9.1: Compact Microchip Green Laser Source for Mobile Projectors

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Abstract

We present a novel microchip green laser source technology based on a periodically poled nonlinear converter (PPMgOLN). This platform is demonstrated to achieve wall-plug efficiency of 12% for output power levels of 50-150mW at 532nm wavelength. We discuss laser package optimization for integrating this green laser source into mobile projector devices.

1. Introduction

Despite considerable industry interest in mobile RGB laser projectors, their progress has been hampered by the lack of a viable green laser source. Mobile projectors are rapidly becoming a potentially huge emerging market, estimated to achieve multi-million unit range [1]. Because of the challenges with green laser availability, first-generation mobile projectors that just appeared in 2008 used white LED light sources. Most of these handheld devices (also known as pico-projectors) produce ~10 lumen output that is not bright enough for widespread use. The low brightness of these devices is related to the inherent difficulties in collecting rapidly diverging light from LED sources. Lasers can solve this problem, but so far only red and blue laser diodes have been readily available.

Since there is no commercially viable direct green laser source, a number of second-harmonic-based approaches has been proposed recently by Corning, Osram, Novalux, etc. [2-4]. However, challenges in wall-plug efficiency and cost structure have not been successfully overcome yet. We demonstrate a novel green laser source, based on the microchip (monolithic assembly of Nd:YVO_4 crystal and PPMgOLN crystal) laser platform. The use of our highly efficient, periodically poled MgO-doped lithium niobate as the frequency doubler allows obtaining significant increase in the overall efficiency of the green microchip laser. At the same time, self-aligned monolithic laser cavity is the key component in the low overall cost structure for Spectralus green laser. In this report, we discuss the design and performance of the PPMgOLN-based microchip green laser source and optimization of this laser for mobile projector market requirements.

2. Spectralus Green Laser Source

While the generation of laser green light via second-harmonic process is very well understood, the main challenge is to meet the set of demands for mobile projection display applications: (i) high wall-plug efficiency ~10% or higher required to enable battery operation, (ii) compact volume <1cm^3 required for handheld devices, and (iii) low-cost architecture required by consumer electronics industry.

In recent years, the adoption of periodically poled MgO-doped lithium niobate (PPMgOLN) as the nonlinear frequency converter from the infrared (1064nm) into the green (532nm) wavelength helped to make significant progress in efficiency levels, from 1~3% to ~7% levels [2-5]. PPMgOLN crystals are the most efficient nonlinear crystals available. PPMgOLN is an engineered material utilizing highest nonlinearity of the lithium niobate and providing efficient conversion by quasi-phase-matching between infrared and visible wavelength due to periodical ferroelectric domain inversion in the crystal. This inversion is achieved via the process called periodical poling – applying an electric field spatially periodically modulated to achieve desired period of inversion. Periodically poled crystals can be engineered for second harmonic generation to any visible wavelength (including blue and red). We have been developing PPMgOLN technology since 2003 and more information about this crystal can be obtained in Refs. [5-6].

Unlike most other green laser architectures that use PPMgOLN as a separate discrete optical component, we developed an alignment-free, microchip laser cavity with the specific goal to meet low cost requirement for mobile projector applications. The microchip (Fig.1a) combines Nd:YVO_4 solid-state laser gain medium and nonlinear second harmonic generating PPMgOLN crystal in one monolithic assembly. High nonlinearity of PPMgOLN allows using very short crystal (<2mm in length) while still achieving high conversion efficiency from the lasing 1064nm infrared beam into the green output. Small dimensions of the nonlinear crystal reduce cost and size of the microchip.

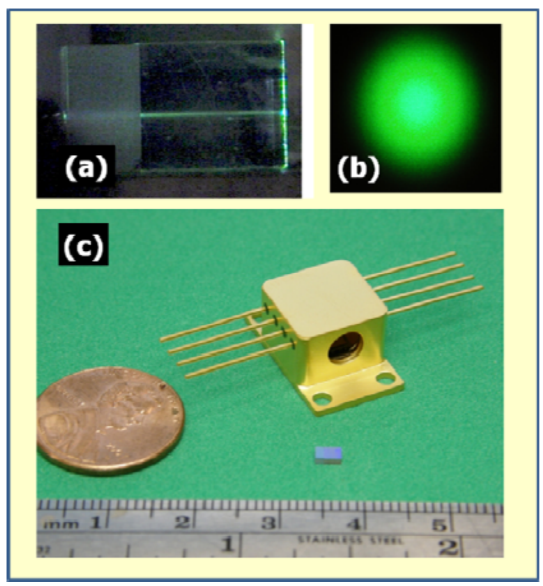

Figure 1. (a) Top-view photograph of Spectralus' PPMgOLN-based microchip showing intracavity beam during laser operation; (b) green beam in the far field; (c) 8-pin mini-butterfly prototype package shown alongside with one US cent and a Spectralus microchip for scale comparison.

