a-Si:H Image Sensor for PC Scanner

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Abstract—In this paper, the image sensor using the a-Si:H TFT is proposed. The optimum amorphous silicon thin film is deposited using plasma enhanced chemical vapor deposition (PECVD). TFT and photodiode both with the thin film are fabricated and form image sensor. The photodiode shows that I_{dark} is ~10^{-13}A , I_{photo} is ~10^{-9}A and I_{photo}/I_{dark} is ~10^4, respectively. In the case of a-Si:H TFT, it indicates that I_{on}/I_{off} is 10^6, the drain current is a few μA and V_{th} is 2 ~ 4 volts. For the analysis on the fabricated image sensor, the reverse bias of -5 volts in ITO of photodiode and 70 μsec pulse in the gate of TFT are applied. The image sensor with good property was conformed through the measured photo/dark current.

I. INTRODUCTION

Today, amorphous silicon is widely used in optical to electrical conversion device and wide area film device. Photodiodes have used in contract image sensors and barcode readers for sensing light reflected from a document or other objects and recognizing characteristics and letters. Especially, a-Si:H is used such as a switching device for active matrix LCD, contact image sensor for a-Si:H TFT and Fax, and a-Si:H solar cell. In all these applications the transistor acts as a switch.

Hydrogenated amorphous silicon (a-Si:H) thin film transistors (TFTs) can be important circuit elements in large-area imaging sensors because of their advantageous material and optical properties.

In resent years, great progress has been made in developing a contact type linear image sensor. As it is the same size with a full document width, it does not need a long optical path for image reduction of a CCD image sensor. This makes a document reader very compact. For this reason, many kinds of the contact type sensors are now being developed. Among those, a sensor using a-Si:H photoconductor has been considered especially promising because it has fast response, simple device structure and good stability.

The proposed idea in this paper relates to photodiodes, and more particularly to a photodiode exhibiting an increased on/off current ratio and a method for fabricating the same. However, each switching TFT of a sensor is connected to an IC chip (or readout circuit) for serial signal reading, many ICs and wire bondings are required. This makes manufacturing processes, especially in wire bonding complicate. In order to solve this problem, the a-Si:H driver has been developed. By using TFTs are as a switching device for block selection, it requires only one IC chip (or simple readout circuit). These make manufacturing process in wire bondings simple and the cost of the sensor much lower.

The accurate control for dark current is very important for gray scale level designation. Where the level of dark current is imperfectly determined, the sensing operation is inaccurately achieved. A plurality of photodiodes are used for a large document including a white part at one portion and a black part at the other portion, the characteristics of the photodiodes should be uniform. For obtaining the accuracy in the sensing operation and the uniformity in device characteristic, a material exhibiting an appropriate energy band gap should be used. Furthermore, a material exhibiting the appropriate energy band gap must have a constant value to maintain the uniformity in device characteristic and control the dark current. On the other hand, where the energy band gap is too large, it is impossible to accomplish the sensing function because all signals generated are detected as dark current. A lot of photo current can flow by controlling a flow of dark current and we can obtain a high I_{photo}/I_{dark} ratio.

It is classified by amorphous silicon, poly silicon and crystal according to regularity on array of mutual array with component of atoms. Amorphous is used as electric device in restricted field because amorphous is very disorder. But, there is a interconnection distance between atoms in amorphous. It is used in the field of electron device in specific usage with low quality of electrical characteristics compared to conventional crystal. This kind of work was advanced after 1980. Compared to other materials, amorphous materials specially have a high quality characteristic in optical to electrical conversion. The new technology of thin film has improved in this kind of field.

