

39.1: Distinguished Paper: Laser+LCOS Technology Revolution

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Abstract

The advent of affordable direct diode lasers changes all the rules for optical designs and the associated technologies that generate the images from the laser light. We foresee these new lasers as driving fundamental changes in the size, power consumption, cost, resolution, and even the uses for pico projectors. This paper discusses these topics from the perspective of laser light illuminated LCOS microdisplays.

1. Introduction

Pico projectors are just in their infancy, and as a technology that has only been on the market for a few years, all but a small percentage of the products are based on affordable LED illumination. There have been to date relatively few laser products based on frequency doubled green lasers. But all this is about to change with the multiple announcements [1-4] of direct green laser diodes and the expectation that they will become affordable over the next few years. In theory, lasers will eventually cost less than LEDs for a given light output since more light can be generated per unit area of the semiconductor substrate.

The focus of our company is on building LCOS microdisplays, and we have been considering how the trends in lasers will drive the requirements for our microdisplays. Lasers are not “just another light source”; they are truly a “disruptive technology” that will drive dramatic changes in the shape, use, and number of end products.

2. Laser Illuminated LCOS(Laser+LCOS)

Lasers are a nearly ideal light source for illuminating small LCOS microdisplays that we will shorthand as “Laser+LCOS.” Since the laser light starts with near zero étendue, it means that very high optical efficiency can be obtained from even small microdisplays. While lasers may cost more than LEDs for the next few years, they save cost by enabling smaller microdisplays and simpler, less expensive optical components. At the same time, Laser+LCOS will be extremely energy efficient compared to other display technologies.

Figure 1 shows the optical laser engine taken out of a production product that uses our 800x600 LCOS microdisplay [5]. The original design used direct red and blue laser diodes and a frequency doubled green laser. We are now using this engine as a test bed for checking out the new direct green as well as alternative direct blue and red lasers.

When many people first hear of laser projection they often think of laser beam scanning (LBS) where one or two mirrors will sweep the 3 (RGB) laser beams in a raster similar to a CRT scanning. We believe Laser+LCOS has several advantages over LBS including eye safety, lower power consumption, higher resolution, and the ability to reduce speckle because the light does not have to use single mode lasers for a good light spot in scanning and fit through a single pixel size aperture.

3. Benefits of Laser Light

One of the hardest things for people (even highly technical ones) to believe is that Laser+LCOS projectors are “focus free” because they have a projection lens. In their common experience with

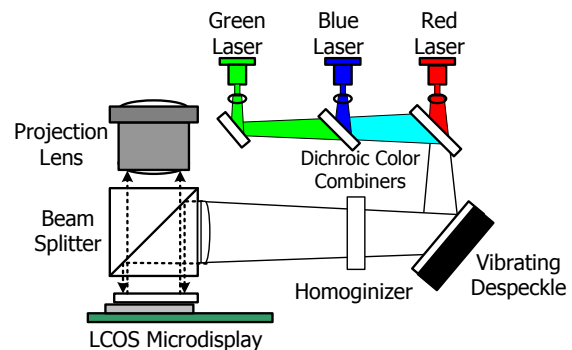
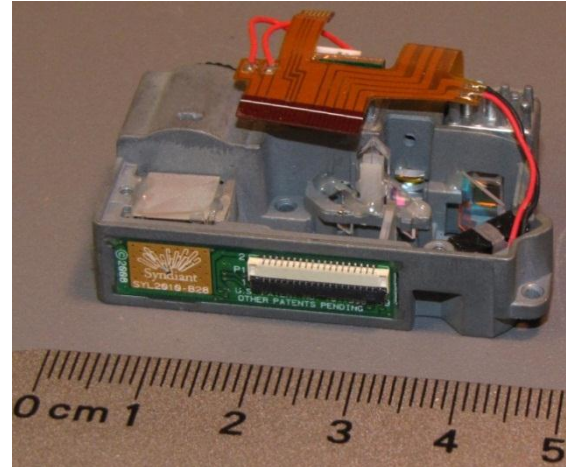


Figure 1. Laser+LCOS projection engine and optics engine

projectors and cameras, a lens is a way to “focus light.” Even after spreading the light and any speckle reduction, the laser light remains at a high f-number. The high f-number of the illumination and the wide angle lens results in a projected image that is in focus from a very short distance from the projector to infinity.

