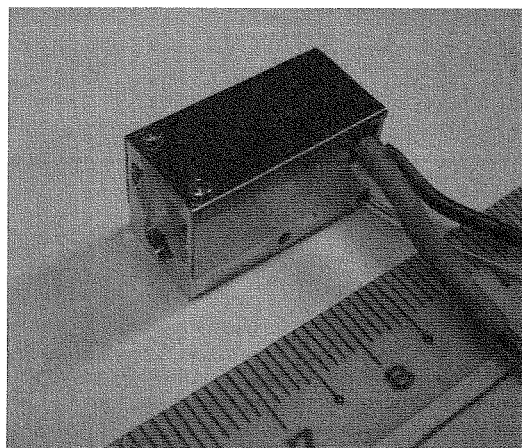


Figure 2. Photograph of the green laser.

1064 nm infra-red laser light. Output mirror configured a cavity with Nd:YVO₄ and emitted 532 nm green light generated by intra-cavity SHG. The wavelength of the pump laser diode (LD) was stabilized by distribution feedback to expand an operation temperature range. To improve wall-plug efficiency of the SHG green laser, an SHG device is a key factor. We succeeded in producing uniform appropriate periodically polarization inversion structures in MgO:LiNbO₃ (PPMgLN), which offered a high wave conversion efficiency by a quasi-phase-matching interaction [7,8]. PPMgLN has the highest nonlinear coefficient in inorganic materials and even short PPMgLN can offer high wave conversion efficiency.

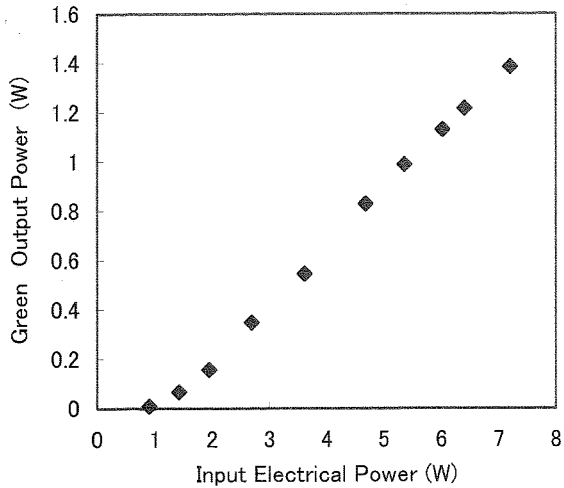


Figure 3. Green output power as a function of input electrical power to pump LD

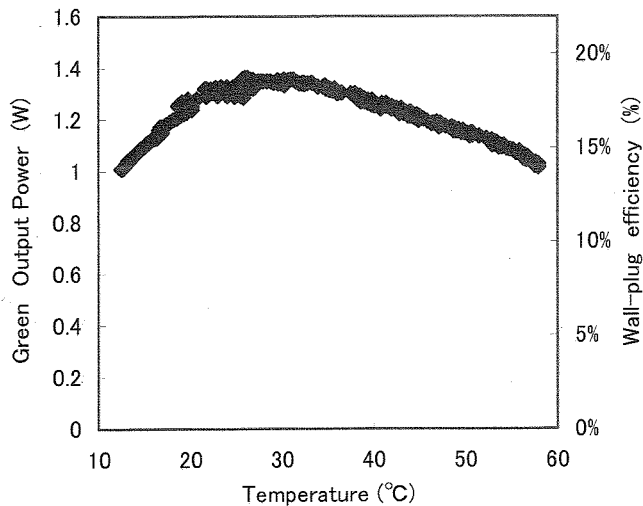


Figure 4. Green output power and wall-plug efficiency as a function of temperature of the green laser

Figure 2 shows a photograph of the developed green laser. In the laser, 0.5 mm-long PPMgLN was used. The short SHG device contributed to wider wave conversion temperature range, less loss in the cavity, and smaller body. The total volume of the green laser was as compact as 2 cc. Green output power of the laser was measured as a function of the input electrical power to the pump LD, as shown in Fig. 3. On the assumption that the laser would be used in color sequential method, the green laser operated in pulse mode. The pulse repetition frequency was 120 Hz and the pulse duty was 33%. The green laser output over 1 W and had high

wall-plug efficiency close to 20%. Figure 4 shows the green output power and the wall-plug efficiency vs the temperature of the green laser at constant pulsed input electrical power. Over wide temperature range of 15 to 55°C, the laser generated over 1 W and showed high wall-plug efficiency of over 15%. Concerning mobile devices, a thermo-electric cooler (TEC) is not suitable because of its additional size and electric consumption. The green laser was able to realize high power and high efficiency over wide temperature range without a TEC system because of its excellent temperature characteristics.

