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A New Silicon Vidicon Target Using an Amorphous-Crystalline Silicon Heterojunction

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We performed the experiments on a p type a-Si:H/n type c-Si heterojunction for the application to an Si vidicon target without a diode-array. Opto-electrical properties were measured on I-V and C-V characteristics in the a-Si:H/c-Si heterojunctions. It was found that the plasma damage during the deposition of a-Si:H caused defect states at the interface between c-Si and a-Si:H, and that using a mesh to protect a c-Si wafer from the plasma bombardment was useful to reduce the defect states and the dark current. A new Si target without a diode-array was demonstrated with low dark current, high sensitivity, few defects and high resolution.

1. Introduction

The typical crystalline silicon (c-Si) target consisting of planer diode array is widely used in vidicon camera tubes for near-infrared imaging and in silicon image intensifier target (SIT) tubes for the low light level use. The c-Si target has some shortcomings such as blooming caused by the diffusion of excess carriers and low resolution limited by the diode-array pitch. Therefore, to obtain a structure free from a diode-array, c-Si/CdTe[1,2] and c-Si/Sb_2S_3[3] heterojunctions were studied on early occasion. However, good heterojunctions were not obtained because of many defects at the interface of the junction. Recently, hydrogenated amorphous silicon (a-Si:H) has been intensively studied as an amorphous material with the controlable Fermi level. We found in a-Si:H/c-Si heterojunctions that controlling the Fermi level in a-Si:H dominated opto-electric performance of the heterojunction such as the injection of photocarriers from n c-Si into p a-Si:H and the I-V characteristics in dark.[4] The generation mechanism of the dark current has not been solved yet, though the low dark current in reverse bias is important for application to imaging devices.

In this paper, we show how the dark current and the photocurrent are influenced by the condition of the junction interface. We also describe the performance of a new Si target without a diode-array which has some advantages such as high resolution, high sensitivity, no blooming and no burning.

2. Experimental

The cross-sectional configurations of the samples are shown in Fig.1. n type, (111) oriented c-Si wafers (2-10Ωcm) were used in this study and were 200μm thick except for sample 5. Sample 5, whose c-Si wafer was etched to 5-15 μm thick, was used as a vidicon-type target. a-Si:H films were deposited on c-Si wafers by means of glow discharge decomposition of SiH_4 (20%, diluted with H_2)- B_2H_6 (200ppm, diluted with H_2) gas

No.	CRYSTALLINE SILICON	AMORPHOUS SILICON	BLOCKING LAYER	ELECT-RODE
1	n-c-Si RESISTIVITY =2~10Ωcm	i-a-Si (6000Å) $B_2H_6/SiH_4=7.2\times10^{-5}$	—	Au
2		p-a-Si (6000Å) $B_2H_6/SiH_4=3.6\times10^{-4}$		
3		i-a-Si (6000Å) $B_2H_6/SiH_4=2.5\times10^{-5}$		
4		i-a-Si (9000Å) $B_2H_6/SiH_4=2.5\times10^{-5}$	Sb_2S_3 (500Å)	
5				

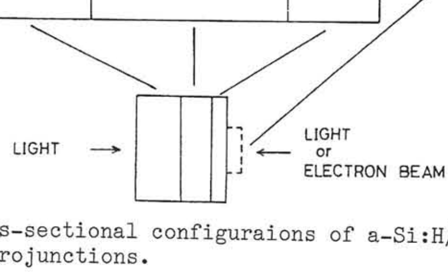


Fig.1 Cross-sectional configuraions of a-Si:H/c-Si heterojunctions.

mixtures. In samples 1 and 2, a-Si:H films were deposited without a mesh to protect the c-Si wafer from the plasma bombardment, and the deposition conditions were a substrate temperature of 250 °C and a pressure of 0.08 Torr. In samples 3-5, when a-Si:H was deposited, the substrate holder and the c-Si wafer were covered with the mesh, whose potential is equal to that of the substrate holder. The deposition conditions of a-Si:H were a substrate temperature of 250°C and a pressure of 0.2 Torr. The gas ratio of B_2H_6 to SiH_4 in boron doping was 7.2×10^{-5} (sample 1), 3.6×10^{-4} (sample 2), and 2.5×10^{-5} (samples 3-5). A Sb_2S_3 layer deposited in high vacuum serves to block electron from the electrode or the electron beam.

For samples 1-4, C-V and I-V measurements were performed, and for sample 5, the experiment on the application to a new Si vidicon target was carried out in a 1-inch vidicon camera tube.