The high f-number light means that all the light is efficiently collected by small, high f-number optics which reduces the overall size of the projector. This high f-number light also makes building very short throw and high (100% or more) offset optics, much simpler as the optics only need to get the light directed to the right places without having to also work to keep it in focus. The ability to implement short throw and high offset projection with small optical components will be important in meeting the form factor requirements for many mobile applications.

Laser light also supports going to very high brightness since the étendue does not increase significantly even with multiple laser emitters. In fact, power efficiency can even improve with bigger laser cavities at higher brightness. This is in sharp contrast with LED illumination where efficiency drops due to increasing étendue and the self-heating of the LEDs.

A benefit particularly important to LCOS microdisplays is that most lasers provide the highly polarized light required by LCOS panels. In the case of “mode hopping” lasers where the polarization varies, the fact that the laser light has such low étendue means that polarization recovery can be used with little light loss while reducing speckle because the two orthogonal polarizations of laser are incoherent with respect to each other.

4. Issues with Laser Light

With the advantages of laser also come some issues, the most important of which are eye safety and speckle. Additionally there are more conventional issues such as shaping the light beams and homogenization.

In terms of eye safety, panel-based projectors have a big advantage over LBS as has recently been discussed in a series of papers by Dr. Ed Buckley [6-7]. The conclusion of these papers was that LBS is limited to less than 20 lumens at Class 2 whereas a panel-based projector would be about 20 lumen at Class 1 and could go to several hundred lumens at Class 2 with a 1.3:1 throw lens. Moreover, for a microdisplay system, the maximum brightness will be significantly increased for each safety classification by using a shorter throw projection.

Speckle is the next issue commonly associated with laser projection. This is an area where the direct green lasers are most desired as frequency doubled lasers typically have a very narrow spectral width of about 0.1nm whereas the direct green lasers [8] can be on the order of 2nm. Microdisplays have an added advantage in that the light is spread and run through multi-path despeckling elements and/or electrically or mechanically modulated diffusers in the process of illuminating the microdisplay. The combination of the wider spectrum direct lasers, high frequency laser modulation to induce mode hopping, and electrical and/or electromechanical despeckling elements results in an image where speckle is no longer an issue for Laser+LCOS systems.

5. Effect of Lasers on Microdisplays

With LED illumination, there is a constant need to trade off panel size versus optical efficiency and this has resulted in relatively large microdisplays with what will soon be seen as large (greater than 7µm) pixels. Lasers, with their low étendue, change all the rules and this will drive significant changes in microdisplays.

Smaller Pixels – The first and most obvious trend will be to go to smaller pixels. Smaller pixels will mean smaller, less expensive microdisplays and more compact optics. Whereas typical microdisplays have pixel pitches on the order of 7.5µm to 9.5µm today, with Laser+LCOS we expect to see pixel pitches below 5µm.

Higher resolution – Lasers will initially be more expensive than the LED light sources they replace and with this higher cost will

be the desire to add more functionality by way of resolution. We expect that 720p and eventually 1080p resolutions will become common with Laser+LCOS pico projectors. The ability to make small pixels with LCOS will enable high resolution with small, cost effective LCOS microdisplays.

Power per pixel (PPP) – Lasers are going to greatly improve the energy conversion to light and enable embedding 30+ lumen projectors in products like cell phones. At the same time they enable (and in some ways drive) the desire for higher resolution.

To stay within the power budget for an embedded pico projector as the resolution increases to HD, the power per pixel (PPP) has to be dramatically reduced. Any power savings on the panel will be directed to giving more light output from the lasers and/or extending battery life.

Field Sequential Balance – Generating a “white” color point requires significantly more green light while the output of the green lasers is going to be substantially less than that of blue and red lasers. Field sequential color systems will compensate for this by giving substantially more time to the green color fields.

Very saturated laser colors at different wavelengths – The wavelengths and highly saturated color of laser light require some processing when dealing with the content using more limited color spaces such as NTSC. Color matrix processing can be performed to prevent over saturation of the images.

More memory and processing on the panel and ASIC – Pico projector microdisplay systems use field sequential color which requires frame rate conversion from a field format to field sequential color. As resolution increases, it becomes impractical to integrate the field buffering on the microdisplay. Our solution is to do the main buffering on the ASIC while a smaller amount of data necessary for the current color field is stored and processed digitally on the microdisplay (see Figure 2). But sending all the data for each color from the controller ASIC to the panel would in and of itself take a lot of power. To address these issues, our new HD designs are incorporating more memory and processing on the microdisplay and new algorithms which will send less data between each change in color.

