3.4M pixel TDI image sensor for confocal scanning microscopy

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Abstract

Recently, confocal microscopy has been attracting attention of various inspection system designers who wish to capture 3D images with the information of depth of the image relief. We have developed a large scale, 3.4M pixel, high-speed, 680MHz data rate, TDI (Time Delay Integration) image sensor suitable for the use of confocal microscope applications. Since the confocal optics has a pinhole aperture that restricts the light intensity, TDI scanning has an advantage in collecting more photons. In this paper we describe the architecture and the operation of the confocal TDI CCD image sensor including its detail performance characteristics

I. Introduction

Fig.1. is illustrated the concept of fundamental confocal operation. The light of optical source goes through the beam splitter, and focused on a plane. The reflecting light is convoluted into the detector through the pinhole that is in front of the detector. The reflecting light from out-of-focus information can not converge, because such light energy is eliminated at the pinhole. We can collect only the information of focused depth through the pinhole.

The confocal application has such a useful technology. But following significant problem arises: since the confocal optics has a pinhole aperture, only the very little signal is used. Therefore the illuminated source is so bright, or the detector is required high sensitivity performance. We introduced TDI approach as a solution that provided larger responsibility than conventional frame shutter operation.

Another key feature of this TDI sensor is high speed read out which is necessary for practical application, especially for FA and inspection system. Since line scan rate is equivalent to one vertical charge transfer, this transfer speed is restricted by pixel data rate and horizontal resolution. This TDI sensor has a capability of the bi-directional charge transfer scan in vertical image direction. It can contribute not only to saving idling time but also to simplification of system mechanical design.

In this paper we address highlight the important design considerations of confocal TDI sensor with high quantum efficiency and the testing result.

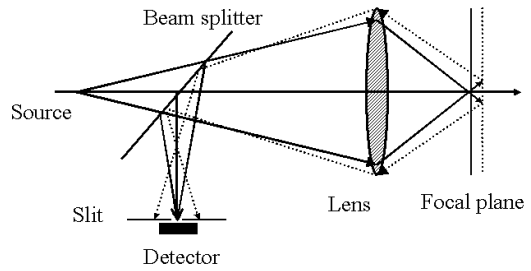

Fig1 Principle of confocal Microscope [1]

II. Device Architecture

The pixel number of image area is horizontal 3400, vertical 1000 pixel. The pixel pitch is 8um in both horizontal and vertical directions and the confocal window size is 16um* 16um consisting of 2 pixel * 2 pixel array. The image area is almost covered metal except opening windows at intervals for confocal optics. Other than the image area, this device consists of format conversion area, multi serial register and channel amplifier circuits. Two outputs regions are made both on upside and downside for bi-directional transfer. A block diagram of the sensor architecture is shown in Fig. 2.

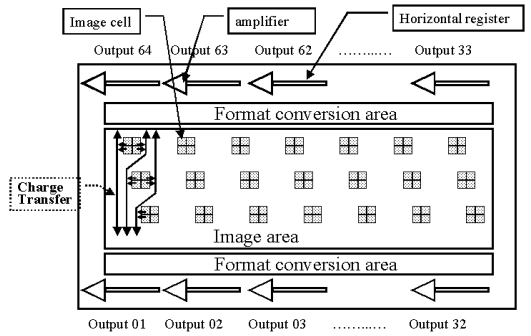

Fig.2. TC293 Block Diagram

A. Image area design

The opening windows are placed at same intervals both on horizontal and vertical direction. And neighbor window shifts vertically one image cell distance.

In order to keep high quantum efficiency of short wave length, it is preferable that no poly silicon gate is laid in photocell area.

Since the confocal window consists of 2 pixel * 2 pixel array, it is not simple task to satisfy the 100% aperture efficiency requirement by either conventional interline or frame transfer architecture which is symmetrical cell layout with periodical cell pitch.

We placed 2*2 virtual phase transistor into the confocal window and arranged vertical charge transfer cell around them. Accordingly the charge transfer cell is not symmetrical shape and is slanted to perform one pixel pitch shift. The vertical transfer cell is made of three phases of double poly gates and Virtual Phase. An additional transfer gate between photocell and vertical transfer is not necessary because of TDI operation, and this structure promises simple operation timing and keeps enough time for charge transfer from photocell to vertical transfer cell. Virtual phase in vertical transfer cell is connected to photocell but the potential step is built between both cells. When electrons are generated in image cell, these electrons move from photocell to transfer cell immediately. The signal charge flow is illustrated in Fig.3.

