Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 276-277

D-3-1 (Invited)

The Dynamic-Range Enhancement Technologies for CMOS Image Sensors

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1. Introduction

CCD and CMOS image sensors have been widely applied to various fields in this decade by the great improvements of basic performances such as sensibility, noise and resolution. Recent image sensors have achieved the pixel size of 2µm or less, the number of pixels of 20 million or more and the input conversion noise of 2 electrons or less. The differences of the basic performances were lost now between CCD and CMOS image sensor. CMOS image sensor has come to exceed CCD greatly in the shipment amount. One of the still insufficient performances is a dynamic range. The dynamic range defined as the ratio of a saturation signal and a noise signal has remained in about 60-80dB even in high quality image sensors. The image sensor with a wide dynamic range (WDR) performance of about 100dB or more that exceeds silver-salt film and human's eyes is especially aspired after in surveillance and automobile camera applications. This paper describes recent WDR image sensors and especially a WDR CMOS image sensor with lateral overflow integration capacitor (LOFIC) that has features that the dark current at photo-diode (PD), the photo-electric conversion gain at floating-diffusion (FD) and the full well capacity (FWC) are able to be designed independently.

2. Recent Progress on WDR Image Sensor

New WDR technologies keep being aggressively developed today [1-2]. WDR image sensors are generally classified from the methods of expanding the dynamic range into nonlinear response type and linear response type. Recently, the WDR image sensors with linear responses are becoming the mainstream because they have potential that can adequately do color signal processing under various lighting and temperature conditions. A lot of the linear response technologies have been based on multiple exposures with long exposure for low illumination condition and short exposure for high illumination condition. The technology paid attention to recently, first of all, includes a multiple exposure CMOS image sensor with column parallel cyclic ADCs [3]. The column parallel cyclic ADCs digitally correct the non-uniformity of capacitances, amplifier gains and DC offsets and are developed into 14bit resolution performance [4]. Next, WDR CMOS image sensors with the control of the integration time of each pixel by charge transfers at intermediate voltage have been also highlighted [5-7]. These CMOS image sensors obtain WDR signals by integrating the photo-electric charges in full integration period in low illuminated pixels and executing the charge transfers at the intermediate voltage at the multi time in highly illuminated pixels. In multiple exposure image sensors, the performance that takes picture of moving image is poor.

3. LOFIC CMOS Image Sensor

On the other hand, the WDR CMOS image sensors with LOFIC in each pixel have good linear responses and low noise performances in a simultaneous exposure, and have advantage to achieve high quality camera system [8-9]. Fig.1 shows (a) the pixel circuit, (b) the chip micrographs, (c) a SNR characteristic and (d) sample images of the LOFIC CMOS image sensor. The experimental results of the LOFIC CMOS image sensors demonstrate to actually improve readout gain G and input-referred noise N and reaches G > 200-µV/e$^-$ and N < 2-e$^-$ with full well capacity of beyond 100-ke$^-$ [10-11]. The concept of the LOFIC WDR CMOS image sensor can be made the best use of for the design of low dark current at PD, high photo-electric

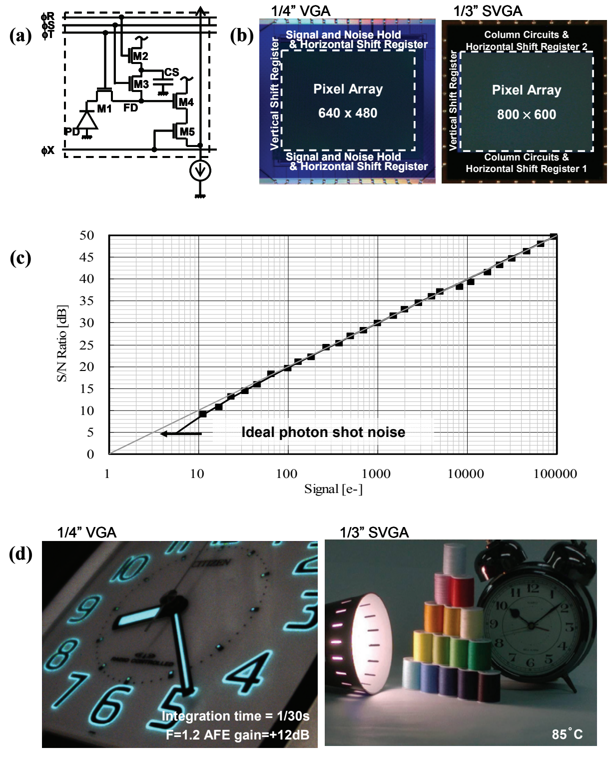

Fig.1 (a) The pixel circuit, (b) the chip micrographs, (c) a SNR characteristic and (d) sample images (a remaining fluorescent image and an image under high temperature) of the LOFIC CMOS image sensors.

