9.3: LCoS Laser Projector

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Abstract

Barco has built a lab-prototype laser projector in the framework of the European FP6 OSIRIS project. The laser sources are supplied by Oxxius and Osram OS. The projector uses QXGA LCoS panels and reaches a light output of 230 lm and a contrast ratio exceeding 8000:1.

1. Introduction

Most of today's projectors use discharge lamps (Mercury or Xenon) as light source. The use of lasers instead of lamps, could improve the performance of the projectors significantly [1]. Lasers have a longer lifetime than lamps (about 10,000hrs or more instead of 1,500hrs for a Xenon lamp), which increases the reliability of the projector and avoids costly lamp replacements. Another benefit is the small spectral width of a laser light source, which means that a laser projector can also reach a larger color gamut as illustrated in Figure 1. As laser beams are well collimated a laser projector is not (or at least less) limited by étendue as a lamp-based system: laser projectors are possibly brighter, more compact, and they can reach a higher optical efficiency, a higher contrast ratio, and a larger depth of focus.

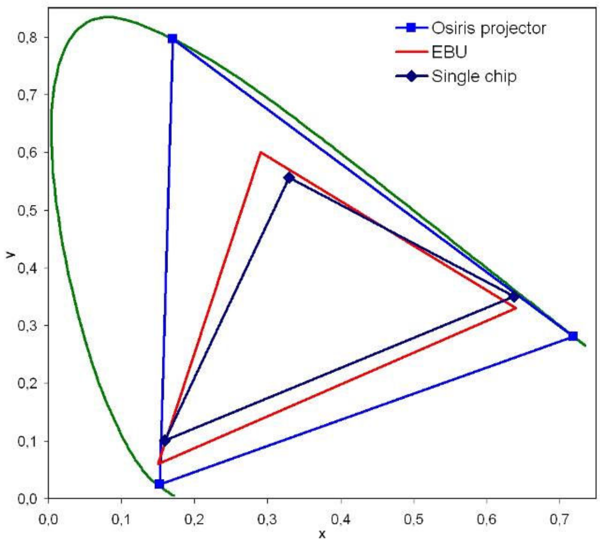

Figure 1: The color gamut of the laser projector compared to the EBU standard and a color gamut of a standard business single chip projector.

However, using lasers may also have some important drawbacks. The main problem is laser speckle, which appears as a random granular intensity modulation, superposed on the image content, which deteriorates the image quality of laser projectors. Speckle will be discussed below in a separate section.

Other problems related to laser light sources are the availability of sufficient laser power at a reasonable cost, the cooling requirements, and safety issues. High-power lasers are very expensive at this stage, and a lot of laser suppliers focus on low-power lasers for embedded pico-projectors. The output power, the wavelength and the lifetime of some of the lasers, especially diode lasers, depend strongly on the temperature of the gain medium. To achieve white point and overall brightness stability, relatively expensive cooling systems have to be used. Finally, laser devices have to comply with the IEC-60825 standard. This will be an issue for high-brightness laser projectors, especially for the scanning laser systems, where the image is formed by scanning a line or a spot over the surface of the screen.

Several laser front projectors have been reported: e.g. based on GLV (Grating Light Valve) [3] or DLP (Digital Light Processing) [4] technology. We have chosen to use LCoS technology as this offers higher contrast ratios as compared to DLP and safety regulations are less restrictive with respect to a scanning laser projector. In addition, polarized light sources are ideal in combination with liquid crystal imagers. In lamp-based LCoS projectors a polarization recovery component is needed to convert the light having the wrong polarization. Using a polarized laser light source, this component can be omitted, making the system cheaper and more efficient.

2. OSIRIS project

The European project OSIRIS (Original System for Image Rendition via Innovative Screens) [5] is a three-year project started at the beginning of 2007. The objective is to create a common technological platform aiming at providing solutions for a broad range of 2D and 3D display applications. This includes solid state light sources (lasers and LEDs), new screens based on interference lithography and holography, 3D capture and 3D rendering of natural scenes.

