Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 373-375 **PC-4-2**

Active Hollow Four Quadrant Orientation Detector Array for Applications to Pattern Recognition

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The active hollow *FO*ur *QU*adrant *O*rientation *D*etector (active hollow FOQUOD) two dimensional 8 × 8 array using amorphous silicon material deposited on a silicon substrate has been fabricated successfully. This array can extract the contrast edges and the edge orientations of the test patterns and the pixel yield is close to 100 percent. Since the measured patterns are consistent with the expected results, part of the traditional data processing steps using software may be replaced by this hardware sensor array, a simpler algorithm than ever had for pattern recognition can then be developed.

1. INTRODUCTION

The goal of our work is to use the microelectronics technology to simulate the pattern recognition ability of human visual system. The first two features deduced from an object image are edge position and orientation in brain [1]. To date, many algorithms have been developed to extract these two information in the field of image processing [2]. However, it needs routine computations of the brightness level of each pixel and the processing time is proportional to the number of pixels. Therefore, to improve the processing speed is to use the hardware detection circuit in place of the software such that the detected signals can be processed in parallel.

Pioneering work has been done by Mead [3], who constructed a silicon retina which can simulate the response of human's retina. However, this man-made device is composed of more than 30 field-effect transistors and one phototransistor as a pixel unit to extract the edge position of an image and thus can save one software processing step.

Recently, our laboratory had implemented the hydrogenated amorphous silicon active hollow *FO*ur *QU*adrant *O*rientation *D*etector (active hollow FOQUOD) for application to neural network image sensor [4-6]. This device can extract the position and orientation of a contrast edge In order to analyze some simple geometric pattern, the active hollow FOQUOD is used as the pixel element to construct a two dimensional neural network image sensor array.

2.EXPERIMENTS

The a-Si:H active hollow FOQUOD with top electrode geometry shown in Fig. 1(a) contains two cross-positioned two-half edge detectors, the vertical and horizontal pairs are called X and Y cells, respectively. Each cell is composed of two p-i-n diodes in back-to-back connection, i.e., the excitatory E_X (E_Y) and the inhibitory I_X (I_Y) diodes. In this device, there are two TFTs locating inside the central empty square as the switching elements of the vertical and horizontal pairs, respectively. The equivalent circuit of each pixel and sensor array are shown in Fig. 1 (b). When a contrast edge lies on the detector and a sufficient voltage is applied to the TFT's gate, the output signal (the short circuit current) can be measured. The detail operation principle of active hollow FOQUOD was published before [6].

Figs. 2(a) and (b) show the top geometry and cross section of a single device. The dimension of the silicon substrate is 1.6 × 1.6 cm^2. There are 8 × 8 pixels locate in the central area (1.2 × 1.2 cm^2) of silicon substrate and each pixel size is 1500 × 1500 μm^2. The side length of the inner and outer squares are 860 and 1300 μm, respectively. Then a 1.8 × 1.8 $inch^2$ ceramic substrate is chosen with 64 Pd-Ag metal lines printed on it and the bonding pad is coated with a thick Au film. Each side of ceramic contains 16 standard pins. The sensor array device is sticked in the center of it. Fig. 2(c) shows the photograph of this 8 × 8 active hollow FOQUOD array which is packaged on the ceramic substrate.

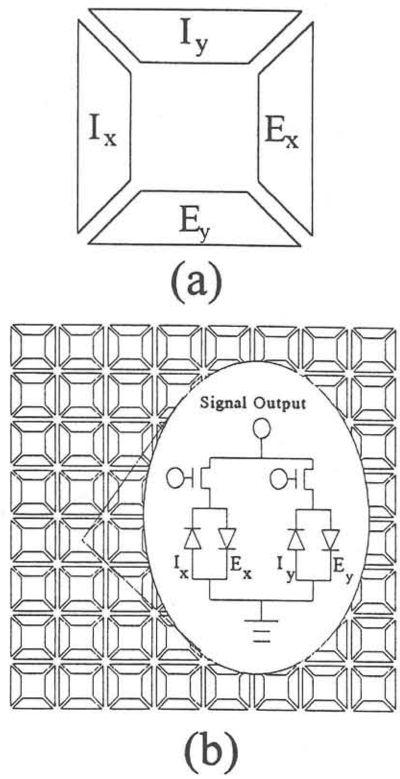


Fig. 1 (a) The top geometry of the hollow FOQUOD. It is composed of two crosspositioned pair edge detectors, i.e., X and Y cells. Each edge detector contains two trapezoid shaped pin diodes, i.e., the excitatory cell (E_X or E_Y) and the inhibitory cell (I_X or I_Y). (b) Equivalent circuit of each diode pair by adding a TFT as switching element and this 8 × 8 sensor array.