Especially, hydrogenated amorphous silicon can obtain high quality of a-Si:H film by reducing localized states after bonding hydrogen and dangling bond of amorphous silicon. Hydrogenated amorphous silicon has low quality characteristics such as carrier mobility and dark current compared to crystal silicon. But it has a superior to optical absorption coefficient, optical bandgap and optical conductivity. It makes sensor device such as solar cell by using its optical characteristics. Hydrogenated amorphous silicon is first commercial optical diode with thin film type. It is not popularly used,

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because a-Si has degradation when it is exposed by light. Intrinsic degradation generating in light absorption is limited 20%. In this paper, the image sensor using the a-Si:H TFT is proposed. TFT and photodiode both with the thin film are fabricated and form image sensor.

The contact type image sensor is made up of a photo sensing array having a plurality of photo sensing elements arranged in a line, and TFTs for switching the photo sensing arrays. Electric charges induced in the photo sensing elements are applied to one output line in a time-series mode by means of a switch which selects the photo sensing elements one after another. In order to drive the plurality of photo sensing elements forming the photo sensing array, it is necessary to provide a number of driving IC chips. In order to eliminate this difficulty, a TFT driven image sensor has been proposed in the art in which processing is carried out in a parallel mode with a-Si thin film transistor (hereinafter referred to as "TFT", when applicable) used for switching several picture elements simultaneously, whereby the number of driving IC chips is reduced, and the manufacturing cost is reduced as much.

II. FABRICATION AND CHARACTERISTICS OF TFT

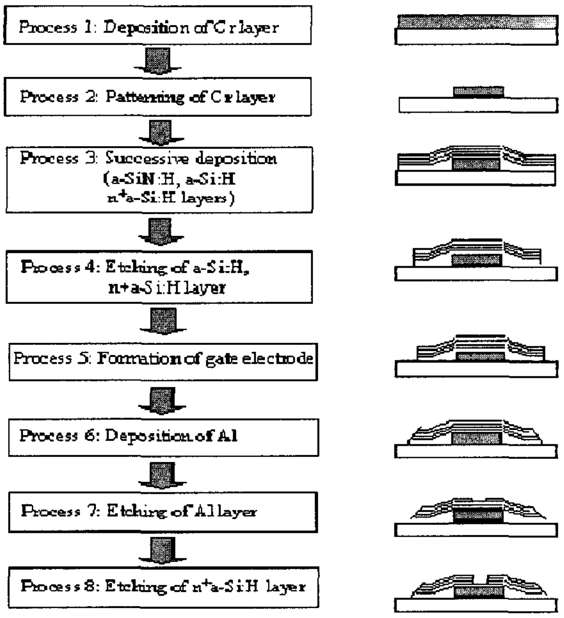
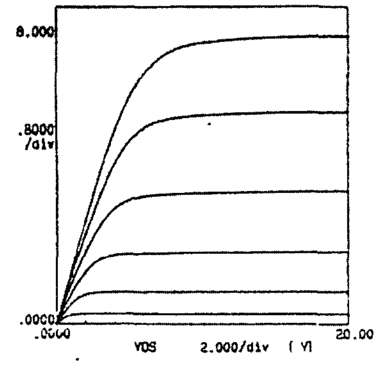
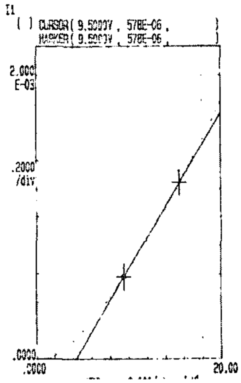


