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WRGB LOFIC CMOS Image Sensor with Color-Independent Exposure and Widely-Spectral High Sensitivity

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1. Introduction

Image sensors with wide dynamic range, good color reproducibility and high SNR are required in security, automotive, chemical and biological application field. Several recent papers have described a wide dynamic range CMOS image sensors with lateral overflow integration capacitor (LOFIC) pixels which have solved the trade-off between full well capacity (FWC) and sensitivity[1, 2, 3]. Also, high sensitivity CMOS image sensors with WRGB color filter[4] and without infrared cut (IR-Cut) filter[5] have been reported. The image sensor without IR-Cut filter can obtain high luminance signals but cannot have good color reproducibility.

In this paper, we have described a WRGB LOFIC CMOS image sensor featuring almost the same saturation exposure with wide dynamic range, good color reproducibility in RGB pixels and high sensitivity luminance in W pixels from visible to Near-IR spectral region. The LOFIC CMOS image sensor with a 1/3.3-inch optical format, $1280^H \times 480^V$ pixels, 4.2-μm effective pixel pitch with 45° direction was designed and fabricated through 0.18-μm 2-Poly 3-Metal CMOS technology with buried pinned photodiode (PD) process. The image sensor has achieved about 108-μV/e⁻ high conversion gain and about 102-dB dynamic range performance in one exposure.

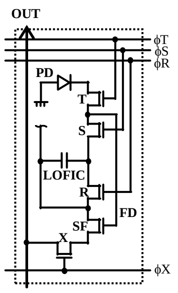

Fig. 1 Schematic diagram of pixel circuit.

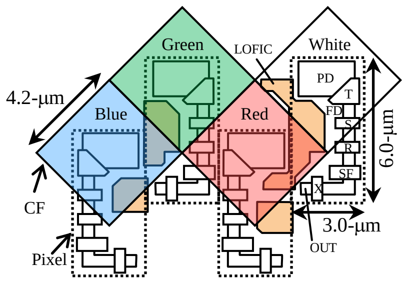

Fig. 2 Schematic diagram of pixel layout and color filters.

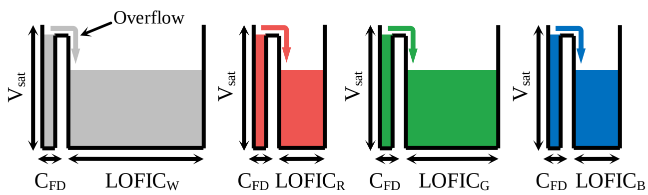

Fig.3 Electron potential of WRGB pixels.

2. General Instructions

Fig. 1 and 2 shows the schematic diagram of the pixel equivalent circuit and the schematic diagram of the pixel layout of the image sensor, respectively. A LOFIC has been placed in a pixel, which integrates overflow photoelectrons from PD and floating diffusion (FD) under strong light intensity. The color filters and on-chip micro-lens are densely and uniformly placed along the direction at an angle of 45° on the PD in a rectangle pixel. Fig.3 shows the electron potential diagrams of WRGB pixels. The capacitance ratio of LOFICs have been set into W:R:G:B = 3:1:2:1 in order to achieve almost the same saturation exposure of all pixel color. Fig. 4 is a micrograph of the chip and the close-up image of color filter arrays. Fig. 5 shows the measured spectral sensitivity response of the image sensor. The good color selectivity of the R, G and B pixels with IR-Cut filter, as well as the high sensitivity of the W pixel with IR-Cut filter are obtained. In addition, W pixel without IR-Cut filter indicates widely-spectral high luminance sensitivity performance from visible to Near-IR region.

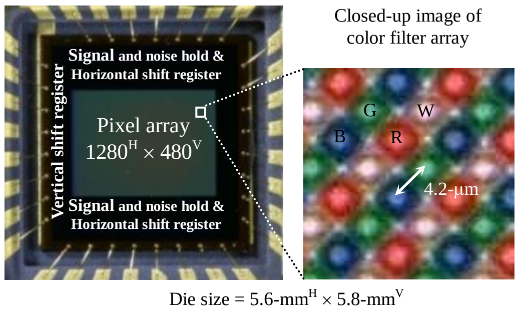

Fig. 4 Chip micrograph.

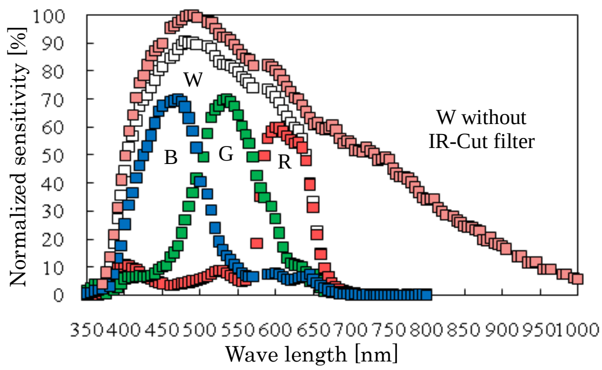

Fig. 5 Spectral sensitivity responses. The W, R, G and B responses have been measured with IR-Cut filter (IRC-65L).

