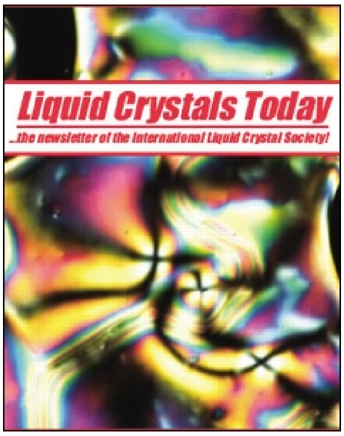

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Lasing Pixels: A New Application for PDLCs

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Lasing Pixels: A New Application for PDLCs

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Pixels in an intracavity polymer dispersed liquid crystal can switch lasing action on and off, yielding addressable lasing pixels for projection applications. The marriage between an efficient PDLC display element and laser illumination consolidates the positive attributes of two different approaches to projection into a very capable technology with greater application potential. This radically different approach to projection certainly meets many of the market needs where current technologies fall short. With these needs met, a new application of PDLC technology is on the horizon.

Laser projection revisited

Consumers in the market for projection systems can choose among liquid crystal, cathode-ray tube (CRT), plasma, and digital micro-mirror technologies. Large screen projection systems are familiar to those of 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 slightly blurred. Most of these problems of dimness and blurring arise from the need for more optical power and greater spectral purity. Both of these requirements can be satisfied by laser sources.

First investigated in the 1970s, the use of lasers in projection systems has experienced a resurgence of interest over the past few years, fuelled by the development of better laser technology. Steady advances in laser technology have not only made laser projection systems pervasive, but have permitted their migration into convention centres 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 centres, entertainment industry, etc.). Second, they typically incorporate three large and power-hungry lasers that have considerable space requirements. Finally, they require scanning techniques with the associated maintenance for all subsystems involved.

The lasing pixel from PDLCs

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-colour pictures by mixing three image sources of different colours (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 unscanned 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 colour purity.

