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CMOS Image Sensor Overlaid with an Organic Photoconductive Film

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1. INTRODUCTION

We have been researching a new type of solid-state image sensor overlaid with three kinds of organic photoconductive films which are sensitive to only red, green, and blue light, with the aim of developing compact and high-resolution color camera without color separation optical systems [1]. The previous experiments confirmed that organic photoconductive films had excellent selectivities in spectral responses [2]. High-resolution of the film was also demonstrated by using an image pick-up tube [3].

In this paper, a CMOS image sensor overlaid with an organic photoconductive film is presented as a next step toward our goal, and the photoelectric conversion characteristics of prototype sensor is discussed.

2. SENSOR ARCHITECTURE

Figure 1 shows the schematic diagram of the new sensor. Figure 2 is the cross-sectional configuration of its single pixel. The sensor is composed of an organic photoconductive film that transports electrons and a CMOS image sensor consisting of passive pixels, pixel-reset FETs (M2), readout circuits, column-select FETs (M5), and vertical and horizontal shift registers.

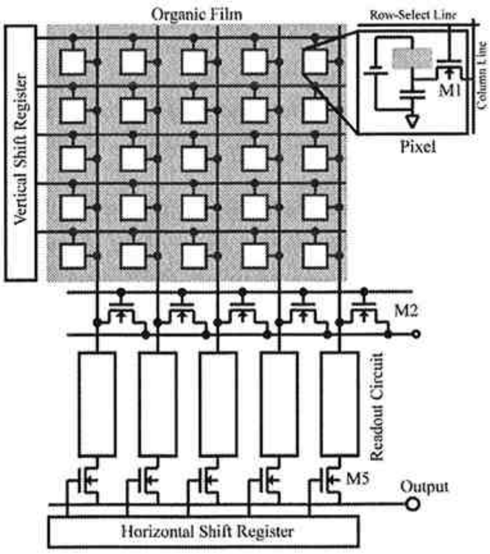

Fig.1 Schematic diagram of the CMOS image sensor overlaid with an organic photoconductive film.

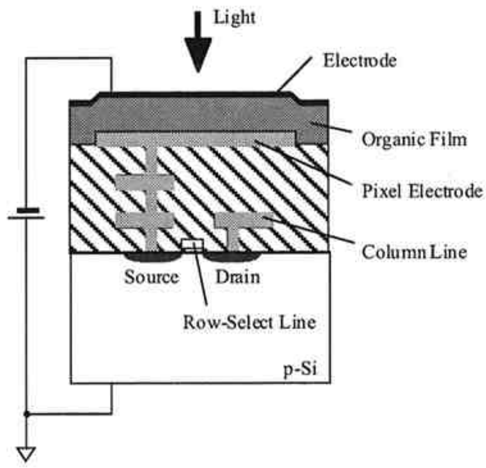

Fig.2 Cross-sectional view of a pixel.

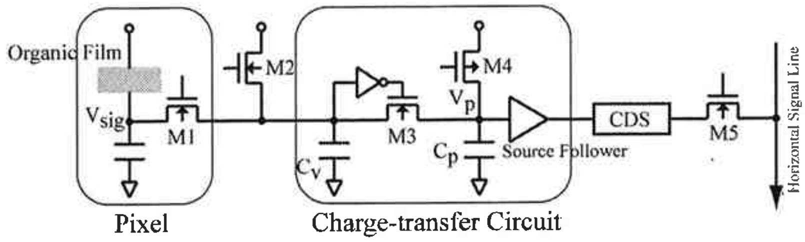

Fig.3 One-column configuration of the prototype sensor.

Figure 3 shows the one-column configuration of the prototype sensor. The readout circuit is composed of a charge-transfer circuit and CDS circuit [4],[5]. The charge-transfer circuit consists of a transfer FET (M3), a C_p-reset FET (M4), an inverter inserted between the gate and source of M3, and a source follower, where C_p is the parasitic capacitance of M3 and M4.

The architecture of readout using the charge-transfer circuit is explained as follows using energy-level diagram shown in Fig. 4. In each pixel of the sensor, incident light is converted into electron-hole pairs in the organic film, and electrons are transported to the pixel electrode side by an electric field applied to the film. When the electrons stored at the pixel electrode are read out to the column line with a large capacitance C_v by turning on the row-select FET (M1), the potential of the column line goes slightly down compared with the initial potential, as shown in Fig. 4(a). This potential change causes the gate voltage of M3 to increase because of the operation of the inverter and the signal charges on the column line to be transferred to C_p, as shown in Fig. 4(b). The potential of the column line rises and the gate voltage of M3 decreases as the signal charges are being transferred to C_p, and the potential of the column line is restored to the initial value when all signal charges have been transferred to C_p, as shown in Fig. 4(c). This CMOS image sensor with charge-transfer circuits has the following advantages.

