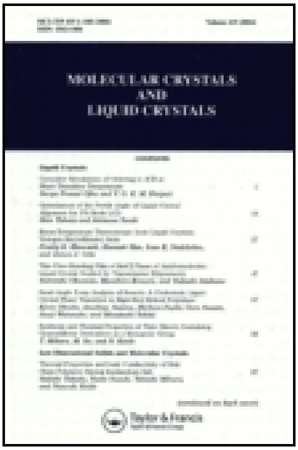

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

ORGANIC OPTICAL IMAGE PROCESSOR

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Version of record first published: 15 Jul 2010

To cite this article: Ken-ichi Nakayama, Yoshihiro Nishikawa & Masaaki Yokoyama (2003): ORGANIC OPTICAL IMAGE PROCESSOR, Molecular Crystals and Liquid Crystals, 406:1, 51-58

To link to this article: http://dx.doi.org/10.1080/744818986

Mol. Cryst. Liq. Cryst., Vol. 406, pp. 51/[245]–58/[252], 2003

ISSN: 1542-1406 print/1563-5287 online
DOI:10.1080/15421400390263299

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The all-organic optical image processor was fabricated combining an organic electroluminescent (EL) layer with photocurrent multiplication layer. In this device, input light image from one side is once converted to a large photocurrent, which is fed to an EL layer emitting output light image from the other side with keeping the image pattern. The photocurrent multiplication in pigment-dispersed polymer films enabled us to fabricate a large area device suitable for image processors. The optical operation was realized by designing the output-input light intensity characteristics in this device. We demonstrated two types of optical image processing, "AND" and "OR", for two input images.

Keywords: image processor; optical computing; organic electroluminescent device; photocurrent multiplication,

INTRODUCTION

Recent remarkable progress of organic light emitting diodes (OLED) brought about practical applications such as flat panel displays and promising direction in organic electronics. The high emission efficiency of OLED provides a great potential not only for display devices but also for all the opto-electronic devices including electron-photon conversion process.

Previously, we have succeeded in fabricating a novel opto-electronic device called an organic light transducer combining a photocurrent multiplication device and an OLED [1]. Photocurrent multiplication phenomenon in organic pigment films realizes a large quantum efficiency of photocurrent reaching 10^5, which is attributed to photo-induced tunneling injection process caused by accumulation of photogenerated carriers at the organic/

metal interface [2,3]. In the light transducer, input photons are once converted to a large photocurrent, and the photocurrent is again converted to output photons by an OLED layer.

In this paper, we applied the light transducer for optical image processors using pigment-dispersed polymer films for the photon-to-electron conversion. Most distinctive feature of the light transducer is shown in that the EL output light pattern keeps the input light pattern while the device has only one pair of electrodes. The photocurrent multiplication in pigment-dispersed polymer films enabled us to fabricate a large area device suitable for image processors. Therefore, we tried to develop an organic optical image processor, which performs a logic operation for two input optical images.

EXPERIMENTAL

The device structure and organic compounds used are shown in Figure 1. The photocurrent multiplication layer was prepared on the ITO substrate by spin-coating a polymer-dispersed pigment film. The perylene-3,4,9,10-tetracarboxyl-bis-benzimidazole (Im-PTC) or 3,4,9,10-perylenetetracarboxylic 3,4:9,10-bis-methylimide (Me-PTC) known to show a large multiplication rate was ball-milled in THF solvent with zirconia beads for 2 days and mixed

