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Miniature green lasers provide the missing color

David Brown, Jerry Kuper, and Sten Tornegard

A new diode-pumped solid-state laser offers the technology to complete the triad of red, green, and blue sources needed to produce full-color images.

The communication and information revolution is driving a need for compact portable high-information-content display sources. Several companies commercially introduced pico- and microprojectors and other portable laser-display technologies in 2008.[1] Our newly developed miniature green laser provides the missing color and enabling technology to complete the triad of red, green, and blue (RGB) light sources required to produce full-color images. While diode lasers can deliver red and blue, direct green-diode light sources are not currently available commercially nor will they likely be for years. Green semiconductor diode-doubled lasers have been incorporated into commercial full-color devices.[2,3] The design—which employs a near-monochromatic laser source—provides a wider color gamut and more lifelike color-rendition display compared to conventional backlit-LCD and phosphor-based technologies such as plasma displays.[4,5]

RGB LEDs have thus far been employed in DLP[6] (Digital Light Processing)-driven microprojector displays. LED sources produce a broader spectrum than semiconductor-based full-color laser devices, comparable to the filtered-light sources used in LCDs. They are also less efficiently matched to the display engine because of their highly uncollimated and unpolarized emission properties. This limits LED-illuminated microprojector display performance.

Diode-pumped solid-state (DPSS) lasers have been generating scalable green-laser emission for over 20 years. Neodymium vanadate (Nd:YVO$_4$) has been shown an efficient laser crystal when pumped with 808nm diodes. The harmonic material potassium-titanyl phosphate (KTP) has been produced for over 30 years and has excellent nonlinear optical properties. We have incorporated this technology into efficient miniature packages which are well suited for microprojector-display applications.[7]

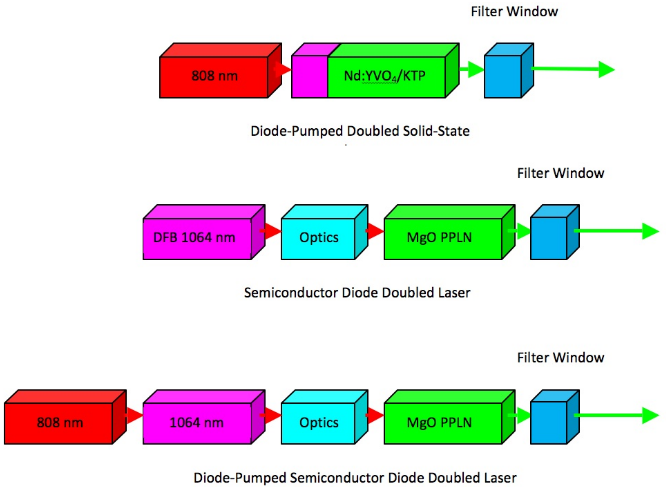

Figure 1. *Schematic diagram of the optical components for three miniature green-laser designs. Nd:YVO$_4$/KTP: Neodymium vanadate/potassium-titanyl phosphate. DFB: Distributed feedback. MgO: Magnesium oxide. PPLN: Periodically poled lithium niobate.*

The major optical components for three commercially available miniature green-laser sources are shown in Figure 1. The DPSS laser employs an electrically pumped 808nm diode to provide the optical excitation. Its laser output is produced in a monolithic crystal that contains the Nd:YVO$_4$ in direct contact with the KTP harmonic crystal. The ends of the crystal assembly have mirror coatings to resonate the 1064nm radiation and emit harmonically produced 532nm emission only in the direction shown. The semiconductor-diode laser employs a 1064nm diode that can be either electrically or optically pumped. Its emission is imaged into the waveguide harmonic crystal. The 532nm emission from the semiconductor-diode design is created in a single pass through the periodically poled harmonic crystal.

Two different harmonic-conversion processes are employed in these miniature laser sources. The fundamental properties of the harmonic crystals are summarized in Table 1. Their values repre-

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Table 1. *DPSS versus semiconductor-diode-doubled (SDD) laser harmonic-conversion crystal properties.*[8]

Parameter	**DPSS**	**SDD**[3]
Harmonic crystal	KTP	MgO PPLN
Nonlinear coefficient (pm/V)	15	5–28
Angular sensitivity (mrad)	68	1–35
Temperature sensitivity (°C)	80–100	0.73
Bandwidth (nm)	3.5	0.2
Walk-off angle (mrad)	1	17.5
Crystal length (cm)	0.25	0.8–1.2

