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Two-Dimensional Contact-Type Image Sensor Using Amorphous Silicon Photo-Transistor

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We propose a novel two-dimensional contact-type image sensor using amorphous silicon photo-transistors (APTs) in which each pixel consists of an APT, a storage capacitor, and a thin-film-transistor (TFT). We have made a prototype 140 × 240-pixel sensor with a pixel size of 160 μm square. It is confirmed the prototype APT sensor can detect an image within 0.5 s in the range of illumination intensity from 5 to 250 lx. This TFT-switched, two-dimensional contact-type image sensor is promising for large-area applications because the fabrication process for APTs is fully compatible with that for conventional TFTs.

1. INTRODUCTION

The recent trend of miniaturizing in information services has necessitated compact image-acquisition devices. Current image scanners such as facsimiles and document readers are inevitably large, because they use linear image sensors with an optical lens system and operate by mechanical scanning.

Over the past decade, amorphous silicon (a-Si) thin films prepared by plasma chemical vapor deposition (CVD) have proved useful for a variety of applications. One of the most promising applications is thin-film-transistors (TFTs) for active-matrix liquid-crystal displays.[1,2] Amorphous silicon has also been applied to photodiodes for contact-type linear image sensors[3] because of its high photoconductivity. These applications show the feasibility of an a-Si large-area sensor.

In this paper, we propose a two-dimensional contact-type image sensor using modified amorphous silicon photo-transistors (APTs) whose prototype has recently been developed.[4] We describe the proposed structure, fabrication, and performance of the sensor, which has no lenses or mechanical scanning systems.

2. CONCEPT OF THE SENSOR

The proposed two-dimensional contact-type image sensor is designed on two basic concepts. First, it operates in two-dimensional charge storage mode and all pixels are scanned electrically (as shown in Fig.1). In operation, the storage capacitor is charged, and then the discharge through the photosensor in the storage time is detected pixel by pixel using a combination of horizontal and pixel switches. An advantage of two-dimensional storage is that the output signals are larger than those of conventional linear sensors because of the larger storage time. Second, the sensor is essentially large-area and contact-type and does not need lenses between the sensor and the document. As shown in Fig.2, the pixel is formed by conventional amorphous silicon technology. Each pixel comprises an APT as the photosensor, a storage capacitor, and TFT as the pixel switch. The APT has split-gate electrodes (gate-A and gate-B in Fig.2) in a conventional inverted-staggered TFT structure. Consequently, both APTs and TFTs can be formed in the same process, which is suitable for large-area fabrication. The sensor can detect images in both reflection and transparency modes as shown in Fig.2. In reflection mode, light incident through the sensor is reflected at a document, while transparency mode detects light penetrating the document.

3. EXPERIMENT

3.1 Device Fabrication

A prototype of the sensor was fabricated as follows. On a glass substrate, a light shield of Cr (0.07 μm), an insulator layer of SiO_2 (0.57 μm), and a gate electrode of Cr (0.14 μm) were deposited by sputtering. A gate insulator of Si_3N_4 (0.3 μm), an undoped amorphous silicon *i* layer (0.3 μm), and a phosphorus-doped amorphous silicon *n* layer (0.04 μm) were successively deposited by rf glow discharge CVD. The material gas mixtures for each deposition were SiH_4-NH_3-N_2, SiH_4, and SiH_4-H_2-PH_3. Conventional photolithography was used to define the amorphous silicon (i + n) pattern for isolation between devices, and the source-drain electrode patterns of evaporated Cr (0.08 μm) and Al (1.0 μm). Finally,

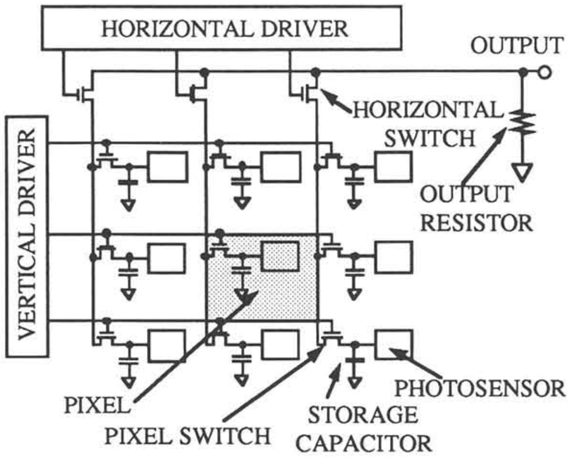

Fig.1 Circuit diagram of the sensor. The sensor scans pixels electrically by the combination of horizontal and vertical drivers.