3. Results and Discussion

3-1 C-V characteristics

Fig. 2 shows C-V characteristics for samples 1-3 measured at 100 kHz. The n c-Si was positively biased to Au electrode. Circle, triangle and diamond signs represent sample 1, 2 and 3, respectively. Solid and broken lines refer to the measured capacitance and the depletion layer capacitance of the c-Si deduced by the calculation[4], respectively. In samples 1 and 2 prepared without the mesh, sample 1 with a light doped a-Si:H film showed little variation of the capacitance on the applied voltage, while sample 2 with a hevier doped a-Si:H film showed considerable variation of the capacitance. Sample 3, which was prepared with the mesh, gave large variation of the capacitance in spite of a one third boron content of sample 1. A critical level of boron doped to spread the depletion layer into c-Si side was 10^{-6} for the sample prepared with the mesh and 10^{-4} without the mesh. These indicate the following results: In samples 1, the depletion layer did not spread on c-Si side because of the defect states at the interface between c-Si and a-Si:H, and the bias voltage was applied a-Si:H layer only. In sample 2, as the defect states at the interface were compensated by the doped boron, the depletion layer spread on the c-Si side. The applied voltage was mainly spent to spread the depletion layer into c-Si side. In sample 3, the depletion layer spread on the both sides of a-Si:H and c-Si even at a low boron content, because the defect states at the interface was reduced by protecting a c-Si substrate from the plasma damage.

3-2 I-V characteristics

Fig. 3 shows I-V characteristics of samples 1-3. (a), (b) and (c) represent sample 1, 2 and 3, respectively. The n c-Si was positively biased to Au electrode. Solid circles were measured in the dark, open circles were under 1000 lx illumination from a standard incandescent lamp, and open triangles, under infrared light illumination obtained by filtering the 1000 lx illumination with an IRD-1 filter. Solid and broken lines were measured under the light illumination projected on the a-Si side and the c-Si side, respectively. For sample 1, the photocurrent was much lower than those of samples 2 and 3, and the dark current showed no saturation. Both photocurrent and dark current in sample 2 showed saturation characteristics, and especilly the dark current showed the distinctive feature such as steep increase followed by the saturation. In sample 3, the higher photocurrent and the lower dark current were obtained in comparing with those of sample 2. The dark current did not show distinct saturation. From these results, it is considered as follows: In sample 1, the depletion layer spread on a-Si:H side only. Since the most part of the bias voltage is applied on the a-Si:H layer, the dark

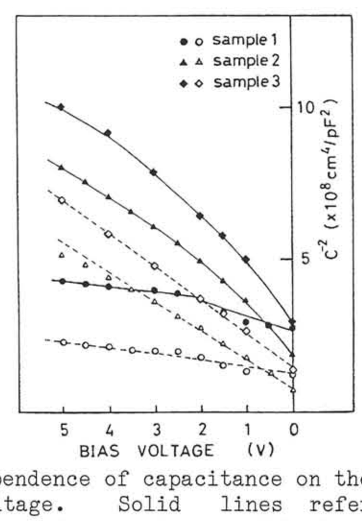


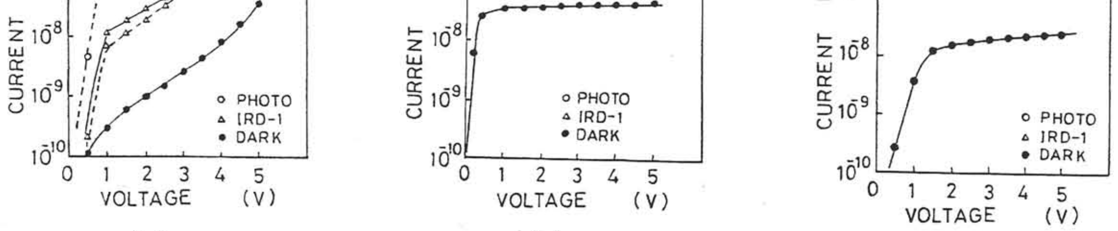
Fig.2 Dependence of capacitance on the applied voltage. Solid lines refer to the measured capacitance and broken lines, to the depletion layer capacitance of c-Si.

current is mainly generated in a-Si:H. In sample 2, the steep increase of dark current just before saturation was correspond to deplete the interface between c-Si and a-Si:H.[5] As increased still more, the applied voltage was spend to deplete the c-Si. Therefore, the dark current is mainly generated by the defect states at the interface, because the defect states in the bulk of c-Si is much lower than those of the interface and a-Si:H. In sample 3, after depleting the junction interface, the applied voltage was spent to spread the depletion layer into both side of a-Si:H and c-Si. Therefore, the dark current is ascribed to both currents generated at the interface and in a-Si:H. The lower dark current in sample 3 indicates that the defect state density at the interface and in the a-Si:H layer is lower, because the c-Si wafer was protected from the plasma bombardment. In more high voltage region of sample 3, the dark current increased exponentially. This is considered due to the defects in the a-Si:H and a-Si:H/Au shottkey blocking. In the photocurrent, the depletion layer at the side of c-Si assists to inject photocarriers from c-Si into a-Si:H layer, seeing that sample 1 has no injection of photocarriers and no variation of capacitance with the applied voltage but that samples 2 and 3 have the high sensitivity and the variation of capacitance. In sample 3, as the depletion layers spread on both sides of c-Si and a-Si:H, the photocarrier is considered to flow most succesfully from c-Si to a-Si:H.