The new ASIC is also supporting more processing, including color matrix processing, to adjust for the color points of the saturated laser light and support trading off color saturation versus

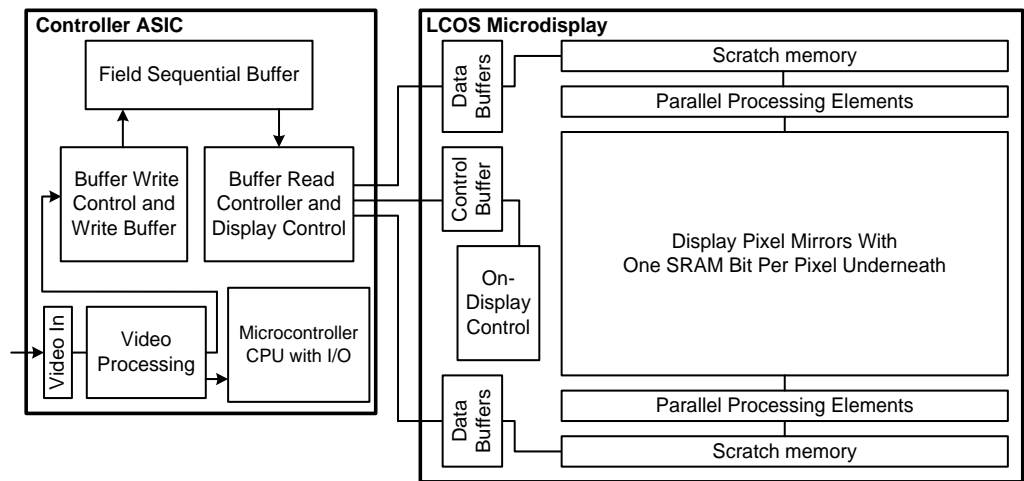


Figure 2. Split of memory and processing between the ASIC and the LCOS Microdisplay

brightness. Additional power savings will be obtained by adjusting the laser brightness in dark scenes, a form of “digital iris.”

6. Impact of Lasers on LCOS LC Design

Lasers have a narrower beam spread than LEDs, which enables the same percentage of light to be collected using smaller LCOS panels, which is critical for embedded applications and reduces cost in both embedded and high brightness projection. As the panel gets smaller, then the pixel size must also shrink in order to maintain high resolution. In order to suppress fringe field effects in the liquid crystal, the cell gap must also decrease [9]. A smaller cell gap is beneficial to the response time, but it could negatively impact yield and/or uniformity. However, the yield loss is mitigated by the increase in chips per wafer and smaller display diagonal, which will improve cell gap uniformity and on the whole result in lower cost [10-11].

A laser’s high f-number will have a measurable effect on the contrast ratio that depends on the angular distribution of residual birefringence in the dark state of the liquid crystal mode employed. Some liquid crystal designs will become simpler to compensate or become acceptable without compensation. (This discussion assumes on-axis illumination using a polarizing beam splitter system). For example, the normally white self-compensated 60° twisted nematic mode has poor contrast off-axis [12], which indicates its contrast ratio should benefit from increasing f-number as the experimental results from other twisted nematic modes show [13]. However, the contrast of the uncompensated normally black vertically aligned mode actually worsens with increasing f-number when a high pretilt angle (from vertical) is used to discourage defects [14].

7. How Lasers Will Change End Products

The most obvious effect of using lasers will be in the size and efficiency of the projection engines [15-16]. Figure 3 shows the expected trend in lumens per watt for Laser+LCOS. This trend is for a “full white” screen with no consideration given to dimming the lasers during dark scenes. The graph factors together a combination of the expected improvements in laser wall plug efficiency (WPE) and more optimal color wavelengths, LCOS microdisplay optical throughput, and improvements in the rest of the optical engine. It should be noted that the efficiency of lasers remains about the same or improves at high brightness, which opens up the market for Laser+LCOS applications in small portable projectors and high brightness projectors. Most high brightness projectors today are illuminated by mercury vapor lamps because LEDs become very inefficient in high brightness projection and it is expected that eventually even movie theater projectors will use lasers for solid state illumination.

In looking at Figure 3, one can see the expected brightness over time for an embedded application (such as a cell phone) that has a power budget of only 1 watt. Lasers simplify and shrink the optical design so that optical engines less than 6mm thick and with volumes on the order of 3cc are feasible and even 1cc may be possible using holographic lenses combining the lasers into a single package. We are working on the LCOS technology that we expect will eventually go to 1080p resolution in this form factor.

