Thin-Film Photosensors for OLED Flat-Panel Displays

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Abstract

Thin-film photosensors on organic light emitting diode (OLED) glass substrates using active-matrix OLED TFT manufacturing processes have been constructed and optimized, and their performance has been characterized. Suitable control circuitry and applications are proposed. The photosensors may be integrated into OLED displays for detection of ambient illumination and for detection of OLED light emission, thereby enabling output, uniformity, and aging compensation.

1. Introduction

Organic light emitting diode (OLED) flat-panel displays face a variety of technical challenges. Restricted brightness, lack of uniformity, and decreased efficiency caused by aging must be overcome before this promising technology can be commercially successful. Photosensors for detecting ambient illumination have been used in commercial products for several years and have also been proposed for controlling light output from OLEDs in a flat-panel display.[1,2]

Thin-film transistors exhibit a photopic effect. Questions remain, however, as to whether this effect is useful in a practical flat-panel device. Do thin-film transistors have sufficient sensitivity to be useful in ambient light detection or, more critically, in detection of light output from OLED devices? Can they be effectively constructed in a flat-panel OLED display?

To answer these questions, SANYO Electric Co., Ltd., and Eastman Kodak Company undertook to construct thin-film, light-sensitive phototransistors on the same glass substrates and using the same processes, materials, and transistor design rules as are employed within the OLED flat-panel display manufacturing facility at the SK Display Corp. manufacturing facility in Gifu, Japan.

2. Experimental

As shown in Fig. 1, a phototransistor was constructed from low-temperature polysilicon having a conventional source, gate, and drain. The phototransistor was constructed on a glass substrate and illuminated from above and below. Several different illumination sources were employed to understand the spectral response of the phototransistor.

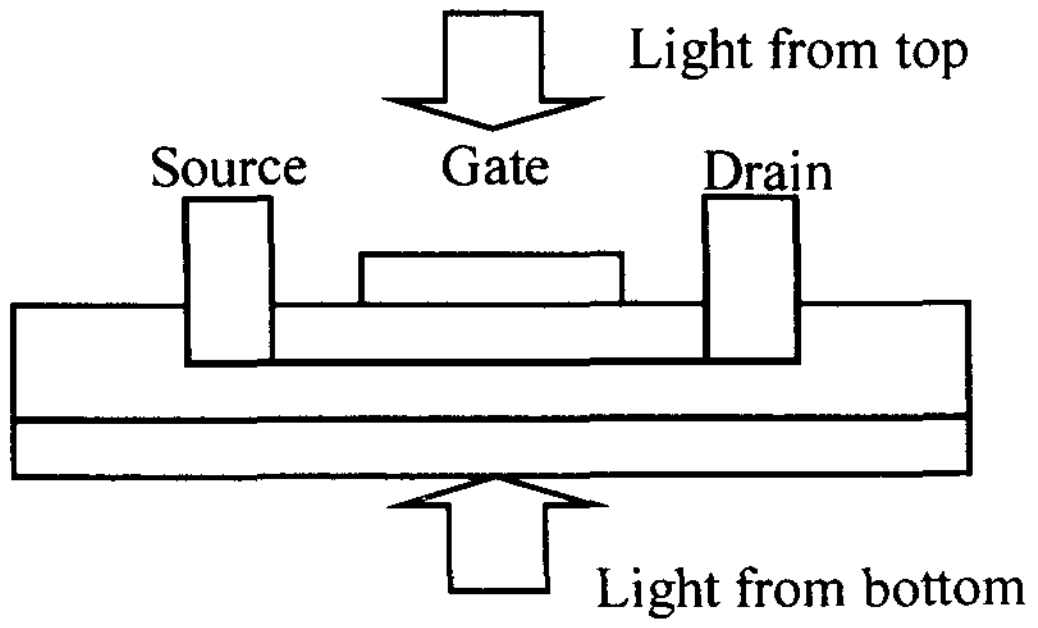
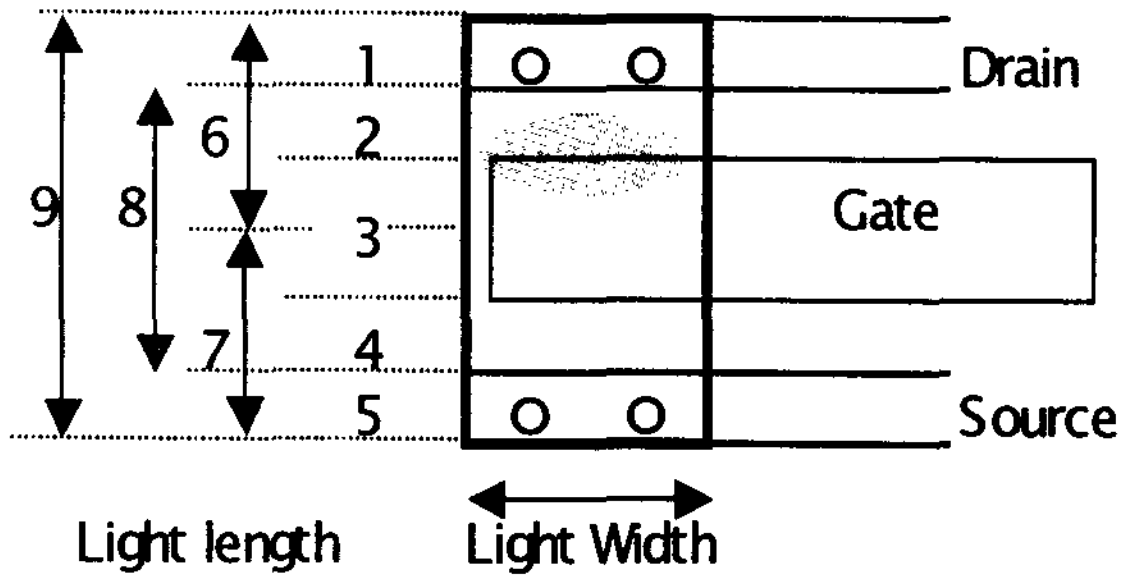