3-4 Silicon-target for camera tubes

Fig.4 shows I-V characteristics of sample 4 with the electron-blocking layer of Sb_2S_3. The n c-Si was positively biased to Au electrode and the light was projected on the c-Si side. Solid circles were measured in the dark, open circles were under 100 lx illumination and open triangles, under infrared light illumination. The I-V characteristics of the sample 6 , which was prepared without the mesh in the previous experiments, are shown by broken line for comparision. In sample 4, for example, dark current, photocurrent and IR photocurrent were 8.7 nA/cm^2, 26 $\mu A/cm^2$ and 14$\mu A/cm^2$, respectively, at the applied voltage of 10 V. The dark current in sample 4 is improved to be about one-tenth as large as that in sample 6. The the photocurrent and IR photocurrent in sample 4 is also improved to be larger because of the reduction of the defect states at the interface.

Figure 5 shows I-V characteristics of the camera tube with this new Si target of sample 5. The scanned area was 9.6 x 12.8 mm^2 for 1-inch tube. Photocurrent was measured under 0.25 lx and 0.53 lx illuminated on the face plate from a standard incandescent lamp. As shown in Fig.5, the photocurrent saturated at a voltage of 6 V and blocking characteristic was observed. The dark current and the photocurrent were 10 nA and 430 nA/lx, respectively, at the target voltage of 6 V,



(a) (b) (c)

Fig.3 I-V characteristics: (a) sample 1 (b) sample 2 (c) sample 3. Solid lines were measured under the light illumination projected on the a-Si:H side and broken lines, on the c-Si side.

indicating almost the same characteristics of a conventional Si vidicon. Figure 6 shows the reproduced image of RETMA chart magnified on the monitor by reducing the scanned area. The horizontal resolution of more than 800 TV lines was obtained without blooming and burning. This wonderful characteristics is due to the improvement of interface properties of the a-Si:H and c-Si heterojunction.

4. Conclusion

In the p type a-Si:H/n type c-Si heterojunctions, we found that the defect states at the junction prevented the depletion layer from spreading into the c-Si side and generated the dark current. We also found that using the mesh to protect the c-Si from the plasma damage during the glow discharge deposition was useful to reduce the defect states density and the dark current. The new Si target using the p a-Si:H/n c-Si heterojunction was prepared with the mesh. The characteristics were as follows: the dark current and the sensitivity were 10 nA and 430 nA/lx, respectively, at the target voltage of 6 V and the resolution was more than 800 TV lines. The picture obtained was with few defects, no blooming and no buring. These characteristics are the best in the Si target without a diode-array studied to date.

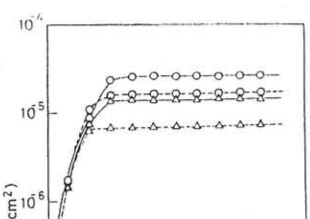


Fig.4 I-V characteristics of sample 4.
Broken lines refer to sample 6 prepared without the mesh in the previous experiment.

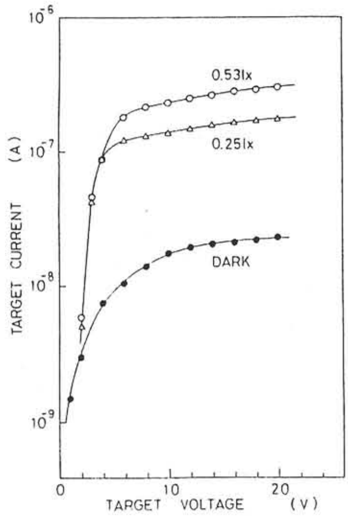


Fig.5 Dark current and photocurrent vs. target voltage characteristics of a new Si vidicon tube.

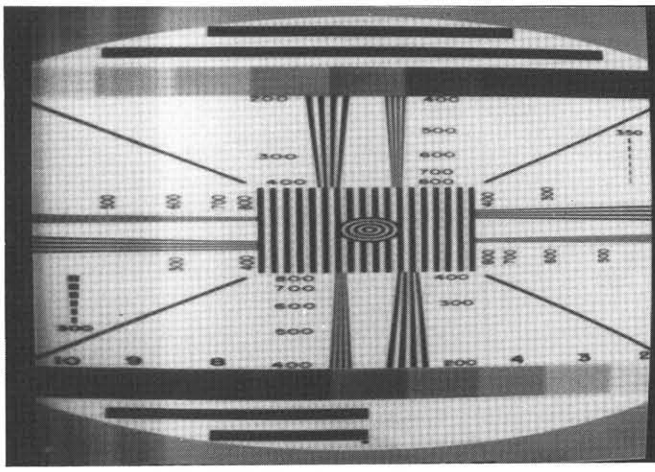


Fig.6 Reproduced monitor image of RETMA chart.

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