20.2: High-Efficiency Green Laser Source for Compact Projectors

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Abstract
We demonstrate a novel green laser source, based on a monolithic cavity microchip laser platform. The use of our highly efficient, Periodically Poled MgO-doped Lithium Niobate (PPMgOLN) as the frequency doubler allows obtaining a significant increase in the overall efficiency of the green microchip laser. Specifically, we demonstrate 200mW green output and >10% wall-plug efficiency in the 35°C temperature range.

1. Introduction
Compact and efficient green lasers are of high interest to consumer electronics applications such as mobile (compact, pocket, handheld, etc) projectors. Mobile projectors are part of a huge emerging market, estimated to achieve multi-million unit range [1]. First-generation, LED-based mobile projectors have just appeared in 2008. One could mention handheld projectors from Toshiba, 3M, and Optoma. However, brightness and efficiency of LEDs (especially green LEDs) are not adequate to satisfy all the requirements for efficient projection of clear and large images. Lasers are superior but there is no adequate product directly producing green (semiconductor red and blue lasers are available now).

Since direct green laser sources are not available, a number of second-harmonic-based approaches have been proposed recently by Novalux, Corning, Osram, etc. (see for example Refs [2-4]). However, challenges in low efficiency and high cost structure have not been successfully overcome yet. We demonstrate a novel green laser source, based on the microchip (monolithic assembly of Nd:YVO4 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. Specifically, we demonstrate 200mW continuous-wave (cw) green output with >10% wall-plug (electrical-to-optical) efficiency in the 35ºC temperature range.

2. Periodically-Poled MgO-doped Lithium Niobate
The 532nm laser source is monolithic assembly of Nd:YVO4 crystal and Periodically-Poled, MgO-doped Lithium Niobate (often abbreviated as PPMgOLN or MgO-doped PPLN). PPMgOLN crystals are the most efficient nonlinear crystals available for Second Harmonic Generation (SHG) from infrared into the visible wavelengths. 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 domain inversion in the crystal. Periodical domain inversion is achieved by a 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).

Widely available periodically poled materials are based on congruent, easily grown, Lithium Niobate crystals (PPLN). This material allows domain inversion and periodical poling; however it has very low resistance to the optical (photorefractive) damage by the intense visible light. To avoid this damage PPLN crystals must be heated to high temperatures (~200^{o}C) which makes this material unsuitable for the mobile projection applications.

PPMgOLN is much more resistant to the optical damage but it is more difficult to create periodical domain structure in this crystal. Proprietary technology of poling thick (1mm) PPMgOLN crystals, suitable for microchip fabrication, has been developed by Spectralus in the last few years [5]. Figure 1 shows 1-mm thick MgO-doped Lithium Niobate wafer (shown on the left) with periodical electrode structure applied to the wafer lithographically. The image on the right shows periodical structure in the processed material observed under the microscope.

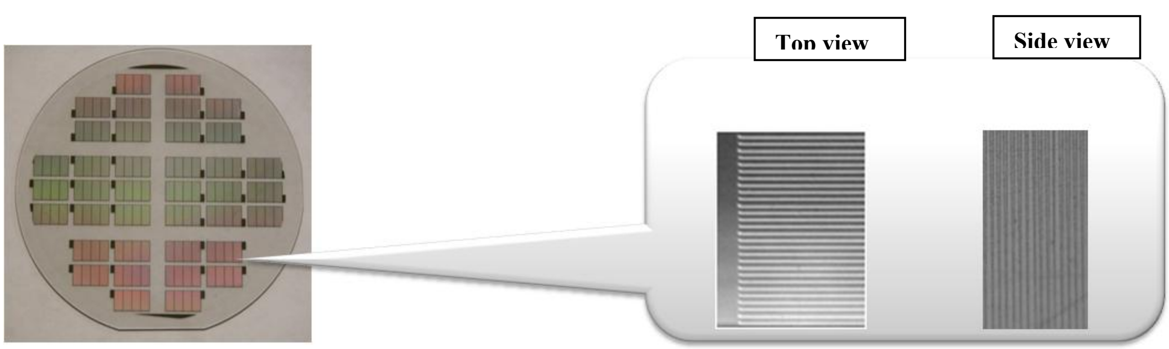

Figure 1. PPMgOLN wafer with periodical electrode structure.
The insert shows periodically inverted domains observed under the microscope.