Fig. 1 Fabrication process of a-Si:H TFT

Figure 1 shows a cross-section of process for thin film transistor fabricated in this experimental setup. The gate electrode is formed by patterning with length of 8 μm~16 μm and width of 80~200 μm after depositing with gate electrode (Cr) 1000 Å under corning 7059 glass substrate. We have fabricated a-SiN:H, a-Si:H and n^{+}a-Si:H samples on gate electrode in sequence a-Si:H and n^{+}a-Si:H samples, respectively. The thickness of these thin films is formed with a-SiN:H (3000 Å), a-Si:H(2000 Å) and n^{+}a-Si:H (500 Å). We have used a RIE (Reactive Ion Etching) method to etch after forming a-Si:H pattern of channel layer. RIE equipment is used RI mode of PECVD. After hole pattern is formed, a-Si:N:H is conducted RIE and the used gas is used by mixing CHF_3 and O_3. To form a source drain electrode, the film is patterned after deposition 4000 Å of Al by E-beam evaporator. Finally, n^{+}a-Si:H is conducted by RIE using CF + O_2 and gas for S/D metal pattern. To compensate a damage by RIE process, the n^{+}a-Si:H is annealed at temperature 200 °C in vacuum state. As shown in the figure 2, we have gained an I-V and V_{th} characteristics by using probe station and HP4145B parameter analyzer.



(a) I-V curve



(b) V_{th} curve

Fig. 2 Electrical Characteristics of a Si:H TFT

As shown in figure 2, The saturation current at gate voltage 20 Volts is 8 μA and V_{th} is 4.3 volts. It has a good electrical characteristic.

III. FABRICATION AND CHARACTERISTICS OF PHOTODIODE

CORNING 7059 GLASS (5cm X 5cm) and Si wafer is used as substrate in this experimental condition. Electrode of optical diode has very critical condition in process that forms electrode and characteristics of material because of characteristics of junction with amorphous. Lower electrode of optical diode is generally used by Cr thin film. In experimental, E-beam evaporator is used. It can form high vacuum with 10^{-6} ~ 10^{-7} Torr by using low temperature pump. It can heat at 350℃with IR lamp

Table 1 E-beam evaporator condition of Cr thin film

vacuum	µTorr	1~2
power	mA	30
substrate temperature	℃	30
deposition rate	Å/sec	4
RPM		20
film thickness	Å	2,000

We have fixed the deposition rate of Cr thin film with 4 Å/sec in experimental. The thickness of Cr thin film in lower electrode is fixed at 2,000 Å. Figure 3 shows the result of measurement with AES(Auger Electron Spectroscopy) of Cr thin film. Amorphous Si was deposited on Cr thin film with about 10,000 Å thickness by PECVD method over that thin film.

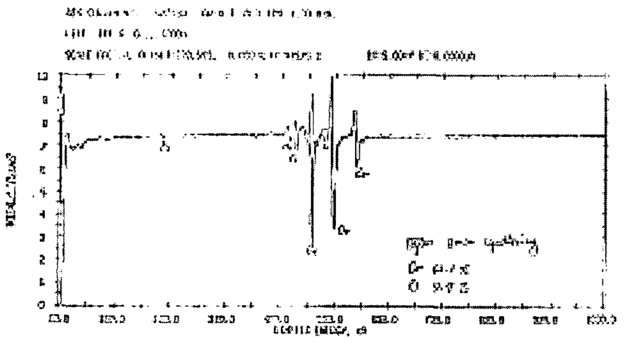


Fig. 3 AES Characteristics of Cr Thin Film

Table 2 shows the deposition condition of amorphous silicon thin film respectively.

Table 2 PECVD deposition condition of amorphous Si thin film

	unit	a-Si:H for Cr silicide	a-Si:H
SiH4	sccm	4	4
pressure	torr	0.3	0.3
temperature	℃	250	250
time	min	0.4	40
power	watt	4	4
thickness	Å	100	10,000

The process of photodiode is as follows. First, it was deposited 1000 Å thickness of ITO with vacuum process by using sputtering equipment over surface. Second, it is patterned ITO by optical etching process and removing a-Si:H by RIE process. Third, photodiode is formed. ITO thin film equipment used in experimental is DC magnetron sputtering, HSD-662M. The density of magnetic can be affected on electron and is not affected on ion , it is very helpful to form an plasma in equal. The main vacuum system use Turbo molecular pump and circle target of 8 inch. It can be fabricated thickness uniformity with ±5% on glass substrate of 300*300㎟.

