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Dual Pixel Reset Voltage CMOS Image Sensor For High SNR Ultraviolet Light Absorption Spectral Imaging

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Abstract

In this paper, we demonstrate a dual pixel reset voltage CMOS image sensor (CIS) for high SNR UV light absorption spectral imaging. The dual pixel reset voltage (VR) was introduced to improve the precision of absorption imaging. The developed CIS exhibited 71dB SNR, 15Me$^-$ full well capacity (FWC) and 190-1000nm wide spectral sensitivity. Using the developed CIS, a diffusion of 0.96ppm ozonated water into ultrapure water (UPW) was successfully visualized under 254nm light wavelength.

1. Introduction

Spectral imaging has been employed to in various fields by utilizing the emission/reflection/absorption characteristics of imaging objects in various light wavebands [1-3]. Spectral imaging technologies in the UV light waveband is expected to be useful to visualize distribution of chemical substances for environmental monitoring and so on. Regarding the absorption analysis, when photon shot noise dominates the total noise of system, the maximum SNR only depends on the number of signal electrons, that is, the FWC of the CIS. In current absorption spectrometry systems, single point detectors such as a photodiode (PD) or a linear array sensor with 70-80dB SNR have been utilized. By adopting an over 70dB high SNR image sensor to absorption imaging, component and concentration distribution can be measured. A high SNR CIS with 15Me$^-$ FWC using lateral overflow integration capacitor (LOFIC) [4] has been reported for absorption imaging [5]. In this previous work, although a high FWC was realized, the fixed pattern noise caused by the pixel SF's threshold voltage (Vth) variation is remained as an issue. In this work, we report a high SNR CIS with newly introduced dual VR function to improve the precision of absorption imaging by removing the fixed pattern noise and the PD technology realizing high quantum efficiency (QE) and reliability toward UV light [6]. As an application of the developed CIS, absorption imaging of ozonated water diffusion into UPW was experimented.

2. Design and performances of the developed CIS

The circuit architecture of the developed CIS is shown in Fig. 1. The VR can be switched between VR1 and VR2 by the pulse ϕVR. Here, VR1 is the PD reset level and VR2 is the reference level for correlated double sampling (CDS). In order to achieve over 70dB SNR, about 1pF LOFIC was implemented using MOS and MIM capacitors in each pixel. Fig. 2 shows the conceptual diagram of input referred floating diffusion (FD) voltage range for (a) conventional operation, (b) High SNR operation in [4] and (c) the dual VR high SNR operation introduced in this work. In (b) and (c), by setting the reference level near the saturation value and reading out the signal with high gain, it is possible to enlarge the microscopic change in signal caused by light absorption which cannot be detected in the conventional operation. Furthermore, since the PD reset level is not read out from the pixel, FWC can be increased by setting it to a higher voltage. However in (b), Since Vline reset voltage (VVCLR) which is the output node voltage of pixel SF was used as the reference level, pixel SF's Vth variation remains in the signal after CDS. In (c), the pixel SF's Vth variation is removed by the CDS operation of taking a difference of the reference and the light signals since the two signals are read out from the same pixel SF. The timing diagrams in H blanking period is shown in Fig. 3. The developed CIS has two operation modes; the wide dynamic range LOFIC operation mode and the dual VR high SNR operation mode, respectively. The developed CIS was fabricated using a 0.18μm 1P5M CMOS process technology with buried pinned PD. The pixel size is $16\mu m^H \times 16\mu m^V$. The micrograph of the developed CIS chip is shown in Fig. 4. The measured photo-electron conversion characteristic and photon transfer curve in the Dual VR high SNR operation mode are shown in Figs. 5 and 6, respectively. The developed CIS exhibited 15Me$^-$ FWC and maximum 71dB SNR. Fig.7 shows the measured spectral sensitivity of the developed CIS. In the UV light waveband, the high QE and high UV light resistance were achieved by employing the PD technology forming a high concentration surface p$^+$ layer with steep dopant concentration profile [6]. Summary of the developed CIS performance is shown in Table I.