The laser projector presented here, is one of the outcomes of the OSIRIS project. The target output power of the projector is 300 lm and its color gamut should cover the complete EBU color gamut. As the development of the lasers is also a part of the research program, we do not have the laser power to reach the final goals, yet.

3. Laser sources

The projector uses a red diode bar, frequency doubled diode pumped solid state (DPSS) lasers for green, and a diode and DPSS lasers for blue. The properties of the lasers are summarized in Table 1. All lasers have polarization ratios beyond 100:1, which is excellent in combination with the LCoS imager.

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3.1. Blue lasers

The blue laser source is supplied by Oxxius. It consists of several laser modules, each having their own heat sink and driving electronics (see Figure 1). The laser modules include TEC devices to keep the lasers operating at the correct temperature and control loops for output power control. The volume of one module is 8 x 4.5 x 2.5 cm^3.

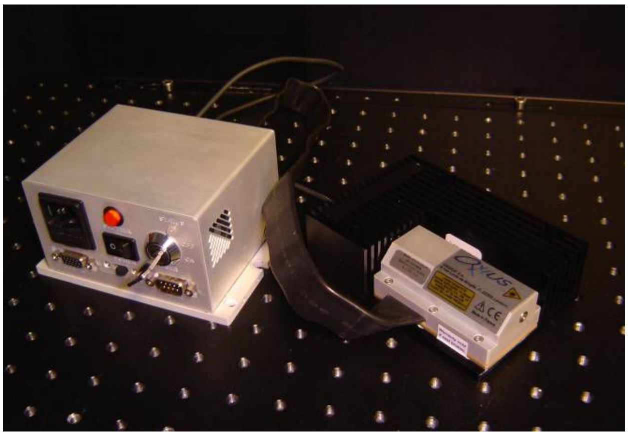

Figure 2: The DPSS lasers supplied by Oxxius.

The DPSS lasers are frequency doubled Nd:YAG lasers emitting at 473nm.They are part of Oxxius' SLIM product family. The technology behind these lasers is the alignment-free monolithic resonator (AMR), which means that all components within the cavity are bond into a single optical subsystem by optical contacting. The AMR offers increased reliability, single-frequency operation, high stability and improved performance. The GaN diode, which emits light at 448nm is packaged in a similar housing.

These two wavelengths were chosen in order to obtain the desired color point as shown in Figure 1. The output power of the diode should be about twice the power of the DPSS laser, in order to achieve a large color gamut without removing the blue corner of the EBU color space. At the moment we only have about half the power of the 473nm laser, which results in cutting a small part of the blue primary of the EBU color space.

3.2. Green lasers

In the Osiris project two types of green lasers are developed. Both are frequency doubled optically pumped Nd-doped crystal lasers (Nd:YAG and Nd:YVO_4) and they emit at 532nm. The doubling is done by means of a KTP crystal.

The green laser source developed by Oxxius consists of two individually packaged Nd:YAG lasers of 350mW and 500mW. The architecture of these lasers is AMR technology, similar to the blue DPSS lasers. The green laser delivered by Osram contains five individual emitters, bundled in one package.

3.3. Red laser

The red laser source is developed by Osram and consists of an InGaAlP laser diode array with emission wavelengths around 640 nm. The laser array contains seven emitters separated by 0.5 mm. The fast axis of the diodes is collimated by a cylindrical lens resulting in a beam divergence of 1° in the fast and 15° in the slow axis. The laser diode array is soldered on a heat spreader in a copper package for efficient heat dissipation. The module design and assembly process is tailored to enable high volume manufacturing. The temperature of the diode is controlled by a TEC device in combination with water cooling.

