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Novel Image Sensor with Organic Photoconductive Films

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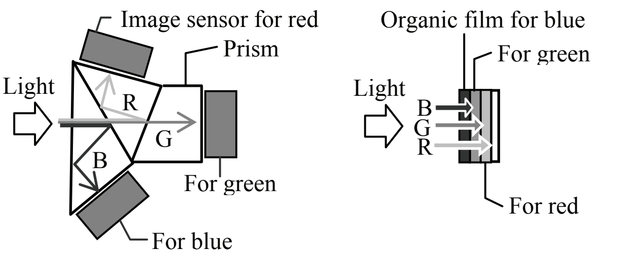
1. Introduction

Our group has been developing a new type of image sensor overlaid with three organic photoconductive films, each of which are sensitive to only one of the primary color components (blue (B), green (G), or red (R) light), with the aim of developing a compact, high resolution color camera without the color separation optical systems used in current color cameras.

We describe the unique characteristics of organic photoconductive films, such as wavelength selectivities[1] and high resolution[2,3], and demonstrate color separation in the vertically stacked structure of three organic photoconductive films[4]. A stacked organic image sensor with optically transparent readout circuits is also introduced.

2. Color separation systems of color cameras and the concept of "organic image sensor"



(a) Prism optical system of three-photosensor pickup system.

(b) Novel single photosensor pickup system.

Fig. 1. Optical arrangements for color cameras.

The optical arrangement for current broadcast television (TV) cameras is shown in Fig. 1(a). Incident light through a lens is separated into three primary color components by using a dichroic prism. Each color is then detected by one of three image sensors, such as a charge-coupled device (CCD), to attain high picture quality. As with photographic film, color separation in the direction of the depth of an image sensor could eliminate the need for the dichroic prism and the other two image sensors (Fig. 1(b)), resulting in a compact, lightweight and high resolution TV camera. Organic materials, especially organic pigments and dyes, which have a variety of spectral responses, are promising candidates for such an image sensor. For the successful fabrication of this type of image sensor, we used vertically stacked structures of three organic photoconductive films, each sensitive to only blue, green, or red light.

3. Unique properties of organic photoconductive films; advantages in application to image sensors

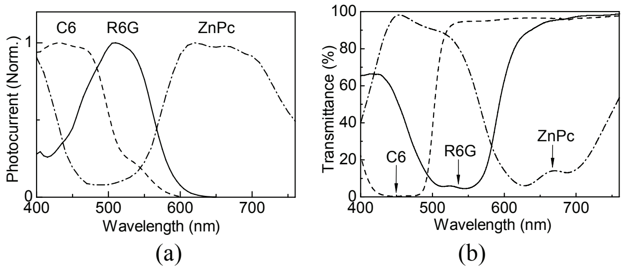


Fig. 2. (a) Spectral photoresponse spectra and (b) transmission spectra of organic photoconductive films.

Figure 2(a) shows the spectral photoresponse characteristics of three organic photoconductive films composed of coumarin 6 (C6), rhodamine 6G (R6G), and zinc phthalocyanine (ZnPc) as B-, G- and R-sensitive materials, respectively. Each device had an indium tin oxide (ITO) electrode/organic film/Al electrode configration. The applied electric field was 5.0 x 10^5 V/cm for all the films. As shown in the figure, each film works as a photoconductive film with excellent spectral responses.

Light transmission characteristics of each film are shown in Fig. 2(b). Although G- and R-sensitive films have weak absorption in the purple region shorter than 450 nm, each film has high transmittance except for the designed absorption wavelength region, which is suitable for using a stacked image sensor.

Figure 3 shows an example of a high-definition TV (HDTV) image obtained from a pickup tube incorporating organic film composed of NN'-dimethylquinacridone (NN'-QA) as a green sensitive photoconductive layer. We can see the subject in detail on the TV monitor, thus demonstrating that organic materials have sufficient resolution for use in HDTV image sensors.

Fig. 3. Monitor photograph of green-sensitive pick up tube at HDTV operation.