We believe that lasers are also going to drive a change in the way most projectors are used. Today almost all LED pico projectors simply project out onto a vertical surface like a wall or a screen. Typical LED pico projectors have a throw ratio (image diagonal:

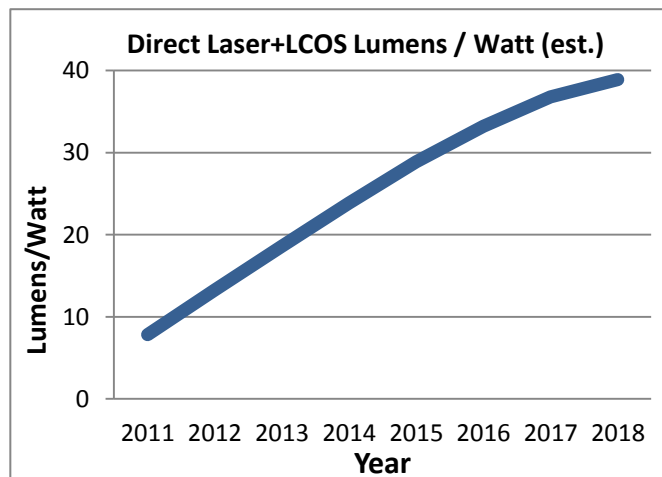


Figure 3. Expected Lumens/Watt Trend for Laser+LCOS

distance to the screen) from about 1:1 to 0.5:1. Because laser light is higher f-number, it will be possible to make very short throw optical engines with throw ratios on the order of 5:1 and with 100% offset (relative to the projected plane). This means that an engine only ~3 inches (~7.6cm) from the screen could project a 15” (38cm) diagonal image.

Very short throw projectors will in turn change how pico projectors are used. We expect to see pico projectors on the wall projecting images and computer information and shooting down on desktops to give image sizes and resolutions higher than an iPad™, but in a form factor that easily fits in a pocket. These projectors will use cameras to read hand gestures for input. Some projectors may also use infrared “structured light” to aid in recognition. Everything from computer uses, to video games, to simple hang-on-the-wall pictures/commercial displays are envisaged. The uses and applications for laser pico projectors are almost boundless.

8. Ultra-Green Television

Flat-panel LCDs currently have only 4–6% transmittance of light generated by LED or florescent backlights due to a combination of color filters, black matrix masks, diffusers, polarizers, metal structures, and transistors with an improvement to 8% being targeted [17]. A Laser+LCOS optical system today can have >35% light throughput and this could rise to >50% with a series of improvements in the LCOS devices and the optical designs as they are optimized for laser illumination. Therefore, there is the potential to build displays that use less than 1/10th the power of today’s flat panels.

There is a second way to view the graph in Figure 3 and that is to consider the power consumption of an energy efficient, ultra-green, television. By about 2014, a 50-inch diagonal television would consume only about 20 Watts.

Because the LCOS microdisplay is so small, only a tiny fraction of the materials needed for LCD flat panels are consumed in the manufacturing processes. The factories for LCOS assembly are also smaller and vastly less expensive to build than an LCD flat panel factory. When this is added to the power savings of the Laser+LCOS displays themselves, it should make television based on this technology very attractive, particularly in emerging markets.



Figure 4. Laser+LCOS side by side projected images with Nichia, OSRAM, and Soraa direct green and blue lasers

9. Direct Green Laser+LCOS Progress

In the last year there has been remarkable progress in direct blue and direct green laser development by multiple companies. As little as a year ago, there were no direct green lasers available except for very short lived lab prototypes, but by January 2011 we were the first to demonstrate side by side working pico projectors that used direct green and blue lasers from three (3) different companies, namely Nichia, OSRAM, and Soraa (see Figure 4).

There is still some significant progress that needs to be made both in terms of power efficiency, color wavelengths, and lifetimes. For example, a green wavelength of about 530 nm to 535 nm is considered most desirable, but the current green laser are generally in the 510 nm to low 520's nm region. The good news is that we continue to see rapid progress with the laser developments.

10. Conclusions

Laser+LCOS can revolutionize the way we view displays today. With ultra-low power, small size, and ultimately low cost, displays can be put anywhere. They are likely to proliferate similar to the way cameras have today. Laser+LCOS supports high resolution while making very small and energy efficient devices and the ability to be focus free will add to their utility.

And when we consider the energy efficiency advantages of Laser+LCOS it could even become a factor in the television market, particularly in the energy conscious world in which we live today.

11. Acknowledgements

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