Figure 1 Phototransistor structure

A variety of structures of this type were constructed. We varied the aspect ratio of the phototransistor, the type of channel semiconductor, the voltages applied to the phototransistor terminals and examined the response of the phototransistor to incident light from both the top and the bottom of the device. Fig. 2 shows that the bottom illumination response provides a better signal. This demonstrates the importance of the gate structure location (top vs bottom) to optimize response-to-illumination direction.

Light direction	Light ON	Light OFF	ON/OFF
from top	5.43E-12	1.82E-12	2.984
from Bottom	7.87E-12	1.30E-13	60.538

Figure 2 Light response for top vs. bottom illumination (amps)



Region	1	2	3	4	5	6	7	8	9
Ioff(pA)	24	114	52	4	2.2	250	7.8	282	292

Figure 3 Ioff dependence for various TFT regions

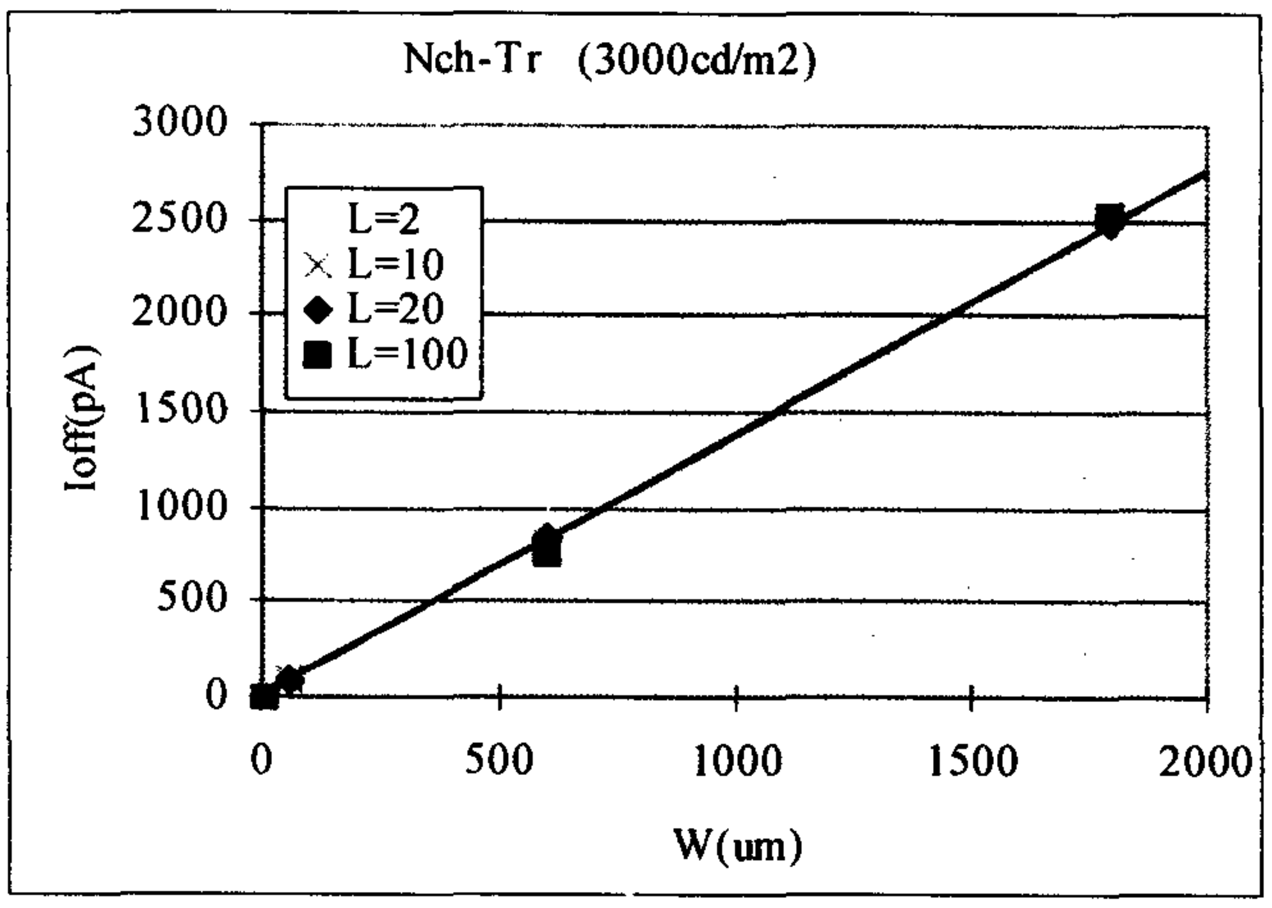


Figure 4 Ioff dependence on TFT width

Test	Light on	Light off	L on/off
N-channel biased	3.69 E-04	3.80 E-04	0.97
N-channel unbiased	1.03 E-11	5.09 E-14	201.36
P-channel biased	3.35 E-04	3.43 E-04	0.98
P-channel unbiased	1.38 E-11	1.27 E-14	1086.50

Figure 5 Luminance Response (amps)