4. Color sensor with vertically stacked organic films

We have demonstrated color separation in a stacked structure of organic films. We fabricated three organic photodetectors composed of B-, G-, and R-sensitive organic photoconductive films on individual glass substrates, and stacked these detectors. Figure 4 is a schematic configuration and a cross-sectional view of a photodetector. We chose tetra(4-methoxyphenyl) porphine cobalt complex (Co-TPP), NN'-QA, and ZnPc as B-, G- and R-sensitive photoconductive materials, respectively. The films were fabricated as follows. A photoconductive material (ZnPc, NN'-QA or Co-TPP) was evaporated on a commercial glass substrate coated with an ITO electrode. Tris-8-hydroxyquinoline aluminum (Alq_3) and naphthalene tetra carboxylic anhydride (NTCDA) were then consequently evaporated. Finally, sputtered ITO film for the transparent counter electrode was formed on the organic film.

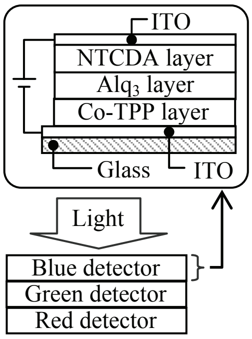


Fig. 4. Schematic diagram of stacked sensor.

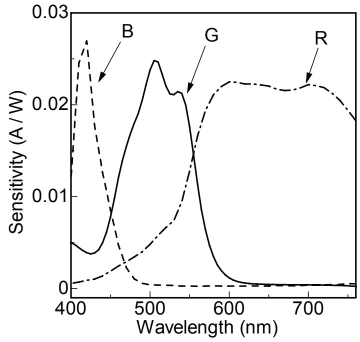


Fig. 5. Spectral photoresponse characteristics of stacked sensor.

Figure 5 summarizes the spectral photoresponse characteristics of the stacked structure shown in Fig. 4. Monochromatic light of 50 $\mu W/cm^2$ was irradiated on the B-sensitive detector side. The applied electric fields of B-, G-, and R-sensitive films were 1.0 x 10^6, 1.3 x 10^5 and 1.6 x 10^5 V/cm, respectively. Positive bias was applied to the sputtered-ITO electrodes of all devices. The spectral photoresponse curves of B-, G- and R-sensitive films had respective peak wavelengths at 420, 510, and around 650 nm. These results clearly indicate that color separation occurred in the vertically stacked structure of organic photodetectors.

5. Progress in organic image sensor development

Figure 6 illustrates a conceptual image of an organic image sensor. It has a structure of stacked organic photoconductive films each of which is sensitive to only blue, green and red light, and is equipped with optically transparent circuits that can read out a color signal generated in each organic film. To obtain the signal read-out circuit with a high aperture ratio, a thin film transistor (TFT) using zinc oxide (ZnO)[5], which is a wide-bandgap (3.3 eV) and transparent oxide semiconductor, was adopted for the transparent readout circuit. We have developed a stacked organic image sensor combining ZnO-TFT with

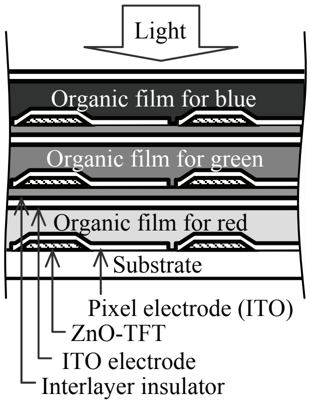


Fig. 6. Conceptual image of organic image sensor.

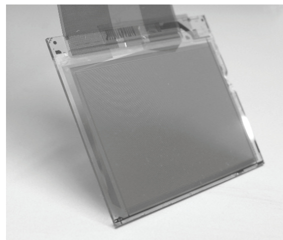


Fig. 7. Prototype image sensor composed of an organic film on ZnO-TFT circuit.

organic films (shown in Fig. 7).

6. Conclusions

We described the unique properties of organic photoconductive films such as wavelength selectivities and high resolution, and demonstrated signal read out in a stacked structure of three organic films, each of which were sensitive to only one of the primary color components. These results show the great potential for the development of high-resolution prism-less color cameras using organic photoconductive films.

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