A 3.0µm-pixels and 1.5µm-pixels combined CMOS Image Sensor for Viewing and Sensing Applications with 106dB Dynamic Range, High-Sensitivity, LED-Flicker Mitigation and Motion Blur-less

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***Abstract*— We propose a new concept image sensor suitable for viewing and sensing applications. This is a report of a CMOS image sensor with Ta-Kuchi pixel architecture consisting of a 1.5µm pixel with four shared pixel structures and a 3.0µm pixel with in-pixel-capacitor. They are arranged in a staggered pitch. This architecture achieves both a High Dynamic Range (HDR) of 106dB and LED Flicker Mitigation (LFM) as well as Motion Artifact Free, and Motion blur less. As a result, moving subjects can be accurately recognized and detected with good color reproducibility in any lighting environment. This allows a single sensor to deliver the performance required for viewing and sensing applications.**

Keywords—CMOS Image Sensor, Automotive, HDR, LFM, Motion Artifact, Motion blur, Ta-Kuchi Pixel.

I. INTRODUCTION

Sensing and Viewing, especially in the automotive sector, must accurately perceive moving objects and obstacles and detect them with high color fidelity in all lighting conditions. For example, in order to recognize people, objects, and features even in dark places, it is necessary to sample images with high sensitivity and low noise. Also, Light Emitting Diode (LED) traffic lights should always appear to be on in the image, even if they are actually blinking. Extending the exposure time to catch flicker tends to saturate the signal, losing luminance and color information within the pixel. To solve these problems, several HDR techniques have been proposed that extend the exposure time to capture the flicker signal but do not saturate the signal.[1-4] However, extending the exposure time causes motion blur, which causes misrecognition. Based on these considerations, we propose an image sensor that is optimal for viewing and sensing, which combines color reproducibility and high dynamic range while maintaining sufficient resolution and eliminating the causes of misrecognition.

II. SENSOR ARCHITECTURE

A. New Concept

There are the following features for sensing and viewing applications. In dark, low-light, and high light environments, the signal is only needed to detect the presence or absence of objects, not the color information. And it is necessary to acquire the signal without saturating the signal even if the exposure time is extended enough for the flickering LED. Taking advantage of the difference in information required for luminance and color, we propose the Ta-Kuchi pixel shown in Figure 1. Incidentally, in Japanese Kanji, Ta-Kuchi is written 田口.So we named this structure Ta-Kuchi pixel because the shape of the pixel resembles 田-口.

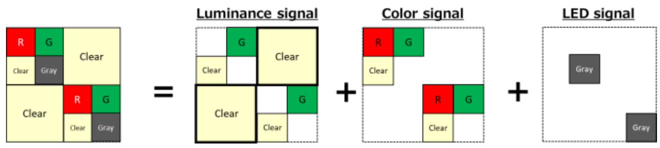


Fig. 1. Pixel configuration that realizes the concept

The color filter of the Ta-pixel consists of Green, Red, Clear, and Gray, and the color filter of the Kuchi-pixel consists of Clear. It specializes in acquiring luminance signals by using high sensitivity Green and Clear pixels in dark or low-light environments. In scenes that require color recognition in medium illumination, the signals of the red, green, and clear pixels of the pixel are used. For LED signal acquisition, low sensitivity gray filter pixel signals that are difficult to saturate even with long exposure are used.

B. *Sensor Configuration*

The Ta-Kuchi pixel arrangement method is a staggered pitch arrangement as shown in Figure 2. The number of pixels is 4.61Mpixel for Ta pixels and 1.15Mpixel for Kuchi pixels. This makes it possible to obtain twice the resolution in color and luminance information compared to the 2.2Mpixel of the usual 3µm pitch pixel array.

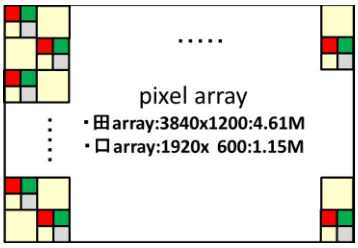


Fig. 2. Pixel array

A Ta-Kchi pixel is a combination of a 1.5µm pixel with a 4-pixel sharing configuration and a Kuchi pixel of a 3µm pixel with in-pixel Floating Capacitor(FC). Figure 3 shows a cross-sectional view of a Ta-Kuchi pixel. The shape of on-chip micro lens (OCL) is arranged in the same shape with Ta-Kuchi pixels. The light attenuation rate of gray pixels is controlled by the thickness of the gray filter and the opening width of the Light Shielding layer. In a Kuchi pixel, the area of photodiode (PD) and the FC are the same.