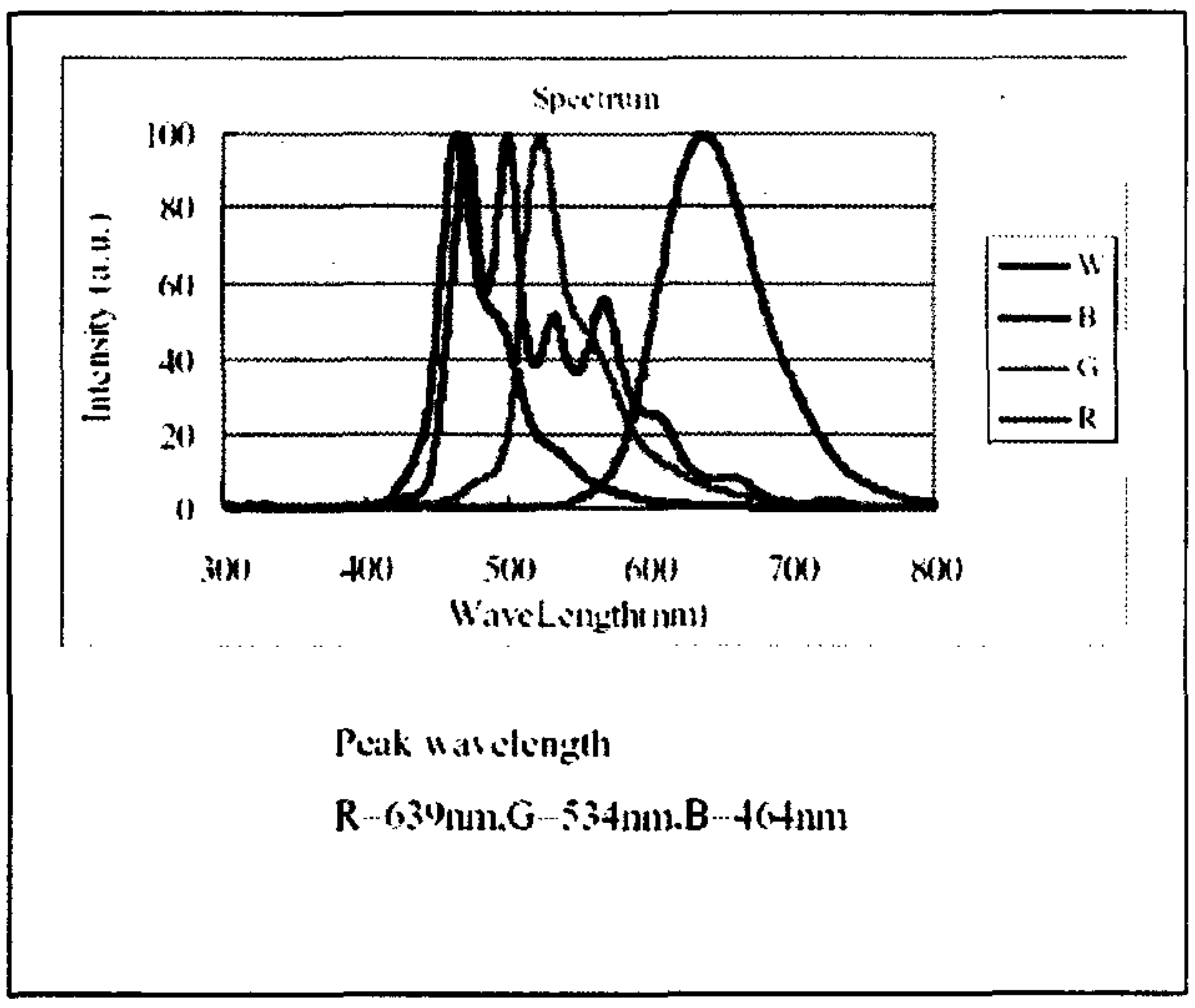


Figure 6a Illumination spectrum

Fig. 3 shows that Ioff (the phototransistor current produced when the gate is unbiased) has a dependence on the various regions within the TFT. In particular, region 6, the side of the drain PN region, supports much of the current response. Ioff responds linearly to a varying TFT width but it has no dependence on length (Fig. 4). This indicates that only the PN drain region determines Ioff so that, in integrating a detector into a panel, we can design a phototransistor without considering the length of the TFT.

Fig. 5 illustrates the response of an n-channel and p-channel phototransistor having an aspect ratio of three (length to width) to a luminance of 6350 cd/m^2 incident on the device under gate-biased and gate-unbiased conditions. As shown in Fig. 5, the response of the phototransistor to light is maximized for a p-channel device in a gate-un-biased state and a signal ratio of 1086.50 is obtained. However, such a current (femtoAmps) is not readily measured with conventional thin-film circuits.

The phototransistor shows good linearity in response to varying levels of incident illumination. Referring to Figs. 6a and 6b, the phototransistor's response (Fig. 6b) to various frequencies of illumination (Fig. 6a) emitted by a white-light OLED is shown. It is clear from this figure that the circuit has the greatest response to blue and the smallest response to green. This is somewhat counterintuitive, because the green signal has more energy than the red. However, optical modeling performed by a Kodak colleague demonstrates that green light destructively interferes in the layers of thin films used in the phototransistor, thereby reducing the green response. [R. Cok and J. Shore, private communication, 2003]

