Modular Laser Light Sources for High-Brightness Projectors

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ABSTRACT

Barco has developed a modular laser light source for high-brightness projectors. The light source consists of a limited set of building blocks and enables a whole range of RGB-laser and laser-phosphor projectors up to 50klm.

1 Introduction

High-brightness laser projectors have been on the market for several years now: the first commercially available RGB-laser projectors for cinema were released in 2014 [1]. Lasers at that time were expensive, mainly due to the lack of efficient green direct semiconductor lasers. This required the use of more complex lasers involving frequency doubling to produce the green light. Due to the high cost of these lasers, this first generation of laser projectors was aiming at the high-end market segment, where a brightness and performance level was required that could not be met with lamp-based technologies. To optimize performance, lifetime and cost, the lasers were cooled by (external) chillers.

The lower brightness segment of the market has been covered by laser-phosphor based light sources, where green and red light are generated by phosphor conversion from blue to yellow light. Such light sources don't require the expensive frequency-doubled green lasers allowing for an affordable solid-state light source replacement for the Xenon lamps.

This situation has changed with the development of direct green laser diodes at the correct wavelength and power level (e.g. [2]). These lasers became available in mass production in the course of 2018 and are much more affordable than the frequency-converted green lasers. In addition, the wall plug efficiency of direct green diodes is much higher, removing the need for a chiller to cool the lasers.

2 Modular Light Source Architecture

2.1 Laser Plates

The key building block of the modular light source is the laser plate as is shown in Fig. 1. The laser plate consists of a PCB and a cooling interface on which the lasers are mounted. The design of the laser plate allows for an automated manufacturing process.

All lasers are direct semiconductor diodes mounted individually in TO9 cans. The blue and green lasers are based on AlInGaN technology and the red lasers are AlGaInP devices. One laser package consists of 8 of these TO9 cans and a base plate to which the cans are attached. The mechanical interface and the electronical pin layout of the laser packages are identical between the 3 different colors. All laser packages have built-in collimation optics. While there are differences between the output beam profiles of the three colors, they are all compatible with a single optical system.

For each color there are two variants of laser plates: one containing 16 laser diodes and one containing 24 laser diodes. An overview of the parameters per laser plate type are indicated in Table 1. Given the geometry of the laser packages and the arrangement of these packages on the laser plate, the lasers form an array of 4 by 4 and 4 by 6 diodes, respectively.

The PCB connects the individual lasers per 8 in series and can store an identification and information on how long and under which conditions the laser has been operated. Connectors for power and data cables are foreseen on the back side of the PCB.

The laser plate is the smallest serviceable part of the laser light source. In case a projector can no longer maintain the required brightness level due to aging, or due to a sudden laser failure, laser plates can be replaced in the field to restore the brightness level of the projector. This modularity offers several operational benefits for the end user, especially in case multiple projectors of the same family are used at the site. There is no longer need for storing a full laser light source for each projector brightness level, instead, a set of 6 relatively inexpensive laser plates is sufficient to maintain a large variety of projectors. The laser plate also features a switch, such that the light source is turned off automatically when a laser plate is removed from the system, to improve the safety of the service personnel.

Fig. 1: Blue laser plate.

Table 1: Overview of the laser plate variants.

Color	Wavelength	Power (16d)	Power (24d)
Red	643 nm	30 W	45 W
Green	526 nm	16 W	24 W
Blue	466 nm	62 W	93 W
Blue	456 nm	82 W	123 W

2.2 Laser Plate Combination Scheme

The power of one laser plate is not sufficient for achieving light output levels exceeding 6 klm. As such a flexible laser plate combining system has been designed that allows combining up to 8 laser plates of each color. The combining scheme is as follows:

First two laser plates of the same color are combined by a mirror system, such that the resulting output beam is an array of diodes with a closer spacing between the laser beams. The orientation of both laser plates on the combining block is such that the output beam is polarized.

