High-power fiber-coupled 100 W visible spectrum diode lasers for display applications

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ABSTRACT

Diode lasers in the blue and red spectral range are the most promising light sources for upcoming high-brightness digital projectors in cinemas and large venue displays. They combine improved efficiency, longer lifetime and a greatly improved color space compared to traditional xenon light sources. In this paper we report on high-power visible diode laser sources to serve the demands of this emerging market. A unique electro-optical platform enables scalable fiber coupled sources at 638 nm with an output power of up to 100 W from a 400 μm NA0.22 fiber. For the blue diode laser we demonstrate scalable sources from 5 W to 100 W from a 400 μm NA0.22 fiber.

Keywords: Visible diode laser, fiber coupling, display applications

1. INTRODUCTION

Laser light sources have changed the world tremendously in the past fifty years. Their unique properties like high spatial and spectral brightness, high energy density and efficiency have led to new applications of light previously not thought of. These applications include for example, optical communication, data storage, materials processing and medical treatments. It can be with no doubt asserted that our digital world as it is today would not be possible without the invention of the laser.

While in many applications traditional light sources were displaced by lasers, it is still not widely used in display applications. The laser would also have a number of advantages here compared to e.g. the generally used short arc lamps. It creates light of high spectral purity, enabling a much larger color space and more natural colors and can be modulated at high speed. Its high brightness simplifies the light gathering optics inside a projector. Finally it has as much higher lifetime of several tens of thousands of hours, making lamp changes during projector lifetime unnecessary.

Fiber coupled high power diode laser sources are the most promising candidates for high power laser sources in the red and blue spectral ranges. Optical fiber interfaces are standardized and provide an easy interface to work with for laser projector designers. A fiber coupled source can be easily replaced without realignment of optics in case of a failure. Optical fibers can take powers up to several kW enabling easy power scaling. Diode lasers are cheaper than other lasers since they allow the direct conversion of electricity to light without any intermediate step. Diode laser bars and emitters in the red and blue spectral range are now available as standard products from several semiconductor manufacturers. Their mass production is believed to decrease the costs of fiber coupled diode lasers considerably.

Because of these developments there is an increasing demand of fiber coupled diode laser sources. We therefore developed modular, power scalable sources for the emerging laser projector market. Our existing, market proven fabrication techniques were adapted for the efficient automated assembly of these new laser sources. This paper reports the development of fiber coupled red and blue wavelength diode laser modules from several watts to 100 W output power at DILAS.

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2. LASER MODULE CONCEPTS

2.1 Fiber coupled red laser diode module

The subunit for the red diode laser sources is based on a previously published concept\(^1\,^2\). The basic idea behind this concept is to use tailored diode laser bars, which are designed to achieve the beam quality in the slow axis necessary for fiber coupling without complicated and expensive beam shaping optics. Such a tailored laser bar is collimated using a fast axis (FAC) and a slow axis (SAC) collimation lens. The collimated output of several laser bars can be combined by stacking multiple laser beams in the fast axis by mirrors. The collimation and stacking optics are arranged side by side on a common base plate (Fig. 1). This approach facilitates the use of automated optic alignment tools and therefore efficient mass production of the submodules. The base plate also works as a heat sink for the laser diode bars and can be cooled with tap water. The tools for the fully automated optical alignment of FAC, SAC and mirrors were developed previously, so one goal of development of the red modules was to use these tools without any changes.

For display applications beam quality does not play a major role since currently used image forming devices like LCDs or DLPs accept a rather large etendue. A beam parameter product (BPP) of 44 mm mrad the output of a fiber with 400\(\mu\)m diameter and a numerical aperture (NA) of 0.22 is sufficient for most applications. For highest power applications it is even possible to combine the output of several fibers for higher power with lower beam quality. Laser diode bars with the necessary beam quality are readily available on the market. On one baseplate 7 bars are combined leading to a nominal raw output power of 56 W. One difficulty of combining the used bars is that the low pitch of the emitters forces the use of a SAC with a very short focal length. This leads to a Rayleigh range of only around 40 mm. The overall optical path difference of the diode bars on the base plate is also in this range. Combining the diode bars in a straightforward way therefore would lead to a degradation of beam quality since every diode bar would have diverged differently at the point of combination. A workaround to this problem would be to design the beam combination in such a way that all beam paths are of equal length. In our application the resulting loss of beam quality is acceptable.

Fig. 1 Schematic drawing of the base plate showing the red module and the position of the bars and optics

The fiber coupling optics consists of a relay cylindrical telescope in the slow axis and an aspheric focusing lens. The use of the relay telescope is necessary, because of the short Rayleigh length of the beam in the slow axis. The telescope has a magnification of 1.5 and is designed to form an image of the collimated laser diode beam directly in front of the focusing lens.

For power scaling several of the base modules can be combined. Since the BPP in the fast axis is rather low, it is possible to combine at least two base plates in the fast axis and since the output of a single plate is polarized, polarization coupling is possible as well. With these beam combination possibilities the power can be scaled to at least 200 W while still providing a BPP of 44 mm mrad.

