52.4: High Speed Green Frequency Converted Semiconductor Laser for Projection Displays

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Abstract
Recent progress on compact green laser for projection applications based on frequency doubled semiconductor structures will be presented. Avoiding external acousto- or electro-optical modulation for scanning laser displays, the green laser prototypes can be directly modulated in the 20-40MHz range.

1. Introduction
Red, green and blue lasers have been considered for a very long time as promising light sources to generate sharp, saturated images with a large colour gamut and high contrast. Especially, the ability to scan the laser beam over the screen (flying-spot) allows for images on curved screens with an almost infinite depth of focus. Major improvements on the scanning technology by introducing MEMS mirrors with high speed and wide scanning angles support the development of laser displays.

Laser display devices so far suffered mainly from the lack of compact and competitive laser sources preventing the breakthrough of this technology besides professional applications. With the recent advent of red (640-660nm) and blue laser diodes (440-470nm) laser display devices become now of considerable interest for a wide range of applications. Power levels of these laser diodes range from a few mW at blue up to hundreds of mW at red. Pocket projectors with monochrome displays made of simple scanning mirrors and TO-can laser diodes have been proposed [1]. Also monochrome automotive head-up displays (HUD) have been demonstrated using scanning mirrors and red laser diodes [2].

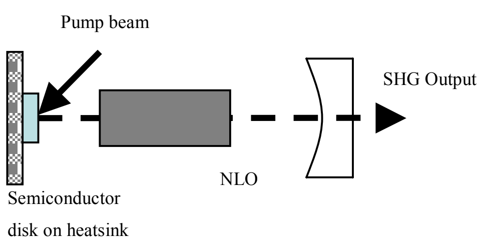

Fig. 1: Schematic setup of a frequency doubled optically pumped semiconductor (OPS) disk laser

Green lasers used in RGB laser projection displays like the pioneering powerful Jenoptik projection lasers [3] so far are solely based on frequency converted diode pumped solid state lasers (DPSS) at 532nm. For flying spot projection direct modulation of the laser source is preferable to avoid expensive and bulky external electro- or acousto-optical modulators. A bandwidth of at least 10MHz is required in order to achieve CGA or higher resolution images. But DPSS lasers can not be modulated due to their relatively long fluorescent lifetime in the µs-range of the solid state gain material.

2. Green Semiconductor Disk Lasers
To overcome the limitation of DPSS green lasers, new concepts are under investigation to pave the road towards mass market applications for scanning laser displays. Our green laser prototype module is based on frequency doubling of a optically pumped semiconductor (OPS) disk laser at 1050nm (See fig.1).

Several groups have reported results from OPS-disk lasers at wavelengths between 660nm and 1550nm [4,5]. By increasing the pump spot diameter the unique power scaling concept of the OPS disk laser has been demonstrated at 1000 nm [6]. The external cavity of OPS disk laser allows for intracavity frequency doubling to get access to blue, green and orange laser sources [7-9].

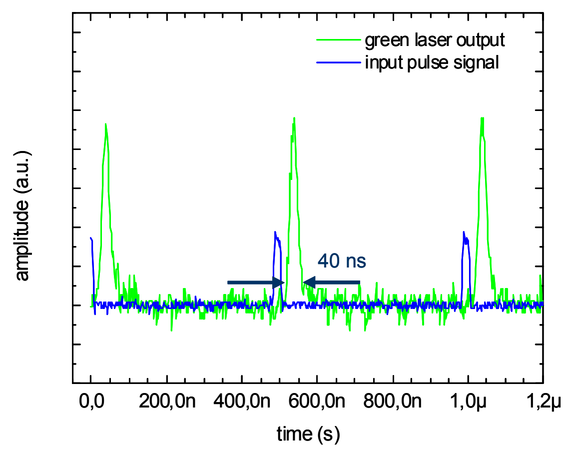

Fig. 2: Short pulse output signal of a green OPS disk laser

A commercial OSRAM broad area laserdiode at 808nm with up to 2W optical power pumps a surface emitting InGaAlAs semiconductor laser material with external resonator mounted on a highly thermally conductive heatsink. Microoptical elements are used to redirect the light to an appropriate pump spot on the semiconductor material. Applying frequency doubling using a nonlinear crystal under type I phasematching conditions we generate green laser light of high beam quality and linewidth of about 0.5nm at 525nm. The length of the resonator is in the range between 25 mm and 10 mm.