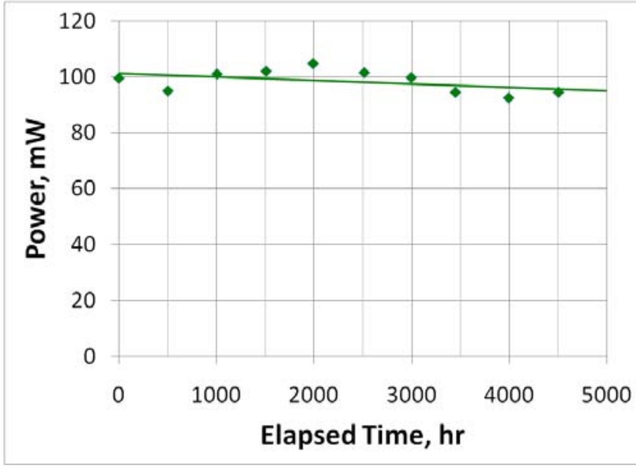

Figure 2. Long-term output power test for a 100mW, cw Spectralus PPMgOLN microchip green laser source.

The monolithic microchip assembly of Nd:YVO_4 crystal and PPMgOLN crystal is directly pumped by an 808-nm semiconductor diode laser. While the pump beam is usually strongly astigmatic and has spatial multi-mode structure, the beam profile of Spectralus microchip, optimized for high efficiency, is Gaussian (Fig.1b) and has linear polarization, advantageous for optical design of projector light engines.

To meet high reliability requirements of the consumer market, we have been performing long-term tests of our microchip green lasers. The results of such tests are shown in Fig.2 for a 100mW power green continuous-wave (cw) laser source. As can be seen, the power stays within 5% of the original set power for up to 4500 hours and this longest-running laser and other units continue to operate without deterioration in performance. Note that we did not use feedback loop to compensate for power variations in these tests.

Thus, we established that a simple, alignment-free solid-state laser architecture based on PPMgOLN can be used as a high-quality, compact and reliable green laser source. One can appreciate the small dimensions of PPMgOLN laser microchip from Fig.1c, in which the microchip is shown as a small optical component between the ruler and the mini-butterfly laser package (used by Spectralus for engineering units).

3. Demonstration of high efficiency and field-sequential operation

In the initial prototypes, we integrated green laser assembly in a butterfly package (Ref.5) and performed design optimization based on extensive laser modeling (optical, thermal, and electrical). The experimental work that followed also included power and efficiency testing for different ambient temperatures, thus addressing one of the major requirements of consumer electronics industry. These initial tests were done under continuous-wave (cw) operating conditions.

However, most micro-display applications we are targeting are single-panel LCOS or DLP based. They rely on field-sequential operation of RGB sources. In this case, red, green, and blue light sources are sequentially turned on and off in the pulsed regime. Depending on the micro-display panel characteristics and projector design, frequencies of interest range from 60Hz to 2 kHz with the typical duty cycles chosen in the range from 25% to 33% to provide optimum color balancing. The target range of average power levels in the green for mobile projectors is 15mW to 60mW. Note that this solid-stare green laser architecture does not target single-scanning-beam laser projector platform that is limited in brightness by eye safety regulations and requires more costly green laser solutions for modulation at frequencies of tens of MHz.

To meet LCOS (or FLCOS) and DLP mobile projector requirements, we have developed two designs that primarily target “fast” (1.6kHz) and “slow” (60Hz) micro-display field-sequential operation.

Figure 3 shows experimental data summarizing the performance of a green laser optimized for “fast” operation at 1.6 kHz repetition frequency. The laser was set to ~80mW output peak power at 25% duty cycle and tested on a temperature controlled plate. There was no “constant power” feedback loop in this experiment. The power curve shows that the power remained stable over the wide range of ambient temperatures. More importantly, the wall-plug efficiency (WPE), which is the ratio of the output power to the overall input electrical power used to drive the laser together with temperature stabilization elements, is very high. The peak value for WPE exceeds 12% and it stays at levels higher than 10% in the wide temperature range from 10^{o}C to 50^{o}C – the range of interest to consumer-electronics mobile projector devices.

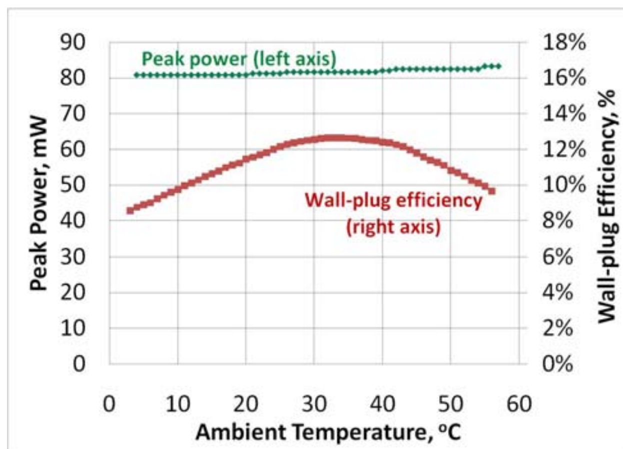

Figure 3. Peak output power and wall-plug efficiency as a function of ambient temperature for a green laser source driven at 1.6kHz frequency with 25% duty cycle and set current of 380mA.