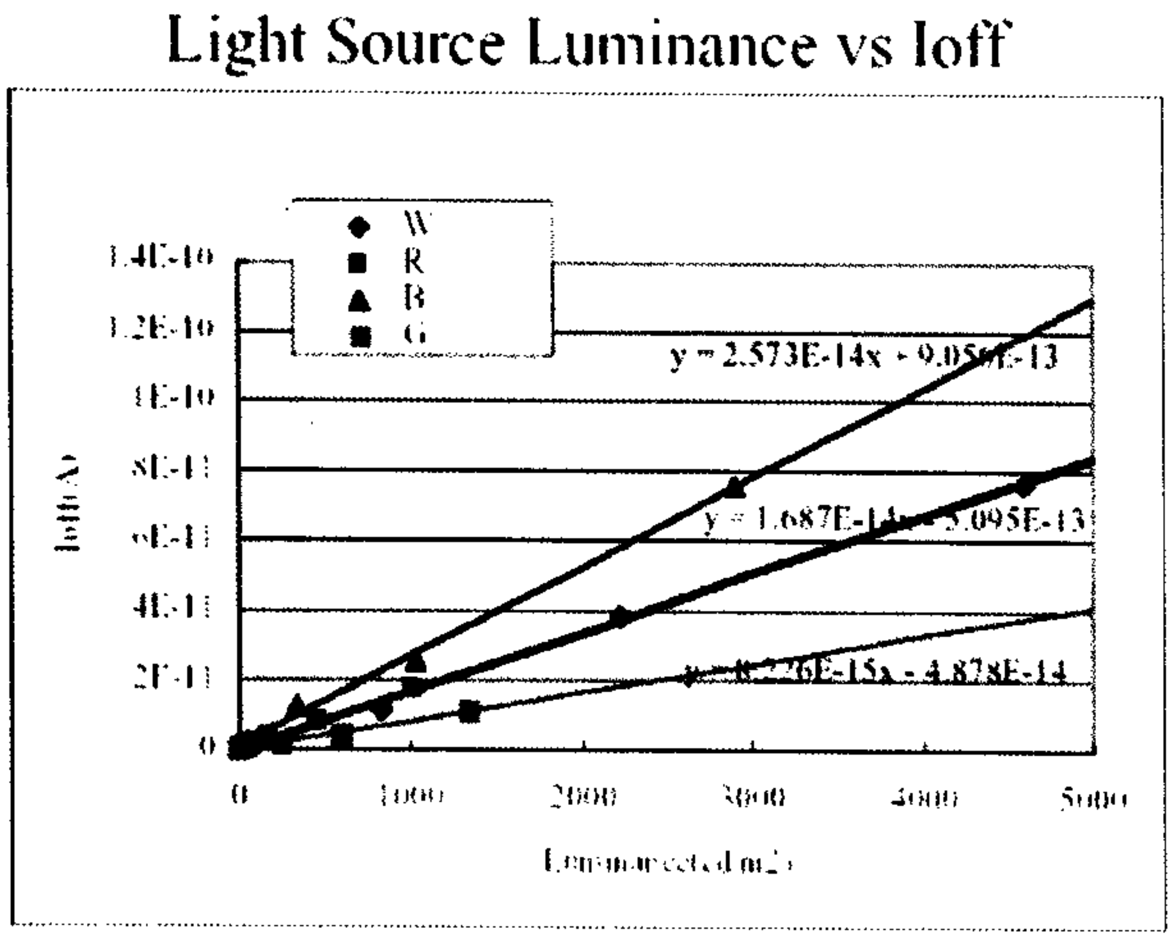


Figure 6b Phototransistor response

Because the current directly produced from the phototransistor is very small, a ganged array of the phototransistors was connected in parallel to form a light-responsive area of approximately 0.012 mm^2. Furthermore, we chose to use a current integration technique to detect the current, whereby the phototransistor's response to illumination is integrated over time rather than directly measured in real time. To accomplish this, the circuit in Fig. 7 was used. This circuit uses a reset transistor to pre-charge a capacitor. Once the capacitor is charged, the reset transistor is turned off to isolate the phototransistor array and the phototransistor array is exposed to light. As photons are absorbed in the phototransistor, the charge in the capacitor discharges through the phototransistor at a rate dependent on the intensity of light incident on the phototransistor.

Over time, the phototransistor circuit provides an exponential response to incident illumination. The amount of time required to fully discharge the capacitor of Fig. 7 is plotted in Fig. 8 for different colors of light. From this graph, we can see that a blue illumination of approximately 80 cd/m^2 incident on the phototransistor results in a saturated signal in about 0.1 s.

The circuit of Fig. 7 uses an array of smaller individual photo-sensitive transistors connected in parallel. This reduces the capacitance of the circuit and improves the response and signal-to-noise ratio. An ARRI HMI daylight lamp with Wratten filters 26, 47, and 61 respectively for the red, blue, and green data was used to illuminate the phototransistors. By varying the frequency of the reset signal provided to charge the capacitor, a wide range of luminance levels can be detected with a single circuit. However, detection may not be possible at video rates.

The response of the photosensor can also be modified through changes in the capacitor size and the area of the photosensor. For example, a 5 pf capacitor was used in a second test in place of the 2.5 pf capacitor and resulted in a response requiring approximately three times as long to reach saturation.

A variable reset signal enables a wide dynamic range circuit response. Unfortunately, such variable signals may not be available on the substrate of a conventional OLED display device. If a static signal is employed instead, the dynamic range of the signal in response to variations in luminance is much reduced.