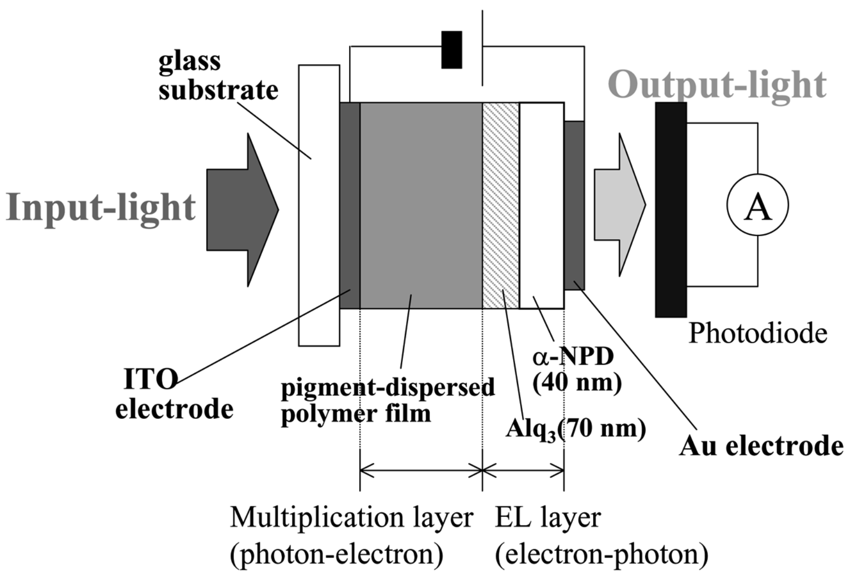


FIGURE 1 The device structure of the organic light transducer. The input light was shone onto the ITO electrode and the output light was detected from the gold electrode side under voltage application.

with a binder polymer of polycarbonate (PC-Z) or poly(vinyl-butyral) (PVB). The concentration of pigment was 50% by weight. The EL layer composed of Alq3 (70 nm) and a-NPD (40 nm) was layered over the multiplication film by vacuum evaporation technique. Finally, a semi-transparent Au electrode with thickness of 20 nm was deposited on the top of the film. The active area of the device was 0.02 cm^2 for the measurement of output–input light intensity characteristics and 1.0 cm^2 for the demonstration of optical processing, respectively.

The photocurrent was measured for a monochromatic input light of Xe lamp shone from the ITO side. The output light from the EL layer was monitored by a silicon photodiode arranged near the Au electrode. The input light penetrating through the device was subtracted from the total output light. The demonstration of optical processing was carried out for two input images projected from expanded He-Ne laser. Each laser beam through a photo-mask was overlapped on the device from the ITO side and the EL output image was captured by CCD camera from the Au electrode side Figure 2.

RESULTS AND DISCUSSION

At first, we measured photocurrent multiplication characteristics of the single-layered device of Me-PTC/PC-Z film sandwiched by two electrodes.

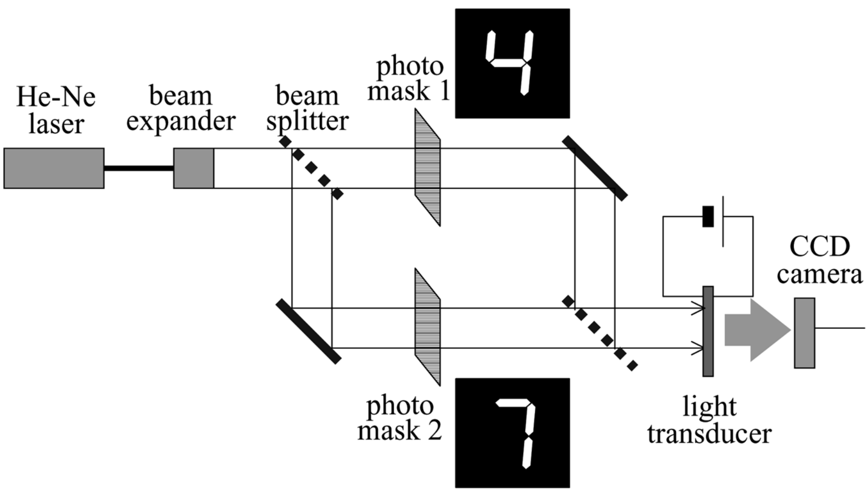


FIGURE 2 Optical system setup for demonstrating optical image processing. Two input light patterns are overlapped onto the device and the output EL pattern is captured by CCD camera.

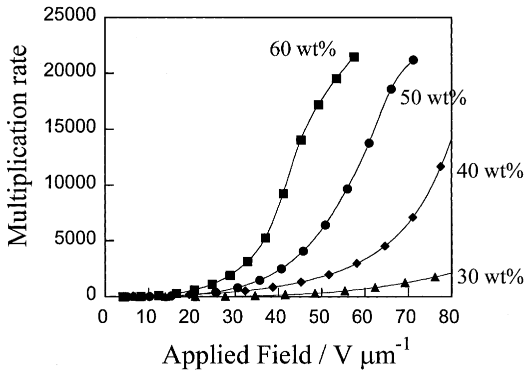


FIGURE 3 Voltage dependence of quantum efficiency in pigment-dispersed polymer films of Me-PTC/PC-Z for various concentration of pigment. The Au electrode was negatively biased with regard to ITO electrode.

