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HIGH DATA DENSITY FOUR-COLOR LIQUID CRYSTAL DISPLAY

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Abstract. A very high resolution and high contrast laser-addressed liquid crystal color display has been developed for use in the acquisition and exploitation of high density alphanumeric and graphic data. The display system consists of two smectic liquid crystal light valves (SLCLV) which are thermally addressed by a single laser selectively. Each light valve is capable of generating 2048×2048 addressable pixels within a 1 in.×1 in. data format. There are 8×10^6 pixels available for data presentation. The laser writing system consists of the laser, a modulator which enables the formation of discrete data elements on the SLCLV, a two-axis galvanometer deflection unit, and beam splitting optics designed to multiplex the writing laser on each SLCLV. A closed-loop galvanometer deflection system can position the focused laser beam to an accuracy of 0.01% across the screen. The laser focus lens is an f/8.0 telecentric designed to produce a 2.54 cm×2.54 cm (1 in.×1 in.) data format on the SLCLV with spot size less than 10 μm (0.0004 in.). Color images from each light valve are superimposed onto the screen by a wide angle f/8.0 projection lens with 48× magnification which relays the combined color image to a 1.2 m×1.2 m (48 in.×48 in.) screen with less than 0.1% of distortion. The possible contrast of the display is up to 60 to 1. The overall dimension of the rear projected color display is 1.52 m×3.2 m×0.74 m (60 in.×52 in.×29 in.).

Keywords: liquid crystal display; smectic liquid crystal; laser writing system; large screen display; high resolution.

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CONTENTS

1. INTRODUCTION

With the increasing needs of data gathering, processing, and storage requirements, and the continued growth of high data density acquisition and handling, the demand for a high resolution display system is greater than ever. The thermally addressable smectic liquid crystal light valve is a very attractive candidate for a high resolution, selectively erasable, graphical data input device with data storage.

Current CRT or CRT-driven large screen displays do not provide enough resolution elements to display massive amounts of information required for presentation. A liquid crystal large screen color display with smectic liquid crystal light valves that was developed to handle the high data density graphic and alphanumeric presentation for status summary has been reported from several other laboratories.[1-5]

This paper describes an ultra high resolution four-color liquid crystal projection system which utilizes two smectic liquid crystal light valves (SLCLV) to present data in three colors on a fourth background color. The SLCLV's are optically addressed by a Nd:YAG laser through the control of a modulator and deflection system which is powered by a microprocessor. There are 2048×2048 pixel elements on a 1.2 m×1.2 m (48 in.×48 in.) screen. A flashing pointer is incorporated into the system to provide the interactive features which enable the operator to enter, modify, or delete alphanumeric and graphic data on request.

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2. PRINCIPLE OF OPERATION

2.1. Smectic liquid crystal light valve (SLCLV)

Both Schiff-based and biphenyl families of the smectic liquid crystals have been investigated in this study. These mixtures exist in a smectic state at room temperature. They may be highly scattered or highly transparent depending on whether molecules are in an ordered structure or not. The structure of the SLCLV is shown in Fig. 1. Liquid crystals are sandwiched between two substrates coated with a vacuum-sputtered indium tin oxide transparent electrode and the organic surfactant. Dow Corning's alkoxysilane, 1, 2, e.g., N, N-dimethyl-N-octadecyl-3-aminopropyltrimethoxysilyl chloride, and carboxylate chromium complexes were experimented with to induce a homeotropic alignment of the liquid crystal molecules.

2.2. Indium tin oxide coating (ITO).

Transparent conductive coatings of SnO_2 doped In_2O_3 were vacuum sputtered on the substrate surface. High optical transmission in the visible and high absorption at the Nd:YAG laser wavelength are essential to ensure the performance of the light valve. In-house sputtered ITO coating has a sheet resistance of less than 2Ω/□ and yet high optical transmission. The optical characteristic of sputtered ITO thin film is shown in Fig. 2.

