# Sub-aF Detection Accuracy CMOS Proximity Capacitance Image Sensors for Inspection, Authentification and More

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## ABSTRACT

*This paper presents CMOS proximity capacitance image sensors achieving sub-aF detection precision with high spatial resolution with real-time imaging capability. Key technologies of the imaging methods, noise reduction, image sensor evolution in terms of pixel size shrinkage and pixel number increase, and examples of applications thereof are demonstrated.*

## 1 Introduction

Proximity capacitance sensors have been utilized in various applications, such as fingerprint sensors, human-machine interface, liquid level detection for manufacturing plants, capacitance manometer for gas pressure detection, non-destructive electrical capacitance tomography and so on [1-2]. Proximity capacitance image sensors capable of detecting two-dimensional proximity capacitance image with high detection precision and spatial resolution will be useful for smart devices, authentication, inspections of flat panel displays and printed circuit boards and biological and medical analyses.

We have been engaged in the development of sub-aF detection precision proximity capacitance image sensors toward its practical usage as inspection equipment as well as, exploration of new applications in various fields. In this paper, key technology developments are overviewed.

## 2 Key Technology and Sensor Evolution

Fig. 1 shows the 3D model of the developed CMOS proximity image sensor and schematic illustration of the measured capacitance distribution. These figures illustrate a case when measuring metal wires as targets. The proximity capacitance (Cs) between the detection electrodes in the sensor chip and the counter electrode: in this case the metal wiring, is measured.

Fig. 2 shows the chip block diagram and the simplified pixel circuit. In the pixel there are a detection electrode, a detection capacitance (Cc), a reset switch, a source follower (SF) driver, and a pixel selection switch. An input pulse is supplied to the counter electrode with a voltage amplitude $V_{IN}$, and pixel signals before and after the pulse transition are readout or each pixel. The output signal is given by the equation shown in the bottom of Fig. 2. The pixel fixed pattern noise and temporal random noise such as low frequency noise of in-pixel SF and power line are reduced by this noise cancelling operation for precise capacitance detection. The signal is digitized by 14 bit ADC outside the chip, and the measured noise level is less than 2 LSB. In order to measure small capacitance accurately, Cc value should be small. In addition, in order to detect a small change of the measured capacitance, Cc value should be the same or close to the value of Cs as can be derived from the signal equation. In this works, the values of Cc were about a few fF depends on the size of the detection electrodes.

Using a 0.18 µm 1-poly-Si and 5-metal CMOS technology, we have developed several image sensor chips. The evolution of the developed proximity capacitance image sensors in terms of pixel size shrinkage and pixel number are summarized in table I; from the first sensor demonstration of the 16 µm pitch 65K pixels [3-4], 12 µm pitch megapixel sensor [5], and to the 2.8 µm pitch megapixel sensor [6].