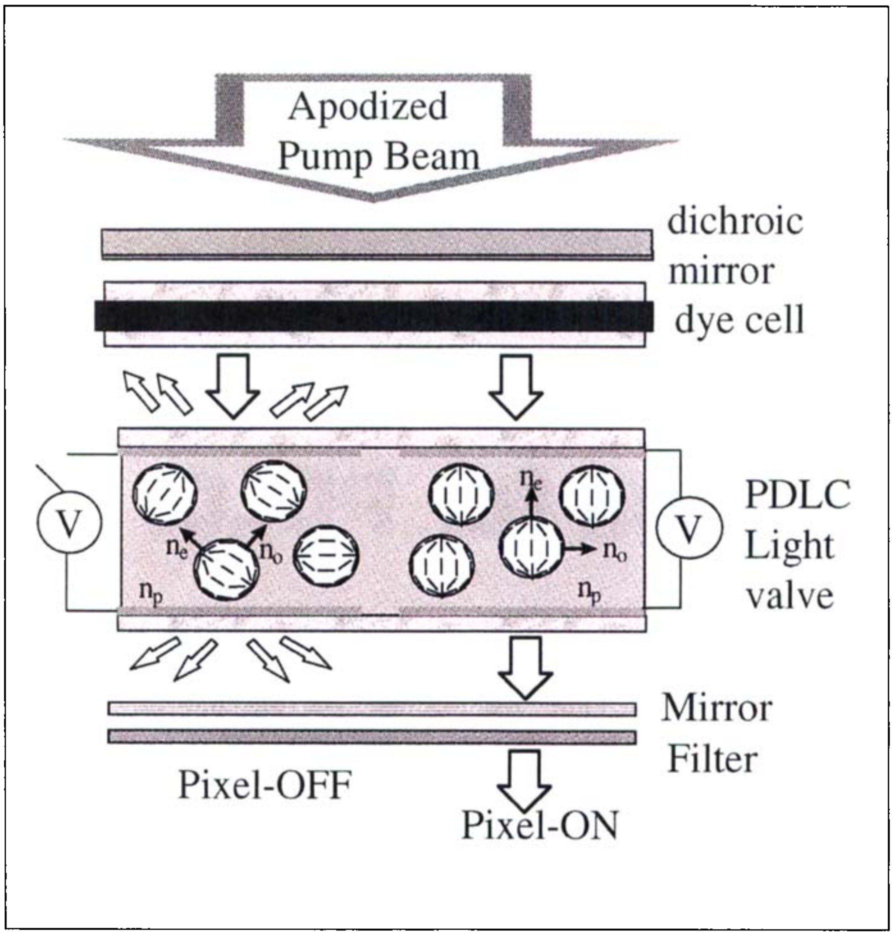

Figure 1. The heart of the lasing pixel projection engine. Schematic representation of a lasing pixel array in the pixel-on (left) and pixel-off states (right).

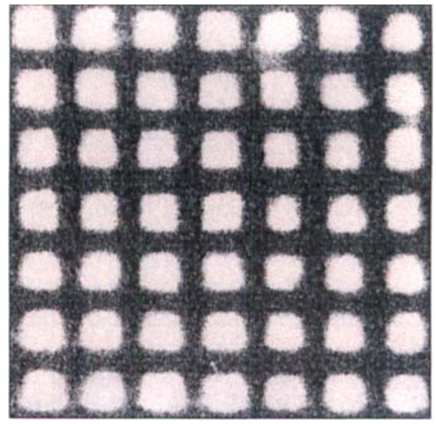

Figure 2. Test image output of an optically pumped 7×7 PDLC array.

The image mode concept behind this evolutionary 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 axes 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.

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 with the liquid crystal material.

The actual display system consisted of a pixellated 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 μm thick cell. The PDLC intracavity loss element was a 7×7

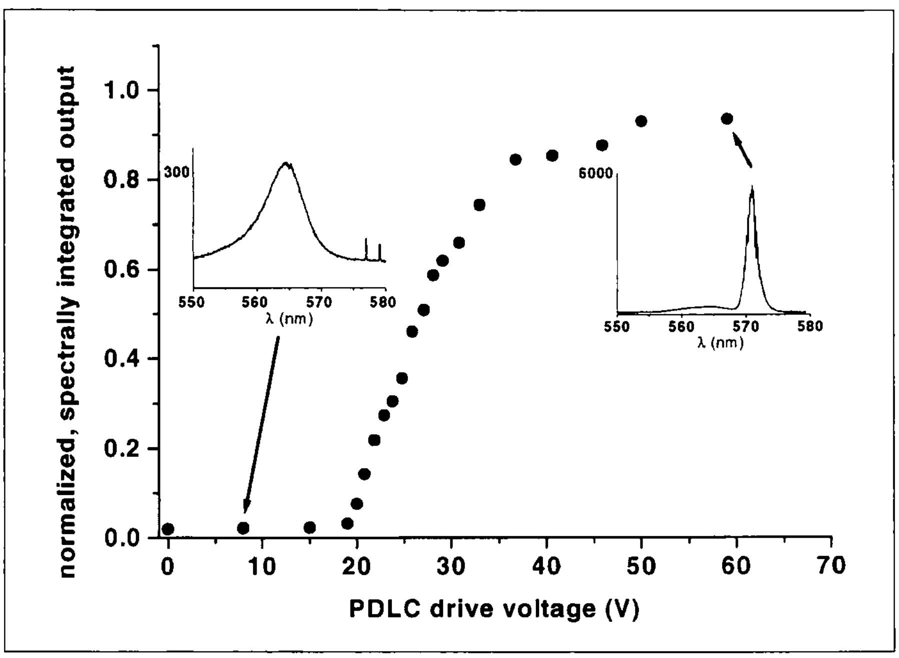

Figure 3. Voltage control of the lasing pixel light valve using rhodamine 6G as a gain medium. The total spatially integrated output energy of a 100 μm lasing pixel is shown. The inserts are representative of the output spectra at low and high voltages, corresponding to fluorescence and lasing well above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

