Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 689-692 **D-9-3**

Reduction of Transient Photocurrent and Dark Current for a-Si:H Photodiodes

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Reducing the transient photocurrent and dark current for reverse biased a-Si:H photodiodes is essential for the development of highly efficient imaging devices using a-Si:H film as the photoconductive layer. The authors have adopted a structure comprising Pt Schottky diodes to remove the influence of hetero-junctions. The current-voltage characteristics were closely related to the space-charge density in the depletion region. The transient photocurrent was described as a function of the hydrogen configuration in the film. The transient photocurrent and the dark current were significantly reduced, and the improvement is sufficient to realize a practical high-efficiency imaging device.

1. INTRODUCTION

Hydrogenated amorphous silicon (a-Si:H) films are unique, for their high sensitivity to visible light and because they can be deposited at low temperature. Such films have been widely used in imaging devices as photoconductive layers, TFTs on glass substrates forming active layers, and so forth.

Reducing the transient photocurrent and dark current for reverse-biased a-Si:H photodiodes overlaid as photoconductive layers is a very important concern in the manufacture of highly efficient imaging devices[1]. Although it has already been reported that electron drift mobility μ_d and the gap states in a-Si:H films have an influence on transient photocurrent characteristics[2], the relationship between the characteristics of a-Si:H films and a-Si:H photodiode characteristics have not been directly understood. In a-Si:H films, the ratio of $Si\text{-}H_2$ bond content to hydrogen content ($C_{Si\text{-}H2}/C_H$) and the hydrogen content (C_H) are very significant properties. The relationship between $C_{Si\text{-}H2}/C_H$ and other characteristics of a-Si:H films have been reported[3]. However, a-Si:H photodiodes generally have hetero-junctions composed of a-Si:H and a-SiC:H and it has been difficult to clarify the relationship between $C_{Si\text{-}H2}/C_H$ and the above-mentioned a-Si:H photodiode characteristics, since the characteristics of the hetero-junctions have to be considered.

The authors have adopted a Pt Schottky structure to avoid the ambiguity arising from the existence of hetero-junctions and have clarified this relationship. As a result of this study, the transient photocurrent and the dark current were significantly reduced, and the values are small enough to realize a practical highly efficient imaging device.

2. EXPERIMENTAL

The a-Si:H films were prepared using mercury-sensitized photochemical vapor decomposition of silane gas, with a low-pressure Hg lamp as a UV source. The schema for the Hg-sensitized photochemical vapor deposition(photo-CVD) reaction system is shown in Fig. 1. The deposition conditions are summarized in Table 1. The distance L between the substrate and the light-transparent window was varied, while other conditions were held constant. When the distance decreases from 30 mm to 8 mm, the 254 nm-light intensity on the substrate surface increases from 4.7 $mW \cdot cm^{-2}$ to 5.3 $mW \cdot cm^{-2}$.

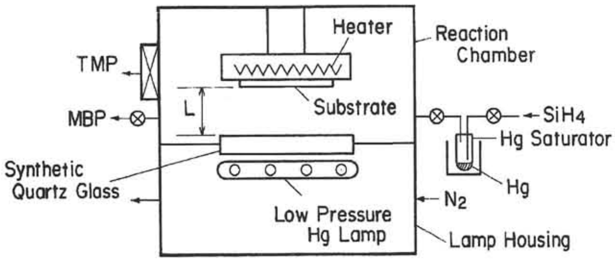

Fig. 1 Schema for Hg-sensitized photo-CVD system.

Table 1 Deposition condition.

Distance (L)	8 - 30 mm
Substrate temperature	230 °C
Gas pressure	0.2 Torr
Silane flow rate	20 sccm
Hg vapor saturator temp.	80 °C

The Schottky barrier diodes were formed as following processes. Films of a:Si:H about 2 μm thick were deposited on heavily doped n-type crystalline silicon wafers whose resistivity was less than 3 mΩ. Al had previously been sputtered and sintered on the reverse side of the silicon wafers as an ohmic contact metal. Then semi-transparent Pt dots 30 Å thick were sputtered onto the a-Si:H films. Before sputtering the Pt dots, the surface of the a-Si:H film was lightly dipped in dilute HF solution to remove the thin native oxide layer.

The characteristics of a-Si:H films and diodes, and the methods used to measure them, are as follows. The hydrogen configuration in a-Si:H films, C_H and C_{Si-H2}/C_H were obtained by infrared absorption spectrometry. Impurity concentrations in the films were evaluated using secondary ion mass spectroscopy(SIMS). The a-Si:H films for these evaluations were simultaneously deposited with the a-Si:H films for the Pt Schottky diodes.