3. Mobile laser projector

A prototype of a mobile laser projector was realized with the green laser. Figure 3 shows a projection image and an appearance of the prototype. The prototype projected a bright light of over 100 lm and displayed a vivid and large image with 50 inch screen from the pocket-size projector. A schematic optical setup of the prototype projection engine is shown in Fig.4. The size of the projection engine was 50 cc. Its SLM was a 0.21 inch SVGA single LCOS panel. The light sources are the 532 nm green laser and a 640 nm red diode laser and a 445 nm blue diode laser, which output over 1W respectively. The RGB lasers were operated in color sequential mode. The each RGB light was put into the same optical axis by a cross prism and a dichroic mirror. The coaxially-coupled laser light was shaped into a rectangular uniform illumination and was despeckled by illumination optics. The LCOS panel was illuminated by these uniform and despeckled laser lights. The RGB lasers were arranged so that their polarization directions coincided, so neither half-wave retardation plate nor pre-polarizer were necessary. Using a wide-



Figure 5. Photograph of the prototype mobile laser projector

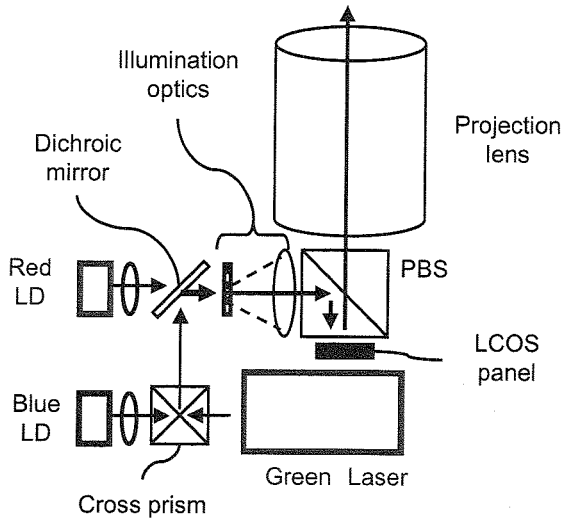


Figure 6. Schematic optical setup of the prototype projection engine

angle projection lens, a large screen was displayed near the small projection engine. By customizing the optics, the size of the projection engine will be smaller than 10 cc.

Table 1 shows the light and power throughput of the prototype. The color sequential mode of the prototype was RGBRG sequence and 300 Hz repetition. The RGB lasers emitted the peak power one after another and lighted the LCOS panel each on-time ratio in one sequence. The average optical light use efficiency from the lasers to the screen including the LCOS panel was as

Table 1. Light and Power throughput of the prototype mobile laser projector

	Red	Green	Blue
Peak Power (W)	1.8	1.1	1.8
(lm)	215	665	37
On-time ratio	0.32	0.32	0.16
Optical use efficiency	0.33	0.38	0.34
Projection light (lm)	23	81	2
Total projection light	106 lm		
Wall-plug efficiency	0.27	0.18	0.26
Power consumption (W)	2.1	2	1.1
Total power consumption	5.2 W		
Projection throughput	20.3 lm/W		

high as 35%. Due to small etendues of the lasers, the light use efficiency reached very high value even with a 0.21 inch small LCOS panel. When the prototype displayed 106 lm white image, the electric consumption of the lasers was only 5.2W. This meant the projector throughput was 20.3 lm/W. By using the developed green laser, the mobile laser projector demonstrated excellent power efficiency above 20lm/W. This high projector throughput brings bright images over several tens of lumens from mobile devices with slight electric power. If LEDs are used with a small SLM to miniaturize a projector, etendue mismatching will occur and the light use efficiency will decrease. Lasers have far smaller etendue than LEDs, the etendue mismatching doesn't occur even with a 0.1 inch SLM. Also, the higher the LEDs' output for obtaining a large image is, the lower the wall-plug efficiency and the projection throughput is. Lasers contribute to decrease the size of the projector and to increase the projection throughput. The high projection throughput above 20 lm/W means the mobile laser projectors can manage both large images and low power consumption.

The prototype displayed a delicate and colorful image. The color gamut was 167% of NTSC ratio in u'v'-chart. The contrast ratio was over 100. The SVGA panel made a fine image even if the screen size was larger than 50 inch. The prototype brought big impression from a small body.

4. Summary

We developed an ideal W-class compact green laser for mobile projector. The green laser output over 1W and had high wall-plug efficiency higher than 15% over wide temperature range of 15 to 55°C.

A prototype of a mobile laser projector was realized by using RGB lasers including this green laser and small LCOS projection optics. The prototype demonstrated a bright image over 100lm and excellent power efficiency over 20lm/W. Mobile laser projectors are expected to give users big displays anywhere and anytime.

5. References

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