3. Spectralus Green Laser

Spectralus green laser source (patent pending) is based on a microchip technology (see for example [6]). Microchip combines Nd:YVO4 laser gain medium and nonlinear second harmonic generating PPMgOLN crystal in one monolithic assembly. The microchip laser does not require any active alignment. High nonlinearity of PPMgOLN crystal allows using very short crystal 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.

The monolithic microchip assembly of Nd:YVO4 crystal and PPMgOLN crystal is pumped by an 808-nm diode laser. We integrated this green laser assembly in a 14-pin butterfly package and performed power and efficiency testing for different ambient temperatures, thus addressing one of the major requirements of consumer electronics industry. Results of wall-plug efficiency (WPE) measurements are shown in Figure 3. WPE is higher than 10% over the operation range of more than 35 degrees Centigrade (from -16°C to 30°C from the design operational temperature). To our knowledge, this is the first reported result on such high efficiency of the green laser in the wide temperature range. The output power of this laser was over 100mW over the entire temperature range

Figure 4 shows how output power depends on the pump diode current. The measurements were performed with current increasing (square symbols) and decreasing (diamond symbols) as shown by the arrows. The two curves overlap rather closely demonstrating that hysteresis in output power dependence on the pump current is minimal.

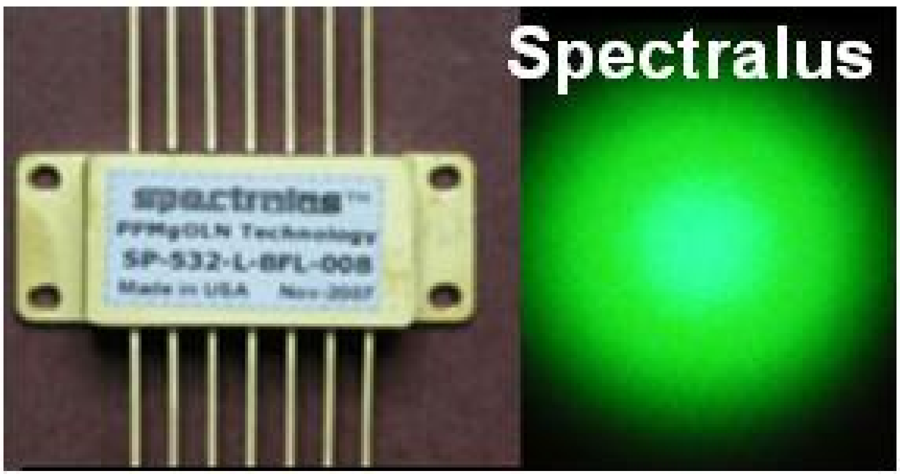

Figure 2. Spectralus Green Laser in the 14-pin Butterfly package. The output beam shape is also shown.

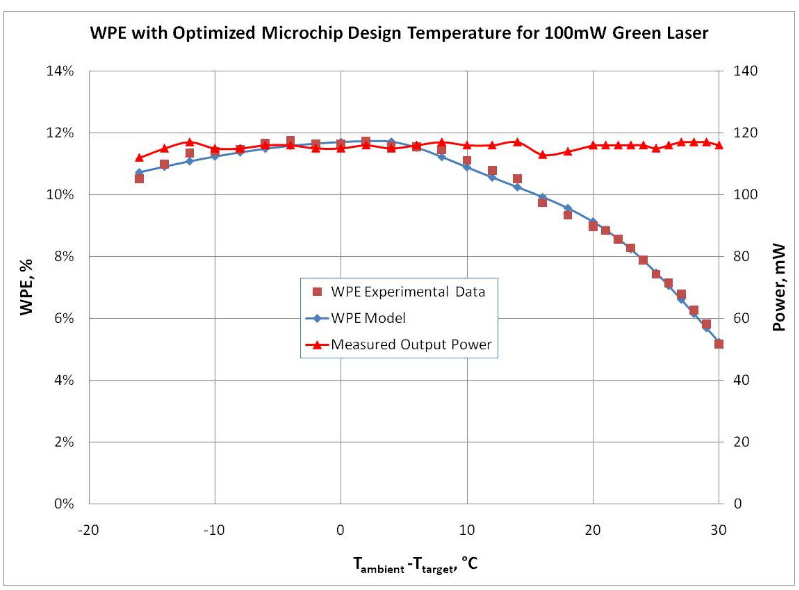

Figure 3. Wall-plug efficiency (WPE) for the Spectralus Green Laser vs. difference between ambient and optimized design temperatures. Also shown measured output power of the laser under environmental test.