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Completely Integrated a-Si: H Linear Image Sensor with Poly Si T.F.T. Drivers

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A new contact type linear image sensor has been successfully developed which integrates a-Si:H photodiodes and poly-Si T.F.T. driving circuits on the same substrate. The photodiode with B-doped a-SixC$_1$-x:H/a-Si:H/non-doped a-SixC$_1$-x:H structure has high photosensitivity and its dark current is $\leq 10^{-12}$ A/mm^2 at -5V. On the other hand, the poly-Si T.F.T. has high ON current and its ON/OFF ratio is $\geq 10^6$ at the channel length/width of 5μm/10μm, respectively. The poly-Si T.F.T. shift register which can operate from D.C. to 2MHz is CMOS static type and has high reliability. As a result, the sensor obtains readout time of 2μs/bit, S/N ratio of 40dB and saturation exposure of $\leq$0.89ℓx•sec at the green L.E.D.

1. Introduction

In recent years, there have been many reports about a contact type linear image sensor using amorphous silicon (a-Si:H), and this sensor contributes much to miniaturizing the image scanners, e.g., a facsimile equipment. An a-Si:H photodiode has short photoresponse time and high photosensitivity. Accordingly, a linear image sensor that consists of an a-Si:H photodiode array, external analog switches and driving circuits has been developed.[1] But this sensor requires a large number of wire bondings. In order to avoid this manufacturing difficulty, an a-Si:H sensor with blocking diodes,[2][3] and an a-Si:H sensor combined with a-Si:H thin film transistors (T.F.T.s)[4] has been developed. Both of these sensors employ a matrix-drive method and require the external driving circuits.

However, all of them have low S/N ratio and are not available because of the complicated external circuits. Development of the sensor which completely integrates the photodiodes and the driving circuits have been expected.

Last year, we developed a liquid crystal video display addressed by poly-Si T.F.T.s.[5] The poly-Si T.F.T. has high reliability, rapid switching speed and low photosensitivity. These characteristics of the poly-Si T.F.T. could realize a liquid crystal video display with integrated drivers.[6] These drivers can be operated at 2MHz. In addition, the poly-Si T.F.T. is so photo-insensitive that it can operate in the light, but an a-Si:H T.F.T. usually malfunctions.

We have developed a new type image sensor which completely integrates a-Si:H photodiodes, poly-Si T.F.T. analog switches and poly-Si driving circuits on the same substrate. This sensor has only nine outlet terminals regardless of the number of pixels, and has high S/N ratio and short readout time. Therefore, the developed contact type image sensor has the characteristics that are almost equal to those of the small-sized linear CCD and MOS type image sensor, and this sensor can be fabricated in larger substrate with much simpler processes than those of conventional types. For testing the characteristics, a 500 bit-sensor (10 bit/mm), 50.1mm X 2.6mm in size is fabricated on the glass substrate. Application of this technology to the fabrication of the A4-size sensor is not so difficult.

2. Equivalent Circuit and Device Operation

Fig.1 shows the equivalent circuit for the sensor. Each photodiode is connected to the poly-Si T.F.T. analog switch in series. These switches are selected in turn by the poly-Si T.F.T. driving circuits, which consist of static type shift registers, NAND circuits and inverter circuits. ϕ_{CL}, $\overline{\phi}_{CL}$ and SP (Start Pulse) are applied to the driving circuits. The T.F.T. analog switch, S_{R1} and S_{R2} are driven by ϕ_C and $\overline{\phi}_C$ and are connected to

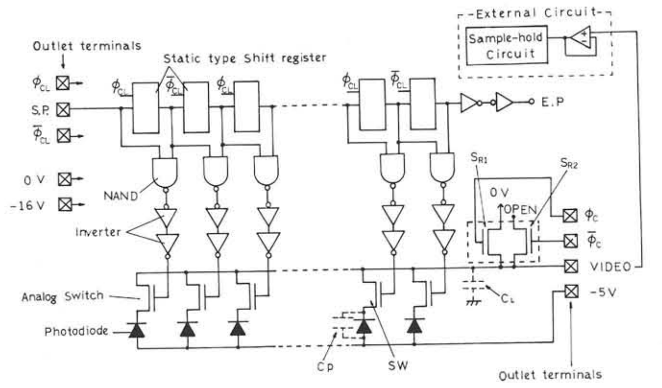

Fig.1 Equivalent circuit and external circuit

a OV line and open, respectively. S_{R2} cancels the switching noise of S_{R1}. S_{R1} chooses "readout" or "charging". C_P and C_L are the photodiode and stray capacitance, respectively. SW is T.F.T. switch, which is connected to one of photodiodes. And this circuit is supplied with 0V, -5V and -16V, and power consumption is less than 1mW.

The following shows the principle of device operation. First, C_P is charged and then both of SW and S_{R1} turn OFF. The stored charge is discharged by photocurrent. Just before C_P is recharged, SW selected by the driving circuits turns ON and the voltage potential of C_L is read out. After the readout, ϕ_C pulse is applied to S_{R1} and C_P is charged again. Readout signals are transferred from the video terminal to the external circuits, which consist of an amplifier of 5 magnifications and the simple sample-hold circuit for noise reduction.