In the next step two of such output beams are combined using a polarization beam combiner, after which a laser beam array is obtained that is globally unpolarized with a maximum optical power level of 4 times the values indicated in Table 1.

The lasers for the blue primary form an exception of the power scaling scheme. A blue laser plate delivers much more power than a green or a red laser plate, as can be seen in Table 1. For most projectors, only one blue laser plate delivers sufficient power for the blue primary. Therefore, the mirror system and polarized beam combiner are not used for the blue primary.

For RGB projectors, beams of the three primary colors are then combined with dichroic filters into a white light beam. The power levels in such a white beam are sufficient for the major part of the high-brightness projection market as it allows for RGB-laser projectors up to 25 klm. A picture of a beam combiner in this 25 klm configuration is shown in Fig. 1. Not taking into account the thermal limitations of the DMD devices, this is the maximum amount of laser power that can be delivered by the modular light source on the 0.69” and 0.98” DMD.

For those applications, where even higher brightness levels are needed, it is possible to combine two white light beams side by side at the entrance of the integrating bar of the illumination optics. This, however, is only possible for the largest DLP devices of 1.38”.

For a laser-phosphor projector, the blue laser source for pumping the phosphor is limited to 490W within the étendue limitations of the 0.98” DLP devices.

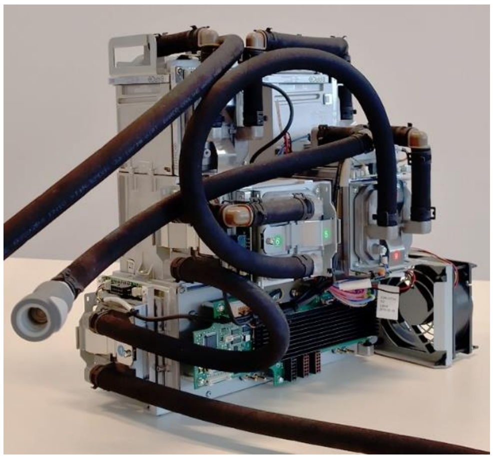

Fig. 2: The modular light source in the configuration with 1 blue, 4 green and 4 red laser plates.

2.3 Laser Cooling System

During the past years, lasers have become more efficient and allow for higher operating temperatures compared to the lasers used in the first laser projectors. As such there is no longer a need for an active cooling system for the green and blue lasers. Each laser plate has its own liquid cooling block that is mounted on the back side of the plate. The heat is removed from the liquid by air cooling with a radiator, which is integrated in the projector.

The performance of the red lasers is more sensitive to the operating temperature: there is a performance loss when the lasers are operated at higher temperatures: e.g., the wall plug efficiency drops by about 1.5%/ºC. To keep the red lasers at a lower temperature than the green and blue lasers, a peltier is mounted between the laser plate and the liquid cooling block.

The typical lifetime of the laser source is 20.000 hours till the optical output of the lasers has dropped by 50%. However, laser lifetime is linked to the operating conditions of the lasers: the package temperature and the drive current. A projector based on the modular laser source, can achieve longer lifetimes, e.g., by an over-designed radiator, such that laser temperatures are kept lower, or by an overdesigned installed laser power level, such that the lasers can be run at a reduced current.

3 Performance of the Modular Light Source

The modular light source is used in several projector families: in cinema, there are the SP2K products with laser-phosphor for small screens and the SP4K product family based on RGB-laser for the largest screens. In non-cinema markets the UDM product line is based on laser-phosphor. The focus of this paper lies on the SP4K family, and the SP2K and UDM are only briefly discussed.