Since photocell area is larger than transfer cell, this device's well capacity is restricted in vertical transfer cell. Our target of the well capacity is 65000 electron considering dynamic range.

Additionally this vertical transfer cell has a function of bi-directional transfer that is controlled by driving pulse timing. This function saves time for mechanical control of TDI scanning.

B. Format conversion area

This device has 32 multiple output to read one horizontal line. Format conversion region work for dividing one horizontal data into 32 horizontal transfer registers. To keep enough area placed output amplifier between each channel, format conversion region is designed by slanted shape.

C. Horizontal Register

This sensor has 32 horizontal transfer registers and amplifier at both top and bottom area. The transfer frequency of each channel is 28MHz. The horizontal transfer register is designed by simple Virtual Phase CCD. It can be operated by single-phase clock. Since Floating Diffusion Amplifier (FDA) has reset noise, CDS circuit is required to reduce reset noise factor. As CDS needs three level drive, it is not preferable when it comes to operating high speed charge transfer. Because of taking into consideration this point, we adopted BCD (Bulk Charge Detector) type amplifier.

D. Charge Detection Node

A cross section of the BCD charge detection node is shown in Fig. 4. As the electrons are transferred under the gate of BCD detector from horizontal transfer register, the signal charge then modulates potential under the gate and this in turn causes a charge in the potential of the source. It is assumed that the BCD central region is connected to a constant current source that supplies the necessary current to this node. The resulting change is the desired signal that is subsequently buffered by amplifier.

The complete charge removal after sensing is the key feature and a very important advantage of this structure. After all charge has been removed from the well, the potential returns to its original level without any uncertainty. Consequently, no kTC noise is generated.[2]

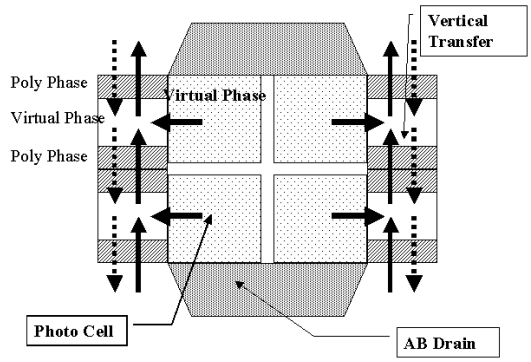

Fig.3 Signal charge flow

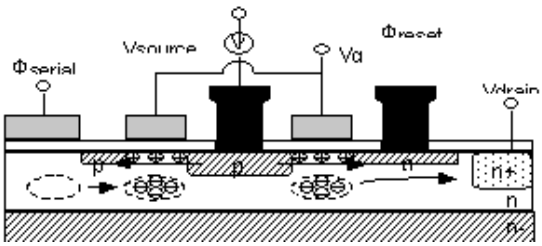

Fig.4 BCD Structure

III. Evaluation results

A. Output Signal Performance

An example of the raw signal that is obtained at a data rate of 28 MHz is shown in Fig.5. A key component of this architecture is the minimization of output amplifier load and parasitic capacitance. This device package has a bipolar transistor to buffer the output of the CCD. Although this way is so useful for high-speed operation, the power consumption is increased drastically. Since the upside and downside amplifiers are not active at the same time, a power supply is switching to turn on only activated side. By this method, power consumption is reduced to almost a half.

B. Imaging Performance

Fig.6 is shown the image by CCD mode that is like normal CCD operation at total data rate of 680MHz. It can be understood that the opening windows are located at same intervals and shifted line by line.

An image taken with the sensor operating TDI mode at same data rate is shown in Fig. 7.

C. Quantum Efficiency

This sensor's quantum efficiency is shown in Fig.8 with TC229 data. TC229 is conventional frame transfer CCD designed by 8um * 8um unit image which poly silicon gate is laid in an image cell. As we have an idea, TC293 demonstrates high quantum efficiency especially under visible radiation.

D. Package

Shown in Fig. 9 is the packaging device. The package is a type of Quad Flat Package with 140 pins. The package size is 60.0mm * 33.0mm. The bipolar transistors are putted behind the light shield plate in this package.

