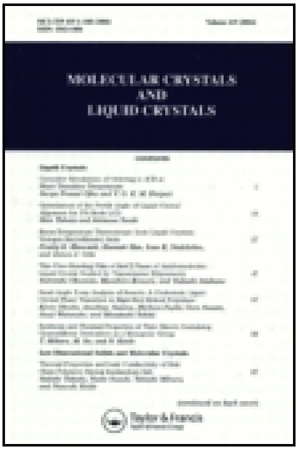

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Lasing Pixels: A New Application for Polymer Dispersed Liquid Crystals (PDLCs)

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Lasing Pixels: a New Application for Polymer Dispersed Liquid Crystals (PDLCs)

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A lasing pixel device that implements a spatially patterned variable loss element placed inside an optically pumped high-gain laser cavity is presented. A polymer dispersed liquid crystal (PDLC) modulator was used as the loss element. A projection device has been developed with high output, high on-screen contrast (>1000:1), and narrow spectral linewidth (~3 nm). These positive characteristics make such a device attractive for a non-scanned laser projection system. A model of PDLC lasing pixel output versus element loss will be presented and compared to electro-optic measurements. PDLC materials from EM Industries have been optimized for this application.

Keywords: polymer dispersed liquid crystal (PDLC); projection; lasing

INTRODUCTION

Consumers in the market for projection systems can choose among liquid crystal, cathode-ray-tube (CRT), plasma, and digital micromirror technology. Large screen projection systems are familiar to us who own one for our home or who have visited a sports bar or night club. Although these systems project very large on-screen images, it is often necessary to dim the room lights to see the screen more distinctly, and even then, the image may appear a slightly blurred. Most of these problems, dimness and blurring, arise from the need for more optical power and greater spectral purity. Both of these requirements can be satisfied by laser illumination sources.

First investigated in the 1970s, the use of lasers in projection systems has experienced a resurgence in interest over the past few years, fueled by the development of improved laser technology. Steady advances in laser technology have not only made laser projection systems pervasive, but have permitted their migration into convention centers and other large forums. Many companies, including *Sony Corporation* (Yokohama, Japan), *Laser*

Corporation for Laser Optics Research (COLOR; Portsmouth, New Hampshire), and *Laser Display Technologies* (LDT; Gera, Germany), have developed laser based projection systems. While current laser projection systems have evolved into highly capable systems (large, bright, and sharp images), they suffer from a number of shortcomings which may limit their future utility in the potentially vast projection market. First, laser projection systems are expensive, considerably more than $100,000 US dollars and are therefore limited to high-end applications (*e.g.* convention centers, entertainment industry, etc.). Second, they typically incorporate three large and power hungry lasers that have considerable space ad electrical requirements. Finally, they require scanning techniques and the associated maintenance for all mechanical subsystems involved.

It is our contention that a transition to projection systems using laser illumination is inevitable; however, the move from today's conventional projection systems to laser projection systems will present a formidable challenge. In an attempt to overcome many of the shortcomings associated with current laser projection systems, we have begun the development of a unique projection system based on the concept of an image mode.[1] The technique involves generating full-color pictures by mixing three image sources of different colors (red, green and blue). Furthermore the approach builds on mature optical configurations used in conventional projection systems (three path RGB) and on the material advances of polymer dispersed liquid crystals (PDLC). Conventional projection systems using PDLC light valves are being developed because of their superior optical performance as compared to polarizer based light valves.[2,3] This novel approach uses an un-scanned solid state laser to provide the pump energy for the lasing process thereby eliminating the need for the scanning of individual lasers while preserving brightness and color purity.

EXPERIMENTAL RESULTS

The image mode concept behind this revolutionary technology is presented in Figure 1. At the heart of this technology is a spatially patterned loss element (PDLC) placed inside the laser cavity. The pixel at zero voltage (left) is highly scattering, due to the random orientations of the symmetry axes of the liquid crystal droplets, and presents a large loss for the cavity. When the voltage is applied to the pixel (right), the liquid crystal droplets align their symmetry axis along the applied electric field direction, and the cell becomes transparent if the ordinary index of refraction of the liquid crystal is closely matched with the polymer index of refraction. The transparent condition brings the selected part of the laser above threshold.

