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NOVEL MATERIALS FOR PHOTO-LUMINESCENT LCD TECHNOLOGY

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SUMMARY: Photoluminescent Liquid Crystal Displays (PLLCDs) combine the viewing angle and brightness of a cathode ray tube (CRT) with the flat panel format of an LCD. Manufacture should be possible on existing LCD facilities without major alterations. Here we explain the PLLCD concept, describe some practical implementation issues and report on various architectures being considered. Results are presented for a number of key components used in our demonstration displays. The opportunities that exist for the development of new components are highlighted.

Introduction

Photoluminescent Liquid Crystal Displays (PL-LCD) have the viewing angle characteristics of a CRT in a flat panel display which is manufacturable on existing LCD facilities. A number of novel materials and components have been developed that are key to the technology.

Conventional colour LCDs use a broadband white backlight to illuminate an LCD incorporating a transparent microdot colour filter. The contrast, brightness and colour of LCDs vary with viewing angle due to the inherent optical anisotropy of the liquid crystal material. The colour filters also absorb more than 75% of the light from the backlight in generating a colour picture.

The Photoluminescent LCD is a novel architecture that overcomes the inherent limitations of conventional LCDs[1,2]. The basic architecture is shown in Fig. 1.

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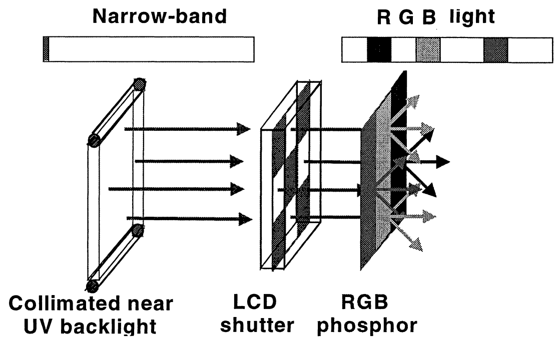

Fig. 1: Photoluminescent LCD architecture

Light from a narrow band near UV lamp (typically a miniature fluorescent lamp) is modulated by an LCD cell and is then incident on a phosphor screen on the front of the display. The phosphor converts the near UV "image" into a visible image using photo-luminescence (the process used to generate white light in fluorescent lamps). If the phosphor screen has red, green and blue pixels aligned in registration with the pixels of the LCD a colour image is generated directly without the need for absorbing colour filters. The image generated has the same contrast, colour and brightness from all angles.

Materials and Components for PL-LCD

Collimated UV Backlight

A narrow band near UV light source is required with emission just below visible wavelengths in order to ensure maximum transmission through the LCD (glass, ITO and PI absorb increasingly at shorter wavelengths). The UV light should not degrade the LCD materials (particularly the polarisers and liquid crystal material). The LCD can also be optimised better for narrow band light. The light source should have high efficiency. In the near term the most efficient light sources for the purpose are the miniature cold cathode fluorescent lamps used by the LCD industry. In order to use these a new narrow band near UV phosphor was needed to replace the tri-phosphor white light composition used for LCDs.

A $CaSO_4:Eu^{2+}$ phosphor was developed with a 388nm peak emission and 15nm full width half maximum[3] and has been used in miniature cold cathode fluorescent (CCFL) lamps to demonstrate the technology.

Alternative light sources for future displays may be near UV laser diodes, where their inherently lower efficiency may be compensated by their inherent collimation and polarisation.

The near UV light is collimated both to achieve optimum performance from the liquid crystal and to minimise the effects of optical crosstalk between adjacent picture elements (particularly for displays where the phosphor screen is outside the display). The phosphor screen on the front of the display converts any incident UV light into visible light. Many commercial brightness enhancement films (a type of collimator) have a secondary peak in transmission at higher angles. Such collimators reduce the contrast for a PL-LCD. STL has taken advantage of the narrow bandwidth illumination in devising a novel reflective collimator which transmits a defined range of angles and reflects high angle light back. A proportion of the light reflected backwards can then be recovered provided the reflectors used have high reflectivity in the near UV.

