A 1/2.7 optical format, 3M pixel and progressive scan PIACCD

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Abstract

A 1/2.7 optical format, 3M pixel and progressive scan pixel interleaved array (PIA) CCD image sensor have been developed. The PIACCD removes inactive wiring area and can enlarge saturation voltage. We have made the pixel of progressive scan CCD downsize to 2.69μm * 2.69μm by using advanced PIACCD architecture with "wedge-shaped electrode". Moreover, this sensor can output high quality 30fps VGA movie provided by a new horizontal signal charge mixing function.

1. Introduction

A 1/2.7 optical format and 3M pixel CCD which is becoming majority for digital still camera (DSC) applications is only conventional interlaced scan ITCCD. An interlaced scan ITCCD can't be used for DSC applications without a mechanical shutter. Therefore, the interlaced scan CCD is unsuitable for continuous shooting. In addition, there is a problem to decrease maximum signal charges by thermal emission to a substrate after closing of the mechanical shutter. On the other hand, a progressive scan CCD doesn't need the mechanical shutter and achieves high-speed electronic shutter operation such as 1/10000 sec, because all signal charges are read out from photodiode to VCCD at once.

The conventional progressive scan CCD has inactive wiring area and is constructed of 3-layer electrode structure and 3-phase VCCD. Resultantly, saturation voltage has reduced, fabrication process becomes complex, and transfer capability of VCCD is smaller than that of 4-phase drive VCCD.

To solve these problems, we developed PIACCD architecture [1] that has 4-phase drive VCCD fabricated by standard 2-layer electrodes, and is progressive scan. The architecture removes inactive wiring area and can enlarge saturation voltage.

2. PIACCD architecture

Fig.1 shows the design concept of the PIACCD. The PIACCD shapes rotating unit pixel of the conventional interline CCD by 45 degrees and has zigzag-shaped VCCD. Horizontal and vertical pixel pitch in PIACCD each is 1/√2 times of that in ITCCD. As shown in Fig.2, a 4-phase drive VCCD is constructed of 2-layer electrode structure and neighboring zigzag-shaped VCCD is separated by channel stops without inactive wiring area. Electrode structure has been simple, and photodiode and VCCD have been enlarged. Moreover, PIACCD is advantageous to guide light rays because an aperture has spatial equality of octagonal.

Fig.3 shows the comparison of Nyquist limit of ITCCD and PIACCD each. Nyquist limit of PIACCD is expanded √2 times of that of ITCCD, because sampling pitch of PIACCD is 1/√2 times of that of ITCCD. This characteristic matches properties of the human eyes and spatial power spectrum in natural scene. A resolution of the human visual system is highest in the vertical and horizontal directions [2], and high frequency power spectrums of natural scene concentrate in the vertical and horizontal directions [3]. In other words, the pixels of PIACCD have optimized resolution characteristics for DSC applications.

3. Downsizing of pixel

Unit VCCD channel length of PIACCD is longer than that of ITCCD, because of zigzag-shaped VCCD. Furthermore, by narrowing the VCCD channel width, potential barriers easily appear and prevent charge transfer. It becomes severe problem for downsizing the pixels. New idea of "wedge-shaped electrode" has been introduced to overcome this problem, which is shown in Fig.4. Conventional PIACCD electrodes have parallel interface with charge transfer direction. The " wedge-shaped electrode" interface isn't parallel with channel and effective channel width is gradually wider in transfer direction. " Wedge-shaped electrode" removes flat potential area and potential barriers. Electric field which formed under the electrode accelerates charge transfer in VCCD channel. Therefore, it is possible to transfer signal charges smoothly.

With downsizing the pixel, there are problems that saturation voltage and optical sensitivity are lowered. The saturation voltage has been enlarged by optimizing dopant profiles of photodiode. The sensitivity also has been heightened by adoption of spaceless on chip micro lenses which guide the all light rays into apertures.

4. High quality movie

This sensor can output high quality 30fps VGA movie by horizontal signal charge mixing function [4]. This function has a line memory (LM) and 6-phase HCCD which are located at the bottom of VCCD. Combination of the LM and the HCCD enables to transfer only selected signal charges from the VCCD to the HCCD, and to mix same color signal charge packets which are neighboring to horizontal direction.

G, R and B signal charge packets in a line store the LM at once. Transfer mechanism from the VCCD to the HCCD is shown in Fig.5 which shows the vertical cross section and the potential profiles from the VCCD to the HCCD. The signal charge is accumulated in V6 and 7, using V8 as the barrier. The charge is transferred to LM when the state becomes HCCD=Low, LM=High and V8=High. Then state changes as HCCD=High and LM=Low, and charges are read out to the HCCD. The charge packets can be read out only under the condition HCCD=High and LM=Low. Under the other conditions, the charge packets are stored under the LM.