2.3. Writing/erasing mechanism

At normal operation, liquid crystal temperature is biased a few degrees below the smectic-nematic transition. Switching between states is done by heating a region of the assembly so that the liquid crystal changes to the nematic or isotropic states. The local heating effect on the liquid crystal (LC) molecules is achieved by focusing a laser beam onto the ITO coating. Absorbed laser energy causes the LC molecules to trans-

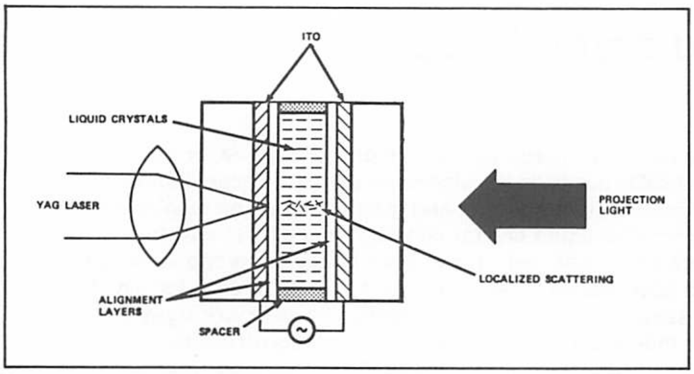

Fig. 1. Storage mode liquid crystal light valve.

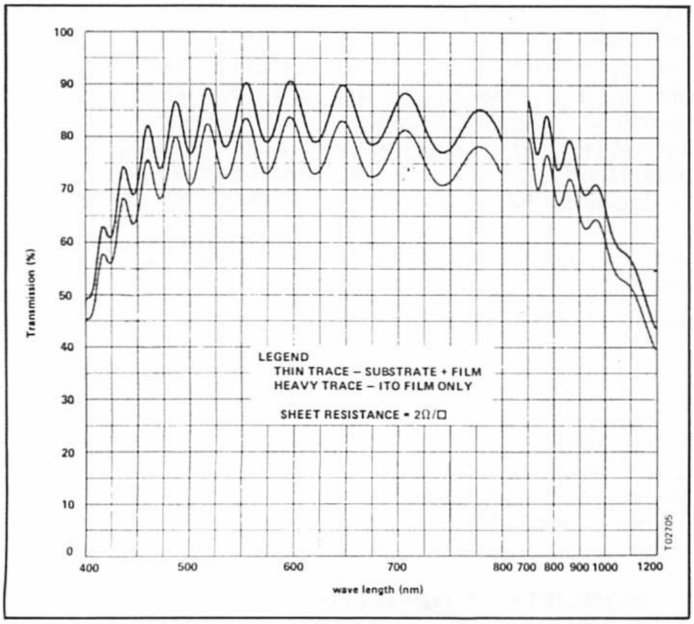

Fig. 2. Optical characteristics of vacuum-sputtered In_2O_3/SnO_2 thin film.

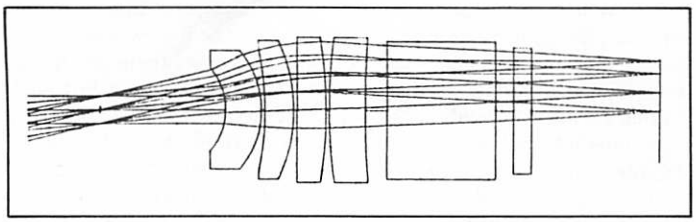

Fig. 3. Computer ray trace of the laser writing focus lens.

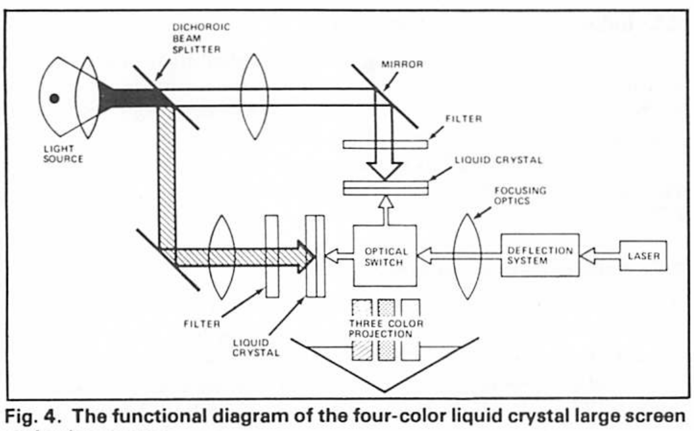

Fig. 4. The functional diagram of the four-color liquid crystal large screen projection system.