A collimation element has been designed and made which has most of the light within a cone of ±30°[4]. The angular distribution of this collimation element is shown in Fig. 2.

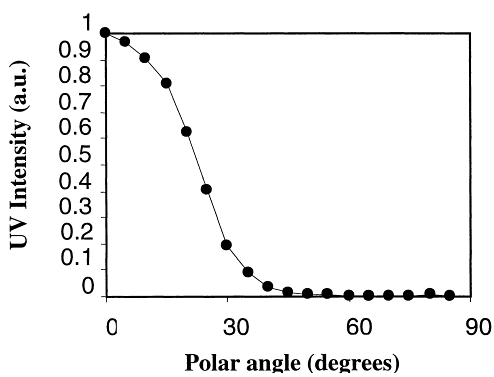

Fig. 2: Angular profile of reflective collimator

Poor contrast at oblique angles of view is familiar to all users of Notebook computers. The higher contrast which could be achieved from higher levels of collimation in PL-LCD are significant but must be offset against achievable levels of efficiency for such collimation systems.

Insufficient collimation can also cause optical crosstalk, where the divergence of the UV light is too great for the separation between the liquid crystal (the image forming layer) and the phosphor screen. Optical crosstalk causes loss of image sharpness, reduction of contrast and colour de-saturation (through light which was intended to fall on one colour phosphor falling onto an adjacent one). The effect on the level of colour saturation achievable can be quite marked[5] as shown in Figure 3 where the effect of 5% optical crosstalk is shown on the CIE colour diagram. The effects become particularly marked for small picture element displays where it is necessary either to form the phosphor layer inside the LCD structure (greatly reducing the separation distance)[5,6], to increase the levels of collimation and/or use novel techniques to image the liquid crystal layer onto the phosphor.

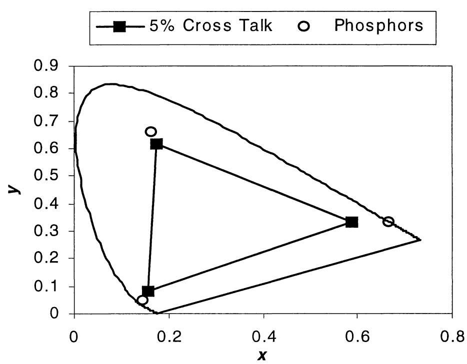

Fig. 3: Colour de-saturation caused by 5% cross talk for individually activated red, green and blue phosphors.

LCDs and Polarisers

Most of the liquid crystal electro-optic effects used in standard LCDs are suitable for PL-LCD. However it will be necessary to optimise the displays for near UV light. Existing manufacturing lines can be used for the optimised displays.

Commercial polarisers used in the LCD industry have excellent performance for visible light but incorporate a UV cut filter to protect the materials used in their construction from the effects of UV light. The UV cut filter absorbs any light at wavelengths shorter than 400nm (sub-visible). The few iodine based dichroic polarisers available without the UV cut filter have inherently poor transmission and extinction in the near UV. Polarisers for PL-LCD must be assessed taking account of the integrating effect of the phosphor screen on the front of the display. The transmission and contrast of the polarisers is measured using the wavelength and angular profile for the collimated backlight.

The best of the standard dichroic polarisers found to date are Polaroid's HN42HE which have an on axis contrast of about 60:1 at 390nm. The contrast reduces to an inadequate 12:1 when integrated across the collimation angle from STL's collimator. STL has been working with a manufacturer of dye based polarisers who has successfully made high contrast narrow band polarisers that work well at 390nm. The performance of one of the polarisers developed is summarised in Table 1[7].

Alternative approaches to dichroic polarisers are being investigated for PL-LCD, including the use of Cholesteric polarisers[8] and the use of polarisation sensitive organic emitters[9].

