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a-Si:H MIS Position Sensitive Detectors

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The first fabrication of hydrogenated amorphous silicon position sensitive detectors(PSDs) using MIS structure by anodic oxidation processes is reported. Design considerations as well as processing procedure of a-Si:H PSDs are investigated. Both one-dimensional and two-dimensional PSDs show good position linearity. The correlation coefficient of lateral photocurrent response is measured to be 0.996 for the one-dimensional PSD. The average error of position detection in the two-dimensional PSD is 10 %.

1. Introduction

Detection of light for various purposes such as image detection and spatial position detection is required in electrical, mechanical, and civil engineering fields. Position sensitive detectors(PSDs) are photodetectors using lateral photoeffect to detect the position of an incident light beam on the detectors. PSDs using crystalline materials, mainly crystalline silicon, have been practically utilized for various purposes since the first report by Wallmark.[1)] PSDs using crystalline materials are, however, limited to small-area and are relatively high-cost. Hydrogenated amorphous silicon(a-Si:H) films have already been accepted as one of the common materials for low-cost large-area devices as seen in high efficiency solar cells. Using a-Si:H for PSD material, it becomes possible to fabricate large-area low-cost PSDs, which are impossible to be fabricated using crystalline materials. Moreover, advantages which arise from the use of a-Si:H films for PSD material include flexibility of the choice of the substrate shape and semitransparent nature of the thin a-Si:H films on glass substrate, which makes it possible to realize an angle detectable PSD system using one PSD on another to detect the angle of the incident light. An angle detectable PSD system has a variety of potential application such as sensors for manufacturing robots.

This paper describes the first successful fabrication of a-Si:H PSDs. a-Si:H MIS structure is chosen as the PSD structure, since it offers high break-down voltage compared to a-Si:H pin or Schottky type structures. This high break-down voltage results in higher speed, increased noise immunity, and enhanced design flexibility. Anodic oxidation process has been employed to fabricate MIS structure PSDs as well as to enhance the fabrication yield of the detectors.

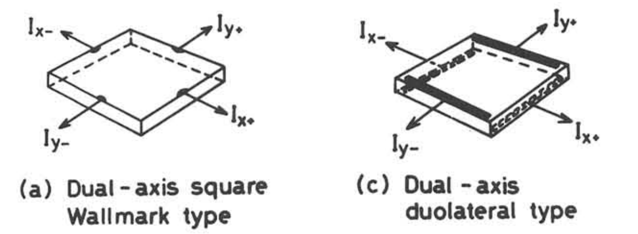
2. Design considerations for a-Si:H PSD

2.1 Conductivity

Generally the highest conductivity obtainable in n^+ or p^+ layers of a-Si:H formed by plasma CVD is 10^{-3}-10^{-2} ohms^{-1} cm^{-1}. Therefore, it is impossible to utilize a-Si:H n^+ or p^+ layers as resistive layers of a-Si:H PSDs. Highly conductive a-Si:H films such as micro-crystallized a-Si:H n^+ or p^+ layers, whose conductivity is 10^0-10^1 ohms^{-1} cm^{-1} [2)], may be able to be used as resistive layers of a-Si:H PSDs. In this work, evaporated metal films, which are superior in uniformity to a-Si:H n^+ or p^+ films formed by plasma CVD, are used as resistive layers.

2.2 Light detection mechanism

The diffusion length of the carriers in a-Si:H is extremely short compared to that of c-Si. Thus generated photocurrent is mainly composed of drift currents which are generated in the depletion



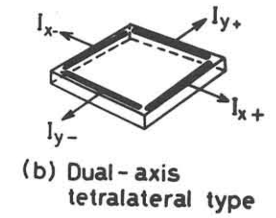


Figure 1.
Three types of
two-dimensional
PSD configurations

region of i-layer. Furthermore, conductivity of undoped a-Si:H films(i-layer) is very small and if one makes i-layer too thick, undepleted region may exist in the layer, which results in higher series resistance and thus lower response speed of the devices. Therefore, an a-Si:H PSD structure in which i-layer can be cmpletely depleted by a reverse bias voltage well below break-down voltage of the device is required. Since MIS structure offers high break-down voltage, this structure is employed in this work.