3. Device Structure and Fabrication

Fig.2 shows a cross-sectional view and a microphotograph of this sensor. The photodiode has a sandwich-like structure with B-doped a-SixC$_1$-x:H and non-doped a-SixC$_1$-x:H blocking layers on both sides of a photosensitive a-Si:H layer. The photodiode is 100µm X 70µm in size. All of these layers are deposited by R.F. glow discharge method. The poly-Si layer is deposited by the low pressure vapor deposition method and the gate insulator is formed by the thermal oxidation of the poly-Si layer. The gate electrode is also formed by poly-Si. Al-Si-Cu alloy is used as the material for interconnections. In order to decrease the number of fabricated processes, Al-si-Cu is also used as the lower electrode of the photodiode. And then it isn't observed that Al-Si-Cu reacts on a-Si:H.

The T.F.T. switch connected to the photodiode is P-channel type whose channels length and width are 5µm and 10µm, respectively. The driving circuits are CMOS type in order to operate at high speed.

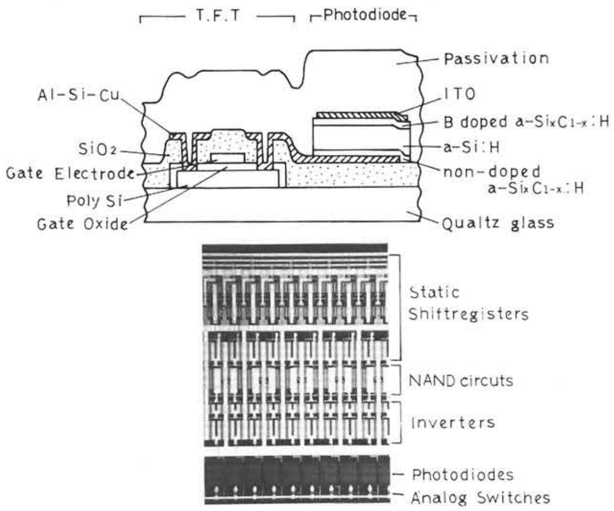

Fig.2 Cross sectional view and microphotograph of fabricated sensor

4. Characteristics of T.F.T. Switch and Driving Circuits

The I_D-V_G characteristics of the P-channel poly-Si T.F.T. are shown in Fig.3. Its T.F.T. has the same size as the analog switch's. The drain voltage is -5V, which corresponds to the maximum voltage applied to a T.F.T. switch. The OFF current is about 10pA and the ON current is more than 10µA at V_{GS}=-16V, which is sufficient to charge an a-Si:H photodiode within 2µsec.

The T.F.T. has such high reliability that no degradation of the characteristics can be observed for more than 1,000 hours at 125°C. In addition, poly-Si T.F.T. has poor photosensitivity, which makes the poly-Si T.F.T. effective in the drivers used to operate photosensitive devices.

Fig.4 shows the characteristics of the poly-Si T.F.T. shift register. It can operate at 2MHz, which means that this sensor can read an A4 size document at a speed of 0.6ms/line. And the insulating substrate also contributes to the high speed operation of the shift register.

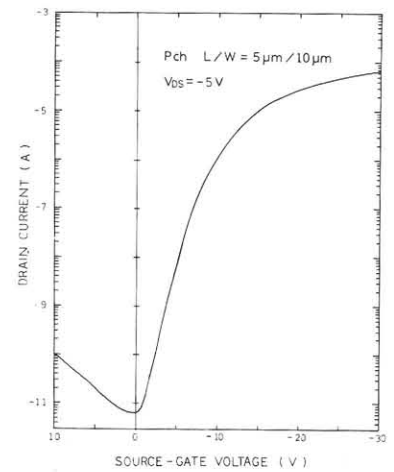

Fig.3 I_D-V_G characteristics of P-channel poly-Si T.F.T.