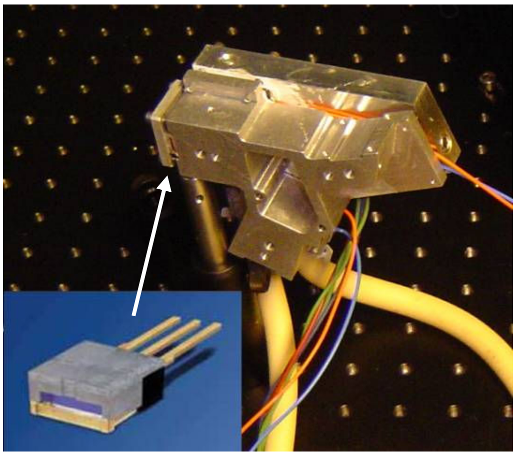

Figure 3: The red laser developed by Osram and the water cooled heat sink.

4. Laser LCoS projector

The projector uses three QXGA (2048×1536 pixels) 0.82" LCoS panels with an aspect ratio of 4:3. As input the projector accepts two DVI-connectors. The projection engine is mounted on an optical breadboard of 75 x 90 cm^2. The height of the setup is about 25cm. The projector requires an external power supply for the red diode bar.

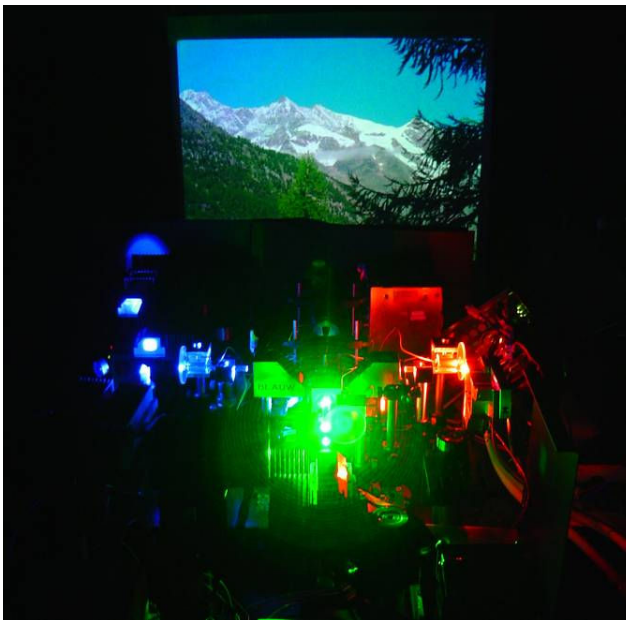

Figure 4: Picture of the laser LCoS projector.

The laser beams are homogenized for each color individually and color combining is done after the imagers by means of a crossed pair of dichroic mirrors, as is usually done in LCoS projectors. While only one laser package is required for the red channel, several laser modules are needed for the two other primaries. Currently two green and three blue lasers are combined by means

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of a set of mirrors. Homogenization of the illumination is performed by the combination of lenses, a diffusing surface, and a traditional light pipe integrator. In principle, all lasers could be combined in one beam homogenizer, which would have the advantage that only one light pipe is needed. However, then one needs more complicated and achromatic relay optics including dichroic filters for color separation. With our approach we only needed simple relay optics consisting of only three lenses. Both beam homogenizers and relay optics were optimized to achieve an F/8.5 illumination of the LCoS panels.

The output brightness of the projector is 230lm, which is still somewhat below the target of the project. This power level will be reached when all laser sources will be integrated in the projector. The target of 300lm is not a fundamental limitation of the projector. As lasers have a very low étendue it is, from a theoretical point of view, trivial to combine more laser sources to reach higher brightness levels. This requires only some small modifications to the optics in order to adapt the light engine to a larger amount of laser sources. The optical efficiency of the projector is different for the three primaries and lies between 20% and 30%.

The contrast ratio (full-white, full-off), which benefits from the F/8.5 illumination, is better than 8000:1. Although this is not an extremely high result, it is very good for an open setup like this prototype, as it is not sealed to keep dust outside the projection engine.