2.3 PSD structure

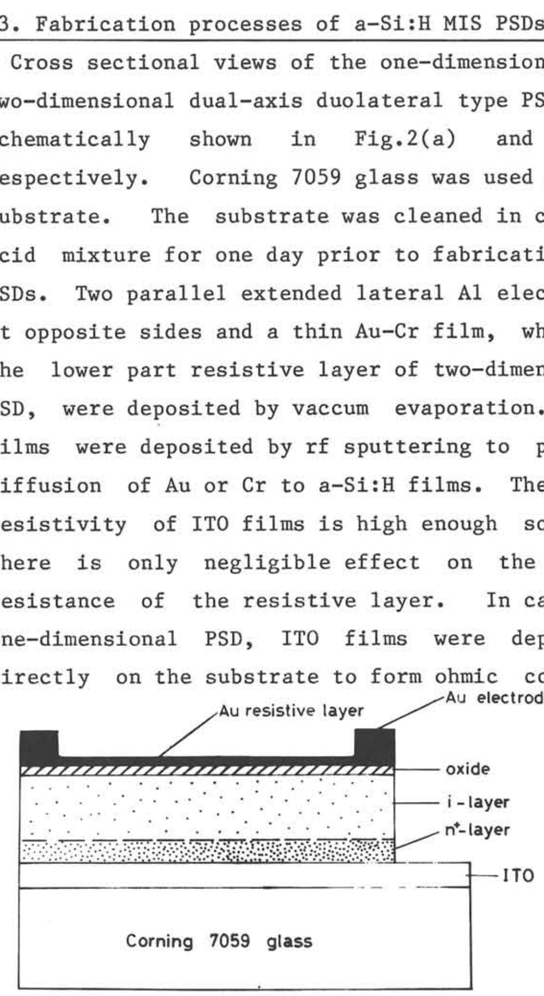
Two-dimensional PSDs are classified into three types; (a) Wallmark type, (b) tetralateral type, and (c) duolateral type(See Fig.1). Theoretical analyses of the lateral photocurrent response of these PSDs were reported by several authors,[3),4)] which were done for PSDs using crystalline materials. Using previously reported analyses with several modifications, the lateral photocurrent response is analyzed to determine the best structure for a-Si:H MIS PSDs. The calculation is done on the assumptions that the PSD is reverse-biased and i-layer is fully depleted. From the calculated output currents, which are I_{y-} (at y=0), I_{y+} (at y=b), I_{x-} (at x=0), and I_{x+} (at x=a), the position information is calcuated by next equations.

$$P_1=(I_{y+} - I_{y-})/(I_{y+} + I_{y-}) \quad (1)$$
$$P_2=(I_{x+} - I_{x-})/(I_{x+} + I_{x-}) \quad (2)$$

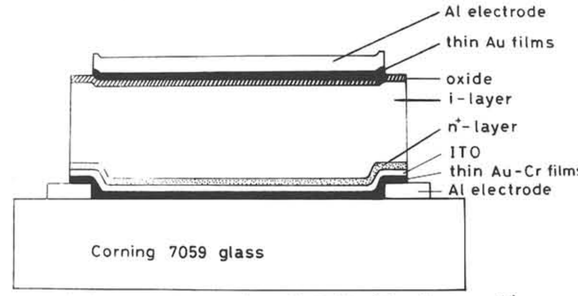
It is found that in case of duolateral PSDs P_1 and P_2 defined by the above equations indicate the exact position of the incident light beam all over the detector, which is not the case for tetralateral type PSDs. For simple fabrication processes of PSDs, tetralateral type PSDs are more suited. However judging from the above analyses, the obtained position information of tetralateral type PSDs are inferior to those of duolateral type PSDs in terms of accurate position detection. Therefore duolateral structure is used to fabricate a-Si:H MIS PSDs in this work.

3. Fabrication processes of a-Si:H MIS PSDs

Cross sectional views of the one-dimensional and two-dimensional dual-axis duolateral type PSDs are schematically shown in Fig.2(a) and (b), respectively. Corning 7059 glass was used as the substrate. The substrate was cleaned in chromic acid mixture for one day prior to fabrication of PSDs. Two parallel extended lateral Al electrodes at opposite sides and a thin Au-Cr film, which is the lower part resistive layer of two-dimensional PSD, were deposited by vaccum evaporation. ITO films were deposited by rf sputtering to prevent diffusion of Au or Cr to a-Si:H films. The sheet resistivity of ITO films is high enough so that there is only negligible effect on the sheet resistance of the resistive layer. In case of one-dimensional PSD, ITO films were deposited directly on the substrate to form ohmic contacts



(a) one-dimensional PSD



(b) two-dimensional PSD (duolateral)