The following characteristics were measured using the Pt Schottky diodes. In the quasi-static C-V method for evaluating Ni, the ramp rate, dV/dt, was $0.005 V \cdot s^{-1}$ and the diode leakage current was subtracted. Transient photocurrent characteristics (I(t)/I(0)) were normalized by the steady-state photocurrent(I(0)). I(0) was kept constant for two seconds at $2.6 \times 10^{-7} A \cdot cm^{-2}$ under 660 nm illumination. I(t) represents the transient photocurrent at time t after the illumination ceases. Typical measurements are described in Fig. 2.

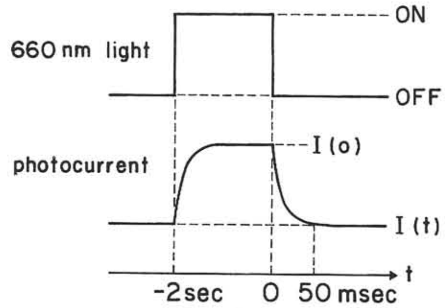

Fig. 2 Schema of measuring I (t)/I(0).

3. RESULTS AND DISCUSSIONS

In Fig. 4, the deposition rate of a-Si:H films and their impurity concentrations are shown as a function of distance, L. The concentration of impurities such as O, N, and C decreased with L from 30 mm to 8 mm. At the same time, the deposition rate of a-Si:H films rose. The higher deposition rate was a result of the increase in UV intensity accompanying the change in distance L. The impurity concentrations in the films appear to correlate with the deposition rate.

Figure 4 shows the relationship between space charge density(Ni) in the depletion region and distance L. The value of Ni decreased from $5.42 \times 10^{14} cm^{-3}$ to $2.84 \times 10^{14} cm^{-3}$ with decreasing L. Impurity concentration and Ni are very closely related through the results described in Figs. 3 and 4. When these impurity concentrations decreased in this study, the value of Ni dropped. A high deposition rate of a-Si:H may cause low impurity concentrations, and Ni depends on these impurity levels.

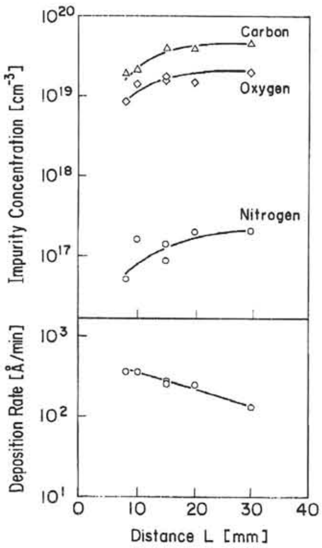

Fig. 3 Deposition rate of a-Si:H and impurity concentrations as a function of distance L.

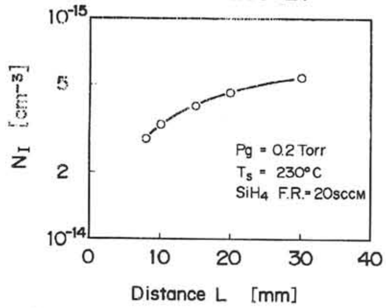

Fig. 4 Space charge density as a function of distance L.

The current-voltage(I-V) characteristics for a forward-biased Schottky diode can be written in the form

$$J=J_0[\exp(qV/nkT)-1]$$

where J_0 is the saturation current density, V is the applied voltage, and n is the diode quality factor. The diode quality factor n and the current density under reverse bias at 1 V (I_R) are shown in Fig. 5 as a function of Ni. The n-value decreased and approached unity with decreasing Ni, while at the same time I_R decreased.

To explain this dependence on Ni, the current transport mechanism needs to considered. If current transport is governed by thermionic-emission or by diffusion, n will approach unity. Carrier recombination in the depletion region, however, results in n deviating from unity. In the reverse current region, the generation-recombination current forms one of the transport mechanisms.

Free electrons and holes in the depletion region can recombine through recombination centers, and space charges in the depletion region can form recombination centers for carriers. Hence the magnitude of generation-recombination current corresponds to Ni, and the I_R and n-values drop with decreasing Ni as shown in Fig. 5.

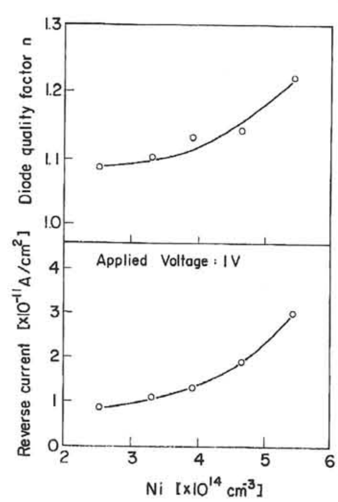

Fig. 5 Reverse current and diode quality factor n as a function of Ni.