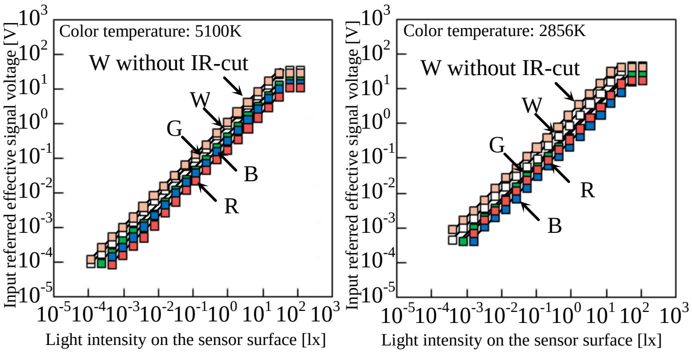

Fig.6 Photo-electric conversion characteristics under 5100K and 2856K light source.

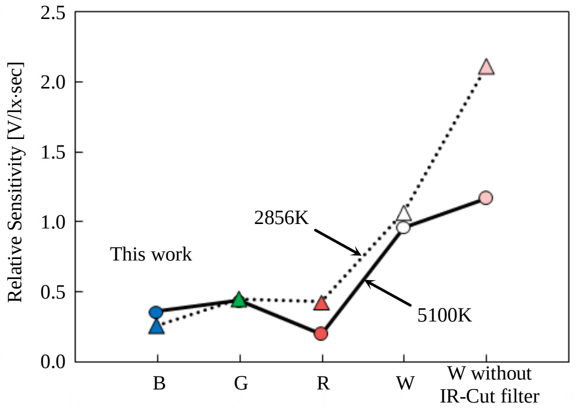

Fig.7 Relative sensitivity of WRGB and W without IR-Cut filter pixels.

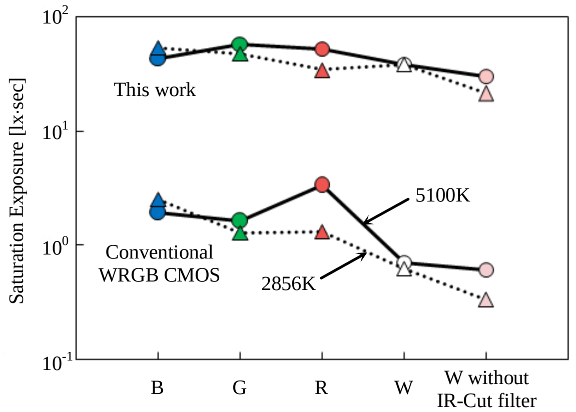

Fig.8 Saturation exposure of WRGB and W without IR-Cut filter pixels.

Fig. 6 shows the photo-electric conversion characteristics under a daylight source (5100K) and an A light source (2856K) respectively. Fig. 7 shows the relative sensitivity of WRGB and W without IR-Cut filter pixels under two light sources extracted from Fig. 6. The W pixels, especially the W pixels without IR-Cut under A light source have four times or more high sensitivity compared with R, G and B pixels. Fig. 8 shows the saturation exposure of WRGB and W without IR-Cut filter pixels extracted from Fig. 6. The saturation exposure is about a digit higher than a conventional CMOS image sensor.

(a) Color image (b) Visible & Near-IR image

Fig. 9 Sample pictures under the light source of 5100K and 2856K.

TABLE I Specification and performance

Process technology	0.18-µm 2P3M CMOS with pinned PD
Pixel size	$3.0\text{-}\mu m^{H} \times 6.0\text{-}\mu m^{V}$
Effective pixel pitch	4.2-µm (45° direction)
Number of effective pixels	$1280^{H} \times 480^{V}$
Conversion gain	$108\text{-}\mu V/e^{-}$
Noise Floor	$2.43\text{-}e^{-}$
Dynamic Range	102-dB (W pixel)

And the ratio of the highest to the lowest saturation exposure between the two light sources has decreased from 5.5 to 1.7. In Fig. 9 (a), the high quality color image from high to low light intensity is obtained in one exposure. In Fig. 9 (b), a wide waveband image from visible to Near-IR is obtained by W pixels without IR-Cut filter. The WRGB LOFIC CMOS image sensor has achieved $2.43\text{-}e^{-}$ dark temporal noise, 3.2×10^{5} e^{-} FWC of W pixels and about 102-dB dynamic range.

3. Conclusions

A WRGB LOFIC CMOS image sensor in which the saturation exposures were designed almost the same, including W pixels with wide-band high sensitivity from visible to near infrared, has been developed. As a result, wide dynamic range, good color reproducibility in RGB pixels and high sensitivity luminance in W pixels have been achieved simultaneously.

References

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