Table 1. Performance of narrow band near UV dye based polariser

	Transmission			
	One piece	Parallel	Crossed	Contrast
390nm on axis	34.2%	23.4%	0.007%	3343
Integrated (wavelength, on-axis)	34.1%	23.2%	0.010%	2320
Integrated (wavelength & direction)	30.0%	20.9%	0.091%	230

Phosphor Screen

The phosphors used on the front of the display emit visible light generated by photo-luminescence. The visible light generated can be emitted in any direction, backwards as well as forwards. In order to achieve maximum brightness a backward emission recovery filter is used behind the phosphor screen that transmits UV light and reflects visible light. Initial designs using dielectric stack filters deposited on glass gave near perfect recovery of the backward emitted light. A more practical design using a small number of layers where the reflection characteristics are designed to match the emission characteristics of the visible phosphors has been implemented on plastic film with OCLI[10] (Fig. 4). A brightness enhancement of 40% has been achieved with this first implementation on plastic film. Considerable improvements are expected. Alternative methods for making mirror coatings are being reported that may have application in this area, such as the work by MIT on a mirror coating process that combines the best of dielectric and metallic mirror coatings, that can be tuned to reflect selected wavelengths[11] independent of angle.

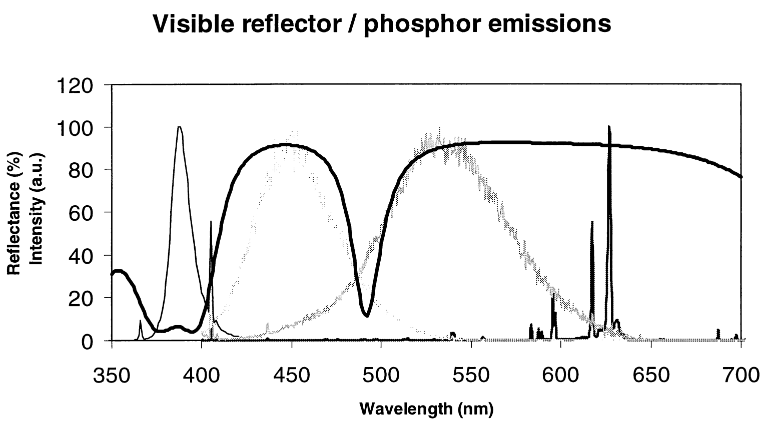

Fig. 4: Reflection characteristics of the plastic film dielectric mirror, shown with the visible and UV phosphor emission spectra.

The phosphor screen must have high conversion efficiency for the near UV light used in the display and colour characteristics that match Colour CRT CIE co-ordinates (the industry standard). A range of suitable inorganic phosphor materials has been found that are suitable for PL-LCD. These can be deposited on a plastic film substrate using standard printing methods. Screen printing was used in recent demonstrators. The materials used in the printing ink must have high transmission of UV and visible light, not affect the stability of the phosphor materials used and have the required stoichiometry for precision printing. Alternative materials being investigated include organic phosphor materials. Materials with quantum efficiency of about 90% at 390nm excitation have been identified.

PL-LCD's, in common with CRTs, Plasma, Field Emission and Electro-luminescent Displays have a phosphor on the front of the display. Inorganic phosphor materials are generally white scattering materials and therefore these displays require contrast enhancement filters to combat the effect of reflection in high ambient light conditions. The techniques commonly used in CRT's are adaptable to use for PL-LCD. The best approach is the use of RGB microdot colour filters over the phosphor dots. These materials can be combined with the phosphors and deposited in a single operation. Approximately twice the level of brightness can be achieved for the same level of ambient suppression of a neutral density filter, or twice the level of ambient suppression for the same brightness.

PL-LCD demonstrators

The results of work on the materials and components above has enabled a number of technology demonstrators to be made including a 12.1" colour display made using an LCD from a standard production line in the Far East (Fig. 5). The principle of PL-LCD has been demonstrated and the performance of the component parts developed to date has been assessed. Materials and components with improved performance are under development, particularly optimised printed phosphor screens, collimators, polarisers and imaging elements.

RGB

Monochrome

Fig. 5: 12.1" PL-LCD Technology Demonstrator

Acknowledgements

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