The device characteristics of a single pixel are measured by HP-4145 parameter analyzer. The whole sensor array performances are measured by outer circuit using computer. An ELH lamp is used as the light source, its intensity is calibrated at the level of the sample plane. Then a piece of glass with a thickness 1mm is put on the sensor for protecting the surface of sensor array. Some simple geometric patterns and characters made by black paper are used for test samples.

3. RESULTS AND DISCUSSION

When a half plane covers entirely a photodiode (E_y) of one diode pair, the short circuit current I_{ph} of I_y cell versus TFT gate bias V_{GS} with the light intensities 0.05 AM1 is shown in Fig. 3. From the above figure, the output signal I_{ph} reaches the saturation value when the TFT gate bias is over 14 V and there is nearly no signal output when the gate bias is below 5 V. The TFT indeed does a perfect switch in this sensor array.

Before several geometrical patterns are tested, the sensor array is tested under the dark and fully illuminated conditions. The purpose of this experiment is to define the noise level and a threshold current. The

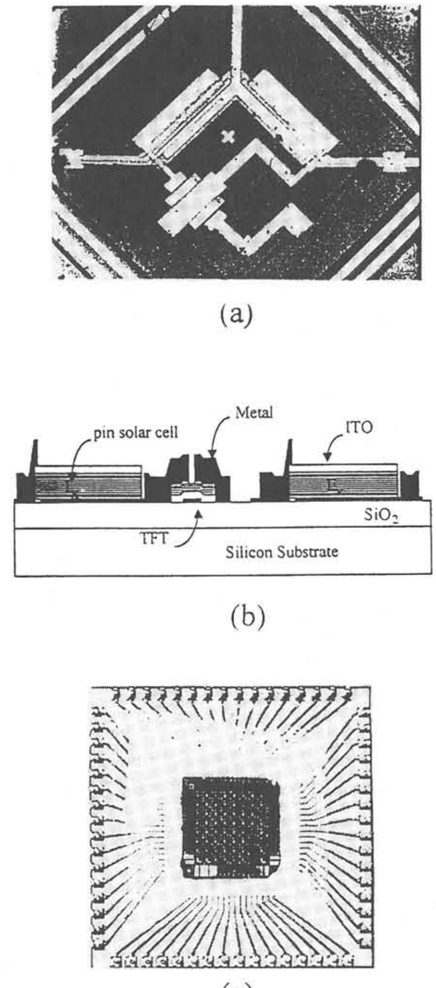


Fig. 2 The (a) top view and (b) cross section of the active hollow FOQUOD. There are two TFTs in the central square. (c) The photograph of this 8 × 8 active hollow FOQUOD array which is packaged on the ceramic substrate.

light intensity is 0.05 AM1. The TFT's gate bias of chosen pixel is kept at 15 V for 0.2 sec and at the same time the output photocurrent is read out as the signal. Then the gate bias is reversed to -15 V for 0.2 sec to repel the charge accumulated in the channel and finally stays to ground until the next time the pixel is chosen. The absolute net current of each diode pair is below 0.5 nA under the dark condition and below 2 nA under the illuminated condition. In this sample the current described above may be caused by the area asymmetry of each diode pair and the current leakage from gate to source of TFT. If the current leakage is omitted and then in comparison with the photocurrent level when only one photodiode is illuminated (from Fig. 3) the noise current is too small to have any important effect on the output signal. Considering the noise current and a suitable tolerance, a threshold current 4 nA is set. If the absolute signal outputs of both X cell and Y cell of each pixel are below this threshold value, the detector is considered to have zero response indicating no contrast edge falling on it.