Figure 4 illustrates the performance of Spectralus’ green laser optimized for “slow” operation at 60 Hz repetition frequency. This microchip laser was designed for higher power, while the nominally the same 808nm pump diode was used. The plot shows two curves: peak output power at 532nm wavelength (the average power is 1/3 of the peak power) and optical-to-optical (O-O) conversion efficiency as a function of current. While the wall-plug efficiency is a more important parameter for end application, optical-to-optical conversion efficiency is a valuable metric of laser design. It characterizes how efficiently 808nm infrared laser photons are used to generate 532nm photons. As seen from Fig.4, peak power levels close to 200mW were generated with maximum optical-to-optical efficiency levels of 28%. Similar high efficiencies were demonstrated in other laser devices we built as well, reaching the level of over 30% in some devices.

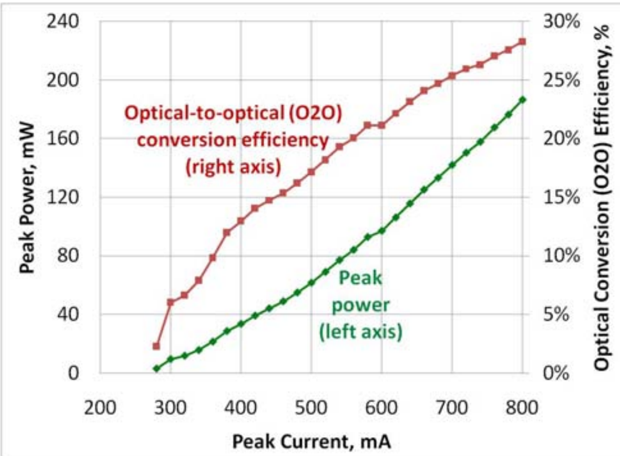

Figure 4. Peak output power and optical-to-optical (808nm into 532nm wavelength) conversion efficiency as a function of current for a green laser source driven at 60Hz frequency with 33% duty cycle and set ambient temperature of 26^{o}C.

It is worth noting that both power and optical-to-optical efficiency in this device were limited by the maximum ratings of the 808nm diode, i.e. the performance of this laser was not tested beyond current levels of 800mA. Nevertheless, the achieved O-O conversion efficiency was quite high. Since most commercial-grade 808nm diode lasers now have wall-plug efficiency at levels ~50%, such high O-O efficiencies allow achieving our target levels of wall-plug efficiencies in the range of 12-15% (as was also shown in Fig.3).

To summarize this section, we have achieved the goal of >10% wall-plug efficiency levels in the range of 60Hz to 2 kHz that is of interest for micro-display projectors.

4. Laser package development for mass production

After establishing high-efficiency and low-cost architecture of the microchip green laser engine, we approached the problem of engineering a compact and low-cost laser package for mobile projector applications.

As of now, there is no industry standard for the green laser package and the simple architecture of Spectralus laser makes it amenable to several package types. We made our choice based choice on the combination of the following criteria:

- low cost structure, including cost of components and assembly automation in volume manufacturing,
- thermal performance,
- size and the ease of laser integration into a mobile projection device.

Figure 5 shows an illustration of our engineering design of the green laser package for mass production.

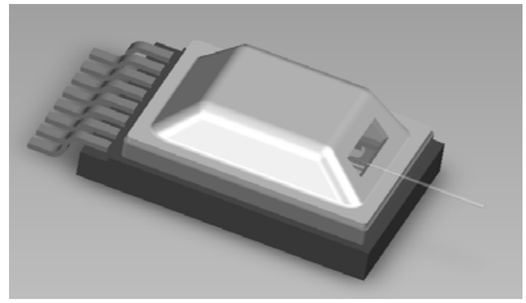

Figure 5. Spectralus green laser package for mobile projectors.

The package shown in Fig.5 has a flat (as opposed to cylindrical) form factor, and has a ceramic base. The output window blocks the remaining infrared light and transmits green beam. The bounding-box volume of such a package is less than 0.4cm^3. Another key parameter for successful integration into embedded projectors is low height. It is less than 4mm in our mass-production prototype design.

At the time of this report, the first units of new design are in assembly and test. Spectralus plans to ship the first units by the end of 2009 and report on their performance shortly thereafter.

5. Conclusions

Spectralus green laser platform offers a compact, efficient, and low-cost solution to mobile projector applications. This paper summarized our prototype development and evaluation data for green laser units optimized for microdisplay projector platforms. To our knowledge, the wall-plug efficiency levels of >12% exceed the efficiency of other green laser platforms at 50~150mW average power levels. We have demonstrated high efficiency levels in the range of 60Hz to 2 kHz laser repetition frequencies that is of interest for field sequential operation in micro-display projectors.

In summary, Spectralus green laser sources used together with direct semiconductor red and blue diodes represent an attractive architecture for RGB laser projectors based on microdisplay technologies, such as LCOS or DLP.

6. References

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