Optical transparency and resistivity are important on transparent electrode and are inverse proportional to quality of O2 gas. In this experimental, the composition rate of In_20_3:$Sn0_2$ is 90:10wt%

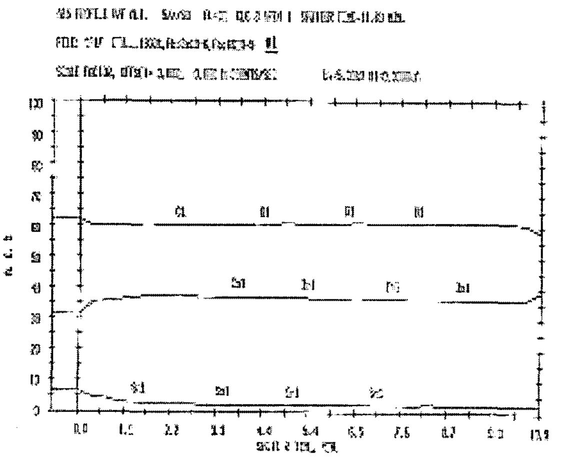


Fig. 3 Measurement result of AES of ITO thin film

Table 3 Sputter condition of ITO thin film

	unit	ITO
Ar	sccm	50
02	sccm	0.5
temperature	℃	200
Target	(In_20_3 : $Sn0_2$)	90:10 wt%
power	W/㎠	1.85
thickness	Å	1000

Table 3 shows the sputter condition of ITO thin film. Amorphous silicon is deposited using plasma enhanced chemical vapor deposition (PECVD). At this time, electrical and optical characteristics of amorphous silicon such as conductivity, optical band gap and deposition rate are changed under deposition condition such as SiH4, flux, chamber pressure, RF power and substrate temperature. Figure 1 shows the characteristics of experimental results according to amorphous deposition condition. From the results shown in figure 1, photo and dark conductivity are diminished according to SiH4 flux, dark conductivity is changed 10-9 ~ 10-11(S/cm), in the case of photo conductivity is varied range from 10-4 to 10-6 (S/cm). Also, optical band gap shows 1.7 ~ 1.8eV, as a flux of SiH4 is increased, it is deposited from 1.0 to 6.9 (Å/sec).

Figure 4 shows the IR spectrum result. The a-Si:H film shows a type of vibration mode, it shows SiH_4 stretching mode at wave number 2000 cm^{-1}. Also, it represents a rocking mode at wave number 635 cm^{-1}. The bond represented at weak bond range 800 ~ 900 cm^{-1} depends on the vibrational mode of SiH_2. Therefore, the fabricated a-SiH film in this experimental setup shows that Si-H bonding of stretching/rocking mode exists. The gate insulator layer and a-SiN:H film of passivation film are fabricated using PECVD by mixing SiH_4 gas and NH_3 gas. Figure 5 shows optical bandgap of a-SiN:H.

Etching rate of a-SiN:H increases and refraction diminishes as NH_3/SiH_4 increases. Also, their characteristics are not related with RF power. The E_{opt} value is around 2.4 eV.