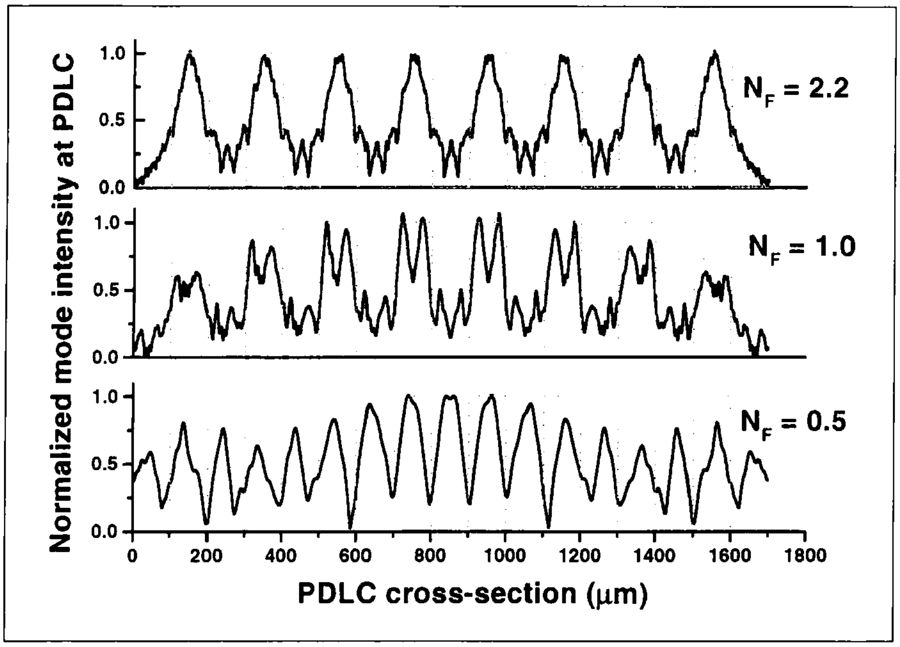

Figure 4. Numerical simulations of stable mode profiles for a device with 8 pixels in the pixel-on state. A lasing transverse mode which reproduces the pixellation pattern is possible for resonators with sufficiently high pixel Fresnel number NF.

passively addressed array with 100 µm square pixels. The PDLC materials used in our system were acquired from EM Industries (TL/PN series). By activating various pixels, you can generate an image. Figure 2 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].

The measured output intensity from a 100 µm lasing pixel was measured and is presented in figure 3. The results clearly demonstrate the precise control over the output lasing intensity giving rise to intermediate levels of intensity (grey scale). Figure 3 demonstrates grey 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.

Optimizing lasing pixels

In order to find the critical dimensions to maintain a desired image mode, numerical simulations were performed using