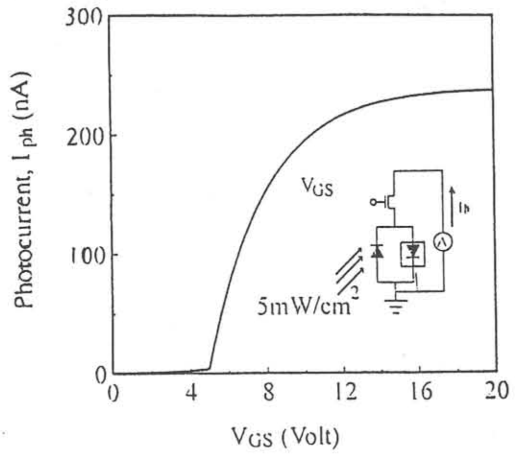
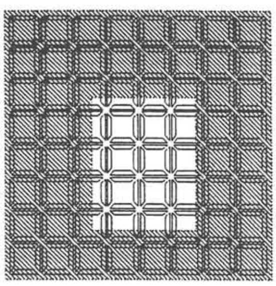
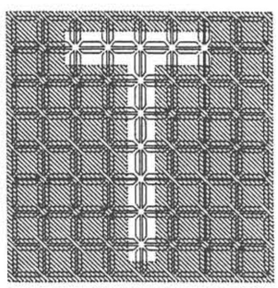


Fig. 3 A half plane covers entirely a photodiode (E_y) of one diode pair, the short circuit current I_{ph} of $\bar{I}_y$ cell versus TFT gate bias V_{GS} with light intensities 0.05 AM1.



(a)



(b)

Fig. 4 The test simple patterns with respect to the position of the sensor array. There are (a) rectangle and (b) a character T, respectively.

Figs. 4(a) and (b) show the test simple patterns with respect to the position of the sensor array. There are rectangle, and a character T, respectively. Figs. 5(a) and (b) are the measurement results of Figs. 4(a) and (b), respectively. Mark " x " indicates no signal is detected in this pixel and the number represents the angle between the edge and horizontal line. Except some corners regions, this sensor array can extract the edge positions and the accurate accurate orientation of the test samples. Now, massive data processeing performed on the image intensity obtained from traditional photodetector array can be neglected and only the information on the edge position and orientation left. After repeating the tests with different relative position to this sensor array, the results are consistent with the shape of test samples, the pixel yield of this sensor is close to 100 percent.

x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x
x	x	28	0	0	-14	x	x
x	x	90	x	x	-90	x	x
x	x	90	x	x	90	x	x
x	x	90	x	x	-90	x	x
x	x	-59	0	0	36	x	x
x	x	x	x	x	x	x	x

(a)

x	75	0	0	0	0	-90	x
x	-15	0	-53	-44	0	90	x
x	x	x	-90	90	x	x	x
x	x	x	-90	90	x	x	x
x	x	x	-90	90	x	x	x
x	x	x	-90	90	x	x	x
x	x	x	-90	90	x	x	x
x	x	x	-36	49	x	x	x

(b)

Fig. 5 The edge and orientation measurement results of the simple patterns of Figs. 4 (a) and (b) are correspondence to (a) and (b), respectively. Mark " x " indicates that there is no contrast edge of the test pattern passing through this pixel and the number represents the edge orientation which respects to the horizontal line.

4. CONCLUSIONS

The active hollow FOQUOD 8 × 8 array using a-Si:H material deposited on a silicon substrate has been achieved successfully. It needs two PECVD deposition processes and the area of two photodiode in each diode pair are symmetrical. The TFT switch of each diode pair can function accurately to control the photocurrent level. Each pixel is demonstrated to have the ability to extract the position and orientation of a contrast edge and the pixel yield of this sensor array is close to 100 percent. Since the test results are consistent with the expected results, part of the traditional data processing may be replaced by this hardware sensor array, a simpler algorithm can thus be developed for visual pattern recognition.

5. ACKNOWLEDGMENT

This work is supported by the National Science Council of the Republic of China under contract no. NSC82-0404-E-002-293.