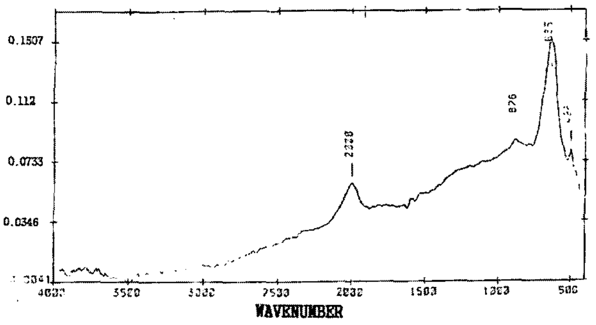


Fig. 4 FTIR characteristics of a-Si:H

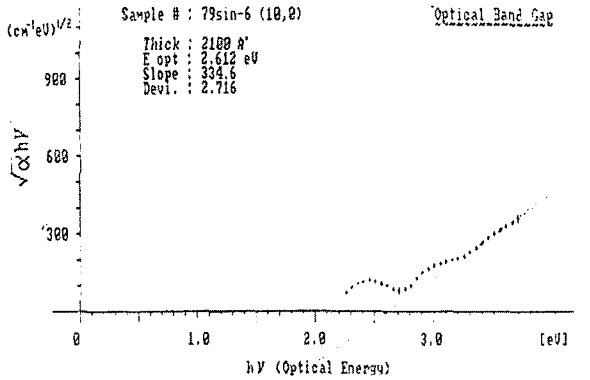
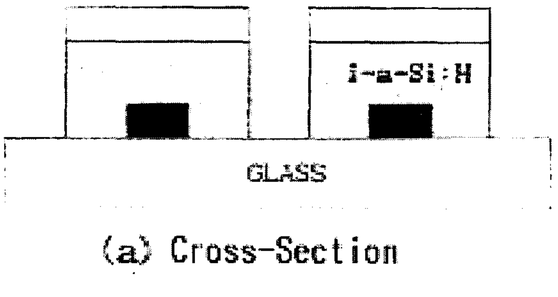


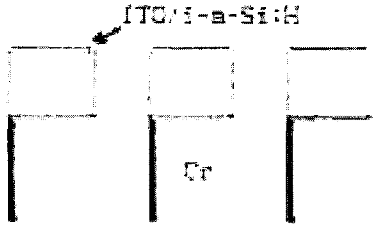
Fig. 5 Optical Band Gap of a-SiN:H

Generally, the amorphorous optical diode withITO/a-Si:H/Cr structure uses schottky effect. a-SiH/Cr has aquasi-schottky characteristics and barrier height with 0.55eV. a-Si:H and ITO has a barrier height with~0.93 eV.. But, Cr and a-Si:H surface has no good condition and it can not meet schottky effect. It makes unstable device. To make a stable schottky characteristics in Cr and a-Si:H layer, we can restrict dark current by inserting shallow Cr sillicide between Cr and a-Si:H. It is very important to grow shallow thin film to tunnel optical charge by protecting the flow of optical current. In this paper, we have obtained Cr thin film and thin film below 100Åby annealing process after deposition a-Si:H with about 100Å.

Figure 6 shows the optical diode structure



(a) Cross-Section



(b) Planar View

Fig. 6 Structure of photodiode

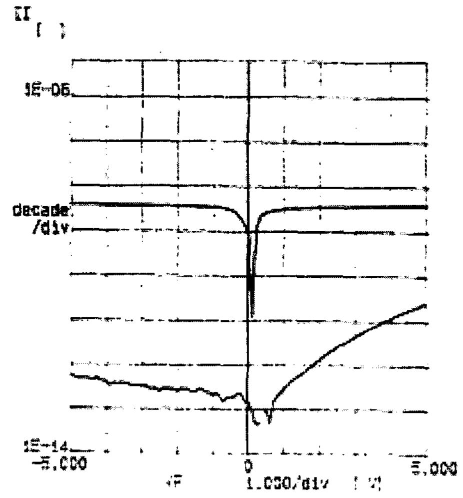


Fig. 7 Electrical Characteristics of photodiode

Fig 7 shows electrical characteristics of photodiode. The photodiode shows that I_{dark} is ~10^{-13}A , I_{photo} is ~10^{-9}A and I_{photo}/I_{dark} is ~10^4, respectively.

IV. CIS OPERATING BY TFT

A cross-sectional view of the layers used in this process for the integration of switching TFT and PD is shown in Fig. 8.

The bottom contact of the PD acts as a light shield from unwanted light through the document, which enables the sensor to be operated as an intimate contact mode to image a document placed direct under the top of the array. It is known that the spectral response of a-Si:H covers the entire visible region.