Figure 2. Cross sectional views of fabricated PSDs

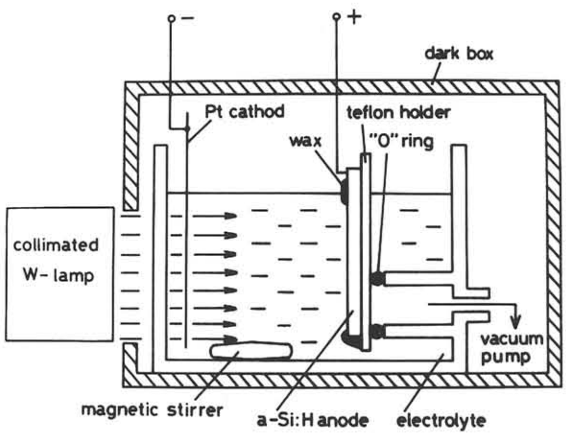


Figure 3. Anodic oxidation set up

to the a-Si:H n^+-layer grown on top of them.

Except these processing steps, the same fabrication processing procedure is employed for one- and two-dimensional PSDs. a-Si:H films were formed by rf glow-discharge decomposition of SiH_4 diluted by H_2(11.6%). The doping in n^+-layer was done by introducing phosphine in the chamber with PH_3/SiH_4=2.4%. The flow rate of silane gas was 50 SCCM and the gas pressure in the chamber was in the range of 3-5 Torr during the deposition. The substrate temperature was kept at 270 C and the rf power(13.56 MHz) was 20-25 W. The resulting deposition rate of a-Si:H films was 2-3 A/sec. The thickness of i-layer was 6000 A and that of n^+-layer was 400 A for both one- and two-dimensional PSDs. The anodic oxidation set up is schematically shown in Fig.3. The PSD to be anodized was fixed on a teflon holder with high-quality wax. The electrolyte is an ethylene glycol solution of 0.04 mol/l KNO_3. Two step anodic oxidation in the electrolyte was done prior to Au deposition. The first oxidation was done in dark to passivate material defects, which utilizes the current crowding enhanced oxidation of the defects.[5] This oxidation was done in constant voltage mode to give enough passivating effects. The second oxidation was done under illumination(W-lamp:70000 lx) to grow thin oxide layer of about 60 A to form MIS structure. This oxidation was also done in constant voltage mode and the formation voltage was chosen to be 1.0-1.5 V. Lastly thin Au films and two parallel extended lateral Au or Al electorodes at opposite sides were deposited by vaccum evaporation. The thin Au films function not only as barrier metal but also as resistive layers.

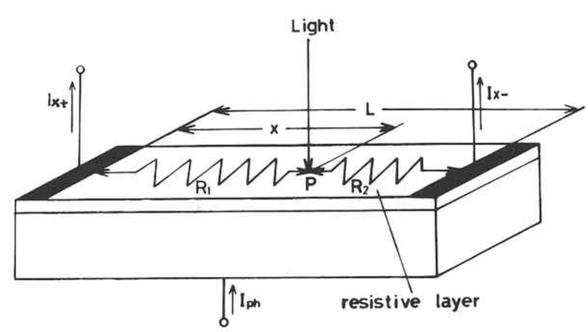
4.Results and discussion

4.1 Anodic oxidation

The anodic oxidation process in dark greatly enhanced the fabrication yield of PSDs from 0-10 % tó 80-90 %. It is found that this process is very useful for fabrication of large-area a-Si:H MIS PSDs,[5] in addition to the fabrication of solar cells[6] or photodiode arrays reported by the same authors separately. The MIS structure by anodic oxidation offers high break-down voltage, as high as over 10 V (best data:15 V) in the present a-Si:H MIS PSDs.

4.2 Characteristics of a-Si:H MIS PSDs

Figure 4 schematically shows the principle of the position detection of an incident light beam on a one-dimensional PSD. Current I_{x-} and I_{x+} were used to calculate the light position. For two-dimensional PSDs, additional current I_{y-} and I_{y+} were also used. The incident light beam position was calculated by eqn.(1) and (2). This way, the light position is stably detected because the fluctuation of the light beam intensity and/or back ground illumination intensity have no effect on the detected position. A GaAlAs LED(1.7 mW/cm^2) was used as incident light source. Figure 5 shows lateral photocurrent response of the fabricated 3mmx26mm one-dimensional PSD, which shows excellent linearity with the correlation coefficient of 0.996. Figure 6 shows the measured position of an incident light in case of the 1cmx1cm duolateral two-dimensional PSD. The



$$I_{x+} = I_{ph} \cdot \frac{L-x}{L} \qquad I_{x-} = I_{ph} \cdot \frac{x}{L} \qquad \Rightarrow P = \frac{I_{x+} - I_{x-}}{I_{x+} + I_{x-}} = \frac{L-2x}{L}$$

