

STUDY OF ARTIFICIAL INTERFACES IN UNDOPED AND PHOSPHORUS DOPED a-Si:H

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Effect of artificial interfaces, produced by interrupting the glow discharge deposition of a-Si:H films, on the electrical characteristics of doped and undoped hydrogenated amorphous silicon(a-Si:H) has been studied. No differences in H content, electrical characteristics, and defect density between solid films and multilayers having interfaces have been observed contrary to reports by others. Possible connection of the plasma reactor with the absence of plasma transients is discussed.

1. INTRODUCTION

It has been reported repeatedly¹⁻⁴ that the first 50-100 Å thick region of hydrogenated amorphous silicon(a-Si:H) grown during the initial transient state (ITS) of the plasma is different from the bulk in many aspects, one of which is that this interface layer contains more hydrogen. It has also been found that there are in a-Si:H two different regions with different hydrogen content, a clustered phase and a homogeneous dilute phase⁵. In view of the fact that hydrogen plays an important role in the defect and dopant equilibration^{6,7}, it is interesting to explore whether doping plays a greater role in the clustered phase or in the homogeneous phase and whether the H in the clustered phase mediates equilibration more efficiently. For this purpose, we prepared undoped and P-doped a-Si:H in two different ways: (1) continuous growth to make solid films; (2) after every 45 sec of film growth the plasma was extinguished for 30 ± 10 sec to make plasma-interrupted multilayers. These multilayers were intentionally made to consist largely of material made in the ITS of the plasma. The H-rich interfaces which were reported^{1,2} to exist in plasma-interrupted multilayers would be expected to influence the electrical characteristics if the clustered H regions indeed play an important role. In the present study, we therefore compare the defect densities and transport parameters of the solid films with those of the artificial multilayers in both the annealed and quenched states.

2. EXPERIMENTAL DETAILS

Our samples were grown by glow discharge under optimal conditions. Undoped samples were made with pure silane and phosphorus doped samples with pure SiH_4 containing either 10ppm or 100ppm PH_3 which is diluted in He to 1%. The deposition temperature was kept at $245^\circ C$, the rf power was $0.25 W/cm^2$, the flow rate 11 sccm, and the pressure 90 mTorr. These conditions produced a deposition rate of 1 Å/sec. During deposition, a Si photodiode monitored the light intensity of the plasma. The deposition chamber contains a rotatable stainless steel shutter which can be moved to less than 1 mm above the substrates to protect the samples from the plasma when desired. Before starting a deposition, we turn on the plasma while keeping the fresh substrates covered for 10 min by the shutter, so that the chamber walls get covered with a fresh layer of the appropriately doped a-Si:H before the substrates are exposed to the plasma.

Ohmic coplanar Mg electrodes were used in the electrical measurements. Photothermal deflection spectroscopy⁸ (PDS) and the constant photocurrent method⁹ (CPM) were used to measure the defect concentration.

3. RESULTS

The hydrogen contents were determined from the $630 cm^{-1}$ infrared absorption peak and using the relation with H content of Shanks et al¹⁰ as well as from H

effusion¹¹. Surprisingly, we do not find a noticeable difference in H content of the solid film and multilayers having the same doping concentration. The H content from IR measurement is 7.8 ± 0.2 at % for solid films, and 7.8 ± 0.1 at % for multilayers, where the error is the scatter in the results of 6 samples of each type.

Fig 1 shows the temperature dependence of the conductivity for 10 ppm and 100 ppm P-doped a-Si:H in the annealed (A), quenched (Q), and slowly cooled (SC) states. In fact, we measured 6 samples for both types for each doping. For the same doping, all solid films and multilayers have the same conductivity, photoconductivity, in the A, Q, and SC states, within 50%, which is typically the scattering of identical samples made at different times. In Fig 1, the conductivity of the Q and A states merge at the same temperature T_E , for all solid films and multilayers having the same doping.

Fig 2 shows the absorption coefficient as a function of photon energy $h\nu$ measured by PDS for 100 ppm, 10 ppm, and undoped samples. We measured 6 samples of different types for each doping level and two undoped samples varying in thickness between 0.3 and $1\mu\text{m}$. The solid films and multilayers have the same subgap absorption within 50% as shown by the scatter bars at 1.2 eV. The α curves measured by CPM also fall within these scatter bars for doped a-Si:H. For undoped samples, the subgap absorption from CPM is about a factor 2 lower and its threshold energy lies at higher $h\nu$ than that of PDS, which is expected.

We also prepared shutter-interrupted multilayers for each doping level by moving the shutter over the substrates for 15 sec after every 45 sec of deposition while maintaining the plasma. The conductivity and α data of these shutter-interrupted multilayers are the same as the other two types within experimental error and were therefore omitted from the figures.

