Amorphous Si:H Linear Image Sensor Operated by a-Si:H TFT Array

F. Okumura, S. Kaneko and H. Uchida

Microelectronics Research Laboratories, NEC Corporation

Miyamae-Ku, Kawasaki 213, Japan

A 64 bit a-Si:H linear image sensor operated by an a-Si:H TFT array has been proposed. This sensor consists of photodiode array, TFT array, matrix circuit and external circuit. TFT on resistance is approximately 400 kΩ and mobility is 0.6 cm²/V·sec at 30 V gate voltage. 5 µsec read out time is obtained in the conventional matrix mode scanning. Moreover, a novel driving method is applied in order to improve effective operation speed. Experimental data confirm the validity of the concept.

1. Introduction

A large scale linear image sensor using amorphous Si is an attractive device for compact and high speed facsimile equipment because of its short photoresponse time and simplicity for fabrication.(1),(2),(3) However, since these sensors consist of an a-Si:H photodiode array and IC scanners, a large number of wire bondings and IC scanners are required. Fabricating switching devices and photodiodes on the same substrate avoids this manufacturing difficulty. K. Ozawa et al. have proposed a linear image sensor with blocking diode.(4) On the other hand, M. Matsunaga et al. have proposed a linear image sensor combined with an a-Si:H thin film transistor (TFT) and obtained a good reproduced image operated at 300 Hz.(5) However, due to low a-Si:H TFT mobility, more than 100 µsec switching time is needed, which is too slow to be used in G III mode facsimile (2.5 µsec/bit).

In order to improve the operation frequency, we have developed a linear image sensor using a photodiode combined with high mobility TFT. Since the photodiode has short photoresponse time, this sensor can be scanned at high speed. Moreover, a novel driving method is applied.

2. Device Operation

Figure 1 shows the 64 bit linear image sensor fabricated and studied. This sensor consists of photodiode array, TFT array, matrix circuit and external circuit, which includes transfer capacitors C_i (i=1~8) and analog multiplexer. TFTs are connected in an 8×8 row-column matrix. Each output terminal is connected to the transfer capacitor, a discrete capacitor, which transfers signal charge from the photodiode to a detection circuit. However, in the case of a large size linear image sensor, stray capacitance in the lines functions as the transfer capacitor.

The sensor operates as follows. Figure 2 shows the timing diagram. In the Tg period for ϕ_i, photo-charge, which are integrated in the photodiodes (S_11 ~ S_in) during integration time Ti, are transferred into capacitors C_1 ~ C_g simultaneously. After the TFTs turn off, the analog multiplexer reads out these charge during T_A of ϕ_A1 ~ ϕ_A8. In this driving method, operation speed for one column is T_g + 8T_a in the shortest case. Therefore, effective operation speed per bit T is given by

$$ T = (T_g + 8T_a) / 8. $$  \hspace{1cm} (1)

In the conventional matrix mode scanning, operation speed is T_g. Reduction in the number of TFT switchings increases the operation frequency.

To explain operation speed for this sensor, consider the charge transfer speed from the photodiode to the detection circuit. Figure 3 shows the
Fig. 1 Equivalent circuit for 64 bit a-Si:II linear image sensor

Fig. 2 Timing diagram

Fig. 3 Equivalent circuit for charge transfer between photodiode and detection circuit

where \( Q_i \) is charge at \( C_i \). It is clear from Eq. (2) that \( C_i \) should be much larger than \( C_a \) in order to minimize afterimage.

When \( C_a \ll C_i \), Eq. (2) is rewritten as

\[
Q_a = Q_i \left(1 - \exp\left(-\frac{t}{C_a R_T}\right)\right)
\]  

Then the time constant is nearly equal to \( C_a R_T \).

At the next step, \( Q_i \) is discharged by switching the analog multiplexer. The time constant is \( C_i (R_A + R_{in}) \). In this sensor, \( R_A \) is 200 \( \Omega \) and \( R_{in} \) is 500 \( \Omega \), respectively. Since \( R_A \) and \( R_{in} \) are sufficiently small, \( T_A \) can be much smaller than \( T_G \). For example, when \( C_i \) is 300 \( \text{pF} \), the time constant is 0.21 \( \mu \text{sec} \). Even if \( T_G \) is 100 \( \mu \text{sec} \), the operation speed per bit is approximately 13 \( \mu \text{sec} \) from Eq. (1). As a result, effective readout time per bit is greatly reduced, compared with conventional matrix mode scanning.