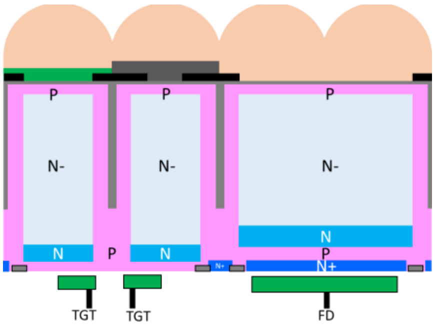


Fig. 3. Cross-Section of Ta-Kuchi Pixel

C. *Pixel Circuit*

Figure 4 shows the pixel circuit.

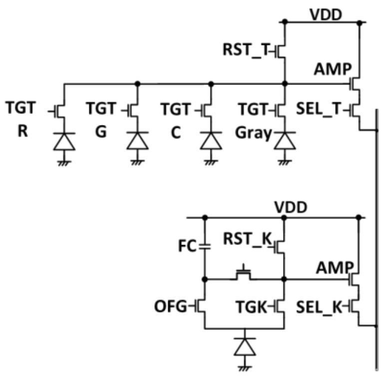


Fig. 4. Pixel Circuit

A Ta pixel consists of four photodiodes, four transfer transistors (TGT), a reset transistor (RST_T), a selection transistor (SEL_T), and a source follower amplification transistor (AMP). Four pixels are connected to one FD. A Kuchi pixel consists of one photodiode, a transfer transistor (TGK), an overflow gate (OFG), a reset transistor (RST_K), a selection transistor (SEL_K), a source follower amplification transistor (AMP) and in-pixel floating capacitor (FC).These drive lines are connected in a zigzag pitch from the vertical scan drive circuit for the Ta pixels and the Kuchi pixels.

D. *Pixel Read-out Method*

Figure 5 shows the read timing sequence. The signals of the Kuchi pixels and the signals of the Ta pixels are read out continuously. The Kuchi pixel signal has two modes: a mode for reading out the charge of the photodiode with low noise due to its high conversion gain, and a mode for reading out the charge overflowing from the charge of the PD and the charge of the FC. Two rows are read out with 8AD in a 1H period by combining long exposure time readout and additionally short exposure time readout.

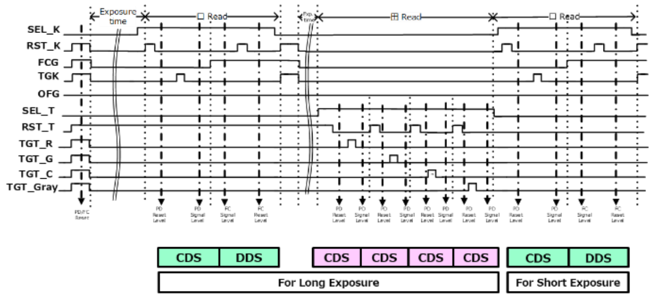


Fig. 5. Timing Sequence

In Kuchi Pixel, two types of signals are read-out in a single exposure. First, an exposure of Kuchi PD and FC begins by the reset of PD and FC. Then, Kuchi PD reset level is sampled and next the PD signal level is sampled. By performing correlated double sampling (CDS) for reset and signal level, signal are read-out. Subsequently, the signal that comes from FC is read-out by performing delta reset sampling (DRS): FC, in which the signal level is sampled first, followed by the reset level . Because the signal charges are accumulated in FD, FD cannot be reset prior to sampling the signal level. The flaw of DRS is that kTC noise cannot be removed; however, it can be suppressed by securing the capacitance of FC sufficiently. Subsequently, the Ta pixels Red, Gray, Green, and Clear are sequentially read out. Finally, read out the Kuchi pixels accumulated for short exposure again.

III. SENSOR CHARACTERISTICS

A. *Ta Pixel Characterristics*

Fig. 6 shows the output against the light intensity of the Ta pixel.

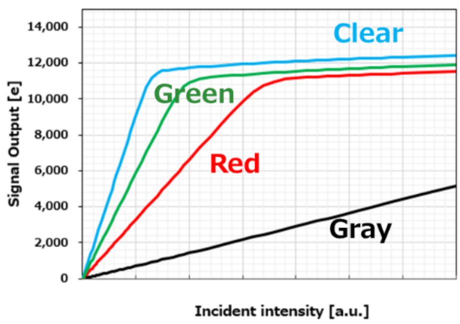


Fig. 6. Photo response of Ta pixels

Ideal linearity is achieved with respect to the amount of light for all colors. Minimum linear full-well capacity (FWC) is 9400e-, and random noise (RN) is 1.4e-.