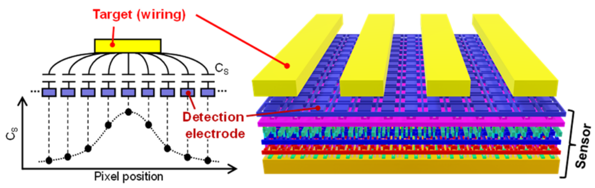


**Fig. 1 3D model of the CMOS proximity image sensor and measured capacitance distribution**

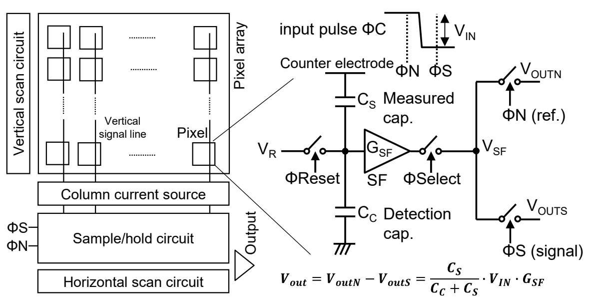


**Fig. 2 Chip block diagram and simplified pixel circuit.**

**Table I Evolution of the developed chips**

| Year | 2018 | 2019 | 2020 | 2021 | 2021 |
|---|---|---|---|---|---|
| Technology | 0.18μm 1P5M CMOS | | | | |
| Pixel area | 4.096mm$^H$ ×4.096mm$^V$ | 4.08mm$^H$ ×4.08mm$^V$ | 12.96mm$^H$ ×12.96mm$^V$ | 12.9mm$^H$ ×12.9mm$^V$ | 3.94mm$^H$ ×3.58mm$^V$ |
| Number of pixels | 256$^H$×256$^V$ | 340$^H$×340$^V$ | 1080$^H$×1080$^V$ | 2304$^H$×2304$^V$ | 1408$^H$×1280$^V$ |
| Pixel size | 16μm$^H$×16μm$^V$ | 12μm$^H$×12μm$^V$ | 12μm$^H$×12μm$^V$ | 5.6μm$^H$×5.6μm$^V$ | 2.8μm$^H$×2.8μm$^V$ |
| Sampling frequency | 20MHz | 20MHz | 20MHz | 20MHz | >20MHz |
| Frame rate | 60fps | 30fps | 11fps | 8fps | >8fps |
| Detection accuracy | 0.1aF or below | | | | |

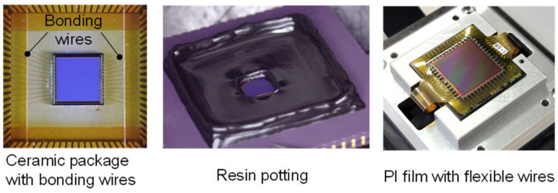


**Fig. 3 Types of chip packaging**

## 3 Applications and Discussion

Fig. 3 shows the several chip packaging options; a regular wire bonding type, a resin potting type for measuring targets in liquid such as biological cells and a polyimide film coated type with flexible wires. The PI type is suitable for measuring large area targets such as FPDs by step and repeat operation [7].

Fig. 4 shows signal transfer characteristics of the 12 μm megapixel sensor chip. It shows the measured output voltage as a function of input pulse amplitude for various capacitance conditions. Less than 100 zF detection precision was achieved at $V_{IN}$ of 20 V, and 5 zF detection precision was confirmed at $V_{IN}$ of 300 V, respectively.

Figs. 5-6 show several applications of the developed proximity capacitance image sensors; inspection of metal wires of a printed circuit board, fingerprint imaging, and authentication application, respectively. Using the developed proximity capacitance CMOS image sensors, electrical information such as defect type and location of wires and detailed biometrics information are obtained. More examples such as surface morphology imaging, liquid sensing for biological applications and realtime proximity capacitance observation by taking a movie will be shown in the presentation.

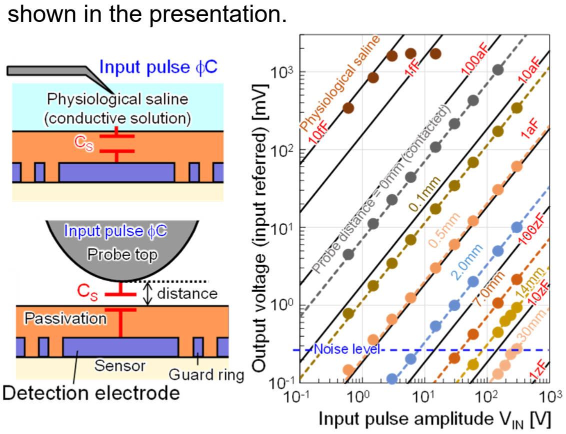


**Fig. 4 Measured signal transfer characteristics**

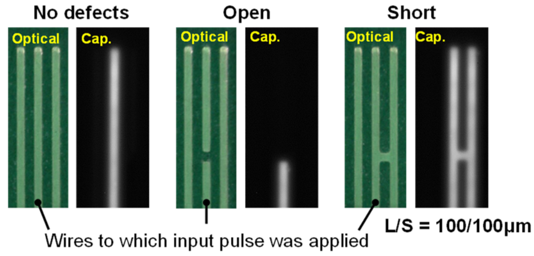


**Fig. 5 Inspection of PCB metal wires**

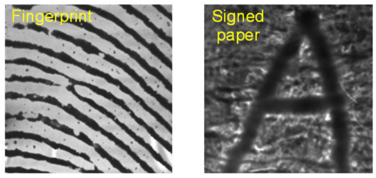


**Fig. 6 Applications for authentification**

## 4 Conclusions

The developed proximity capacitance CMOS image sensors provide an easy-to-use high precision capacitance imaging solutions for inspections, authentificaions and more. Further developments toward improved sensor performances are on the way. In addition, due to its simple structure, multimodality with other sensors such as optical and impedance sensors will be possible as useful information input devices.


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