3. Device Structure and Fabrication

Figures 4 and 5 show a cross sectional view and photograph for this sensor, respectively. The photodiode has a sandwich-like structure with \( \text{SiN}_x \) and p-a-Si:H blocking layers on both sides of a photosensitive a-Si:H layer. These blocking layers decrease dark current and provide high photosensitivity. The effective photosensitive area is 100 \( \mu \text{m} \times 100 \mu \text{m} \) (8 bits/mm). The a-Si:H TFT configuration is inverted staggered structure. The gate insulator is \( \text{SiN}_x \). A thin phosphor-doped layer is deposited on top of the undoped layer as an ohmic contact to an evaporated Al electrode. Channel length and width are 20 \( \mu \text{m} \) and 1 \( \text{mm} \), respectively. Polyimide is used for a matrix.
which are the 4 evaporated layers fabricated A n+a-Si:H 0.3 200 sputtering. 0.5 µm thick SiO2 film and a 400 µm electrode transparent IT0 film light shield layer, gate electrode and evaporated follows: A circular insulator. o.1 µm thick SiNx.

Fig.4 Cross sectional view of a-Si:H linear image sensor operated by a-Si:H TFT array

Fig.5 64 bit a-Si:H linear image sensor

circuit insulator. Fabrication procedures are as follows: A 1000 Å thick Cr film was first evaporated on Corning 7059 glass and formed into a light shield layer, gate electrode and lower electrode for matrix circuit. Polyimide was coated and chemically etched by phototching process. A 0.5 µm thick SiO2 film and a 400 Å thick transparent ITO film were deposited by rf sputtering. The ITO film was etched to form a 200 µm wide common electrode. To fabricate TFT, 0.3 µm thick SiNx, 0.3 µm nondoped a-Si:H and 500 Å n+a-Si:H layers were deposited continuously. To fabricate the photodiode, 300 Å thick SiNx, 2.5 µm i-a-Si:H and 0.2 µm p-a-Si:H layers were deposited continuously. Both SiNx and a-Si:H layers were deposited by the capacitively coupled rf glow discharge technique. Finally, Al was evaporated and formed.

4. Experimental Results

Characteristics measurements for the TFT and the photodiode were performed using test elements, which are fabricated on the same substrate for this sensor.

Figure 6 shows $I_D-V_G$ characteristics for a-Si:H TFT. Typical TFT on resistance is 400-500 kΩ at $V_G=30$ V. Mobility and threshold voltage for TFT obtained from $V_G=\sqrt{I_D}$ characteristics are 0.6 cm²/V·sec and 6–7 V, respectively. On/Off ratio is $10^5$ or more. Photo-current for a photodiode under 100 lx (550 nm) exposure is $9 \times 10^{-19}$ A in over 3 V saturation voltage. Dark current is less than $10^{-15}$ A at 0 to 15 V. Photoresponse time for the photodiode is less than 0.1 msec. Therefore, high speed image processing is possible. The storage capacitor in the photodiode is 10–20 pF. Then, from Eq.(3), the time constant for photodiode and TFT pair is expected to be $\approx 10$ µsec.

Figure 7 shows the charge transfer characteristics from photosensor to Cl. Cl is 330 pF and $T_A$ is 2.5 µsec. In this case, the time constant for the analog multiplexer is approximately 0.2 µsec. Charge transfer time is 20 µsec at $V_G=20$ V and 5 µsec at $V_G=30$ V. $C_a$ is estimated at 10 pF, from Eq.(3) and Fig.7. Therefore, afterimage is less than 3 percent. These results agree with estimation from the test elements.

The output wave forms for integrator and voltage developed across $C_a$ at 4 lx/sec exposure (550 nm) and in the dark are shown in Fig.8. $T_q$ is 20 µsec and $T_A$ is 2.5 µsec. The interval between $\phi_{Ai}$ and $\phi_{Ai+1}$ is integrator reset time. In this

![Fig.6 a-Si:H TFT $I_D-V_G$ characteristics](image-url)
case, operation speed is 10 μsec/bit. A large feedthrough, which is due to capacitive coupling of interrogating pulse, appears across C3. In general, such a noise is cancelled when the interrogating pulse is off. Nevertheless, an uncancelled value exists which causes a reduction in signal to noise ratio. This uncancelled value is considered due to trapped electrons, which will be released from the traps in the a-Si:H TFT, and the analog multiplexer feedthrough. This noise will be reduced by miniturization of TFT and using the noise reduction method\(^3\). Integrator output waveform indicates that charge read out from C3 is completed within 1 μsec. The read out time per bit can be reduced by increasing the number of elements which are switched at one time, as mentioned above. When \(T_G\) is 10 μsec and \(T_R\) is 1 μsec, operation speed corresponds to 1.3 μsec/bit in a practical 32 bit/column. This speed satisfies the G3I mode facsimile requirement.

5. Conclusion

An a-Si:H linear image sensor operated by a-Si:H TFT array has been proposed. In this sensor, a photodiode, which has short photoresponse time, and a high mobility TFT are used to increase operation speed. The photodiode and TFT pair shows 5 μsec read out time at 30 V gate applied voltage. Moreover, effective read out time is greatly reduced by using a novel driving method. Experimental results indicate that operation speed for this sensor is high enough for use in practical facsimile equipment.

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Reference