3. UV light absorption spectral imaging result

As an application of the developed CIS, spectral absorption imaging of ozonated water with absorption peak at around 260nm was experimented [7-8]. In the semiconductor industry, ozonated water which is a kind of functional water dissolving ozone into UPW is widely used because it has a high removing effect against contamination on wafers and glass substrates. On the other hand, since ozone has short duration of effect by self-decomposition, also large amount of ozone is harmful to human bodies, it is important to monitor ozone concentration of ozonated water at the use-point and draining point for reduction of environmental burden [9]. Fig. 8 shows setup of ozonated water absorption imaging. Ozonated water was dropped into a cell containing about 3ml UPW. As a light source, a UV ramp having a light wavelength of 254 nm was used. UV light was irradiated to the cell, and the transmitted light was captured by the developed CIS. Fig. 9 shows the diffusion of ozonated water with concentration of 0.96ppm taken at 4fps. Here, the concentration of dropped ozonated water was externally measured by the KI method. The color changes from blue, green to red as the amount of absorption increases. The state of diffusion and convection of ozonated water were successfully visualized by the UV light absorption analysis.

4. Conclusion

We designed and fabricated a new CIS with dual VR to improve the precision of absorption imaging. By using the dual VR, pixel SF's Vth variation is removed and a high SNR is achieved simultaneously. The developed CIS achieved 71dB SNR, 15Me$^-$ FWC, 190-1000nm spectral sensitivity with a resistance to UV light irradiation. With the developed CIS, a diffusion of sub-ppm concentration ozonated water into UPW was successfully visualized under UV light. The developed CIS is expected to be useful for the detection of substances harmful to human bodies and environment.

Acknowledgment

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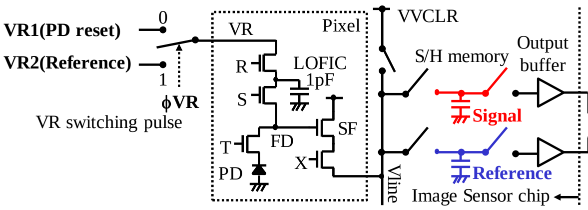


Fig. 1 Circuit architecture of the developed CIS.

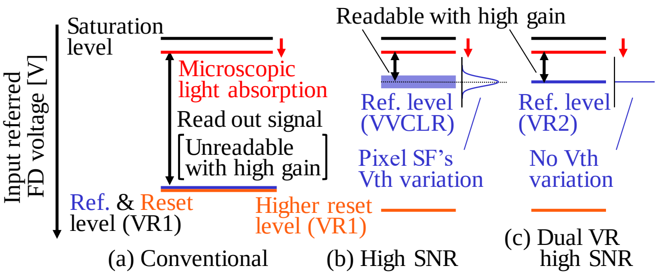


Fig. 2 Conceptual diagram of the three operation modes.

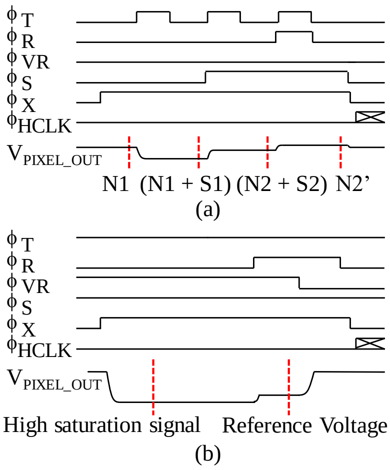


Fig. 3 Timing diagrams in H blanking period of (a) the wide dynamic range LOFIC S1 & S2 operation and (b) the Dual VR high SNR absorption imaging operation.

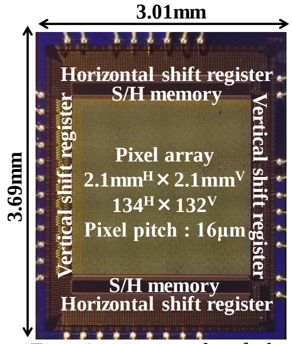


Fig. 4 micrograph of the developed CIS chip.

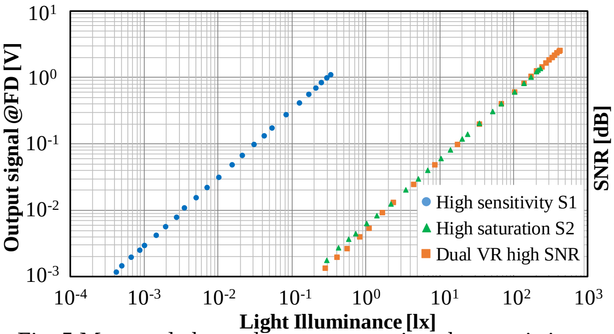


Fig. 5 Measured photo-electron conversion characteristic.

