UNIVERSITY OF CALIFORNIA
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EE290D Handout #58
Spring 1999 T.-J. King

HOMEWORK ASSIGNMENT #6 SOLUTIONS

Problem 1: Inorganic Electroluminescent Displays

a) As compared to LCD displays, TFEL displays are more rugged (resistant to shock and vibration for higher reliability), have superior viewing angle (almost +/- 90 degrees both horizontally and vertically), and can be operated over a wider range of temperatures (-25^{o}C to 65^{o}C).

b) i) The light output of an ACTFEL display is directly proportional to the charge induced per applied voltage pulse. This charge is proportional to the capacitance of the insulating layers as well as the applied voltage. High-permittivity insulator layers are necessary in order to achieve high capacitance, for either higher display brightness (for a given operating voltage) or lower operating voltage and hence improved reliability (for a given display brightness).

ii) Because ACTFEL displays operate at fairly high electric fields (1-2 MV/cm), high-breakdown-strength insulator films are required for high reliability.

iii) Voids in the insulating layers can lead to catastrophic device failure, so pinhole density must be minimized. In practice, no thin-film deposition process can produce defect-free material, so the best TFEL insulator materials exhibit a non-propagating or “self-healing” nature, where minute defect areas can burn out and clear themselves, leaving barely visible and stable dark spots.

c) In an ACTFEL display, with each applied voltage pulse, electrons tunnel out of interface states at the phosphor-insulator interface and are accelerated in the high field, gaining sufficient energy to impact excite luminescent centers in the phosphor layer before becoming trapped at the phosphor-insulator interface at the anode side. Light emission subsequently occurs when the emitter centers relax to their ground state. An ACTFEL display hence emits bursts of light, and its apparent luminance increases with the frequency at which the pixels emits the bursts of light.

d) Low-voltage operation would be desirable for <u>low power consumption</u>, as well as for compability with conventional (CMOS technology) integrated-circuit drivers (instead of customized high-voltage DMOS ICs) for <u>low display module cost</u>. The operating voltage of an ACTFEL display can be reduced by reducing the thickness of the EL phosphor and dielectric layers.

Problem 2: Color TFEL Displays

a) The following are approaches to achieving a full-color TFEL display:

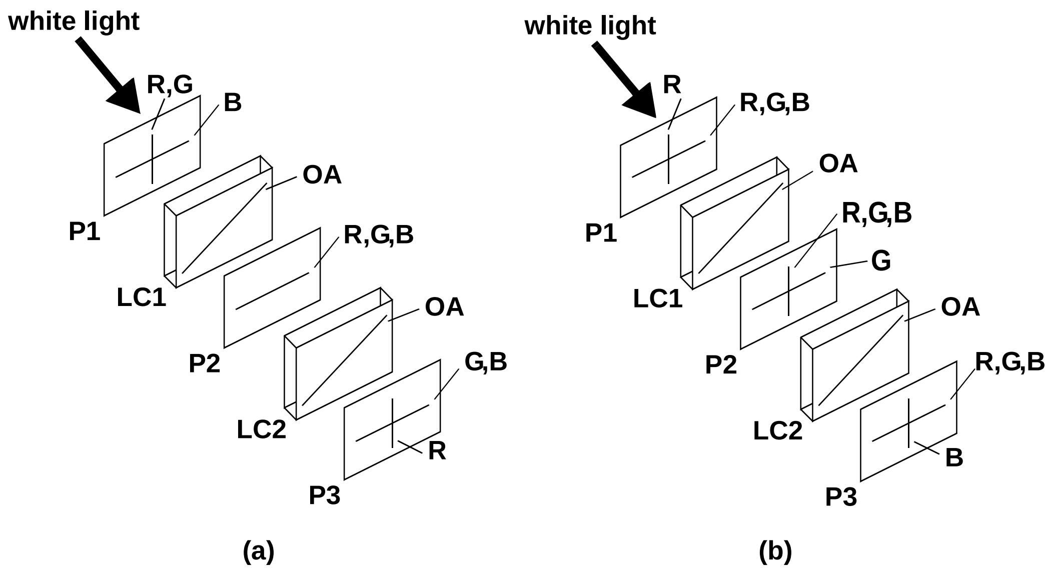
i) Stacking approach: R, G, and B EL multilayer stacks are combined (stacked together) to form a single stack. The advantages of this approach are that patterning of the R, G, and B phosphors is not needed (i.e. the fabrication process is relatively simple) and that a color display will have the same resolution as a monochrome display. The main disadvantage is that the multi-stack structure is more susceptible to reliability issues because the self-healing property of the dielectric layers is destroyed.

