CMOS Color Image Sensor Overlaid with Organic Photoelectric Conversion Layers : Depression of Dark Current

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ABSTRACT

We have proposed the new CMOS color image sensor overlaid with organic photoelectric conversion layers in order to overcome the problems in sensitivity, moiré and color shading, which current CCD and CMOS image sensors have been facing with. Although the proposed image sensor and an organic solar cell depend on the photoelectric conversion by organic layers in common, the former distinctly differs from the latter in that the dark current should be markedly reduced to be as small as that in a silicon photodiode. Confirming the fact that the charge carriers of the dark current were predominantly injected from electrodes by applied field, we examined the effect of injected charge blocking layers upon the dark current in the proposed sensor and the quality of the pictures, which were taken by it and would be shown during this presentation.

INTRODUCTION

Both CCD and CMOS are the current image sensors predominantly used for digital imaging and continuously making progresses. They are principally the same in the method for color separation and the structure of photodiodes. While visible light is divided into the regions of three primary colors (i.e., blue, green, and red), each pixel is regularly arrayed on a plane and has a built-in color filter, which transmits and allows incident light in the region of one of the three primary colors to reach a photodiode for photoelectric conversion. This should be a principal reason for their deficiency in image-capturing ability, since incident light is uselessly absorbed in the regions of the other two primary colors by a filter in each pixel. In addition, they are facing with such problems as the color moiré caused by regularly arrayed color filters, the color-shading caused by inclined light incident to a color filter and a diode, which are apart from each other in a pixel, the decrease in the number of incident photons captured by a pixel and therefore the decrease in sensitivity with decreasing the size of a pixel.

In order to overcome these problems, we have proposed a multiply layered image sensor having a CMOS read-out circuit overlaid with three photoconductive layers, as illustrated in Fig. 1[1-2]. In this sensor, each of three photoconductive layers absorbs incident light in the region of one of the three primary colors, and transmits incident light in the regions of the other two primary colors, making it possible for each pixel to capture incident light in all the visible region for image formation. In addition, the proposed image sensor has several important advantages over current image sensors including large fraction in a pixel area available for capturing incident light owing to the

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structure with photoconductive layers on a read-out circuit, absence of color moiré owing to the structure without any color filter in each pixel, reduction of color-shading by causing the color separation and photoelectric conversion at the same place in each pixel. Although the proposed image sensor and an organic solar cell depend on the photoelectric conversion by organic photoconductive layers in common, the former distinctly differs from the latter in that the organic photoconductive layers in the former need sharp absorption spectra for color separation, rapid operation, and reduced dark current, which should be as small as that in a silicon photodiode. Usually, the dark current is enhanced by the increase in bias voltage, which is applied for the enhancement of the photoelectric conversion efficiency, and is therefore an important problem to be solved for the realization of the proposed image sensor.

In order to depress the dark current, we studied it in the proposed image sensor, in which bias voltage was applied to organic photoconductive layers. It was judged from the analysis of the current-voltage characteristics that the dark current predominantly arose from injected charges from electrodes to organic photoconductors. Then, we tried to depress the dark current by putting injected charge blocking layers between an electrode and a photoconductive layer, as illustrated in Fig.2. Furthermore, we produced a trial product of the proposed image sensor with a CMOS read-out circuit overlaid with a photoconductive layer, in which the dark current was depressed according to the result obtained in this study.

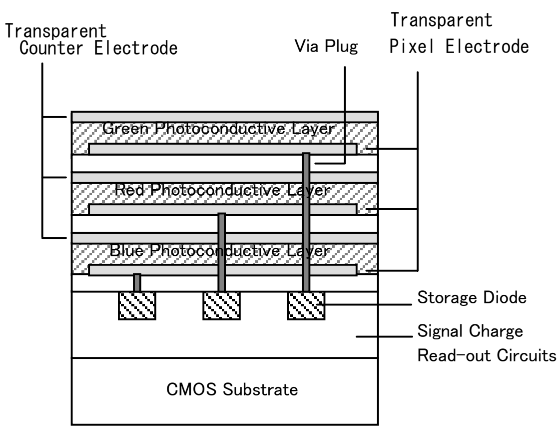

Fig. 1 Structure of image sensor with organic photoconductive layers.

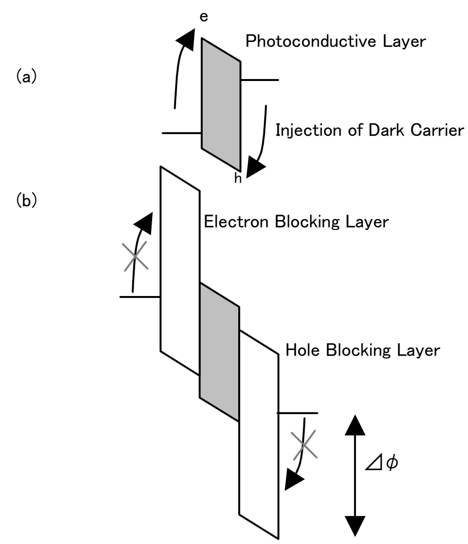

Fig. 2 Schematic energy diagram of photoconductive layers (a) without blocking layers, and (b) with blocking layers.

EXPERIMENTS

In order to study the dark current in the proposed sensor in the presence of applied voltage, a device was prepared by depositing one after another on an ITO electrode with a glass substrate an organic layer with variation of ionization potential (Ip) for hole-blocking, a photoconductive layer composed of quinacridone, and an Al electrode by means of high-vacuum thermal evaporation method. Then, the dark current was given by the current-voltage characteristics of the device in the presence of positive bias voltage to the ITO electrode.

