INTRODUCTION

The unique advantage of projection displays is the possibility to produce large images from very small devices. Therefore portable projection devices also known as pico-beamers or microprojectors, which enable to quickly share data or pictures, are very attractive. These devices need to be of course compact enough to fit in the pocket. Integration with other existing devices, like cell phones or cameras, could enable a really wide market. For portable devices, battery operation is necessary, which implies low power consumption and hence high efficiency of the light source.

Such integrated microprojectors have been recently launched in the market (Standalone mini-beamer Samsung MBP200, Samsung 17410 integrated in a mobile phone or Nikon Coolpix S1000pj in a camera). However, since most of them rely on LEDs as projection light sources, their actual achieved brightness, of about 20 lm, is barely sufficient to see the picture in a darkened room [1]. The brightness as well as the efficiency can be dramatically increased by using laser-based microprojectors, with three primary color sources: red, green and blue. A luminous flux of 200 mW of laser power in every color is enough for a luminous flux on the projection screen of 169.4 mW, which corresponds to a total power conversion efficiency of 7%. Moreover, lasing in red can be obtained with the same crystal with similar or even better output powers. This makes the Pr:YLF laser an ideal candidate for an RGB projection source together with blue InGaN diodes.

Laser for Projection

The most widely used projection technologies are based on light valve projection. Various technologies like LCD (Liquid Crystal Display), DLP (Digital Light Processing) and LCoS (Liquid Crystal on Sili-
con) are used in combination with lamps or LEDs. Three or more colored pictures are superimposed to build the final image. These approaches enable excellent picture quality with high resolution, contrast and homogeneity. Here, lasers are also of great interest, since due to their excellent collimation, laser light can be very efficiently collected into the small étendues of projection displays.

A projection technology that is especially tailored for lasers is the flying spot technology. In this approach the light beam is scanned over the whole projection screen. For this aim, a high collimation as well as a high beam quality ($M^2 < 2$) is required. Moreover the source needs to be modulated at frequencies of 10 MHz or higher depending on the resolution. The advantage of this technology is that one can reach very high optical throughput efficiencies, even exceeding 70%. However, the image quality is lower than with conventional light valve technologies. This technology will be very suitable for microprojectors, where the requirements are less strict than for professional projectors.

For an integrated projector, a brightness of 20 lm is already of interest, since it enables to see a picture reasonably well in a darkened environment. The optical power needed in this case is ~50 mW per color. On the other hand a standalone pico-beamer should allow for use under normal illumination condition. For this purpose, a luminous flux of 100 lm is at least required, which corresponds to roughly 200 mW of laser power for each primary color [1].

The total efficiency of a projection system is the product of the efficiencies of each part: power conversion efficiency of the source, color balancing efficiency, and optical efficiencies like the efficiency of the light collection, of the display and of the involved optics. The actual best efficiency, achieved with UHP (Ultra High Performance) lamp and 3LCD projection, is 11 lm/W. Although the power conversion efficiency of lasers is lower than for UHP lamps, typically 15% for RGB-lasers (assuming 20, 10, and 20% for the red, the green, and the blue laser source respectively) compared to 30% for the UHP lamp, the total projection efficiency can be much higher with laser sources.

The most saturated colors can be obtained with lasers. RGB laser sources offer a great flexibility for the color gamut: maximal efficiency can be achieved by choosing the following laser wavelengths: 445, 550 and 610 nm, and balancing for white with the ratio 0.9:1.0:0.46. This corresponds to a luminous efficacy of 375 lm/W. The widest color gamut is obtained with 445, 523, and 635 nm and a ratio of 0.6:0.8:1.0 for white ($T_e = 8000$ K). The efficacy is then reduced to 250 lm/W. As a practical rule of thumb an equal ratio of red, green and blue with 455, 545, and 635 nm will give an efficacy of ~300 lm/W (Fig. 2). In comparison, the best spectral efficiencies of a UHP lamp, with rebalancing to white can reach 160 lm/W.

Due to the narrow spectral linewidth and the collimated beam of lasers, the requirements for the display and optics are less stringent, smaller optics or simpler coatings are possible, which results in higher efficiency. Very important is the much superior collection of a collimated beam compared to a lamp: even with very compact systems, characterized by the smallest étendue, efficiency values close to 1 can be obtained with lasers, compared to 0.6 with UHP lamps and

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**Fig. 1.** Energy level scheme of Pr:YLF with several transitions in the visible wavelength range.

**Fig. 2.** Color gamut from RGB lasers on CIE 1931 Chromaticity diagram.