2.2 Fiber coupled blue laser diode module

The blue laser diodes are now available mainly as single emitters with a power of up to 2 W from one emitter. These packaged emitters are commercially available as a standard TO can. Therefore a completely different module concept compared to the red modules is necessary. To facilitate power scaling a modular approach for the submodules is chosen. Submodules for 8 and 12 diodes were developed. The 8 diode submodule was developed with the aim to minimize
alignment of the single diode collimation and combining optics. The collimation optic consists of a single aspherical lens and the 8 collimated beams are combined side by side by turning prisms which redirect the beam about 90 degrees. The mechanics of a submodule consists of an internally water cooled heat sink block for the diodes to which the turning prisms are glued without active alignment. The aspheric collimation lens is fixed in front of the diode with a laser cut stainless steel sheet. This sheet holds the lens in its center position but allows small adjustment in the lateral directions by means of two screws (Fig. 2). The advantage of this approach is that after assembling the submodules only emitters with intolerable deviations from their center position have to be realigned for their pointing. Emitters which have low deviations from their center position show negligible pointing errors and don’t have to be touched for alignment.

To achieve higher output powers the cooling water and electrical connections are designed for the combination of up to 6 basic building blocks. This adds up to a maximum of 48 emitters combined in one polarization. Two of these blocks can be coupled via polarization coupling, leading to a raw power of well over 100 W.

Fig. 2 Basic building block for 8x450 nm single emitters and passive alignment.

To achieve the highest possible beam parameter product of a submodule it is still necessary to align every diode separately. For this case a building block for 12 single emitters was developed. This block consists of a heatsink which holds 12 diodes and the 12 corresponding aspheric collimation lenses. Three emitters are stacked in the slow axis with a pitch of 2 mm. 4 of these stacks are subsequently stacked by turning prisms, which are all actively aligned (Fig. 3).

A prototype accommodating 24 emitters was built (Fig. 4). This prototype is expected to deliver 25W from a 400µm 0.22 NA fiber.

Fig. 3 Basic building block for 12 450 nm single emitters and active alignment

Fig. 4 CAD model of the 25W 450nm single emitter module
3. RESULTS

In this section the performance of the realized submodules and fiber coupled sources will be presented in detail.

3.1 Free space red laser module

In this section the results for a single red wavelength base plate will be presented. Fig. 5 shows the measured output power of the single base plate behind the combining mirrors. A threshold current of 3.2 A, a slope efficiency of 6.6 W/A and a nominal output power of 56 W at 12A is achieved. A caustic scan was performed to measure the beam quality (Fig. 6). The slow axis BPP is slightly bigger than the target BPP of 44 mm rad, so slightly increased losses at fiber coupling are expected. The coupling optic was designed to overfill the fiber diameter and stay in the fiber target NA of 0.22. Since the beam quality in the fast axis is very good (15 mm mrad) the expected losses scale only linear with aperture overfilling.

![Fig. 5 Output power of the collimated base plate as a function of current.](image1)

![Fig. 6 Caustic scan of the collimated base plate. The caustic scan was recorded after the 1:1.5 telescope in the slow axis with an f=50mm focal length and then scaled to the focal length of the fiber coupling optics.](image2)

3.2 Fiber coupled red laser diode module

Based on the single base plate described in section 3.1 a fiber coupled beam source with a nominal output power of 40W was developed (Fig. 7).
Its measured performance is shown in Fig. 8. The nominal output power is achieved at 10.5A. A fiber coupling efficiency of 84% including Fresnel losses at the uncoated fiber was achieved into a 400µm NA0.22. The overall electro-optical efficiency was measured to be 25% at nominal output power.

For the 100 W beam source a housing was developed, which can accommodate two base plates (Fig. 9). Both modules are combined via polarization coupling. The degree of polarization of a single module was measured to be 96%, resulting in slightly lower coupling efficiency due to small polarization combining losses.
3.3 Free space blue laser diode module

The 24 single emitter beam source was built and characterized. Fig. 10 shows the output power and electro-optical efficiency of the module. All 24 emitters are connected in series. A threshold of 250mA and a slope efficiency of 38.3 W/A are measured. At the nominal current of 1.2A 32 W of output power are achieved. A caustic scan was done to determine beam quality (Fig. 11). The results show a beam quality of 9.4 mm mrad in the fast axis and 31 mm mrad in the slow axis. The slow axis beam quality is currently largely determined by fabrication imperfections which are caused by shrinkage during gluing of the turning prisms.
3.4 Fiber coupled blue laser diode module

Fig. 12 shows the output power of the 24 emitter module from a 400µm NA0.22 fiber. A fiber coupling efficiency of 82% including Fresnel losses from the uncoated fiber was achieved. The nominal current of 1.2A resulted in an output power of 26W. The BPP from the collimated beam source allows scaling to >100W by spatial and polarization coupling of up to 4 subunits.

Fig. 12 Left: Output power Right: spectrum of the 24 single emitter blue wavelength module from a 400µm NA0.22 fiber

4. SUMMARY AND CONCLUSIONS

In this paper the development of fiber coupled diode lasers for display applications was reported. More than 50 W of red output at 638 nm and more than 30 W of blue output at 450 nm were reported experimentally. The modular system developed at DILAS enables the production of scalable laser diode sources with output powers of more than 100 W from a 400 µm NA 0.22 fiber.

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6. REFERENCES