Figure 3 shows the voltage dependence of quantum efficiency of photocurrent for various concentration of Me-PTC. The multiplication rate is defined as a ratio of the number of carriers flowing through the device to the number of absorbed photons. The multiplication rate exceeded 2×10^4 at 55 V in the case of 60% of pigment concentration, and it was found that photocurrent multiplication occurred even in the pigment-dispersed polymer films as well as vacuum deposited films. This observation of large photocurrent multiplication in pigment-dispersed polymer films having the uniform film surface is meaningful to fabricate a large area device suitable for image processors, since generally the case of vacuum deposited films often encountered unavoidable pinholes. Thus, we fabricated a light transducer combining with deposited OLED layer as shown in Figure 1.

Figure 4 shows the EL output pattern when a star-shaped input light was irradiated through a photo mask from an ITO electrode. Since the photocurrent multiplication occurs only at the area illuminated and the multiplied photocurrent is injected to the EL layer, consequently, green visible EL output light corresponding to the input pattern comes out.

In this way, this device has a distinctive feature that output light EL keeps spatial pattern of input light, which implies a great potential to deal with 2-D optical images as input and output signals. Therefore, we tried to apply this device for optical image processors, which can emit output EL pattern as a result of a logic operation between two input optical images. In order to achieve an operation, we paid attention to the relationship between input and output light intensity. If the output intensity increases abruptly with a certain threshold and reaches a saturation for increasing input intensity, optical image processing of "OR" can be performed for the

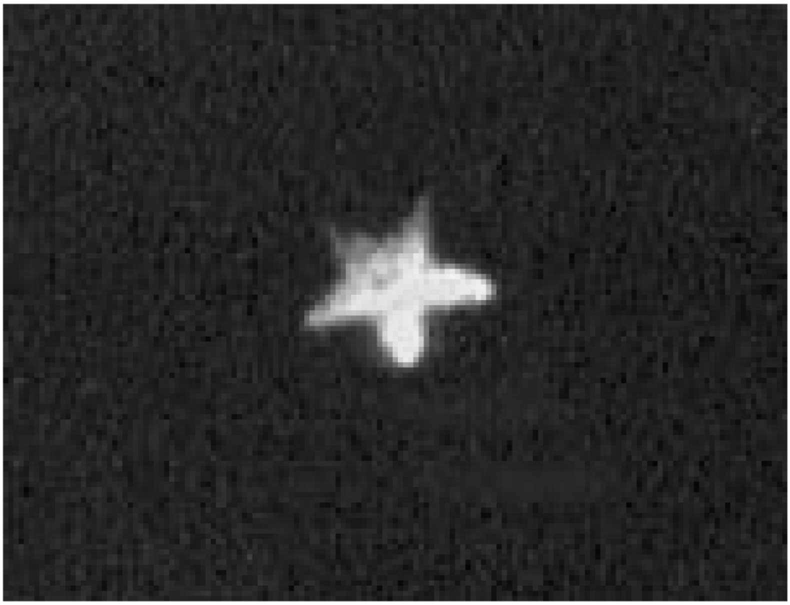
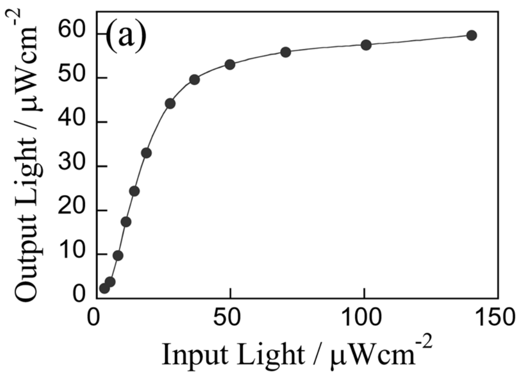


FIGURE 4 EL output pattern from the light transducer composed of Me-PTC/PC-Z film and EL layer. The input light through a star-shaped mask was illuminated from the other side.

two input images having intensity more than the threshold, and "AND" operation can also performed for intensity less than the threshold.

We fabricated the organic light transducer consisting of the thicker photocurrent multiplication layer (thickness of 1.0 μm) of Im-PTC utilizing PC-Z as a binder polymer. Figure 5(a) shows the relationship between input and output light intensity. Fortunately, it was found that the output intensity showed strong saturation for increasing input intensity at 90 V. This characteristic means that the output light intensity hardly changes for input intensity more than about 50 μWcm^{-2}. Therefore, this device can be concluded to be suitable for an optical "OR" operator, which emits output light with almost equal intensity for irradiation of either input light. In practice, we captured the EL output image by CCD camera when two input images were overlapped on the device. For input patterns of digit 4 and digit 7, an EL output pattern of digit 9, the portion included in either input images, was observed as a result of optical "OR" operation Figure 5(b).