ii) Spatially patterned phosphor approach: Each pixel consists of three sub-pixels of patterned R, G, B phosphors. The main advantage of this approach is that the display consists of a single EL stack, for better reliability than the multi-stack approach; the main disadvantage is that high-efficiency R, G, and B EL phosphors are not yet available. (The fabrication process is also more complicated, because of the need to pattern the phosphors.)

iii) “Color by white” approach: An efficient broadband (white-emitting) phosphor is used in conjunction with spatially patterned color filters to achieve R, G, B sub-pixels. The main advantage of this approach is that the fabrication process is fairly simple -- no phosphor patterning is required; the structure consists of a single EL stack for high reliability. The main disadvantage is that the blue emission of existing phosphors is rather weak; to produce a color display with acceptable luminance, it is necessary to use a light blue color filter but this in turn leads to a poor blue chromaticity and display color gamut. (Note that true blue has CIE coordinates x=0.10, y=0.15, approximately; the CIE coordinates of blue in a "color by white" TFEL display are larger, indicating less saturated color.)

iv) Field-sequential color: An efficient broadband (white-emitting) phosphor is used in conjunction with a liquid-crystal color shutter to sequentially display R, G, and B sub-frames. The main advantage of this approach is that a color display will have the same resolution as a monochrome display. The main disadvantages are that the color display will have low luminance (due to the low transmission of the shutter), and will require faster data rates (hence more costly driver chips).

b) Figure P2 is reproduced here for convenient reference:



<u>Figure P2</u>: Examples of liquid crystal shutter filters, used to create full-color images from monochrome white displays. The polarization axes for the R, G, and B components of the white light are indicated for each polarizer. The optic axes of the LC cells are labelled "OA".

(a) Shutter used in AMEL diplays. Note that polarizer P2 is a neutral polarizer, while polarizers P1 and P3 are pleochroic. (Cyan = Blue + Green (i.e. no Red); Yellow = Green + Red (i.e. no Blue))

(b) Example of shutter employing only pleochroic polarizers. Each polarizer transmits only one

<u>Figure P2b LC shutter operation</u>:

- **Both cell LC1 and cell LC2 on:** only green light (horizontally polarized) is transmitted because the cells have no effect on the polarization state of the light.
- **Cell LC1 on and cell LC2 off:** light exits the first polarizer (P1) and passes unaffected through cell LC1. Exiting the second polarizer (P2), red light is vertically polarized and green light horizontally polarized. Cell LC2 transforms the linearly polarized green light to be vertically polarized, and the linearly polarized red light to be horizontally polarized. The final polarizer (P3) then absorbs all of the green light and transmits purely red light.
- **Cell LC1 off and cell LC2 on:** linearly polarized white (R, G, B) light exits the first polarizer (P1) and is transformed by cell LC1 to be vertically linearly polarized. This light passes through the middle polarizer (P2) and is unaffected by cell LC2. The final polarizer (P3) then absorbs all of the red and green light and transmits purely blue light.

		LC1	LC2
Figure P2b	R	ON	OFF
	G	ON	ON
	B	OFF	ON

<u>Problem 3</u>: Organic Display Technology

a) As compared to LCDs, OLED displays are much simpler to fabricate and thus can potentially be fabricated at much lower cost (important especially for very large direct-view displays). OLEDs also have wider viewing angle and wider operating temperature range (although reduced operating lifetime at elevated temperatures is an issue) than LCDs.

b) Approaches to reducing OLED driving voltage:

- Use thinner organic layers.
- Use low-workfunction cathode and high-workfunction anode to lower the potential barriers to injection of electrons and holes.
- Use multi-layer structure (e.g. hole-transporting layer + electron-transporting and emitting layer) to improve device efficiency.

c) The color of the light emitted by an OLED can be tuned by doping the emitter layer with appropriate dye molecules.

d) The primary advantage of using polymer materials is that they can be spin-cast and hence offer easier and lower cost of processing. Another major advantage of polymer LEDs is that they have superior mechanical properties and are better suited to flexible display applications.