3. Modulation Properties
Scanning laser display applications start with moderate resolutions of e.g. 320 times 240 pixels. Assuming a refresh rate

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of 60 Hz, this results in roughly 5 million pixels to be displayed per second. In other words, the on-time for a single pixel is approximately 200 ns. This number decreases down to less than 40 ns for high quality images, like SVGA resolution at higher rates. Typically, the minimum time per pixel is further reduced by nonlinear scanning effects and by invisible parts of the image (time for scanner return, for example).

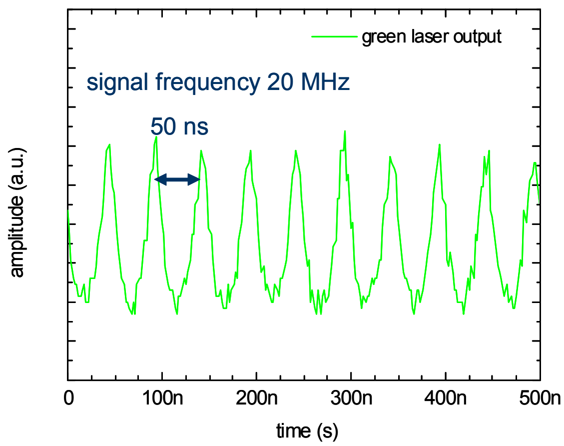

Fig. 3: High frequency modulated output signal of a green OPS disk laser

Edge emitting diode lasers are known to offer modulation speeds much higher than described above. The concept of the frequency doubled optically pumped semiconductor disk laser however has some intrinsic properties that make the behavior on the short time scale different from edge emitting lasers. The gain modulation of the OPS disk laser is achieved by modulating the pump laser. As the pump diode is fast, this does not make too much difference as long as the absorption and carrier life times within the OPS disk material are fast enough, too. The frequency doubled signal is generated by an intracavity setup. This cavity is designed to store the circulating infrared light emitted by the OPS gain disk. Round trip time and cavity losses influence the short pulse behavior of the green OPS disk laser.

The first requirement for a high speed green laser would be a minimum pulse length of well below 100 ns. A time trace of a green laser output together with its corresponding input signal is given in figure 2. Although the shape of the electrical pump pulse is not yet optimized, pulse lengths as short as 40 ns could be realized. The electrical input signal in this case was not a pure square shaped pulse but consisted of a flat portion of 20 ns and additional rise and fall slopes of 5 ns duration each. A biasing of the pump laser above threshold was used to minimize the rise time of the green output signal.

High frequency modulation is another way to look at high speed properties. In this case, neighboring pixels would have alternating brightness values on / off. This is rarely the case in real images but may characterize the modulation quality. Sharp edges of image contents to be displayed require the abrupt transition from on to off, for example. This situation is modeled by a square wave modulation signal with a duty cycle close to 50 %. A signal frequency of 20 MHz could be realized, which corresponds to a pixel frequency of 40 MHz. The green laser output signal is given in figure 3. The input signal frequency is clearly reproduced by the green laser, but on-time and off-time are not precisely equal. Rise and fall times of the green laser pulse contribute to the total pulse length, therefore the on-time is increased with respect to the off-time.

4. Conclusion

There is still some way to go for green OPS lasers in order to reach to modulation requirements of high quality, high resolution images. The work for further improvements of their modulation properties concentrates on laser cavity design and on the optimization of the electrical input signal. This approach is expected to end up at pixel frequencies somewhere between 60 and 100 MHz. OPS disk lasers like those demonstrated here have the potential of enabling laser display technology in mass markets as they represent the only currently available green source with sufficient power, beam quality and speed.

5. Acknowledgements

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