Table 2. *DPSS versus electrically pumped SDD laser performance specifications.*[3]

Parameter	**DPSS**	**SDD**
Output power (mW)	30–200	60–120
Modulation frequency (MHz)	>0.010	>10
Mode quality (M^2)	1.1–1.6	<1.5
Envelope volume (cm^3)	0.23–0.83	0.69
Wall-plug efficiency (%)	9–16	12–15
Operating voltage (V)	2.2	3.3

sent the parameter variation that produces a 50% drop in the peak performance of the conversion process. The KTP harmonic crystal in the DPSS laser is dramatically less sensitive to ambient temperature variations. The values in Table 1 take into account the typical harmonic-crystal length. The shorter harmonic crystal used in the DPSS design broadens the acceptance bandwidth for all KTP properties by a factor of four. The periodically poled lithium niobate (PPLN) harmonic crystal's tight temperature sensitivity requires active temperature control to maintain its peak efficiency. The PPLN crystal is also more sensitive to changes in the fundamental input wavelength and has a larger walk-off angle. The walk-off effect is mitigated in the PPLN design by confining the 1064 and 532nm beams in a waveguide.

The 532nm-laser performance specifications for two of the miniature green lasers are included in Table 2 (DPSS specifications from Snake Creek Lasers, SDD performance from Corning). The DPSS laser can be scaled to >400mW output power from a 9mm titanium-oxide package. The semiconductor-diode-doubled (SDD) laser produces up to 120mW on the basis of a smaller rectangular package. It can be modulated at very high frequencies, which are required for microelectromechanical scanned-laser displays. The lower modulation frequency for the DPSS laser can be used with DLP and 'liquid-crystal-on-silicon' display engines. We recently added features to our green DPSS lasers that eliminate the need for any external temperature control to maintain the tabulated values over a 30–60°C temperature range.[7,9] The SDD-laser design employs an active adaptive-optics design to maintain alignment of the 1064nm emission with the harmonic waveguide structure over a 50°C temperature range. Both of these miniature green-laser designs provide efficient 532nm output power compatible with portable battery-powered display technology.

The development of miniature green-laser sources is revolutionizing portable-display technology. Further improvements in the power and efficiency of these sources are inevitable. The color gamut accessible with an RGB laser source will lead to a dramatic improvement in the display quality. The capability to display high-content text and video on demand on any available flat surface will enhance our communication ability and enrich our entertainment experience.

We will next explore the inclusion of higher-efficiency 808nm pump-diode sources for the DPSS laser design. Our current diodes provide up to 50% wall-plug efficiency. Recent advances promise >65% efficiency for next-generation versions, potentially yielding green lasers with >20% wall-plug efficiency. We will also investigate improvements to the laser and harmonic-crystal quality aimed at providing higher-efficiency green-laser output.

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David C. Brown is the founder, president, and chief technology officer of Snake Creek Lasers. He earned BA and PhD degrees in physics from Adelphi and Syracuse Universities, respectively.

Jerry Kuper, a senior laser physicist, has been with the company since its inception. He received a BA in chemistry from Williams College and obtained MS and PhD degrees in physical chemistry from the University of Rochester.

Sten Tornegard is marketing and sales manager with over 20 years of experience in the photonics industry. He obtained an MS in engineering physics from Lund Institute of Technology in Sweden.

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References

1. Combined Exhibition of Advanced Technologies, Japan, 2008.
2. U. Steegmüller *et al.*, *Green laser modules to fit laser projection out of your pocket*, **Proc. SPIE 6871**, p. 687117, 2008. doi:10.1117/12.764657
3. V. Bhatia *et al.*, *Efficient and compact green laser incorporating adaptive optics for wide operating temperature range*, **Soc. Inform. Display**, p. 63.2, 2008.
4. A. Deter and W. Biehlig, *Color reproduction complex*, **Int'l Planetarium Soc.**, 2004.
5. J. Morovic, **Color Gamut Mapping**, Wiley, 2008.
6. DLP is the digital light-projector technology offered by Texas Instruments.
7. D. Brown *et al.*, *Miniature solid-state lasers for pointing, illumination, and warning devices*, **Proc. SPIE 6952**, p. 69520R, 2008. doi:10.1117/12.777700
8. V. Dmitriev, G. Gurzadyan, and D. Nikogosyan, 2nd ed., **Handbook of Nonlinear Optical Crystals**, Springer, 1999.
9. http://www.snakecreeklasers.com Snake Creek Lasers new product announcement. Accessed 11 December 2008.