FIG. 7 shows the quantum efficiency for each wavelength of clear pixels, green pixels, red pixels, and gray pixels. Clear pixels show up to 82%. Fig. 8 shows a Macbeth chart taken using this pixel with a light source of 6500K. Exhibits high color reproducibility. Also, the sensitivity of the gray pixel for LED is 550e-/lux·sec, which is 1/20 of the clear pixel sensitivity of 10800e-/lux·sec. As a result, the Dynamic Range for Gray pixels is 103 dB, and the illuminance saturation is 5600 cd/m2 after 11 msec accumulation. It is said that it takes 10msec or more to capture the flicker signal of the LED, and the saturation illuminance is said to be 4000cd/m2 or more, which are sufficiently high values. In addition, constant and stable quantum efficiency is obtained for wavelengths in the visible light region.

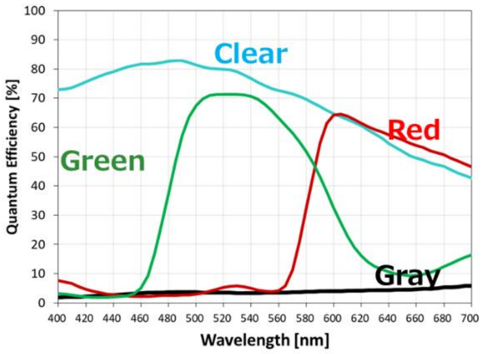


Fig. 7. Quantum efficiency (Ta Pixel)

Fig. 8. Macbeth chart

B. Kuchi Pixel Characterristics

FIG. 9 shows a cross-sectional view of a portion of a Kuchi pixel having a pixel transistor.

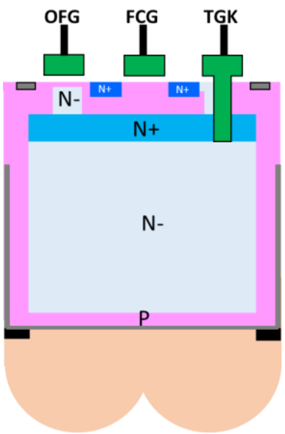


Fig. 9. Cross-Section of Kuchi Pixel

The PD signal transfer electrode TGK is a vertical Transfer Gate(VTG), and the overflow electrode to FC is a planar gate. By arranging VTG on the TGK side, it is possible to collect the charge generated in the photoelectric conversion area efficiently, which is almost the entire area of 3μm square area. The OFG side is a planar type so that the saturation charge can surely overflow to FC while minimizing the dark current generated in the PD and FC.

As shown in FIG. 10, PD saturation and Photo Response Non-Uniformity (PRNU) of FC have a trade-off relationship depending on the OFG voltage. As the OFG applied voltage increases, the PD saturation decreases, and overflow to FC becomes easier, so PRNU decreases. By setting it to -0.5V, sufficient saturation and PRNU reduction are achieved. The dark current can be sufficiently suppressed without depending on the OFG voltage.

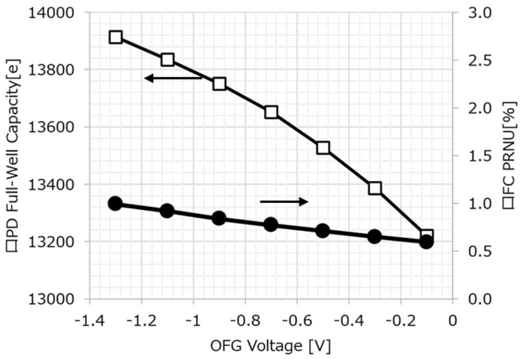


Fig. 10. OFG dependency FWC and PRNU

Fig. 11 shows the output against the light intensity of the Kuchi PD and Kuchi FC. The sensitivity is 40400e-/lx·s, the PD saturation is 13500e, and the PD+FC saturation is 280000e. Since RN is 1.4e, Dynamic Range is 106dB.

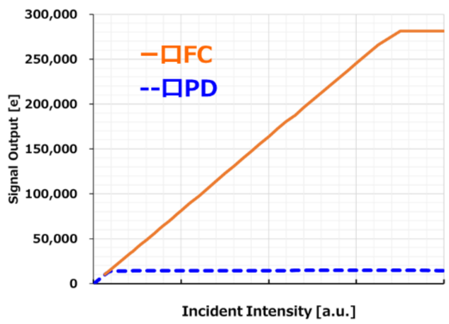


Fig. 11. Photo response of Kuchi pixels

Fig. 12 shows the illuminance vs. Signal to Noise ratio (SNR) when combining two types of signals with 10 msec accumulation and two types of signals with 0.16 msec accumulation.