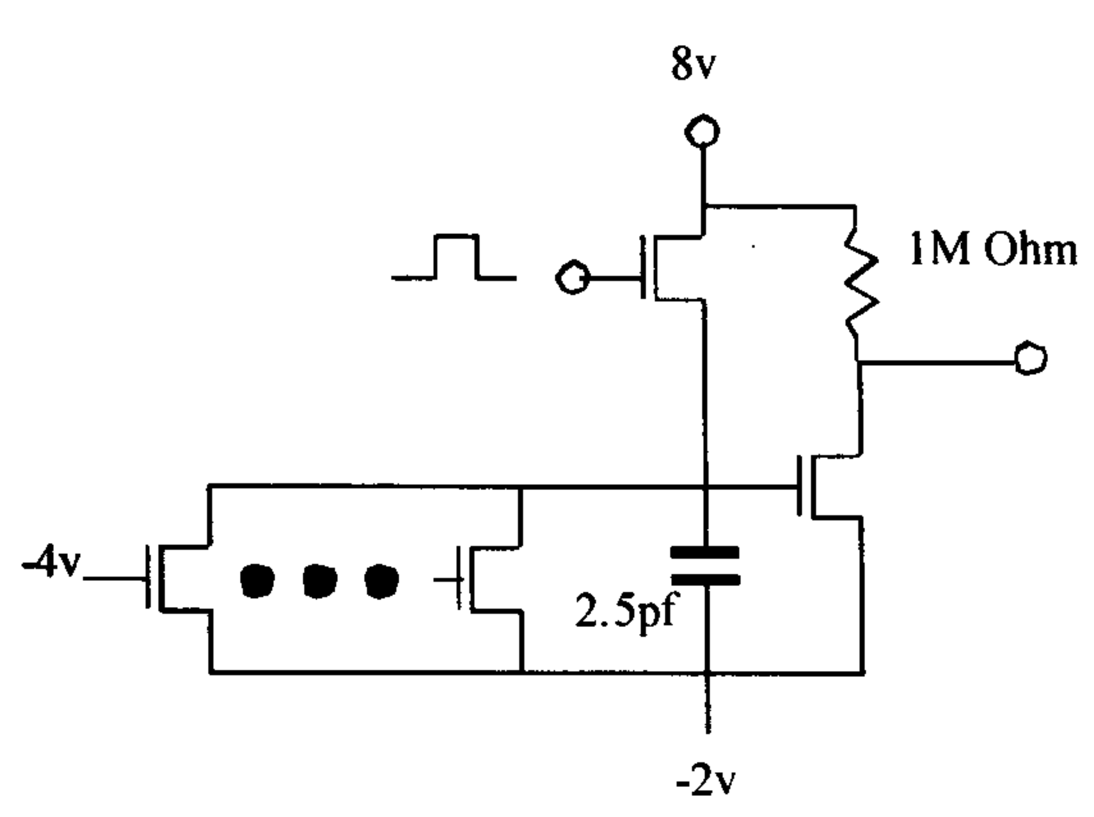


Figure 7 Detection circuit

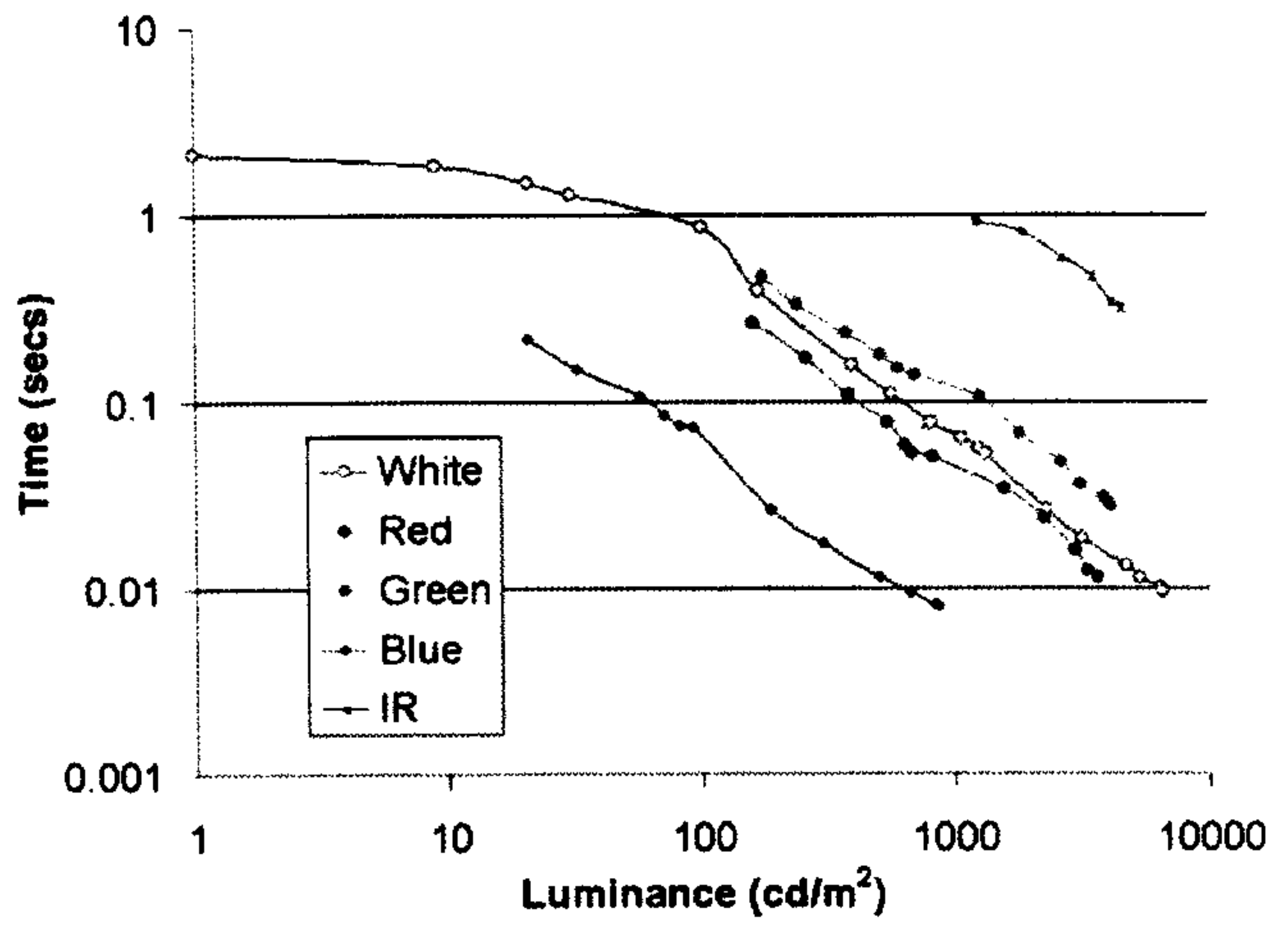


Figure 8 Phototransistor circuit response

