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Image Sensor with In-pixel Calculation using Crystalline IGZO in Display

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Abstract

With use of transistors using crystalline oxide semiconductors for channels, which have been adopted for a display, an image sensor provided with an arithmetic circuit in a pixel is prototyped and evaluated. Inner product operation of imaging data and filters (weight) is conducted in the pixel and a chip, resulting in verification of feature extraction.

1. Introduction

With the progress of machine learning research, demand for automated driving has increased. In particular, an algorithm such as a convolutional neural network (CNN) makes machine learning suitable for image processing. Inputting data into a brain is mainly done visually. Demand for image sensors as means of machine learning inputs has increased. Most of commercially-available image sensors only capture image data, and machine learning and inference processing are conducted by GPUs. The GPU extracts necessary data from image data captured by the image sensor; however, the data transmitted from the image sensor to the GPU includes a large amount of unnecessary data, which is inefficient operation. Thus, there has been demand for arithmetic operation conducted in the image sensor since 1990s, and a research of embedding an arithmetic circuit in a pixel was reported [1]; however, such a research resulted in an increase in pixel size. A recent research has reported that an arithmetic circuit is mounted in a 15-μm square pixel using a crystalline oxide semiconductor [2].

Researches on oxide semiconductors started from 1985 when Kmizuka et al. succeeded in synthesis of an oxide of indium, gallium, and zinc (IGZO) [3]–[6]. Table I shows classification of the IGZO crystallinity. Yamazaki et al. have discovered *c*-axis aligned crystalline IGZO (IGZO). Kimizuka pointed out that the CAAC-IGZO has a morphology belonging to an “intermediate state” between amorphous and crystal structures. Morphology having the intermediate state are defined as crystalline, and CAAC-IGZO, nano crystal (nc) IGZO, and cloud-aligned composite (CAC) are classified as crystalline. CAAC-IGZO is suitable for fabrication of submicron transistors for LSI, and in the above-mentioned research [2], CAAC-IGZO has been used.

Displays using nc and CAC as backplanes to replace LTPS or a-Si:H have been widely used and commercialized. Oxide semiconductors contribute to power saving and thus are used for mobile terminals. In accordance with multi-functionalization of the mobile terminals, their security protection is essential. A research on fingerprint identification using a display screen as an image sensor has been reported [17]. In this study, an image sensor provided with an arithmetic circuit in a pixel using a crystalline oxide semiconductor, which has been used for a display, is fabricated.

2. Circuit Configuration

Table II shows specifications of our prototyped sensor circuit, and Fig. 1 shows a die photo. The imaging area was suitably set considering an area where a finger is placed to take a fingerprint. A sensor structure was the same as a display structure except for the use of a light-receiving device instead of a light-emitting device.

Since researches on machine learning advances quickly, unfixed network configuration is convenient. If all CNN operations are done in an image sensor, there is no flexibility. Only the first CNN operation, that is, inner product operation of imaging data and filters is conducted in the image sensor. The filters can be rewritten outside. Figure 2 shows a pixel circuit diagram. FD is reset by a transistor connected to RS. After that, a photoinduced charge is stored at FD through a transistor connected to TX. The transistor uses an oxide semiconductor for a channel, which has an extremely low leakage current and thus retains the charge for a long time. The voltage at BW is fixed and VPI is set to have a high voltage, so that data can be read out as a normal image sensor. By contrast, when the voltage at BW is changed, the changed voltage is added to the voltage at FD. When VPI is set to have a low voltage, due to saturation (square-low) characteristics of a transistor whose gate is connected to FD, multiplication results are obtained [2]. Addition is caused by simultaneous selection of a plurality of pixels by the drivers. The change of selected pixels allows a stride to be changed.

3. Measurement Results and Discussion

To validate the accuracy of the arithmetic operation, data x is input after reset, and a weight w is input from BW. The output voltage is plotted as shown in Fig. 3. An error bar represents a standard deviation calculated from all pixel values. By fitting of an ideal straight line, the accuracy of 38 values was observed.