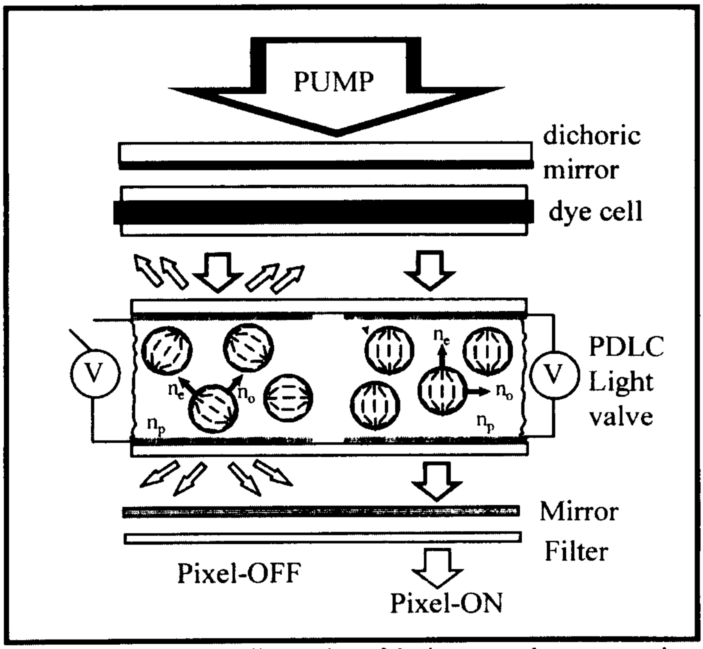

Figure 1: Schematic illustration of the image mode concept using a PDLC in intracavity operation.

This is in contrast to placing a PDLC in front of an intense coherent or incoherent light source, resulting in the situation in which maximum brightness is limited by the amount of incident light that the PDLC can withstand before being irreversibly damaged. In the intracavity mode use, only when a part of the PDLC is rendered transmissive does a significant internal optical field interact within the liquid crystal material.

The actual display system consisted of a pixelated dye laser source pumped with 2 W of light in the form of 7 ns pulses from a Q-switched Nd:YAG laser operating at 532 nm at 30 Hz. The gain medium consisted of Rhodamine 6G in ethylene glycol solution, at a 0.025 molar concentration flowing through a 500 mm thick cell. The PDLC intracavity loss element was a 7×7 passively addressed array with 100 μm square pixels. The PDLC materials used in our system were acquired from *EM Industries* (TL/PN series). We optimized the PDLC system (20% PN393 photoreactive polymer and 80% TL205 liquid crystal) to provide low switching voltages, acceptable scattering efficiencies, and no hysteresis.

By activating various pixels, you can generate an image. Figure 2(a) shows the far-field image that was created by focusing the output beam to image the plane of the PDLC onto the screen. Lasing efficiencies of approximately 40% were recorded when a 100% reflective dichroic mirror and the glass-air interface were used as the laser cavity mirrors corresponding to a 600 lm/cm^2 at 570 nm. This result can be compared to projection CRT devices with recorded outputs of 5 lm/cm^2.[4]

For demonstration purposes, we also inserted an ITO etched PDLC display inside the cavity to show a text image projected onto the screen (see Figure 2(b) and (c)). In addition to the change in the PDLC, we also replaced the flowing dye cell with a solid polymer dye sheet. A solid dye sheet have several advantages; namely, it is lightweight and robust, easy to change, and does not have the associated noise of the flow pump. The dye sheet was fabricated from a 75%:25% mixture of MMA/HEMA with Rhodamine 610 as the dye dopant. The output is at 585 nm with a 3-4 nm lineswidth. These three positive attributes make it advantageous to use; however, lifetimes of these films are only hours at best. Concurrently to the lasing projection development, we are also investigating dye doped polymer films for improved lifetimes.

(a) (b)

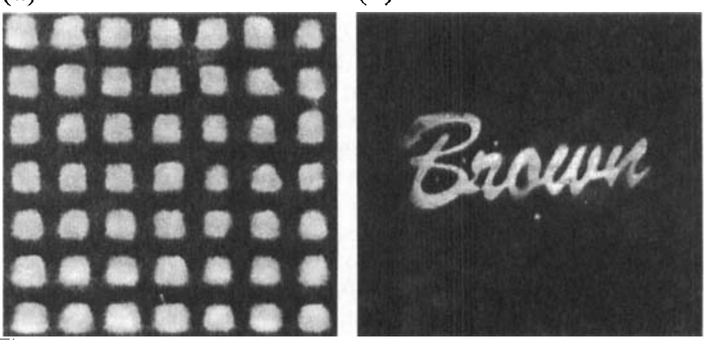

Figure 2: Lasing pixel output projected onto a screen demonstrating a 7×7 array of 100 μm pixels (a) and text (b).

The measured output intensity from a 100 mm lasing pixel was measured and is presented in Figure 3. The results clearly demonstrate the precise control over the output lasing intensity gives rise to intermediate levels of intensity (gray scale). Figure 3 demonstrates gray scale control and high on-screen contrast, and the inserts show the spectral purity of the emitted light in the pixel-off and pixel-on states. Spectral purity is of the utmost importance when full-color is considered. Our actual on-screen contrast, measured with a spectro-radiometer, exceeds 1000:1.

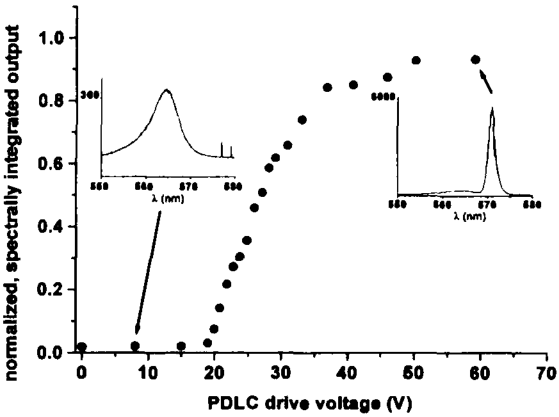

Figure 3: Voltage control of the lasing pixel light valve using rhodamine 6G as a gain medium. The total spatially integrated output energy of a 100 mm lasing pixel is shown. The inserts are representative of the output spectra at low and high voltages, corresponding to fluorescence and lasing well above threshold.