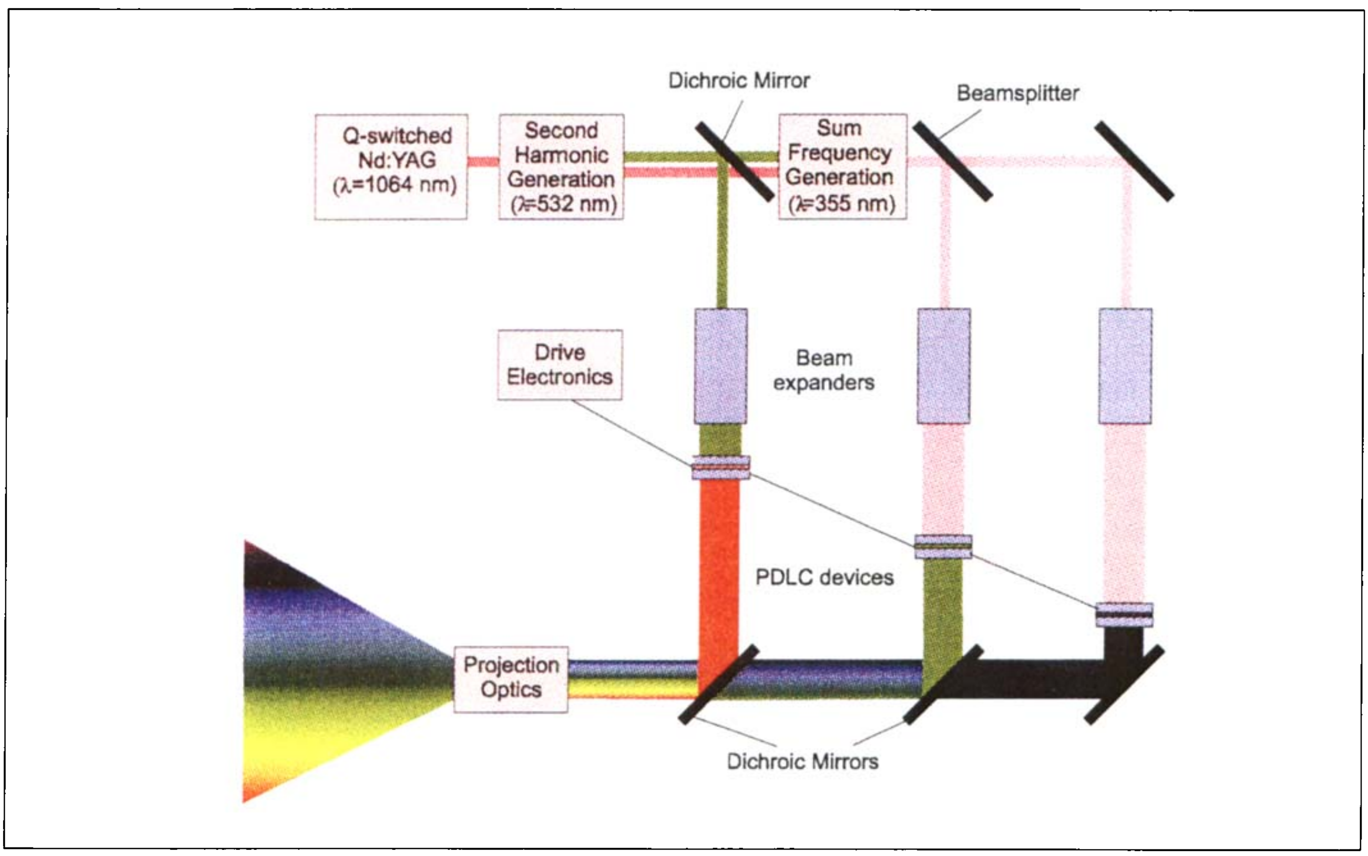

Figure 5. One example of a full-colour lasing projection system using one pump source. The green and blue gain media are pumped with the third harmonic while the red is pumped by the second harmonic.

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 modelled as infinitely thin slits, placed in the resonator in accord-ance with our experimental geometry. The resonator is modelled 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 8-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.

The future

Lasing PDLC pixel arrays look very promising for a new generation of advanced projection systems. We are currently moving from laboratory passively driven prototypes to high resolution active matrix substrates and drive schemes. In addition we are developing novel optical configurations for the proliferation of full-colour 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 colour 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.

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]. More technical details on the lasing PDLC pixels will appear in the literature [8].

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COMPANY AND MARKET NEWS

Market Trends for Flat Panel Displays

A recent report from Stanford Resources entitled 'Flat Panel Monitor Market Trends 1998' presents a realistic forecast for the FPD market, which is expected to reach a shipment value of $4 billion in the year 2000. The Flat Panel Display market covers active matrix twisted nematic displays (TFT-LCD) and matrix-addressed super-twisted nematic displays (STN-LCD), and the following are highlights from the market analysis and forecasts.

- The world market for FPD monitors will reach 21.7 million units in 2004, rising from 729,000 units in 1998, and the overall market penetration of the desktop monitor market will increase from less than 1% in 1998 to 17.3% in 2004.
- The world-wide value of all FPD monitors (TFT-LCD and STN-LCD) will reach $12.5 billion in 2004 increasing from $1 billion in 1998.
- Beginning in 2000, 14 inch and 15 inch FPD monitors will dominate all other screen size categories. Sales of 14 inch monitors will surge in late 1998 and early 1999, when unit street costs fall below $1000 in the US.
- The Japanese share of FPD production will fall from 65% in 1997 to less than 55% in 1998, as production accelerates in Taiwan, Korea and Europe.
- The total potential market for TFT-LCD monitors is more than 4.7 million units in 1998, but only 600,000 units are expected to be sold.
- By 2004, 15 inch LCD monitors at unit prices around $500 are expected to dominate the FPD market with sales of 9.3 million units.

Further information from:

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