<u>Problem 4</u>: Organic Display Operation

a) In a matrix-addressed display, data is read into the display one row at a time. In a passive-matrix-addressed OLED display (which does not employ a memory circuit at each pixel), each pixel OLED is turned on for only one row-addressing time during each frame. Therefore, in a 64-row display such as Pioneer's dot-matrix display, a pixel OLED is on for only 1/64th of the time.

As described in the paper, the anode electrodes are formed in stripes 340 µm wide, separated by 30 µm gaps, and the cathode electrodes are formed in stripes 300 µm wide, separated by 30 µm. From this information, the pixel aperture ratio is calculated to be (340-30)(300-30)/(340x300)=82%. Therefore, in order to achieve a display luminance of 100 cd/m^2, the active area of each pixel must have an apparent luminance of 100/0.82=122 cd/m^2. Since each pixel OLED is turned on for only 1/64th of the time, the OLED must operate at 64 times the apparent luminance: 64x122=**7808 cd/m^2**.

From Figure 5 in the paper, the luminous efficiency of the display at 7808 cd/m^2 is **6 lm/W**.

The power required to generate light is equal to the areal power density (in W/m^2) multiplied by the active display area (in m^2):

$$\{[(7808\ \mathrm{cd/m^2})/64]/(6\ \mathrm{lm/W})\}\{4\pi\ \mathrm{lm/cd}\}\ \mathrm{x}\ \{(256)(64)(300\mathrm{x}10^{-6}\ \mathrm{m})(340\mathrm{x}10^{-6}\ \mathrm{m})\} = \mathbf{0.43\ W}.$$

b) For a pixel aperture ratio of 95%, the active area of each pixel must have an apparent luminance of 100/0.95=105 cd/m^2, in order to achieve a display luminance of 100 cd/m^2. Since there are 240 rows in a quarter-VGA display, a pixel OLED must operate at 240 times the apparent luminance: 240x105=**25200 cd/m^2**.

From Figure 5 in the paper, the luminous efficiency of the display at 7808 cd/m^2 is **4.8 lm/W**.

The power required to generate light is equal to the areal power density (in W/m^2) times the active display area (in m^2):

$$\{[(25200\ \mathrm{cd/m^2})/240]/(4.8\ \mathrm{lm/W})\}\{4\pi\ \mathrm{lm/cd}\}\ \mathrm{x}\ \{(0.95)(3\ \mathrm{in})(4\ \mathrm{in})(6.4516\mathrm{x}10^{-4}\ \mathrm{m^2/in^2})\} = \mathbf{2.0\ W}.$$

For comparison, the power consumption of a <u>10-inch diagonal VGA</u> LCD is less than 3 W nowadays. In order for OLED displays to be competitive with LCDs for portable display applications, the power consumption must be reduced. Hence, active-matrix addressing will be necessary to allow the OLEDs to operate at lower peak brightness, for higher efficiency.

c) The benefits of using active-matrix addressing are:

i) Because the pixel OLED operates at 100% duty cycle, lower peak operating brightness is used, resulting in increased efficiency, hence lower power consumption.
ii) If poly-Si TFT technology is employed, driver circuitry can be monolithically integrated into the periphery of the display, to produce a more compact and reliable display module.

The main disadvantage of using active-matrix addressing is that the fabrication process becomes more complex (i.e. costly).

d) For a pixel aperture ratio of 80%, the active area of each pixel must have a luminance of 100/0.80=125 cd/m^2, in order to achieve a pixel luminance of 100 cd/m^2. From Figure 5, the pixel OLED must operate at a current density of 0.9 mA/cm^2. From Homework Assignment #1 (Problem 2a), the pixel size of a 10-inch diagonal VGA display is 317.5 μm, so for a pixel aperture ratio of 80% the active pixel area is $(0.8)(317.5\text{x}10^{-4})^2$ cm^2=$8.0645\text{x}10^{-4}$ cm^2. The TFT in series with the OLED must supply a current of (0.9 mA/cm^2)($8.0645\text{x}10^{-4}$ cm^2)=**0.73 μA**.