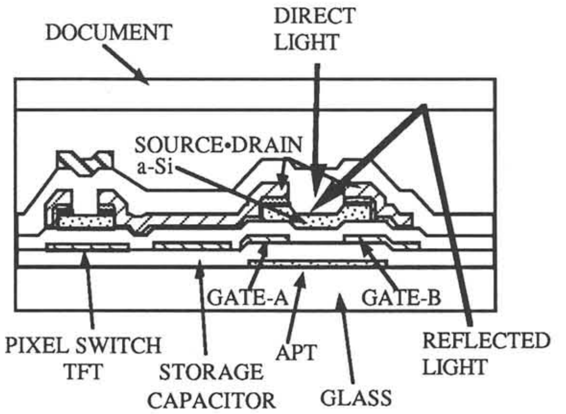

Fig.2 Cross-section of a pixel. The contact-type sensor has no lens system.

passivation layers of Si_3N_4 (1.2 μm) and poly glycidyl methacrylate (PGMA; 2.0 μm), a light shield of Al (1.0 μm), and a passivation layer of PGMA (2.0 μm) were deposited.

The sensor consisted of 140 × 240 pixels with a pixel size of 160 μm square. The channel widths of the APT and TFT were 65 μm and 200 μm, and both of their channel lengths were 8 μm. The capacitance of the storage capacitor was 1.4 pF. LCD-driver ICs were used for both the horizontal and vertical drivers. The APT has split-gate electrodes and the configuration of the electrodes is different from that of previously reported APTs[4,5]

3.2 Measurements

The charge stored at each pixel corresponding to the intensity of the detected light was measured by analyzing the output voltage waveform. This waveform was displayed on a digitizing oscilloscope and the stored charge was calculated as a function of exposure by integrating the waveform.

An external control circuit was designed to operate the sensor. It has three main functions, (1) operating of horizontal and vertical drivers, (2) amplifying and digitizing the output signal, and (3) storing of the digitized data. The image detected by the sensor was reproduced on a computer display from the stored digitized data.

4. RESULTS AND DISCUSSION

Figure 3 shows the transfer characteristics of the APT for a source-drain voltage (V_D) of 10 V and a gate-A voltage ($V_{G\text{-}A}$) of 10 V. As shown in Fig.3, the ratio of photocurrent to dark current, Iph / Id, is large for a gate-B voltage ($V_{G\text{-}B}$) of -10 V. The APT has a relatively long response time in the order of several hundred μs, because the main carriers in the APT are secondary photo-injected carriers. However, the two-dimensional storage operation compensates for this relatively long response time.

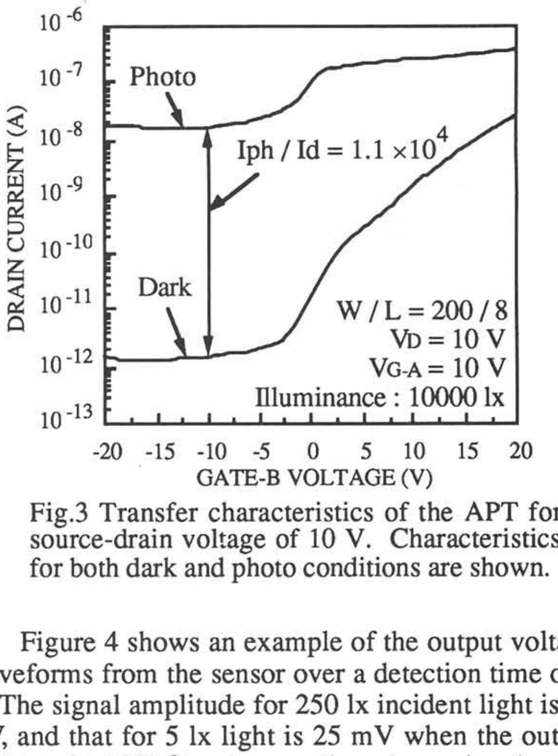

Fig.3 Transfer characteristics of the APT for source-drain voltage of 10 V. Characteristics for both dark and photo conditions are shown.