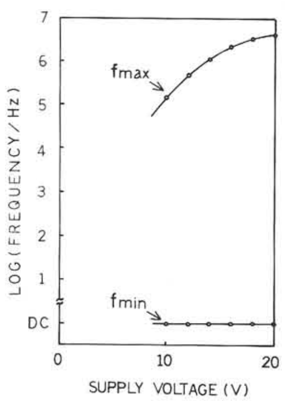

Fig.4 Characteristics of poly-Si T.F.T. shift register

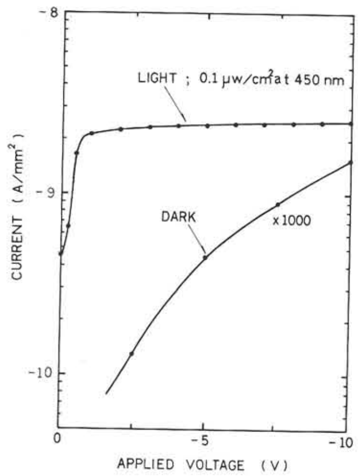

Fig.5 I-V characteristics of a-Si:H photodiode

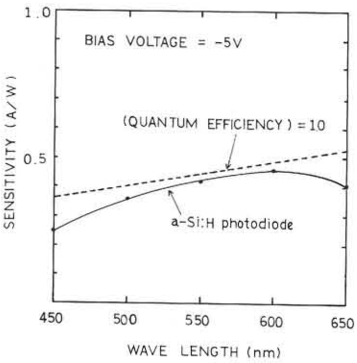

Fig.6 Spectral sensitivity of a-Si:H photodiode

5. Characteristics of Photodiode

Fig.5 shows the I-V characteristics of the a-Si:H photodiode both under photo and dark conditions. Bias voltage from -10V to 0V is applied, and photocurrent is measured under the illumination of 450nm light whose photoenergy is 0.1μW/cm². The breakdown voltage is found to be less than -40V. In the range from -0.5V to 0V, photocurrent is steeply reduced. The change in slope is due to the carrier-recombination in $SixC_{1}$-x:H layers. It was observed that the recombination can be reduced by doping boron or phosphorus into them.

Fig.6 shows the spectral sensitivity of the a-Si:H photodiode. Applied voltage to this diode is -5V, where applied voltage in this sensor varies from -5V to 0V. In the range from 450nm to 650nm, the photodiode has quantum efficiency (ηex) of more than 0.68 without regard to reflective loss. If the reflective loss is considered, quantum efficiency is more than 0.83. In addition, the photodiode has photoresponse time of less than 20μs, which depends on wave length.

6. Performance

A video terminal of this sensor is connected to the external circuit as shown in Fig.1. Output signals both under photo and dark conditions of the fabricated sensor are shown in Fig.7 The illuminated light intensity is slightly lower than the saturation exposure. The non-uniformity at this photo condition is less than ±5% and the read time per pixel is 2μs, which is rapid enough to be used in GIII mode facsimile. The dark output voltage of each pixel is less than 5mV.

The relation between the light intensity and the output voltage of this sensor is shown in Fig.8. A 200W xenon lamp is used as a light source, which is filtered off at more than 750nm. The light intensity in Fig.8 is normalized by the saturation exposure. The slope of this curve (γ) is almost unity except in the region of high irradiation. The saturation in this region is caused by the steep change in slope of the I_P-V character-

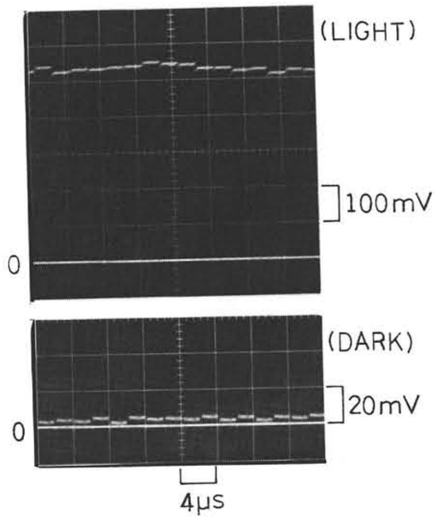

Fig.7 Output signals both in photo and dark conditions

istics shown in Fig.5. However, with the exception of this region, the amplitude of the output voltage has good linearity from 5mV to 500mV, which corresponds to S/N ratio of 40dB. It is very evident that this sensor can read gray scale images, e.g., photographs, speedily. And the spectral sensitivity of this sensor corresponds to that of the photodiode shown in Fig.6.

7. Summary

A new contact type linear image sensor has been proposed. This sensor integrates a-Si:H photodiodes and poly-Si T.F.T. driving circuits on the same substrate. Both a-Si:H and poly-Si can be deposited on the large area. The a-Si:H photodiode has high photosensitivity and short photoresponse time, and the poly-Si T.F.T. has high switching speed, large ON-OFF ratio and very low photosensitivity. Due to this combination of the a-Si:H photodiodes and the poly-Si T.F.T.s, this sensor is successful in achieving the high performance at low cost shown in Table 1. Furthermore, it has been confirmed that this sensor can reproduce photographs.

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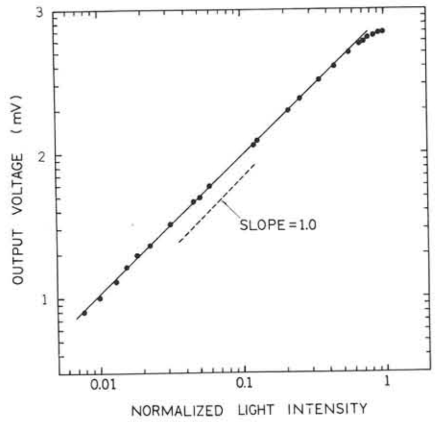

Fig.8 Relation between light intensity and output voltage

	Performance
Supply voltage	0V, -5V, -16V
Clock frequency	250 kHz (typ.)
Readout time	2 μs/bit (typ.)
S/N ratio	≥ 40 dB
*Saturation exposure	≤ 0.89 lx·sec
η_{ex} value	≥ 0.68
γ value	0.95 (OUT PUT ≤500 mV)
Uniformity	≤ ±5%

* Light source is Green L.E.D.

Table 1 Performance

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