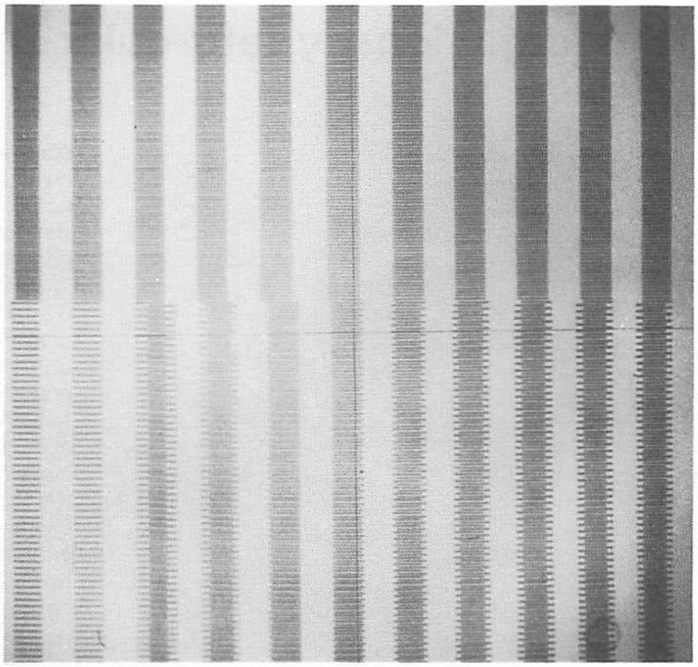

Fig. 5. Photomicrograph of liquid crystal data cell with stored resolution test pattern. Lines and spaces are 10 μm wide.

form into the isotropic state and possess a randomly oriented order. If the cooling is slow, LC molecules will align themselves and produce a clear state due to the boundary condition induced from the alignment layer on the light valve substrates. However, if the cooling is rapid, they will not be able to align themselves in time and therefore assume the random orientation to form a highly scattered state. This will show as a dark image on the screen if the light valves are projected by the projection optics to the screen.

To erase selectively, an ac bias is applied simultaneously with the laser scan. Liquid crystal molecules respond to the electric field and align into the field direction while still in the nematic state to erase the previously written image.

Bulk erase is also possible by applying an ac bias across the light valve with a higher amplitude or raising the light valve temperature to nematic state externally and then erasing by the ac bias. The typical writing and erasing rate per pixel element is about 5 microseconds, and the time delay for the erase is about 1 msec per each erase.

Due to the inherent characteristics of the smectic liquid crystals, the written image on the light valves will be stored in the display for hundreds of hours without degrading the contrast. There is no "refresh" required to display constant data on the screen.

Twelve levels of the gray scale have been generated digitally with the microprocessor control. This is achieved by laser intensity and ac bias amplitude modulation.

2.4. Optic design

A writing system consisting of a focus lens and a relay lens was designed to focus infrared energy from the Nd:YAG laser upon the SLCLV's. The entrance pupil of the scanning focus lens is located sufficiently in front of the lens to enable placement of the last deflection mirror without the mirror striking the lens or its housing. The telecentric focus lens is designed to work at f/8.0 for 1.06 μm wavelength. A schematic of the scanning lens is shown in Fig. 3. The laser spot diameter is approximately 10 μm at 50% power level.

Light valve images are projected to the screen by means of light source optics and a projection system. An f/8.0 telecentric wide angle projection lens is designed to project a 1 in. × 1 in. image on the SLCLV onto a 48 in. × 48 in. screen with distortion of less than 0.1%. The projection lens has a modulation transfer function of 50% at 40 line pair per mm. A contrast of greater than 50 to 1 is typical for the color system.