3.1 SP4K cinema projectors: RGB-Laser

The SP4K family consists of 8 RGB-laser projectors targeting the cinema market and covering a range from 12 klm to 50 klm in light output. As the name indicates all projectors offer 4K resolution (4096 x 2160). The range in light output is covered by two different imager sizes: the 4 lowest models (< 25klm) are based on the 0.98" DLP devices (C), while the higher light output variants make use of the larger 1.38" chips (B). The B-series projectors are larger than the C-series projectors, due to the larger size of the imaging optics (projection lenses and color splitting prism) and due to the larger laser source and its cooling and driving requirements. A picture of both variants is shown in Fig. 3.

The contrast ratio of the standard SP4K projectors is typically around 2000:1 and 2300:1. The 1.38" variants have a slightly lower contrast ratio than the 0.98" variants. This is due to the different mirror design of the DLP devices and the differences in projection optics. One model based on the 1.38" (SP4K-27HC) has a modified optical system (e.g., high contrast apertures), such that the cone angle of the light arriving onto de DMD is reduced. Combined with the high-contrast variants of the projection lenses, a contrast ratio of 5000:1 (typical) is reached.

Fig. 3 SP4K-B and SP4K-C

Table 2. Typical light output and contrast ration of the projectors based on the modular light source.

Model	Light Output (klm)	Contrast Ratio
UDM	14.5, 21.0	2200:1
SP2K	6.0, 8.0, 11.0, 14.0	2200:1
SP4K-C	12.0, 17.0, 20.0, 23.5	2300:1
SP4K-B	35.0, 40.0, 48.0	2000:1
SP4K-HC	27.0	5000:1

The color gamut of all 8 projectors is identical, as this is determined by the wavelengths of the laser source. It is compliant with the DCI-P3 color space and encompasses nearly the full Rec2020 color gamut as can be seen in Fig. 4. The green primary of the SP4K source deviates from Rec2020 specification, while the other colors are compliant with the Rec2020 gamut. Rec2020 requires the green lasers to be around 532nm, which is a bit longer than the 526nm of the SP4K's green laser source. The spectrum of the SP4K is shown in Fig. 5.

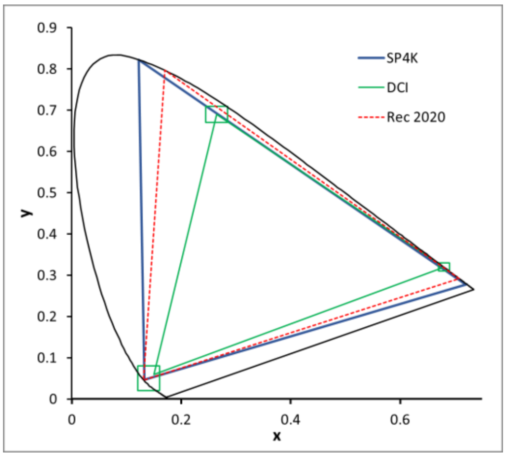

Fig. 4: Color gamut of the SP4K RGB-laser source. The DCI color gamut (including tolerance boxes for each primary) and Rec2020 gamut are shown as well.

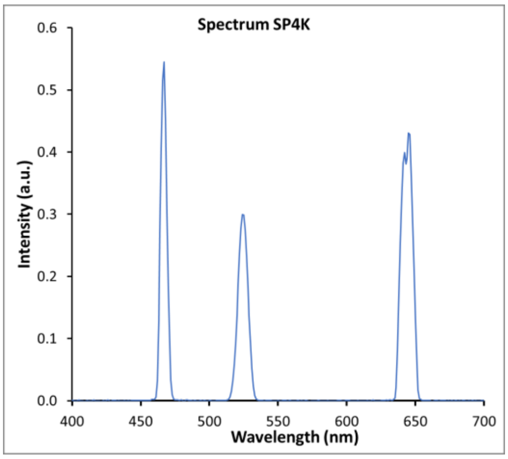

Fig. 5: Spectrum of the SP4K laser source.