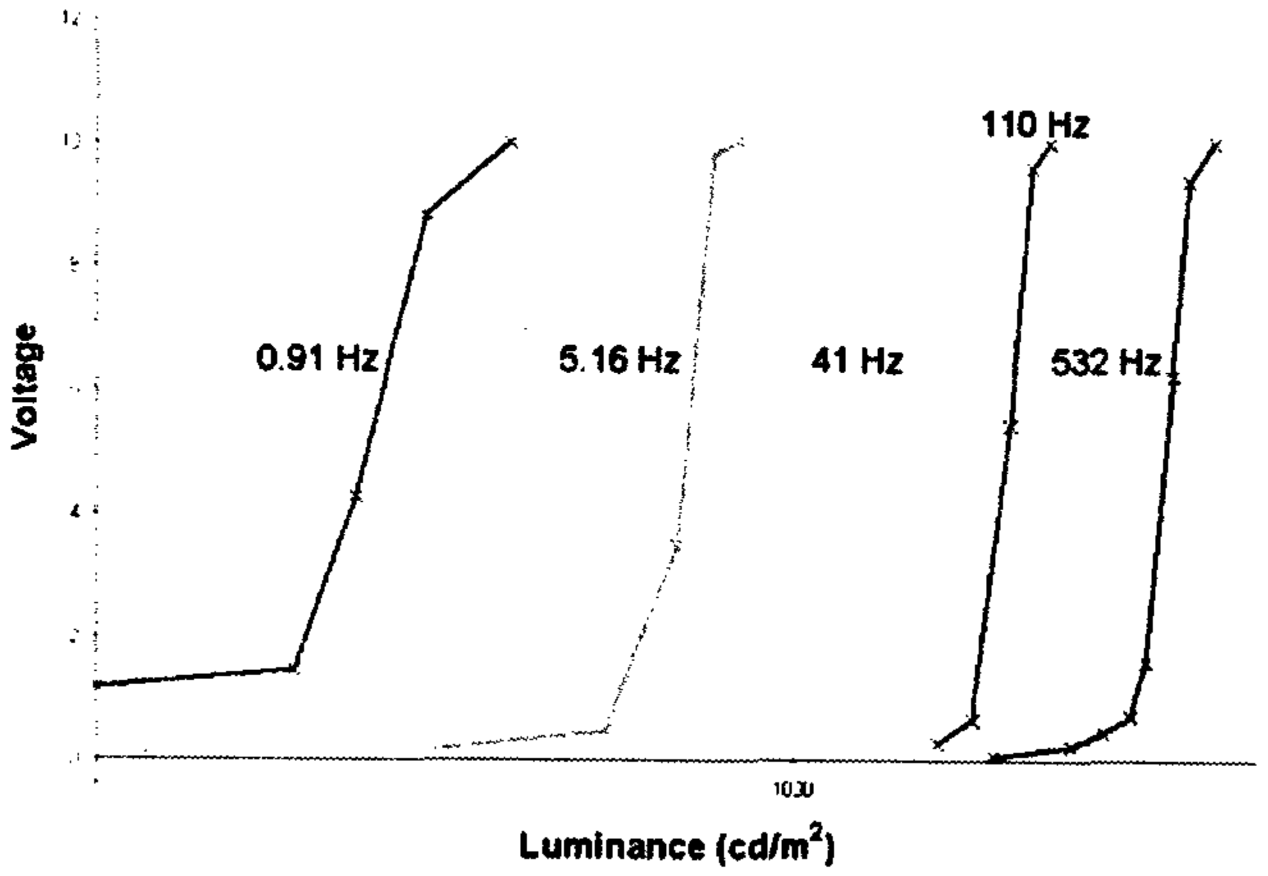


Figure 9 Phototransistor dynamic range

Fig. 9 illustrates the dynamic range of the 2.5 pf circuit with a variety of fixed reset frequencies. As shown, the phototransistor circuit itself has only a dynamic range of approximately a factor of three, much less than the range of illumination typically encountered by a portable display.