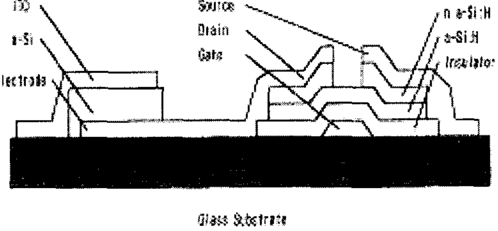


Fig. 8 Structure of CIS

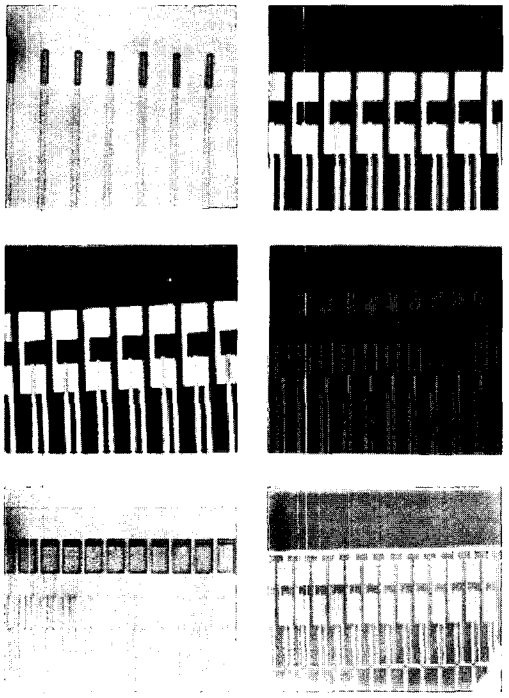


Fig. 9 Microscope picture of CIS

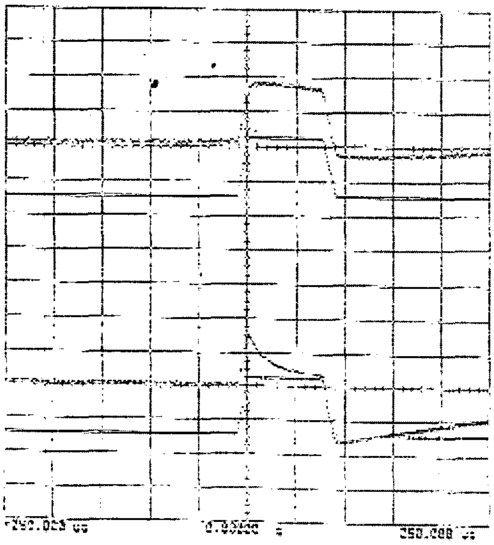


Fig. 10 Characteristic of CIS

Figure 9 shows microscope picture of CIS. Figure 10 shows electro-optic characteristic of CIS

For the analysis on the fabricated image sensor, the reverse bias of -5 volts in ITO of photodiode and 70 µsec pulse in the gate of TFT are applied. The image sensor with good property was conformed through the measured photo/dark current. The signal amplitude at 100 lx incident light is a few hundred mV, and that at dark state is scores mV.

CONCLUSIONS

In this paper, the image sensor using the a-Si:H TFT was proposed. The a-SiH TFT shows that drain current is 3.4µA at 20 gate voltage, I_{on}/I_{off} is a ratio of $10^5 \sim 10^8$ and V_{th} is 4 ~ 5 volts, respectively. The photodiode shows that I_{dark} is $\sim 10^{-13}$A , I_{photo} is $\sim 10^{-9}$A and I_{photo}/I_{dark} is $\sim 10^4$, respectively. For the analysis on the fabricated image sensor, the reverse bias of -5 voltage in ITO of photodiode and 70 µsec pulse in the gate of TFT are applied. From the results, we can estimate that the contact image sensor with good property was conformed through the measured photo/dark current. Therefore, the contact image sensor can be used in contract image sensors and barcode readers for sensing light reflected from a document or other objects and recognizing characteristics and letters.

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