A key parameter of laser-based projectors is the speckle performance of the projected image. Optimizing a projector for speckle involves a combination of polarization mixing, angle diversity, wavelength mixing and/or moving screens [3]. As the motion of screens adds complexity to the installation, especially for large screens, we have optimized our projectors such that they can be used on the screens that are typically used for cinema, without the need for screen motion.

As explained in section 2.2, the combination of laser plates offers the possibility to mix two polarization states of the laser light by means of the polarization beam combining optics. The best result is obtained when equal number of lasers are used for each polarization state.

Angle diversity is optimized by filling the aperture of the projection lens as uniform as possible with the light from the lasers. A tradeoff needs to be made between speckle and other image parameters such as contrast ratio. Larger contrast ratios involve higher F-numbers on the DMD, and hence less room for angle diversity. In the standard SP4K configurations angle diversity was optimized to F/3 illumination of the imager.

The last design parameter of the laser source is related to the spectral width of the laser primaries. Speckle is a phenomenon determined by diffraction and interference. Diffraction patterns scale with the wavelength of the light, so it is most difficult to solve speckle for the red laser primary. For obtaining a good speckle level on the red primary, it is required to combine lasers with a different wavelength specification. In the modular light source 3 different wavelength groups are used for the red primary. The wavelength broadening can be observed in the spectrum (Fig. 5).

For the evaluation of speckle, we have used the method as described in LIPA's recommended practice for speckle measurements [4]. A CCD camera with a 4.65µm pixel size was used in combination with a camera lens with a focal length of 16mm and the aperture set to F/4. Neutral density filters are used in front of the camera lens, such that the exposure time could be fixed to 50ms. The image was projected onto a matt white cinema screen and an image of the screen was taken from a distance equal to the height of the image. The resulting speckle contrasts were 3.6% for blue, 4.0% for green and 4.2% for red. These values are corrected for the under-sampling of the speckle pattern (correction factor 1.22, for this particular camera and lens combination) as described [4].

3.2 SP2K and UDM: Laser-Phosphor

RGB-laser offers many advantages in terms of image quality. However, at this moment there are several situations, where laser-phosphor-based projectors might serve better the customers' needs. This is for example the case in applications where smaller imagers are used, or in situations where a wide color gamut is not needed.

The SP2K product family serves a segment of the cinema market, where 4K is not required and screens are relatively small. For these applications, it can be more cost-effective to use a projector based on the smaller 0.69" DMD. However, as the intended use is cinema, image quality and speckle remain critical parameters. As speckle in combination with RGB-laser increases with reducing imager sizes, it is for these applications better to use a laser-phosphor light source at this moment.

The main challenge of laser-phosphor in the cinema market is related to the relatively wide color gamut (DCI-P3), which requires filtering of the phosphor spectrum with a notch filter. This filtering reduces the optical efficiency. To provide the most cost-effective solution for a given light output requirement, the SP2K family comes in two flavors: laser-phosphor with and without red laser assistance. The two higher brightness models have a built-in red laser plate to improve the overall efficiency, while the two lower brightness models have only blue lasers.

In many applications (other than cinema) there is no need for a wide color gamut: for fixed installations, such as in museums, or for projection at live events, the Rec709 color gamut is often sufficient. In these cases, where the native primaries from the laser-phosphor source (as filtered by the coatings of the color splitting prism) are close to the target primary colors, large light losses due to notch filters can be avoided and laser-phosphor is an efficient light source technology. UDM is designed for such applications and is for that reason equipped with a laser-phosphor source.

Both the SP2K and UDM projectors are shown in image Fig. 6.

Fig. 6: SP2K and UDM.

4 Conclusions

Barco has introduced a modular laser light source in several new projectors for the high-brightness projection market. The light source, based on a few building blocks, can be configured in many ways, such that a wide range of brightness levels can be addressed. The modularity of the laser source also offers operational advantages for the user. The light source can be used for both RGB-laser as for laser-phosphor conversion. The maximum brightness is at the moment 50 klm for the largest DMD imager size.

References

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