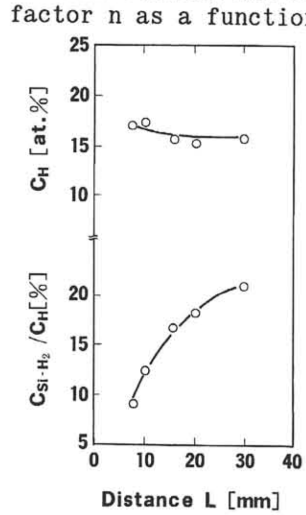

Fig. 6 Hydrogen content and ratio of $Si\text{-}H_2$ bond content to hydrogen content as a function of distance L.

Figure 6 shows the relationship between C_{Si-H2}/C_H, C_H, and distance L. C_{Si-H2}/C_H decreased from 20% to 8%, as the distance L decreased from 30 mm to 8 mm. On the other hand C_H remained constant at 15 at.% throughout the experiments. Decreasing L is equivalent to increasing the 254 nm intensity of the low-pressure Hg lamp. We have already discussed the great influence of light intensity on C_{Si-H2}/C_H[4].

As for photodiodes with a hetero-junction comprising p-type a-SiC:H and undoped a-Si:H, it has been reported that I(t)/I(0) can described as a function of electron drift mobility, μ_d[2]. Otherwise, reducing C_{Si-H2}/C_H would lead to fewer band tail-states and higher μ_d[3]. Thus it has been predicted that I(t)/I(0) is a function of C_{Si-H2}/C_H. That is, I(t)/I(0) decreases with decreasing C_{Si-H2}/C_H. However μ_d and I(t)/I(0) were evaluated with hetero-junction photodiodes, and C_{Si-H2}/C_H was evaluated with a-Si:H mono-layers. The ambiguity arising from the existence of hetero-junctions still remains, considering the above relationship.

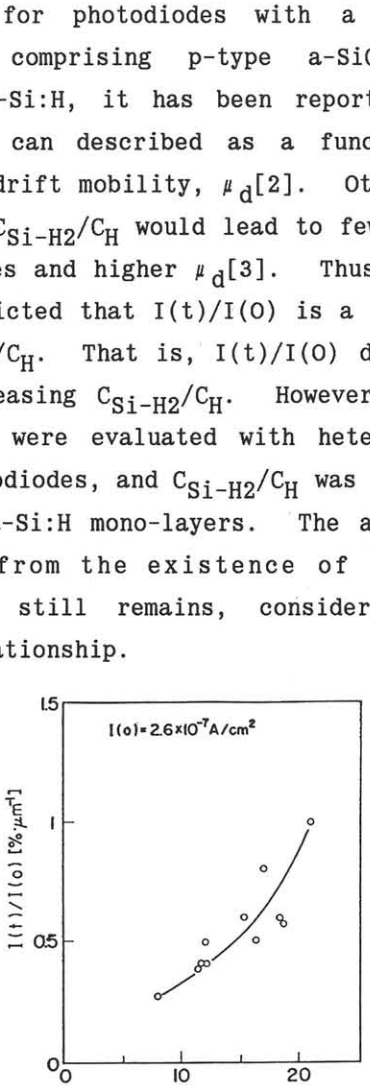

Fig. 7 I(t)/I(0) as a function of C_{Si-H2}/C_H.

Good correlation is observed between I(t)/I(0) for Pt Schottky diodes and C_{Si-H2}/C_H in Fig. 7. This relationship was the same that was predicted for p-type a-Si:H/undoped a-Si:H photodiodes. Hence C_{Si-H2}/C_H are essential in order to determine the transient photocurrent characteristics. The relationship shown in Fig. 7 does not involve any ambiguity because Schottky diodes have no hetero-junctions, and the a-Si:H films for the Schottky diodes and for evaluating the infrared absorption were deposited together.

4. CONCLUSION

The use of Pt Schottky diodes in this evaluation enabled the relationship between the characteristics of a-Si:H films and a-Si:H diodes to be clarified without considering the properties of hetero-junctions.

The transient photocurrent(I/(t)/I(0)) of a-Si:H Schottky diodes was reduced by lowering the ratio of $Si-H_2$ bonds to hydrogen (C_{Si-H2}/C_H) in a-Si:H films prepared by mercury-sensitized photochemical vapor deposition. Also, the dark reverse current was reduced and the diode quality factor, n, approached unity as a result of the reduced space-charge density(Ni) in the depletion region. This was because the lower Ni resulted in a reduced generation-recombination current component. The reduction of Ni was achieved by the lower impurity concentration that accompanies increased deposition rate of a-Si:H films.

ACKNOWLEDGEMENT

The authors would like to thank Mr. S. Sano for his helpful discussions and encouragement.

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