Following step is to mix same color signal charge packets in HCCD. Fig.6 shows the diagram of horizontal signal charge mixing function. The 6-phase HCCD is constructed of 6 electrodes named H1, H2, H3, H4, H5 and H6. First, R signal charge packets are read out to H5 and transferred to H1. Second, R, G and B charge packets are read out to H1, H4 and H6 respectively. Then R charge packets are mixed in H1. The G and B charge packets are transferred to H2 and H3 respectively. Third, G and B charges are read out to H2 and to H3 respectively. Then G and B charges are mixed. Fourth, R and G packets are transferred to locate every charge packets in alternate electrode. Lastly, all packets are transferred to a flouting diffusion charge detector.

The horizontal signal charge mixing function heightens the sensitivity by 4 times combined with the vertical signal mixing in movie operation shown in Fig. 7.

5. The device specification and characteristics

A block diagram of fabricated 1/2.7 optical format, 3M pixel and progressive scan PIACCD is shown in Fig.8. It has total 3.14M pixels. Progressive scan has been realized with the pixels downsized to 2.69μm * 2.69μm. G filters cover the pixels located on square lattice points, R and B filters cover the pixels located on mosaic respectively. VCCD is 4-phase drive and has 10-clock lines for various readout modes such as movie operation. The LM is located between the VCCD and the 6-phase drive HCCD. Combination of the LM and the 6-phase drive HCCD enables horizontal signal charge mixing function.

Table 1 summarizes the characteristics of the developed image sensor. Green sensitivity of 400mV (5100K, IR cut, 1200cd/m2, F5.6, 60sec), saturation voltage of 700mV and smear ratio of 0.0025% have been accomplished.

6. Conclusion

A 1/2.7 optical format, 3M pixel and progressive scan PIACCD have been developed. We have made the pixel of progressive scan CCD downsize to 2.69μm * 2.69μm by using advanced PIACCD architecture without sacrificing saturation voltage and optical sensitivity. Moreover, horizontal signal charge mixing function can produce high quality 30fps VGA movie.

7. References

[1] T. Yamada, et al. “A Progressive Scan CCD Image Sensor for DSC Applications”, IEEE Journal of SOLID-STATE CIRCUIT Vol.35, No.12, DEC 2000

[2] A. Watanabe, et al. “Spatial sine-wave responses of the human visual systems”, Vision Res., vol. 8, pp.1245-1263, 1968

[3] M. Tamaru, et al. “Development of new structure CCD for digital still camera”, ITE Tech. Rep., vol.23, 1999

[4] T. Misawa, et al. “3.35M Pixel Interleaved Array (PIA) CCD Image Sensor with the Horizontal Pixel Addition Function”, Proc. of International Congress of Imaging Science, MAY 2002