Figure 4 shows an example of the output voltage waveforms from the sensor over a detection time of 2 s. The signal amplitude for 250 lx incident light is 80 mV, and that for 5 lx light is 25 mV when the output resistor is 100kΩ. As mentioned previously, the output charge can be calculated by integrating the waveform. The results are shown in Fig.5. In the linear region in the exposure range from 10^{-1} lx·sec to 7 lx·sec, the slope γ is defined by the output charge Q and exposure X as $\gamma = \partial \log(Q) / \partial \log(X)$. The γ value of 0.64 agrees with that of the APT itself. This shows that the fabricated pixels works as designed. Saturation is observed for the exposure intensities larger than 7 lx·sec as a result of limit on the charge stored in the storage capacitor.

Figure 6 is an example of an image detected by the sensor. This image is produced by placing a shadow mask over the sensor under room light in transparency mode. It is found that the sensor has a resolution of 160 μm since the narrowest line in the character "A" is the same size as a pixel. The total detection time is 0.5 s, which is mainly determined by the speed of the horizontal-switch TFTs.

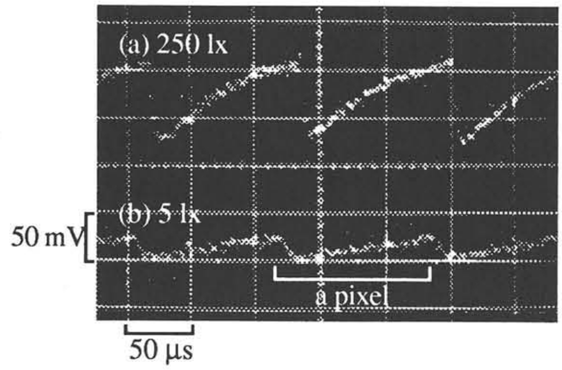

Fig.4 Output signal waveforms for (a) 250 lx and (b) 5 lx illumination

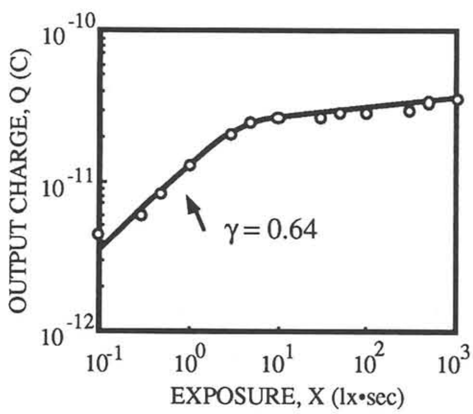

Fig.5 Dependence of output charge on exposure. The γvalue agrees with that of the APT.

5. CONCLUSION

We have developed a two-dimensional contact-type image sensor free from lenses and mechanical scanning systems. The sensor operates in two-dimensional charge storage mode and is scanned electrically. A prototype sensor was made using APTs whose process technology is compatible with that for conventional TFTs. The sensor consists of 140 × 240 pixels each 160 μm square. The sensor successfully reproduces images in a detection time of 0.5 s. These results with the prototype sensor show promise for a two-dimensional contact-type image scanner with a large-area format.

Fig.6 Output image detected by the sensor. The detection time is 0.5 s.

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REFERENCES

1) M. J. Powell, B. C. Easton, and O. F. Hill, Appl. Phys. Lett., **38**, 794 (1981).
2) T. L. Credelle, Proceedings of the International Display Research Conference, San Diego, 1988 (IEEE, New York, 1988) p. 208.
3) H. Yamamoto, M. Matsui, T. Tsukada, Y. Eto, T. Hirai, and E. Maruyama, Jpn. J. Appl. Phys., **17**, 135 (1978).
4) Y. Kanako, N. Koike, K. Tsutsui, and T. Tsukada, Appl. Phys. Lett., **56**, 650 (1990).
5) M. Hack, A. G. Lewis, R. H. Bruce, and R. Lujan, Mat. Res. Soc. Symp. Proc., **219**, 167 (1991).