In order to evaluate a picture taken by the proposed image sensor on the basis of the result of the above-stated experiment, a device was prepared by depositing a quinacridone sandwiched between injected charge blocking layers, which were the best in performance by high-vacuum thermal evaporation method, and an ITO counter electrode by sputtering on an ITO pixel electrode installed on a CMOS read-out circuit. The devices thus prepared were sealed. All the above-stated processes were carried out without breaking vacuum. Since each pixel in this CMOS sensor has a quinacridone layer on a silicon diode, this sensor is sensitive to two color regions (Fig. 3). Namely, incident light is absorbed in green region by a quinacridone layer for photoelectric conversion, while incident light is transmitted in blue and red regions by a quinacridone layer for the absorption and photoelectric conversion by a silicon photodiode. Incident light is captured separately in blue and red regions by a photodiode through color filters transmitting light in blue and red regions, respectively. Then, a full color image was constructed by the images, which were separately captured in blue, green, and red regions according to the above-stated procedures.

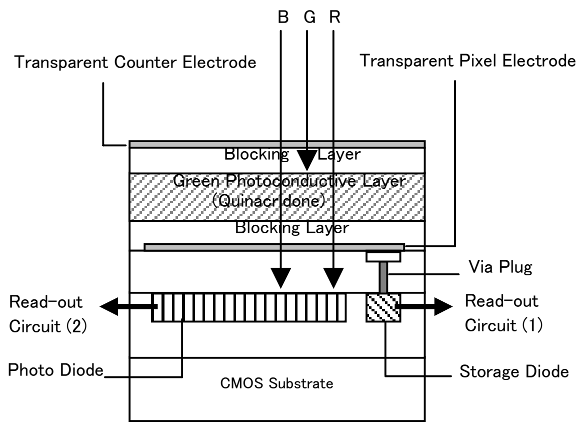

Fig. 3 Structure of trial product of CMOS image sensor with overlaid organic layer.

RESULTS and DISCUSSIONS

Fig. 4 shows the relationship between Ip of a hole-blocking material and the resultant dark current, indicating the tendency that the increase in the former results in the decrease in the latter. The hole-blocking layer with the largest Ip among those examined could decrease the dark current by as large as five orders of magnitudes. This result seems to indicate that a hole-blocking layer could depress the dark current by increasing the barrier height for the positive hole injection ($\Delta\phi$; the difference between the work function of an ITO electrode and the Ip value of an organic layer in contact with the ITO electrode) . It is however noted that the dependence of the dark current on $\Delta\phi$ is too small to explain the observed dark current according to the scheme shown in Fig. 2. In addition, the observed dark current differs considerably among the hole-blocking materials with similar $\Delta\phi$ values. It is therefore considered that the hole-blocking ability depends, not only on Ip, but also on intermediate levels in a hole-blocking layer.

Fig. 5 shows the picture taken by the proposed CMOS image sensor having a green-sensitive photoconductive layer composed of quinacridone in contact with the best blocking layers. The obtained picture was fairly good, indicating that the green image, which was captured by an organic photoconductive layer, was comparable to the blue and red images captured by a silicon photodiode in the ratio of the number of signal charge carriers to that of dark charge carriers.

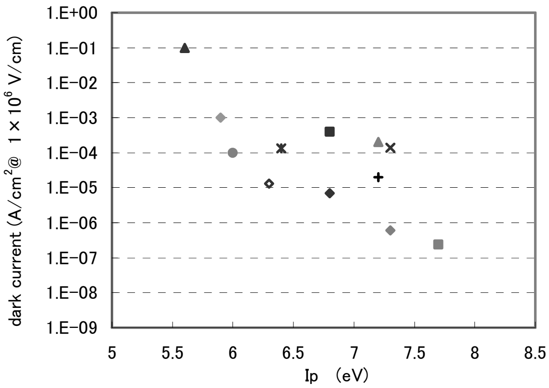

Fig. 4 Dependence of dark current on Ip under voltage biasing condition.

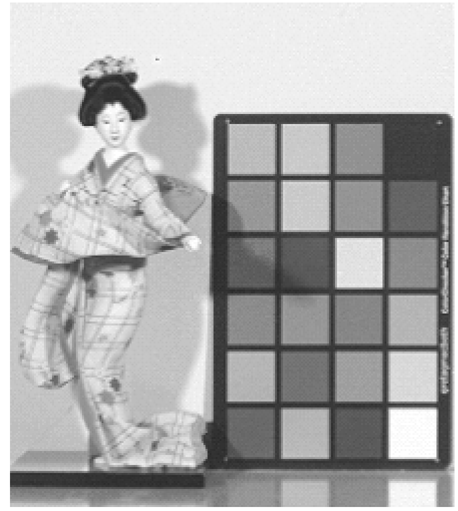

Fig. 5 Color picture taken by trial product.

CONCLUSION

The dark current in an organic photoconductive layer in the presence of applied electric field could be markedly depressed by introducing injected charge blocking layers between electrodes and the photoconductive layer. The introduction of the best blocking layers into the proposed CMOS image sensor overlaid with an organic photoconductive layer made it possible to take fairly good color pictures.

ACKNOWLEDGEMENTS

The present authors thank Prof. Shoji Kawahito of Shizuoka University and Prof. Takahiro Saito of Kanagawa University for their collaboration in designing the CMOS circuit and in simulating the optimized spectral sensitivity of proposed image sensor, respectively.

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