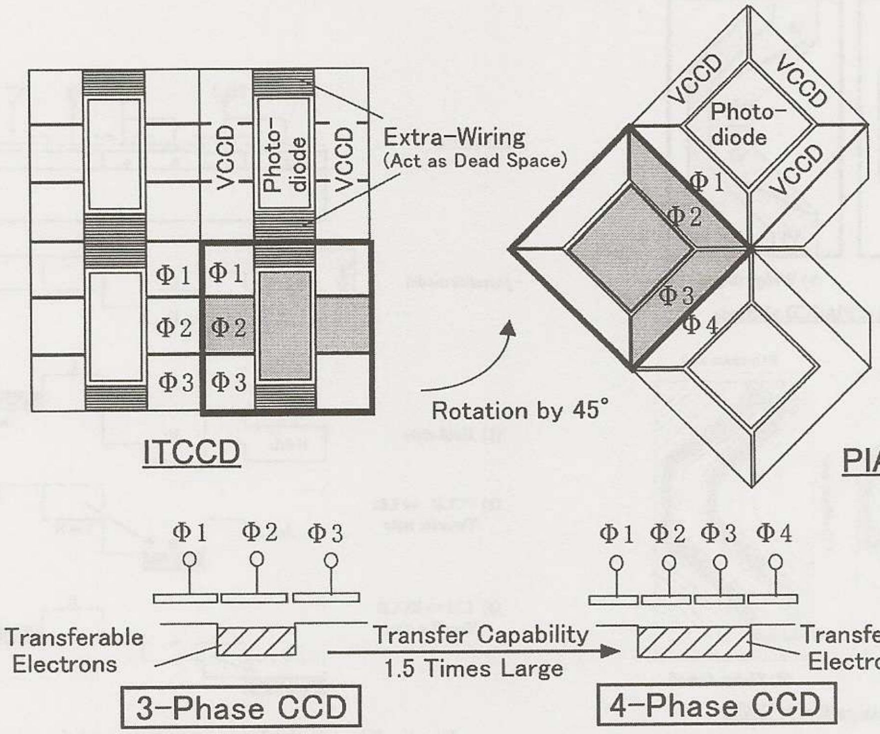


Fig.1 Design concept of the PIACCD

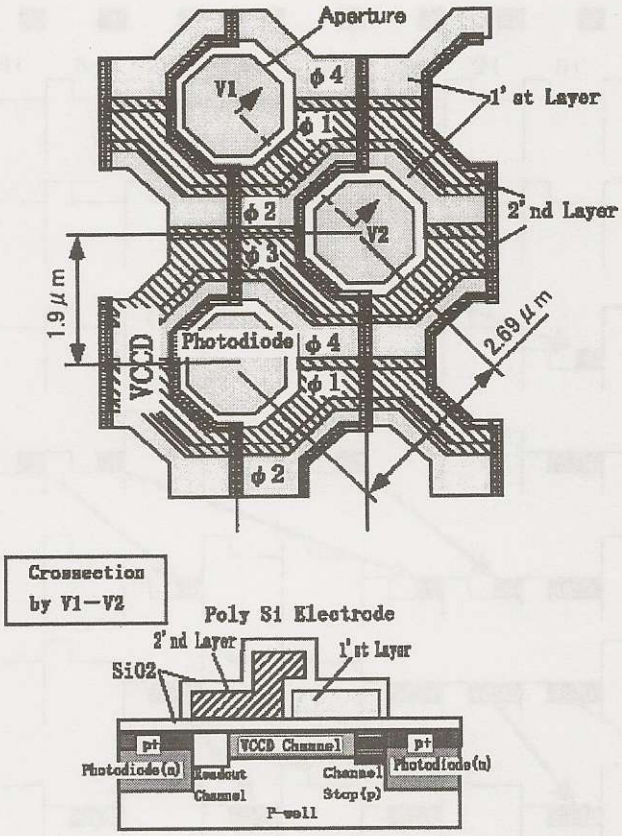


Fig.2 Pixel pattern layout of the PIACCD

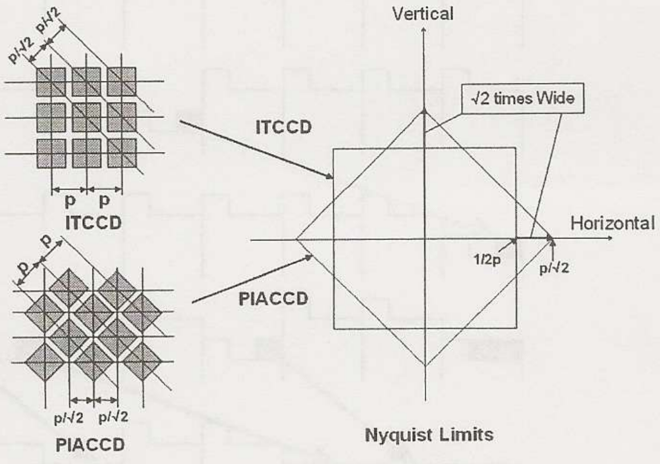
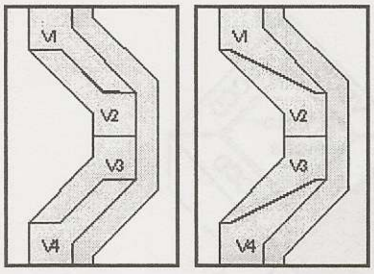
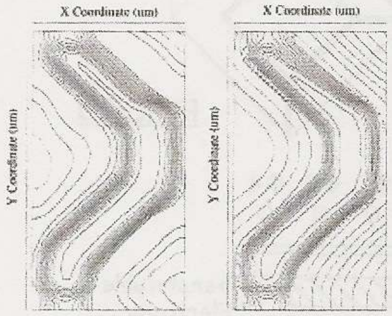