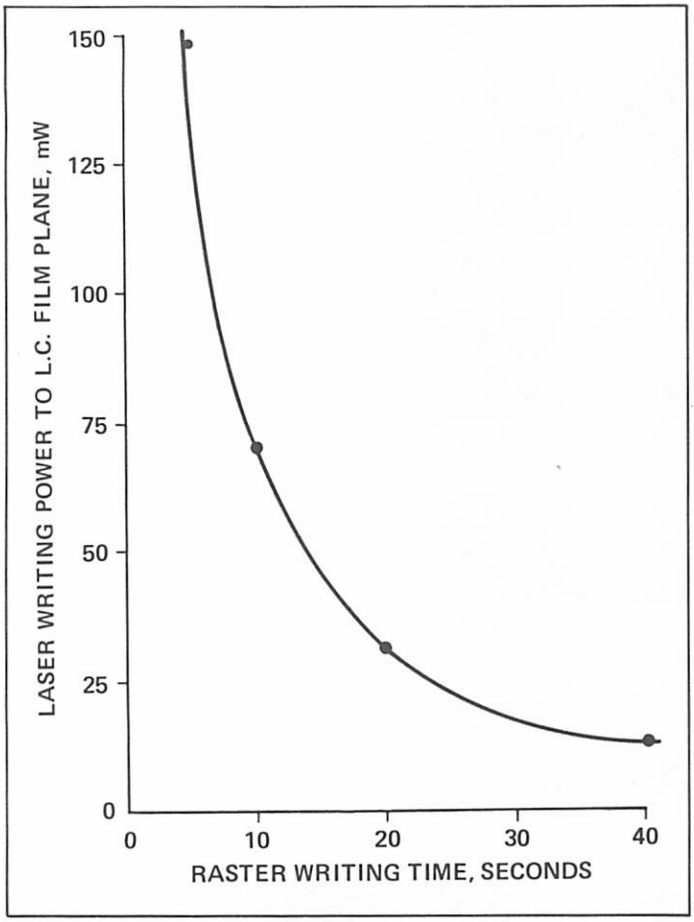

Fig. 6. Lineal writing time to produce a 1.2 cm×1.2 cm 1024 line raster versus laser writing power.

2.5. Color generation

Two SLCLV's are used in this display system to produce four colors. Information can be displayed in three colors with a fourth one as background. Figure 4 illustrates the optical arrangement of the system. The YAG laser beam is directed to address on an assigned light valve channel by means of a proprietary optical channel-selecting element. Either light valve can be addressed selectively or simultaneously to create a color spectrum between the two prime colors determined by the color filters inserted in each light valve projection path.

Through the illumination optics, the two SLCLV's are projected separately through a color filter to generate two colors (red and green) of different images on the screen. The third color image (yellow) is obtained by superimposing two identical images from both the liquid crystal light valves. The fourth color (black) is produced by clocking off the projection light by the same image in both channels. Each light valve can be operated in both bright field mode (black image on color background) or in the dark field mode (color image on a black background). Therefore, an interesting concept of color combinations can be generated by this scheme.

3. RESULTS

Figure 5 is a photomicrograph of a portion of the light valve with an image of resolution test pattern. Lines and spaces on Fig. 5 are 10 μm wide. A resolution of 2500 TV lines per inch on the SLCLV has been demonstrated.

In general, the line width of the written information is a function of operating temperature, laser power, and the writing speed. With constant writing, the line width of a written image is a linear function of the laser power. Figure 6 is the data collected from a Schiff-based smectic liquid crystal mixture.

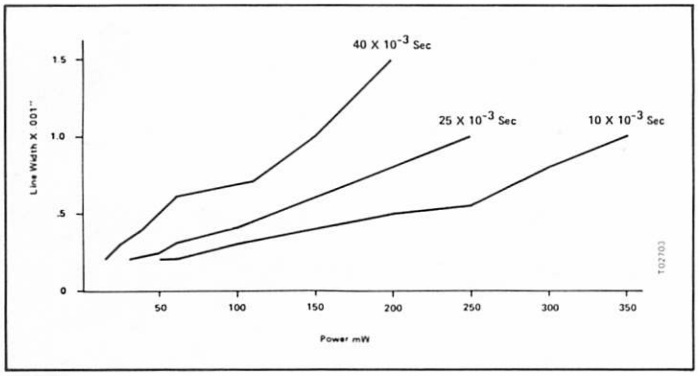

Fig. 7. Liquid crystal line width versus laser writing power at constant raster write rate. Numbers shown on the curves indicate the time for a single scan.