4. DISCUSSION AND CONCLUSIONS

We are surprised not to find any differences in H content while other workers observed nearly a factor 2 more H in the plasma-interrupted multilayers than in equivalent solid films. Maybe this is due to the different

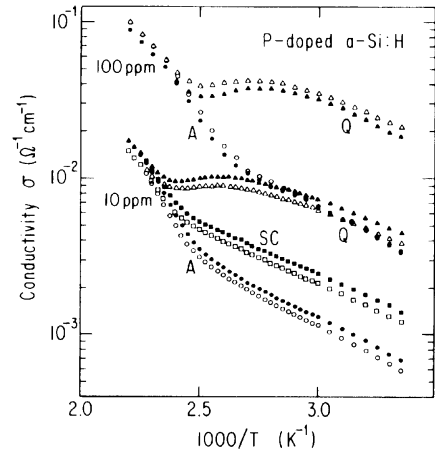


FIGURE 1

Conductivity as a function of temperature. No noticeable difference is found in conductivity between the solid films (solid symbols) and the multilayers (open symbols).

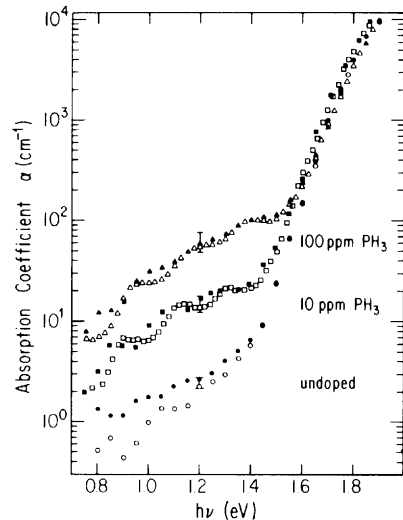


FIGURE 2

Absorption coefficient vs $h\nu$ for different doping level. No difference is found between the solid films (solid symbols) and the multilayers (open symbols).

construction of our plasma reactor. Instead of a big chamber so that the chamber walls are far away from the deposition plasma and growing surfaces, we used a relatively small cylindrical stainless steel chamber which has a diameter of 15 cm and a distance of 3 cm between the

anode and cathode plates. We usually keep the substrates protected by the shutter for 10 min after starting the plasma, so that the chamber walls get covered by a 600 Å thick layer of the material to be deposited. Therefore, the walls have little effect on the plasma, which may reduce the initial plasma transients.

The light intensity of the plasma during deposition is shown in Fig 3. We see ITS of the plasma only right after chamber cleaning or after the chamber has been exposed to air. After the chamber walls are covered with a-Si:H, we no longer see transients in the plasma light intensity, as shown under "Normal Deposition" in Fig 3. The absence of plasma transients may explain the absence of excess H in our plasma-interrupted multilayers, because there are no H-rich interfaces produced under our normal deposition condition. Lack of noticeable differences between solid film and multilayers in dark and photoconductivity of A and Q states, in T_E , in subgap absorption further proves that there is essentially no difference between these two types of samples grown under our normal deposition conditions, regardless of how we disturb the plasma.

There may still be some plasma transients, which cannot be seen by a Si diode detector. Even if that is so, these transients appear not to affect the quality of our samples.

Our original plan to study the effect of excess H produced by plasma interruption on the doping efficiency and thermal equilibration of doped a-Si:H could not be carried out, because we did not obtain excess interface H in plasma-interrupted multilayers. The important question whether doping efficiency and H equilibration differ in the clustered phase and the dilute homogeneous phase therefore remains open. However, the fact that detrimental transients can be avoided may lead to high quality homogeneous films.

In conclusion, we do not see excess H in plasma-interrupted multilayers, in contrast to other workers. Furthermore, we do not observe any difference in electrical characteristics and defect density measured by PDS and CPM between solid films and multilayers. No initial transients of the plasma are observed in our plasma reac-

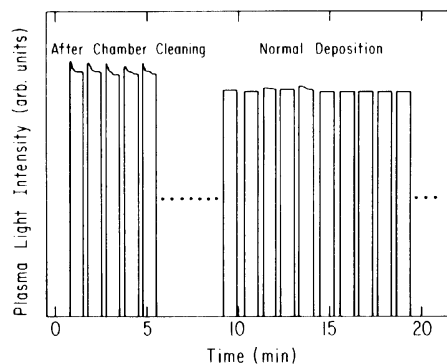


FIGURE 3

Plasma light intensity during different deposition period.

tor. One therefore can prepare good quality films without worrying about the initial disturbance to the plasma. The films are homogeneous vertically.

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