Fig.3 Nyquist limits of ITCCD and the PIACCD



(a) Original (b) Wedge-shaped

Pattern layout of PIACCD electrode



(c) Original (d) Wedge-shaped

Potential profiles in VCCD

Fig.4 The comparison of original and "wedge-shaped" PIACCD electrode

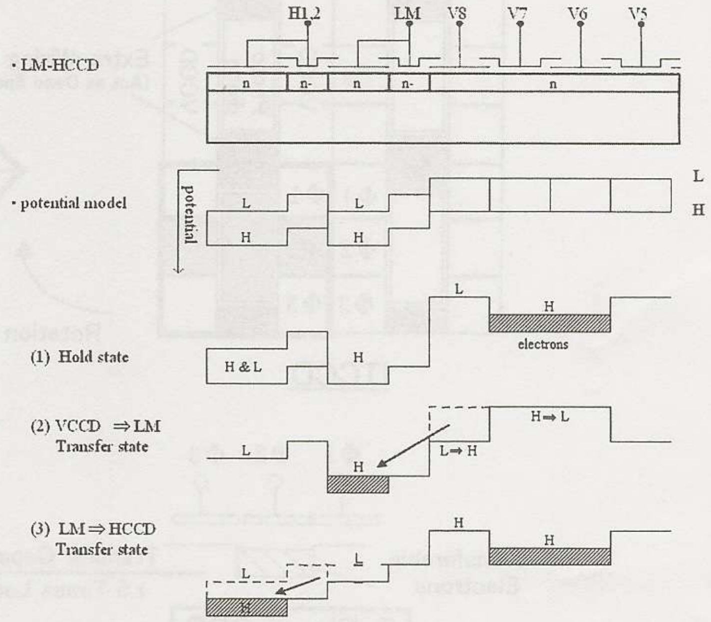


Fig.5 The vertical cross section and the potential profiles from the VCCD to the HCCD