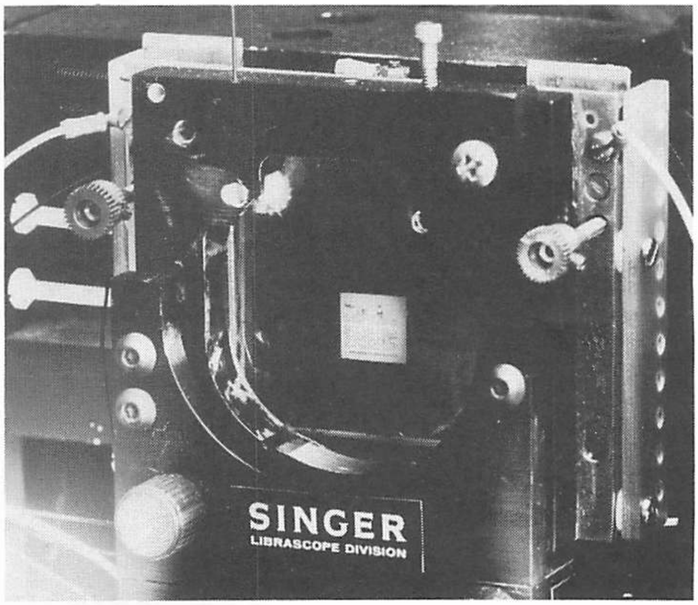

Fig. 8. Smectic liquid crystal light valve with stored image.

The laser power required to form 60 to 1 contrast at different writing speeds is shown in Fig. 7. The horizontal axis indicates the time required to perform a raster scan of 1024 TV lines on a 1.25 cm×1.25 cm (1/2 in.×1/2 in.) format on the SLCLV.

The laser writing on the liquid crystal light valve can be in raster or random access modes. The writing speed per pixel for a 2048×2048 line display is typically 5 μsec. With the raster scan mode, 2500 alphanumeric characters can be generated within a second. Figure 8 is a photo of a stored image on a 5.0 cm×5.0 cm (2 in.×2 in.) liquid crystal light valve.

A black and white photo of a three-color graphic pattern is shown in Fig. 9. These images were generated from a microprocessor which then controls the deflection system and laser intensity to write on the SLCLV in random access mode.

A three-color Army symbol presentation is shown in Fig. 10. The images shown on both figures were generated within 1.25 cm×1.25 cm (1/2 in.×1/2 in.) format (1024×1024 pixels) on the light valves with registration accuracy of less than 1/2 of the pixel element.

4. ACKNOWLEDGMENTS

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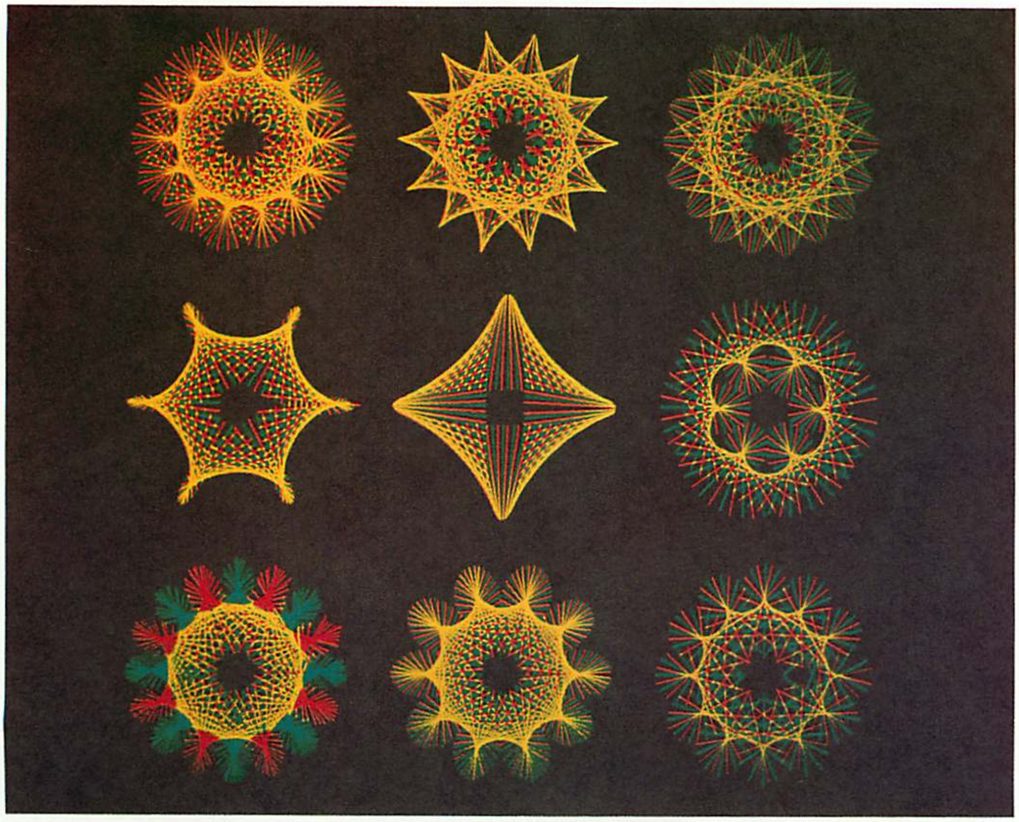