Next, we tried to develop an optical "AND" operator. To obtain an abrupt increase with a certain threshold in the output-input intensity curve, we paid attention to the optical feedback effect. This effect is caused by that the EL output light driven by the multiplied photocurrent is absorbed



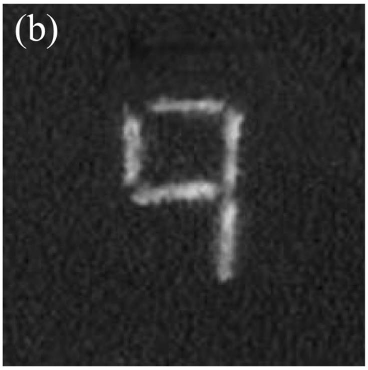


FIGURE 5 (a) Output-input light intensity curve in the organic light transducer having a thick multiplication layer (thickness of 1.0 μm) of Im-PTC utilizing PC-Z as a binder polymer. The ITO electrode was negatively biased at 90 V with regard to Au electrode. (b) EL output image of the optical "OR" operator.

to the multiplication layer and recursively enhances the photocurrent and EL output itself. Consequently, the output light intensity is expected to increase abruptly when the input light intensity exceeds a certain threshold.

In order to enhance the optical feedback effect, we fabricated the device with a thinner photocurrent multiplication layer of Im-PTC having a thickness of 0.53 μm by utilizing PVB as a binder polymer, which enables the EL output light to reach the active interface between ITO and Im-PTC layer. Figure 6(a) shows the output-input intensity curve in this device. On the contrary of the previous case, the output intensity increases abruptly with an increase of input intensity. This characteristic is available for an

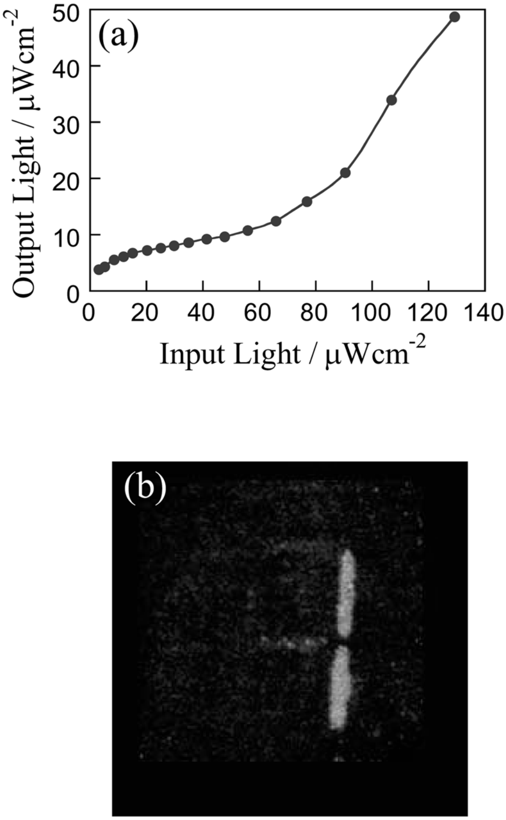


FIGURE 6 (a) Output-input light intensity curve in the organic light transducer having a thin multiplication layer (thickness of 0.53 μm) of Im-PTC utilizing PVB as a binder polymer. The ITO electrode was negatively biased at 65 V with regard to Au electrode. (b) EL output image of the optical "AND" operator.

optical "AND" operator. Figure 6(b) is the output EL pattern in the device having a thin multiplication layer for the same input images of digit 4 and digit 7. In this case, an EL output image of digit 1, the overlapped portion between two input images was observed as a result of optical "AND" operation.

CONCLUSION

In conclusion, we succeeded in fabricating two different types of the organic optical processors based on the organic light transducer combining an electroluminescent layer with a photocurrent multiplication layer. The pigment-dispersed polymer films showed large photocurrent multiplication and enabled us to fabricate a large area device suitable for image processors. We designed the relationship between input and output light intensity by controlling the thickness. As a result, optical operations of "OR" and "AND" were demonstrated for two input light images.

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