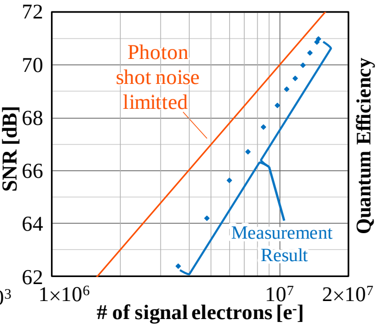


Fig. 6 Measured photon transfer curve in dual VR high SNR mode.

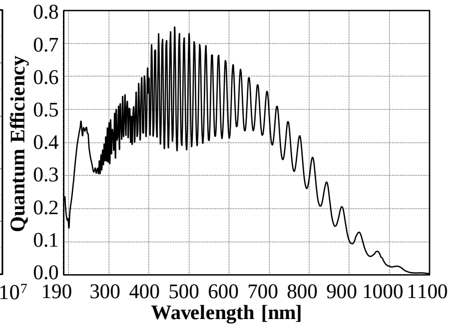


Fig. 7 Spectral sensitivity characteristic.

Table I Summary of the developed CIS performance.

Process technology			1-Poly 5-Metal CMOS with pinned PD
Power supply voltage			3.3V
Die size			3009μm^H×3687μm^V
# of effective pixels			128^H×128^V
Pixel size			16μm^H×16μm^V
Maximum Frame Rate			685fps
Capacitance of FD			2.0fF
Capacitance of LOFIC			1pF
FWC	LOFIC operation	High sensitivity S1	10ke$^-$
		High saturation S2	8Me$^-$
	Dual VR high SNR operation		15Me$^-$
Maximum SNR			71dB
Spectral sensitivity range			190nm – 1000nm

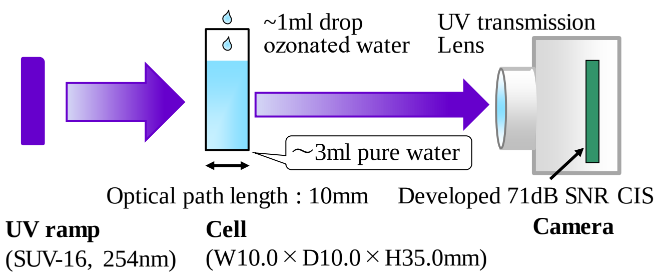
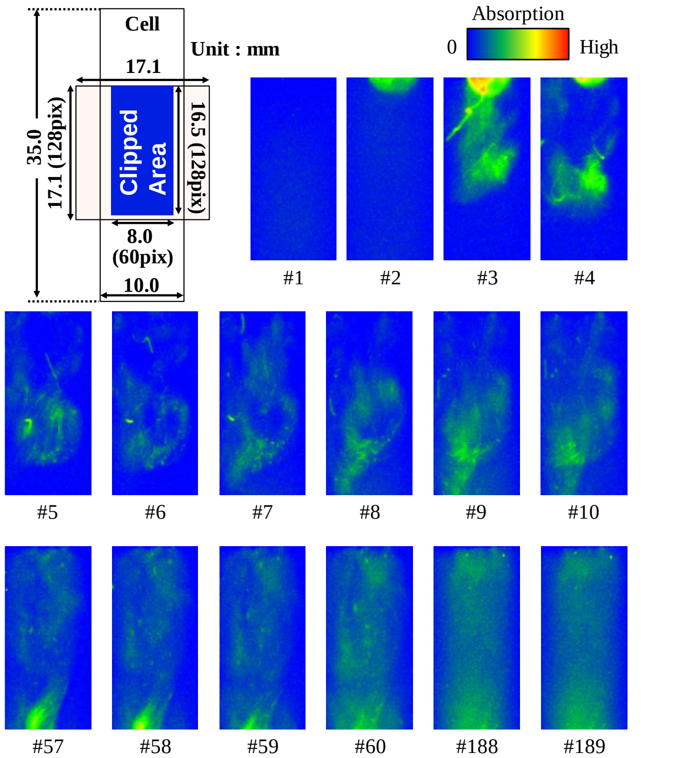


Fig. 8 Set up of Ozonated water absorption imaging.



Frame rate : 4fps, # : Frame number

Fig. 9 Diffusion of 0.96ppm ozonated water visualized by 254nm light wavelength absorption imaging.