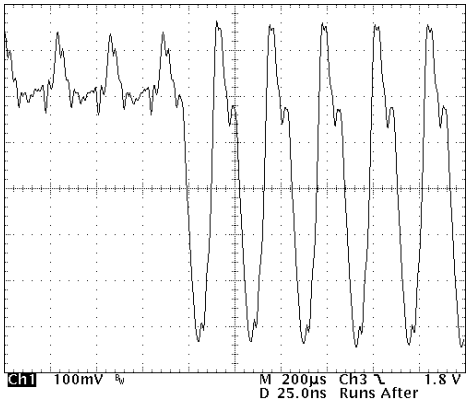

Fig.5. Example of raw signal at the start of the line

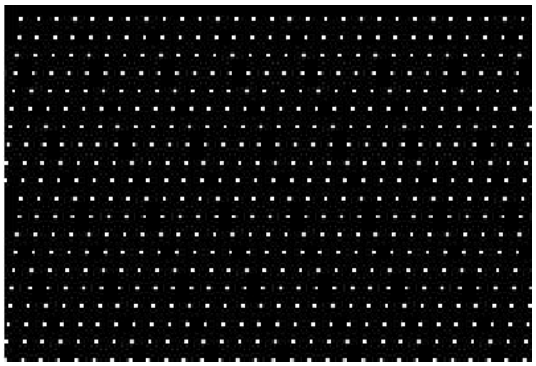

Fig.6. Sample image with data output rate of 680 MHz by normal CCD function

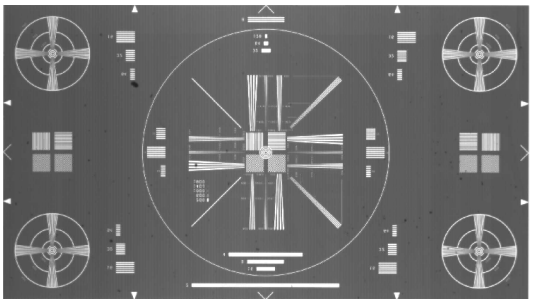

Fig.7. Sample image with data output rate of 680 MHz by TDI function

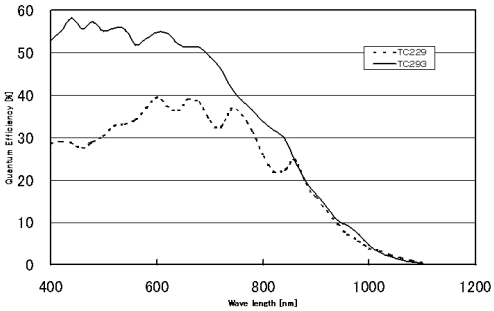

Fig.8. Example of quantum efficiency

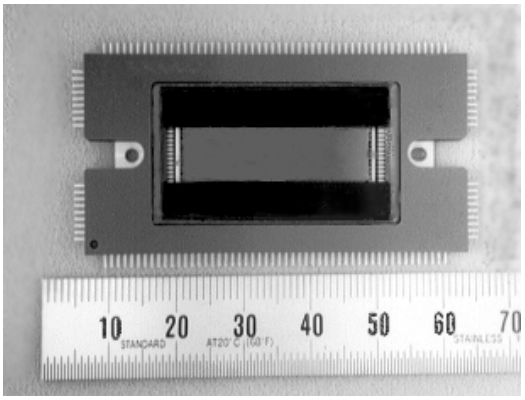

Fig.9. Picture of package device

Table 1. Device Performance

Parameter	Value
Sensor type	Confocal TDI
Pixel numbers	3400(H) * 1000(V)
Vertical transfer	Bi-directional
Pixel size	8.0um * 8.0um
Well capacity	65000 electron
Aperture efficiency	100%
Data rate	680MHz
Line rate	200kHz
D-range	70 dB
Power consumption	995mW
Output	32 * 2 channels

IV. Conclusions

In this paper, we proposed the confocal TDI sensor with high quantum efficiency and high speed. And we developed a unique TDI cell by novel Virtual Phase CCD technology.

The measured quantum efficiency is approximately a double of conventional Virtual Phase CCD.

As for read out speed, the data rate is achieved 680MHz by multi channel and BCD technology. It is concluded that this TDI sensor will very useful for confocal scanning microscopy.

V. Acknowledgement

The authors would link to thank their contribution of the Texas Instruments DISP design, PI, camera development group.

And we would like to express special thanks to Jaroslav Hynecek on ISETEX for his valuable suggestions and K. Sasada for management support.

VI. References

[1]. Y. Ichikawa and J. Toriwaki "Confocal microscope 3D visualizing method for fine surface characterization of micro structures" SPIE Vol.2862 pp98 – pp101

[2]. J. Hynecek and H. Shibuya "BCD-A New High Performance Nondestructive Charge Detection Concept for CCD image Sensors" 1999 IEEE Workshop on Charge-Coupld Devices and Advanced Image Sensors