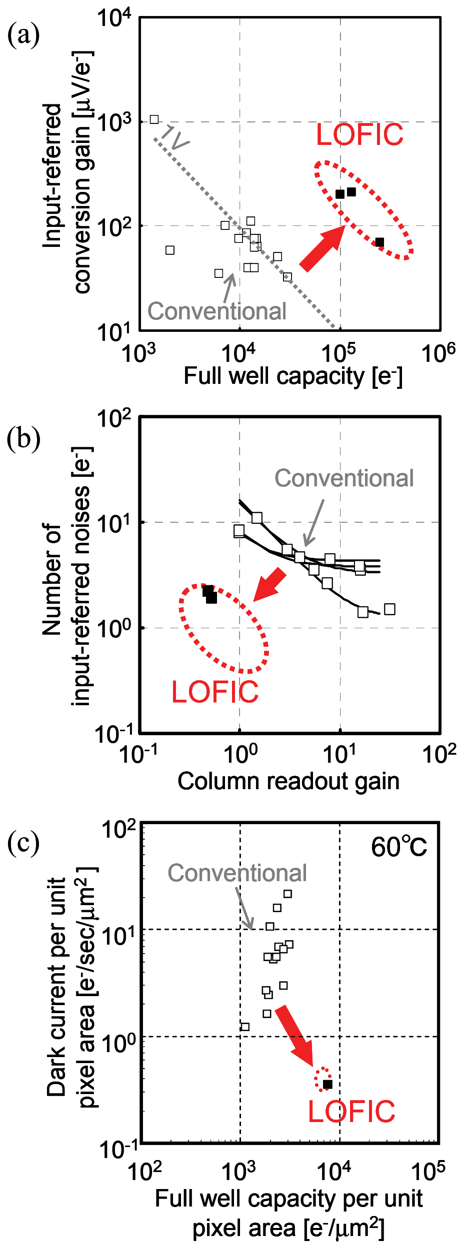

Fig.2 (a) The relation between the input-referred conversion gain and the full well capacity, (b) the relation between the input-referred noise and the column readout gain, and (c) the relation between the dark current and the full well capacity per unit pixel area of the LOFIC CMOS image sensors including recently reported image sensors.

conversion gain at FD and high full well capacity. Fig.2 shows (a) the relation between the input-referred conversion gain and the full well capacity, (b) the relation between the input-referred noise and the column amplifier gain, and (c) the relation between the dark current and the full well capacity per unit pixel area [12] of the LOFIC WDR CMOS image sensors including recent image sensors [13-27]. It is clear for these new tries in the LOFIC CMOS image sensors to solve the trade-off between low dark current, high sensitivity and high full well capacity and to can achieve a ultimate high SNR image sensor.

4. Conclusion

It has been given priority until recently in the developments of image sensors to increase the number of pixels by the pixel size reduction sacrificing the number of injection photons. However, it is indispensable that not only resolution but also other basic performances such as sensitivity, SNR, power consumption and dynamic range, etc. and high function performances improve overall to enhancing the image sensor. Wide dynamic range image sensors are expected to be going to expand to many fields in the future very much. To ensure them, the cooperation of image sensor technology, image processing technology and the display and print technology becomes extremely important.

References

[1] S. Sugawa, *Int'l Display Workshops* **1** (2007) 307.
[2] K. Mizobuchi and S. Sugawa, *Int'l Solid-State Circuits Conference, Imager Design Forum* (2008).
[3] M. Mase et al., *IEEE J. Solid-State Circuits* **40** (2005) 2787.
[4] S. Kawahito et al., *Int'l Solid-State Circuits Conference* (2008) 56.
[5] Y. Egawa et al., *IEEE Asian Solid-State Circuits Conference* (2006) 135.
[6] Y. Oike et al., *Int'l Image Sensor Workshop* (2007) 30.
[7] Y. Egawa et al., *Int'l Solid-State Circuits Conference* (2008) 52.
[8] S. Sugawa, N. Akahane, S. Adachi, K. Mori, T. Ishiuchi and K. Mizobuchi, *Int'l Solid-State Circuits Conference* (2005) 352.
[9] N. Akahane, S. Sugawa, S. Adachi, K. Mori, T. Ishiuchi and K. Mizobuchi, *IEEE J. Solid-State Circuits* **41** (2006) 851.
[10] S. Adachi, W. Lee, N. Akahane, H. Oshikubo, K. Mizobuchi and S. Sugawa, *IEEE J. Solid-State Circuits* **43** (2008) 823.
[11] S. Adach, W. Lee, N. Akahane, H. Oshikubo, K. Mizobuchi and S. Sugawa, *Japanese J. Applied Physics* **47** (2008) 2761.
[12] K. Mizobuchi, S. Adachi, T. Yamashita, S. Okamura, H. Oshikubo, N. Akahane and S. Sugawa, *J. Image Information and Television Enginerres* **62** (2008) 368.
[13] K. Yoon et al., *IEEE J. Solid-State Circuits* **37** (2002) 1839.
[14] A. Krymski et al., *IEEE Workshop on CCDs and AISs* (2003).
[15] S. Yoshihara et al., *Int'l Solid-State Circuits Conference* (2006) 492.
[16] Y. C. Kim et al., *Int'l Solid-State Circuits Conference* (2006) 494.
[17] J. Yang et. al, *Int'l Solid-State Circuits Conference* (2006) 496.
[18] Y. Nitta et al., *Int'l Solid-State Circuits Conference* (2006) 500.
[19] K. B. Cho et al., *Int'l Solid-State Circuits Conference* (2007) 508.
[20] H. Takahashi et al., *Int'l Solid-State Circuits Conference* (2007) 510.
[21] Y. Lim et al., *Int'l Image Sensor Workshop* (2007) 311.
[22] X. Liu et al., *Int'l Image Sensor Workshop* (2007) 327.
[23] M. Iwane et al., *Int'l Image Sensor Workshop* (2007) 295.
[24] G. Agranov et al., *IEEE Workshop on CCDs and AISs* (2005) 206.
[25] Y. Kudoh et al., *Electronic Imaging Science and Technology* **6501** (2007) G-1-8.
[26] K. Holmen et al., *Electronic Imaging Science and Technology* **6501** (2007) Q-1-10.
[27] J. Prima et al., *Int'l Image Sensor Workshop* (2007) 5.