A lens was located in front of our prototyped chip, and an image of zebras displayed on another display device was captured. Figure 4(a) shows a normal captured image. Fig. 4(b) shows an imaging result of extracting vertical stripes from the captured image by setting a filter detecting a longitudinal direction, which shows a change in output of the extraction result in the vertical stripe portion of the zebras. When the filter is rewritten, another feature is extracted.

Table III shows power consumption of a pixel-data read-out circuit portion, which shows that power consumption in the operation with capturing the zebra image is lower than that in the normal imaging. In the normal imaging, data is read out by the source follower circuit, and accordingly the FD-VPI voltage (V_{gs}) is constant, which means that power does not depend on the captured image. By contrast, in the imaging with arithmetic operation, data is read out by a source grounded circuit, and accordingly when V_{gs} becomes low, the current decreases in proportion to the square of (V_{gs} − V_{th}). Although current per pixel decreases, data from a plurality of pixels is simultaneously read out for addition, and the reading speed is adjusted to be the same as that in the normal imaging.

4. Conclusions

Feature extraction with low power consumption was verified with an image sensor provided with an arithmetic circuit in a pixel with transistors, which have been adopted for a display, using a crystalline oxide semiconductor for a channel. When such an image sensor is combined with a display portion, efficient fingerprint identification is expected.

References

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Table I Classification of IGZO.

Amorphous [15, 16]	Crystalline ("Intermediate state" [7], Novel boundary region [8])	Crystal [4, 13, 14]
completely amorphous	· CAAC [9] (2009) · nc [10, 11] (2013) · CAC [12] (2016) excluding single crystal and poly crystal	· single crystal · poly crystal

Table II Specifications.

External size	30 mm (H) × 40 mm (V)
Imaging area size	23.04 mm (H) × 23.04 mm (V)
Resolution	256 (H) × 256 (V)
Pixel pitch	90 μm (H) × 90 μm (V)
Pixel component	4T1C
Transistor size	W/L = 3 μm/3 μm
Peripheral circuit	Row and column drivers, CDS, Source follower
Output	8ch analog voltage output
Frame frequency	15 fps
Filter size	3 (H) × 3 (V)
Stride	1, 2, 3 (H)

Table III Power Consumption of Pixel-data Read-out Circuit

		Power [μW]
Normal imaging		800
Arithmetic Operation	All black	125
	Zebra	450
	All white	1500

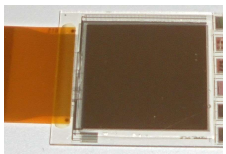

Fig. 1 Die Photo.

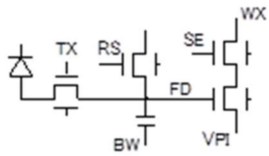

Fig. 2 Pixel Circuit Diagram.

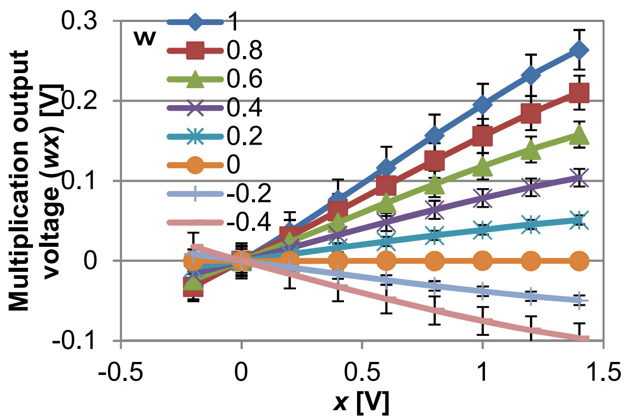

Fig. 3 Multiplication Performance.

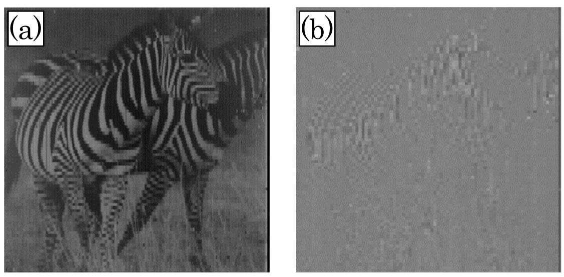

Fig. 4 Imaging Results.