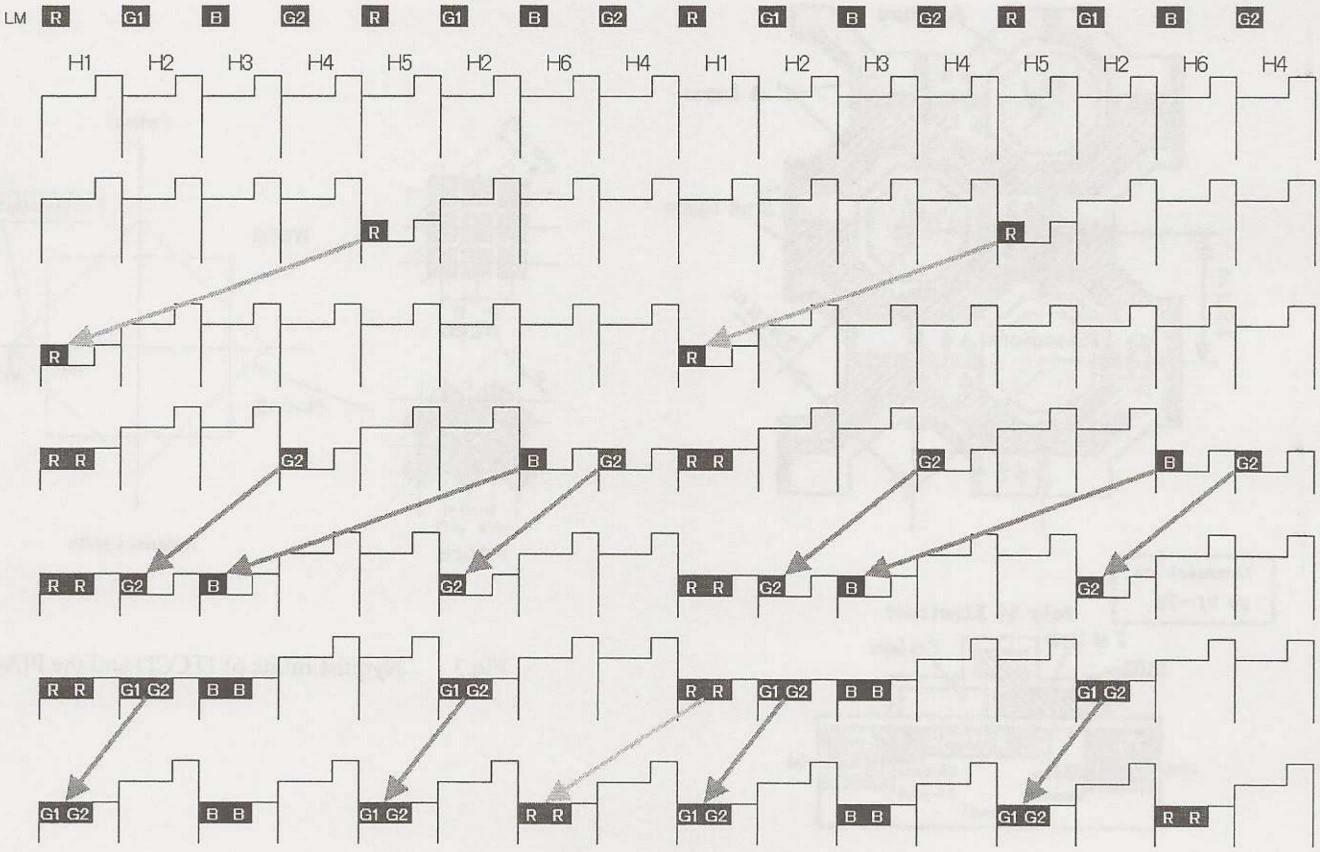


Fig.6 The diagram of horizontal signal charge mixing function

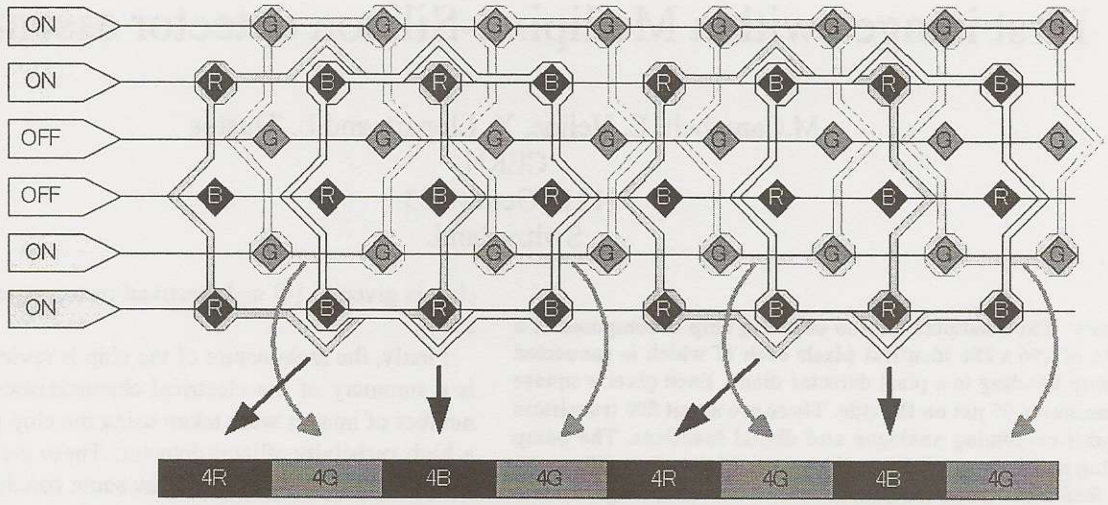


Fig. 7 The schematic diagram of vertical and horizontal mixing

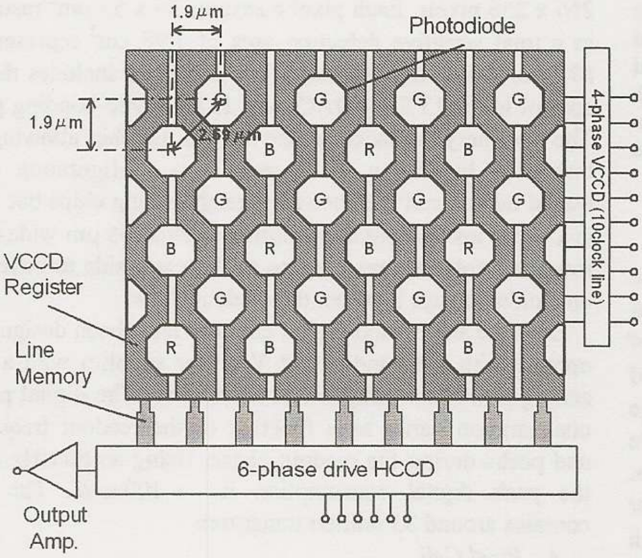


Fig.8 The block diagram of fabricated sensor

Device Structure	Progressive Scan PIACCD
Chip Size	6.39mm * 5.27 mm
Total Number of Pixels	3.14M
Number of Imaging Pixels	2.98M
Pixel Spacing (Line Pitch)	2.69μm (1.9μm)
Imaging Area	5.35mm * 4.01 mm
Color Filter	G : Square Lattice R, B : Mosaic
Data Rate	24.54MHz (H3.0V drive)
Saturation Voltage	700mV
G Sensitivity (5100K, 1200cd/m^2, F5.6, 1/60sec)	400mV
Smear	0.0025%

Table 1 Specification and characteristics