3. Discussion

Indoor illumination levels typically run from 50 to 500 cd/m^2, while outdoor illumination from sunlight can exceed 25,000 cd/m^2. The phototransistors and circuits described here and integrated within an OLED display can be readily adapted for use in detecting ambient illumination.

The phototransistors and circuits may also be used to directly detect the light output from an OLED emitter. A typical OLED emitter in a flat-panel display can output light of several hundred cd/m^2. If adapted to receive light from an OLED emitter, the phototransistor can provide feedback information on the brightness of the OLED emitter.

Fig. 10 illustrates a possible arrangement for a top-emitter OLED discussed in the literature. A substrate with a phototransistor formed on it is positioned beneath a conventional OLED emitter. The phototransistor may have a reflective back while the anode must be transparent to enable the phototransistor to receive light from the OLED emitter.

An OLED emitter in a display device is typically about 0.010 mm^2, comparable in size to the phototransistor described above, therefore, it is feasible to detect the light output of the OLED with this arrangement. The reflective back ensures that light not absorbed by the phototransistor may be emitted by the OLED display.

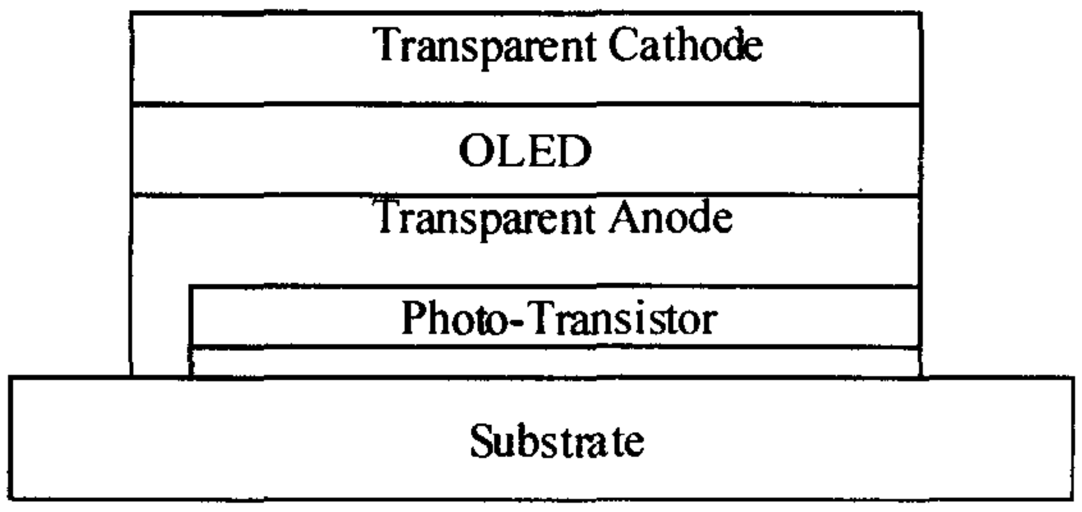


Figure 10 Phototransistor and OLED stack

By associating each OLED emitter with phototransistors in this fashion, the light output of each OLED emitter can be measured. This information may be employed to provide compensation for uniformity problems or OLED materials aging.

3. Conclusion

The results from these experiments show clearly that useful thin-film phototransistors can be made using a common process with conventional active-matrix OLED devices on an OLED flat-panel display. Simple circuits employing time integration techniques can provide feedback for ambient illumination on the display or for detecting the light output from OLED emitters. The response is frequency dependent, and a variable control method is necessary to meet the dynamic range requirements for portable displays.

By integrating phototransistors on the substrate of OLED flat-panel displays, ambient illumination compensation may be enabled as well as compensation for variable light output from OLED emitters. Uniformity and aging compensation may thus be provided.

4. Acknowledgments

The authors are grateful for the advice of Constantine Anagnostopoulos and the measurement work done by Felipe Leon of Eastman Kodak Company, Research and Development Laboratories.

5. References

[1] Hewlett Packard iPAQ PDA employs a photo-sensor and circuits for adjusting display brightness in response to ambient illumination.

[2] N. Young and J. Shannon, "Light-Emitting Matrix Array Display Devices with Light Sensing Elements," U.S. Patent 6,489,631, Dec. 3, 2002.