The color gamut is about a factor of two larger in (x,y)-color space than the EBU color gamut (see Figure 1). This is a very wide color space for which there is no content available, yet. Color corrections have to be applied to the highly saturated primaries of the projector in order to be able to display standard video signals with correct colors. The output power of the diode lasers (both blue and red) were set in order to achieve a D65 white point.

5. Speckle

There are several ways to reduce laser speckle, however, each of them has its own limitations. An overview of different speckle reduction techniques can be found in e.g. [2]. They can be grouped into four classes: polarization diversity, angular diversity, wavelength diversity and the use of special or moving screens. By means of polarization diversity, speckle can be reduced up to a factor of 2, by using an unpolarized laser source and a depolarizing screen. Angular diversity is achieved e.g. by using multiple incoherent sources or by reducing the coherence of a laser beam, and results in a speckle suppression, which is limited by the diameter of the aperture of the projection lens. The combination of laser light with slightly different wavelengths also results in a reduced speckle contrast. Finally, and probably the most powerful technique to reduce speckle is e.g. moving the screen. Unfortunately this technique can only be applied in some rare occasions.

Relying on one single technique will not yield a satisfying result, so it is necessary to develop a complete speckle reduction scheme, which uses as many of the available techniques. The final goal would be to reduce speckle to the point that it is not perceived by the observer, even for a stationary screen.

In the prototype despeckling is performed mainly by angular diversity, which includes the use of multiple incoherent emitters and a rotating diffuser to break the coherence of the laser light. The spectral width of the diodes yields an additional speckle reduction by wavelength diversity. As the LCoS needs polarized light, polarization diversity is only exploited by using a depolarizing screen.

The observed speckle contrasts of the projected image depend on the central wavelength and the spectral width of the laser source. We measured values on the projector from 8% for the blue diode to 18% for the green and blue frequency doubled DPSS laser. The speckle of the red diode bar was about 11%. Speckle measurements were performed by taking a picture of the screen with a CCD camera. A high-pass filter was applied to the recorded speckle patterns before calculating the contrast in the image [6].

These levels of speckle are visible, especially for green and red, whereas it is much harder to perceive the speckle in a purely blue image. One way to reach lower speckle contrasts will be using lasers with a larger spectral width, which is hard to achieve, especially for the green primary as there are no direct diodes available.

It has to be noted that speckle measurements are very difficult, as the result depends on many parameters. Therefore, it is not trivial to compare the results of different speckle measurements, which were performed with a different setup. It is desirable that a standard for speckle measurements would be defined [7]. We used a black and white camera with a CCD-sensor of 1024 x 768 pixels, having a diagonal of 6.0 mm and a pixel size of 4.65 x 4.65 μm^2. A 12 mm lens with f-number F/4 was mounted on the camera and focused on the screen made out of paper. This camera was positioned at a distance from the screen equal to the height of the image.

6. Conclusion

A laser LCoS projector has been built in the framework of the European project OSIRIS. The laser sources were developed by Osram OS and Oxxius, and the system integration was done by Barco. Currently, the projector delivers 230 lm, which will be increased to 300 lm by the end of the project. The combination of LCoS and a polarized laser light source is beneficial for the contrast ratio and the optical efficiency. However, it turns out that more research has to be done in order to reduce speckle sufficiently.

7. Acknowledgements

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Table 1. Overview of the laser sources.

Wavelength	**Type**	**Material**	**Power**	**Polarization**	**Supplier**
448nm	Diode	GaN	1 W	> 500:1	Oxxius
473nm	*2f* DPSS	Nd:YAG	1 x 110 mW 1 x 120 mW	> 300:1	Oxxius
532nm	*2f* DPSS	Nd:YAG	1 x 350 mW 1 x 500 mW	> 300:1	Oxxius
532nm	*2f DPSS*	*Nd:YVO$_4$*	*1.5 W*	*> 100:1*	*Osram OS*
640nm	Diode bar	AlGaIn	2.5 W	> 100:1	Osram OS

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