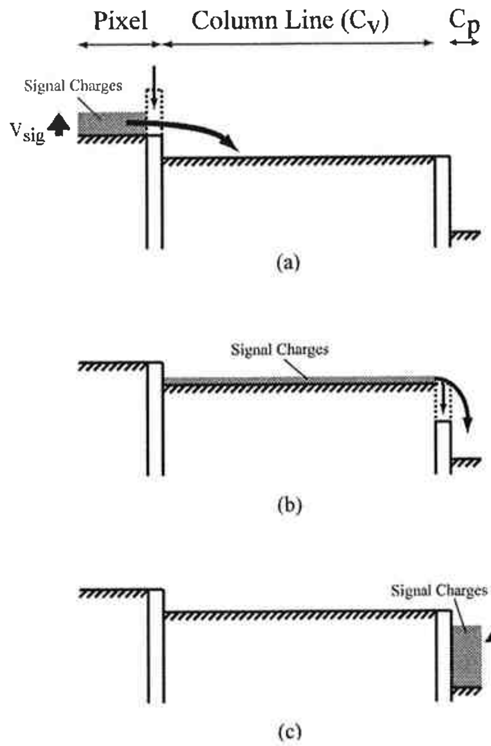

Fig.4 Schematic energy-level diagram of the signal readout circuit. (a) readout of the signal charges from pixel, (b) transfer of the signal charges to C_p, and (c) completion of charge-transfer from pixel to C_p.

1) The FPN caused by the C_v variation between the columns can be suppressed because the signal charges can be transferred from the pixel to C_p without being disturbed by C_v.

2) Large-signal output can be obtained by transferring the signal charges from the large capacitance of the pixel to the small capacitance C_p, and by reading out the signal charges via the source follower and the CDS circuit. This suppresses the FPN caused by the clock-feedthrough variation of M5 between the columns.

3. PROTOTYPE SENSOR

Figure 5 shows the microphotograph of the prototype image sensor. The CMOS image sensor was produced with the 0.5-μm 2-poly 3-metal CMOS process and had 128 x 128 pixels, each with a pixel size of 10.5 x 10.5 μm^2.

The organic photoconductive film consists of a zinc phthalocyanine (ZnPc) layer as the red-light sensitive photoelectric conversion part with hole-transport property, and a tris-8-hydroxyquinoline aluminum (Alq_3) layer with electron-transport property. High quantum efficiency up to 20% can be obtained with this layer structure [2], and the ZnPc film insures high-resolution for HDTV use [3]. Figure 6 shows the absorption spectrum in the visible wavelength region of the fabricated film. Two peaks at 615 nm and 700 nm correspond to the absorption of the ZnPc layer. The film also has a weak absorption in the wavelength region shorter than 450 nm, which originates from the absorption of the Alq_3 layer.

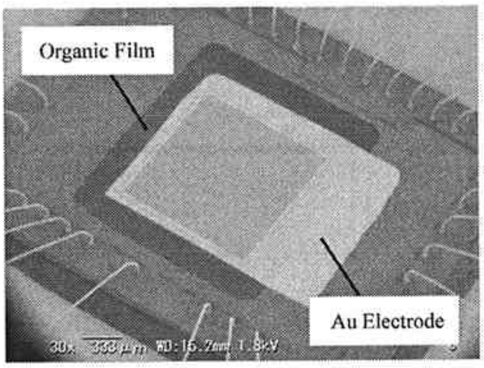

Fig.5 Microphotograph of the fabricated sensor.

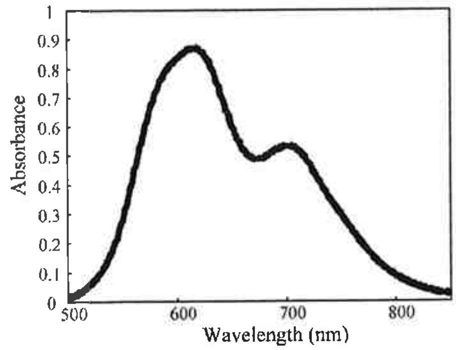

Fig.6 Absorption spectrum of the fabricated film.

The film was fabricated as follows. The Alq_3 and ZnPc layers were successively evaporated onto the pixel electrodes of the CMOS image sensor with a deposition rate of 0.05 nm/sec. The thickness of both layers was about 100 nm, respectively. Semi-transparent 15-nm-thick Au electrode was then deposited onto the ZnPc layer. Transmittance of the Au electrode is about 30 % at 650 nm irradiation.

Figure 7 shows the dependence of the output signal voltage on the applied voltage of the organic film, when red light generated with a white light and red optical filter (HS-R1) was used as incident light. The output signal voltage based on signal charges generated by the organic film was observed under an applied voltage of -9 V or less, and it increased until the dark current of the organic film sharply increased; i.e., the applied voltage reached -14 V.

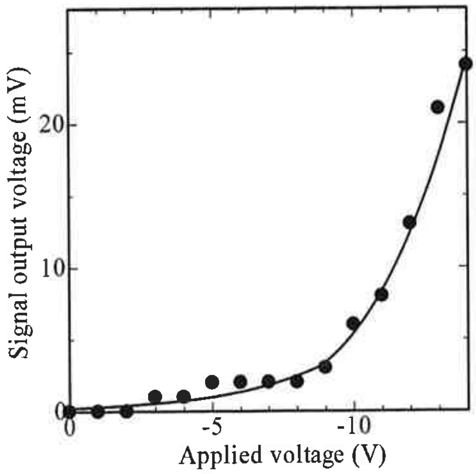

Fig.7 Signal output voltage vs. applied voltage of the organic film.

4. Summary

We have fabricated and tested the new type of CMOS image sensor overlaid with an organic photoconductive film, and the output signal voltage based on signal charges generated by the organic film has been observed for the first time. This result promises to open the way to the development of high-resolution prism-less color cameras.

References

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