SIMULATIONS

In order to find the critical dimensions to maintain a desired image mode, numerical simulations were performed using the Fox and Li formalism.[5] The two mirrors depicted in Figure 1 were assumed to be perfectly reflecting and infinite in extent as compared to the pixel width. The pixels were modeled as infinitely thin slits, placed in the resonator in accordance with our experimental geometry. The resonator is modeled as an infinite progression of slit apertures, with a length between apertures alternating between twice the distance from the PDLC to the dichroic mirror, and twice the distance to the output coupling mirror. Because the flat high Fresnel number geometry violates the small-angle approximation, the complete integral of the Fresnel diffraction kernel was used in the simulations.

A variety of simulations were performed for a simple eight pixel array. The numerical experiments varied the resonator lengths, pixel widths, and pixel separation in order to find the regime of resonator conditions where the system would emit an image mode which was a replica of the internal loss pattern. Defining a pixellation Fresnel number, $N_F = ab/2\lambda L$, where a is the pixel width, b the pixel separation, and L is the distance from the PDLC to the most distant mirror, we were able to show that this quantity had to be of the order of $N_F \geq 2$ to produce image modes. Figure 4 shows how the mode confinement in an 8-pixel array breaks down as N_F decreases. Confining the mode is an important requirement for producing the desired image as well as preventing the off-state area from damage due to a high optical field .

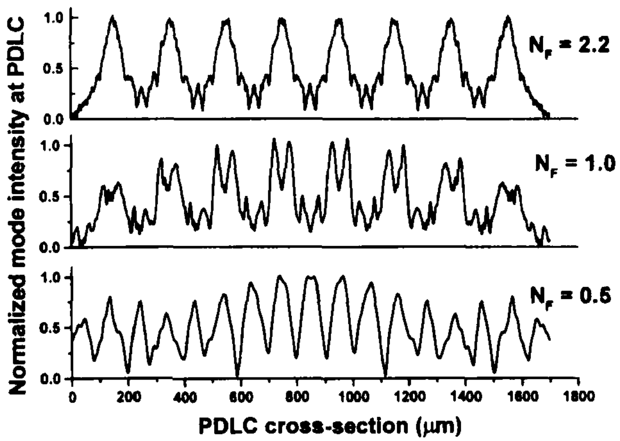

Figure 4: Numerical simulations of stable mode profiles for a device with 8 pixels in the pixel-on state. A lasing transverse mode which reproduces the pixellation pattern is possible for resonators with sufficiently high pixel Fresnel number N_F.

CONCLUSIONS

Lasing PDLC pixel arrays look very promising for a new generation of advanced projection systems. We are currently transitioning from laboratory passively driven prototypes to high resolution active matrix substrates and drive schemes. This is extremely difficult because active matrix substrates are sophisticated technologies that are difficult to assemble in the laboratory. In addition, active matrix substrates put limitations on the PDLC materials; for example, they must be low switching voltage, they must be hysteresis free, and they must have a high voltage holding ratio (VHR). We believe that the PN/TL materials set from EM Industries meets these three criteria. In addition we are developing novel optical configurations for the proliferation of full-color using the third harmonic of a Nd:YAG laser as a pump source. Based on our demonstration of this concept, with 355 nm pumping of other blue and green emitting laser dyes such as the coumarins and stilbenes, we believe that a single pump laser system based on a long life diode pumped Nd:YAG laser is quite feasible. Figure 5 shows a schematic of such a configuration. In order to achieve the greatest possible image color palette, the RGB components must be chosen near the three corners of the chromaticity diagram by a proper choice of the organic dyes and dichroic mirrors in the individual systems.

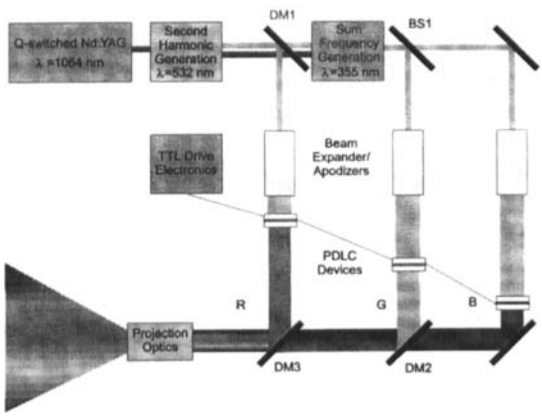

Figure 5: A three-pass lasing projection system using only one laser. The green and blue gain media are pumped with the third harmonic while the red is pumped by the second harmonic.

Experiments are also in progress to integrate the gain into the PDLC light valve so that the dye cell and mirrors can be removed and scattering is used to provide the requisite feedback for laser action.[6,7]

Acknowledgments

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