Figure 4. Schematic diagram of the principle of detection of an incident light position in one-dimensional PSD

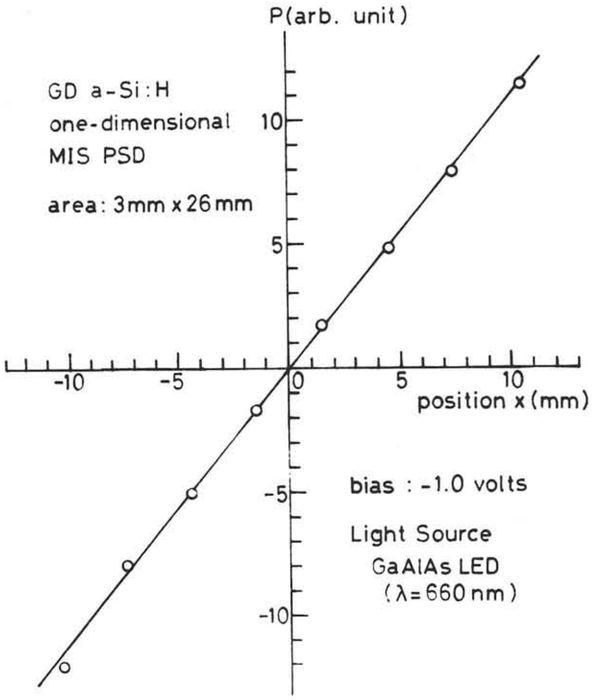


Figure 5. Typical lateral photocurrent response of one-dimensional PSD

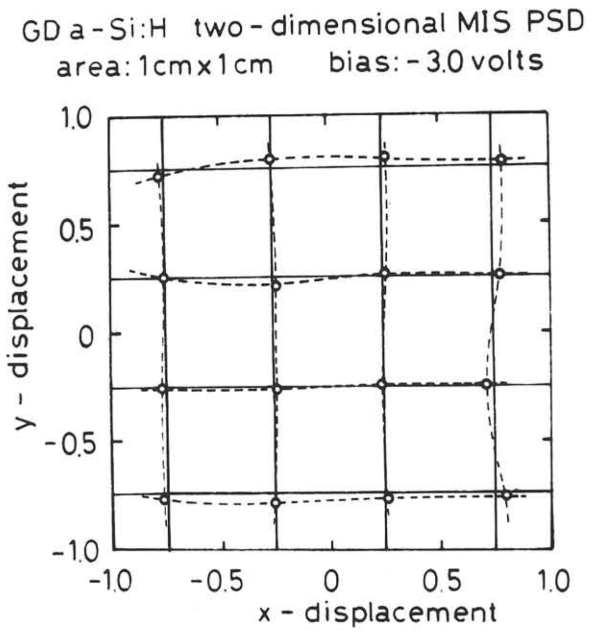


Figure 6. Experimental P_1-P_2 plots, calculated from eqs.(1) and (2), of two-dimensional PSD

maximum error between the actual light beam position and the obtained position information is about 20 %. The average error is within 10%. The error between actual light beam position and calculated position is expected to become smaller by improvement of measurement accuracy and formation of more uniform resistive layers. Furthermore, these fabricated a-Si:H MIS PSDs have semitransparent nature. These results show the possibility of fabrication of an angle detectable PSD system using semitransparent nature large-area two-dimensional PSDs.

5. Conclusions

a-Si:H PSDs have been fabricated for the first time using MIS structure by anodic oxidation processes. The fabricated one- and two-dimensional PSDs showed good position linearity and semitransparent nature. The correlation coefficient in one-dimensional PSDs was 0.996, whereas average error of position detection was 10% in two-dimensional PSDs.

References

1) J.T.Wallmark : Proc. IRE 45(1957)474

2) A.Matsuda, M.Matsumura, S.Yamasaki, H.Yamamoto, T.Imura, H.Okushi, S.Iizima and K.Tanaka : Jpn. J. Appl. Phys. 20(1981)L183

3) H.J.Waltring : IEEE Trans. ED-22(1975)581

4) D.J.W.Noolag and S.Middelhoek : Solid-State Electron Devices 3(1979)75

5) H.Yamamoto, M.Moniwa and H.Hasegawa : Jpn. J. Appl. Phys.21(1982)Suppl.21-2,53

6) M.Moniwa, S.Arimoto and H.Hasegawa : Jpn. J. Appl. Phys. 21(1982)Suppl.21-2,57