Fig. 9. Three-color computerized graphics.

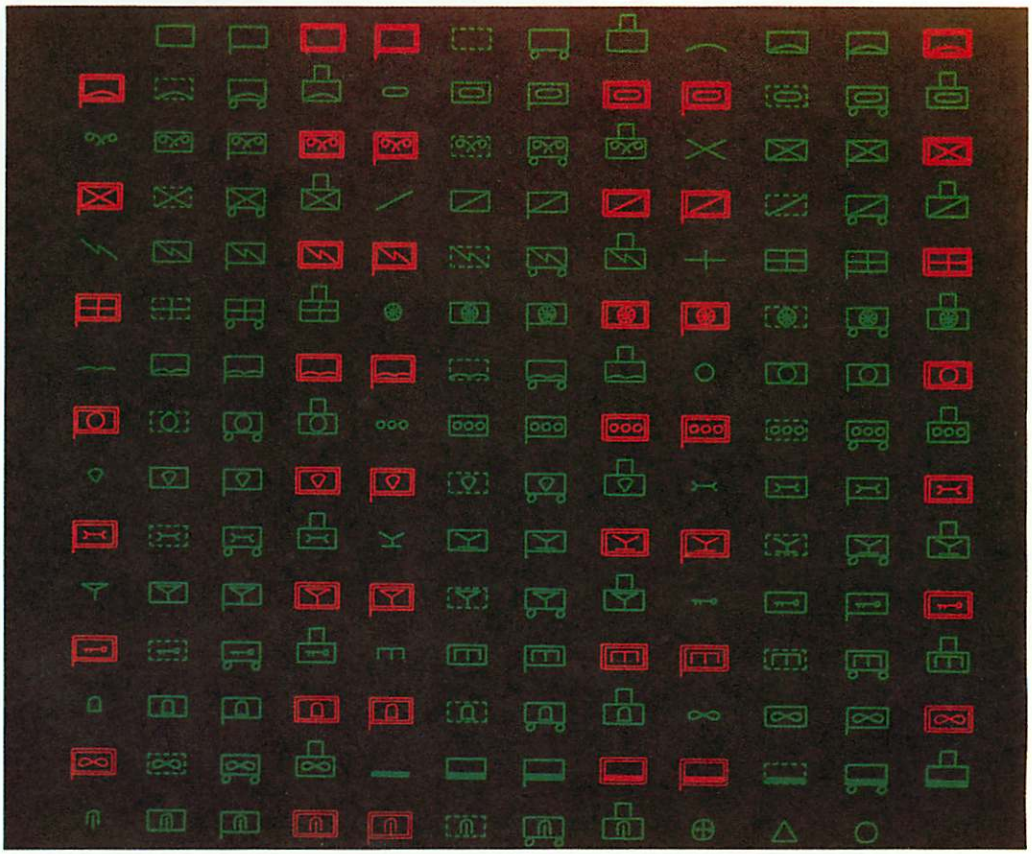

Fig. 10. Random access writing of the three-color Army symbols.

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