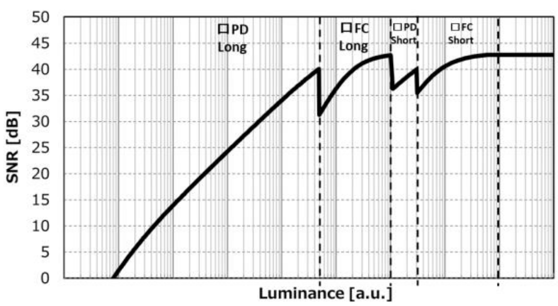


Fig. 12. SNR curve of synthesized signal

The high conversion gain signal is used in the low illumination area, and the PD+FC signal is used in the high illumination area. The SNR drop amount when connecting from the Kuchi PD to the Kuchi FC also maintains 30 dB at 85°C. The dynamic range from the SNR graph is 138dB when combined with 0.16msec short exposure.

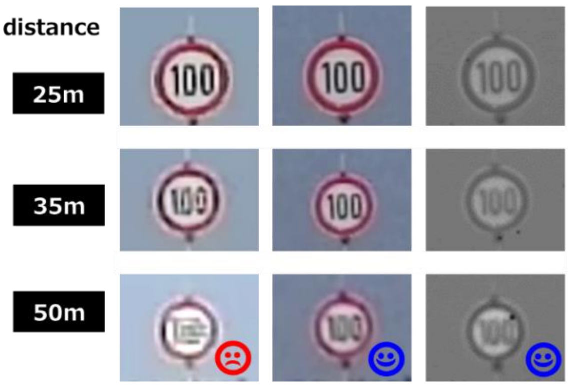
C. Synthesized Image

FIG. 13 shows an image of a moving object. In (a) is an image of one shot HDR in long exposure for LFM. Motion Blur occurs during exposure. In (b) is an image of Digital Overlap (DOL) HDR synthesis with time-division exposure, and motion artifact occurs. In (c) is an image of using Ta-Kuchi architecture. Motion Artifact Free and Motion Blur less are realized because it includes long exposure and short exposures with Kuchi pixel. This work uses motion detection. Each signals of the long exposure and the short exposure are compared for each pixel to determine whether there is a signal difference. At this time, the short accumulation Kuchi signal is multiplied by the exposure ratio gain for comparison. If there is a difference, the short exposure signal is selected, and if there is no difference, the long exposure signal with low noise is selected. In this way, motion detection is performed for each pixel and synthesized.

(a)one shot HDR (b)DOL HDR (c)This work

Fig. 13. Image of a moving object

Figure 14 shows the road signs captured at 25m, 35m, and 50m distances.



(a)3µm pixel Bayer (b)2.25µm pixel Bayer (c)This work

Fig. 14. Image of a road sign

(a) shows image captured using a Bayer array with 3um pixel, and cannot read numerical values 50m away. (b) shows image captured using a Bayer array with 2.25µm pixel. With this pitch, the numerical value 50m ahead can be read. (C) shows image captured using a Ta-Kuchi architecture. This performance equivalent to the 2.25µm Bayer array. In principle, interpolation with a Bayer array has limits on the performance of demosaic processing. A direction detection error occurs every frame. In this work, thanks to the array of 1.5µm pixels, there are clear pixels in all pixels within the 3µm pitch. Horizontal, vertical, and diagonal edge detection is easier than the 3µm pitch Bayer array, and aliasing is improved. This also improves resolution.

FIG. 15 shows a composite image of Ta-Kuchi pixels at 22 msec exposure. (a) is an image in which green, red, and clear pixels of Ta pixel are used as color signals and clear pixels as luminance signals. Ideal image quality without line defects due to complicated drive lines. The resolution is high enough to read numbers.(b) is an image of Gray Filter. Image quality without unevenness is obtained.

(a)口 PD+FC+田 RGC Image (b)田 Gray Image

Fig. 15. Synthesized Image

IV. CONCLUSIONS

TABLE1 shows pixel performance.

TABLE1 Pixel performance

		Unit	Ta 田	Kuchi 口
Power Supply		V	2.9/1.8/1.2	
Process Technology		-	90nm 4Cu 1AL	
Pixel pitch		µm	1.5	3.0
Pixel Array		pixel	4.61M	1.15M
Color		-	Red,Green,Clear,Gray	Clear
HDR Technology	Sensitivity ratio	times	20(Gray)	non
	in-pixel capacitor	-	Non	MOS
Random noise@RT		e- rms	1.4	1.4
Sensitivity(3200K witn IR cutfilter)		e-/lx·s	10800 (Clear)	40400
Full-well Capacity		e-	9.4K	280K
Real-Full-well Capacity		e-	188k(Gray)	280K
Dynamic Range(SingleExp.)		dB	103(Gray)	106

We have developed a new image sensor using new concept 田口 pixel architecture for Viewing and Sensing applications with 106dB DR, LFM, Motion Artifact Free and Motion Blur-less.

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