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Preparation and Characterization of Hydrogenated Amorphous Silicon Thin Films and Thin Film Solar Cells Produced By Ion Plating Techniques

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Abstract

Using quartz, sapphire and stainless steel substrates, hydrogenated a-Si films have been prepared by ion-plating techniques through a 1000-2000 volt hydrogen glow. The highest hydrogen content to date has been 18 a/o in a film evaporated in partial pressure of 55μ of hydrogen.

Optical band gaps of these films varied from 1.67 eV to 2.21 eV. Films made on sapphire substrates were used in IR-spectroscopy measurement; they had a doublet absorption peak at approximately 2000 cm^{-1} corresponding to SiH bond stretching.

A. Introduction

Ion plating is a deposition process in which evaporation of a metal or semiconductor into a plasma glow discharge about a negatively biased substrate is used to affect both the character and the surface bonding of the resulting thin film deposit. Ion plating has also been carried out by direct ion beam methods but can still be distinguished from ion implantation by the use of the low ion energies typical of glow discharges. The energy level of the evaporated metal or semiconductor is increased through their interaction with the glow discharge. It is the increased energy state of the depositing material that affects both the nature and adherence of the deposited thin films.

The term ion plating was itself introduced in 1964 by Mattox. To date, the method of ion plating has been used primarily for the coating of substrate materials, including non-conductors such as plastics, with metals. This is so because an immediately recognized advantage of this method was the drastically improved adhesion of ion plated films versus vacuum deposited films. This increase in adhesion is due to the controllable arrival energy of the incident metal vapor flux. Both the glow discharge voltage and evaporation rate can be separately controlled.

This program has as its primary goal the development of methods for the preparation of efficient, low cost amorphous thin film solar cells involving the direct use of the ion plating techniques.

A complete apparatus dedicated to ion-plating has now been constructed. Hydrogenated a-Si films have been made by ion-plating and characterization of their optical and semiconducting properties is underway. Hydrogen contents of a number of films have been measured and found to vary from 5.7a/o to 18.0a/o. Infrared spectroscopy of those films deposited on sapphire substrates have shown strong doublet absorption around 2000 cm^{-1} corresponding to the Si-H bond stretching modes. The doublet effect is similar to that observed by Brodsky.

Film thicknesses have been measured using a Bendix Proficorder profilometer accurate to better than 500Å. Using the measured film thickness and transmittance versus wavelength data from a Beckman DK-2A photo-spectrometer optical gaps were determined using the method of Freeman and Paul. Optical gaps ranged from 1.67 eV to 2.21 eV. (See Table 1).

Determination of the effects of magnetic field confinement of the hydrogen glow on the a-Si properties are underway. No results are yet available, the magnetic field, however, can be seen to visibly concentrate the glow below the substrate holder (see Fig. 1).

B. Experimental Program

Figure 1 shows schematically the ion-plating apparatus with the glow concentrating magnet in place. The substrate temperature is controlled by 2 heaters inserted radially into the stainless steel base plate. Temperature measurements are made using a copper-constantan thermocouple which contacts the rear of the substrate throught a hole in the base plate. The silicon charge is evaporated using an RF heating coil. Using a Mettler balance in a dry box substrates are weighed before and after deposition.

At the present time low deposition rates on the order of 10-20 Å/sec are being employed. There should be no difficulty in increasing this significantly when optimization of deposition rate is required. Standard ion plating techniques can deposit as much as 4,000 Å/sec.

C. Results

Below is a summary of the results obtained to date on the preparation and characterization of hydrogenated a-Si produced by ion plating. Table 1 lists the optical band gap, thickness, hydrogen content and deposition rate for a number of ion-plated a-Si films. IR-spectroscopy shows distinctly the doublet absorption peak at approximately 2000 cm^{-1} indicative of Si-H bonding.

At the present time substrate temperatures in the range from 150°C to 250°C are being utilized. Substrate temperature has yet to be optimized for the ion plating technique.

D. Continuing Work

Work is now concentrated on determining the effects of deposition conditions on the hydrogen contents of the films. We are varying hydrogen partial pressure, substrate temperature, glow voltage, and in particular the strength of the magnetic field. As previously stated Si-H bonding has been observed in earlier films by IR-spectroscopy. We are preceding a step further and attempting to determine approximately the relative amounts of $Si\text{-}H_1$, $Si\text{-}H_2$, and $Si\text{-}H_3$ complexes, by observation of the bond bending absorption peaks which occur around 900 cm^{-1}. Absence of bond bending would demonstrate the sole presence of Si-H.

An apparatus for measuring resistivity versus temperature has been constructed. Characterization of the electrical resistivity and electrical gap of rhe deposits is now underway. The dependence of the optical gap on deposition conditions is being determined.

E. Summary

Initial results have indicated that fairly substantial amounts of hydrogen may be incorporated into a-Si films by ion-plating in a hydrogen glow. Optical gaps of films produced so far have varied from 1.67 to 2.21 eV. Characterization of the effects of deposition conditions on hydrogen content, optical and electrical properties is underway.

TABLE I

Film	Optical Band Gap (eV)	Thickness (μ)	Hydrogen Content	Deposition Rate
E	1.89	3.8	8.35	5.3 Å/sec
F	2.21	4.45	8.72	12.3 Å/sec
I	1.88	8.0	N/M	22 Å/sec
J	1.67	2.41	N/M	3 Å/sec

N/M - not measured

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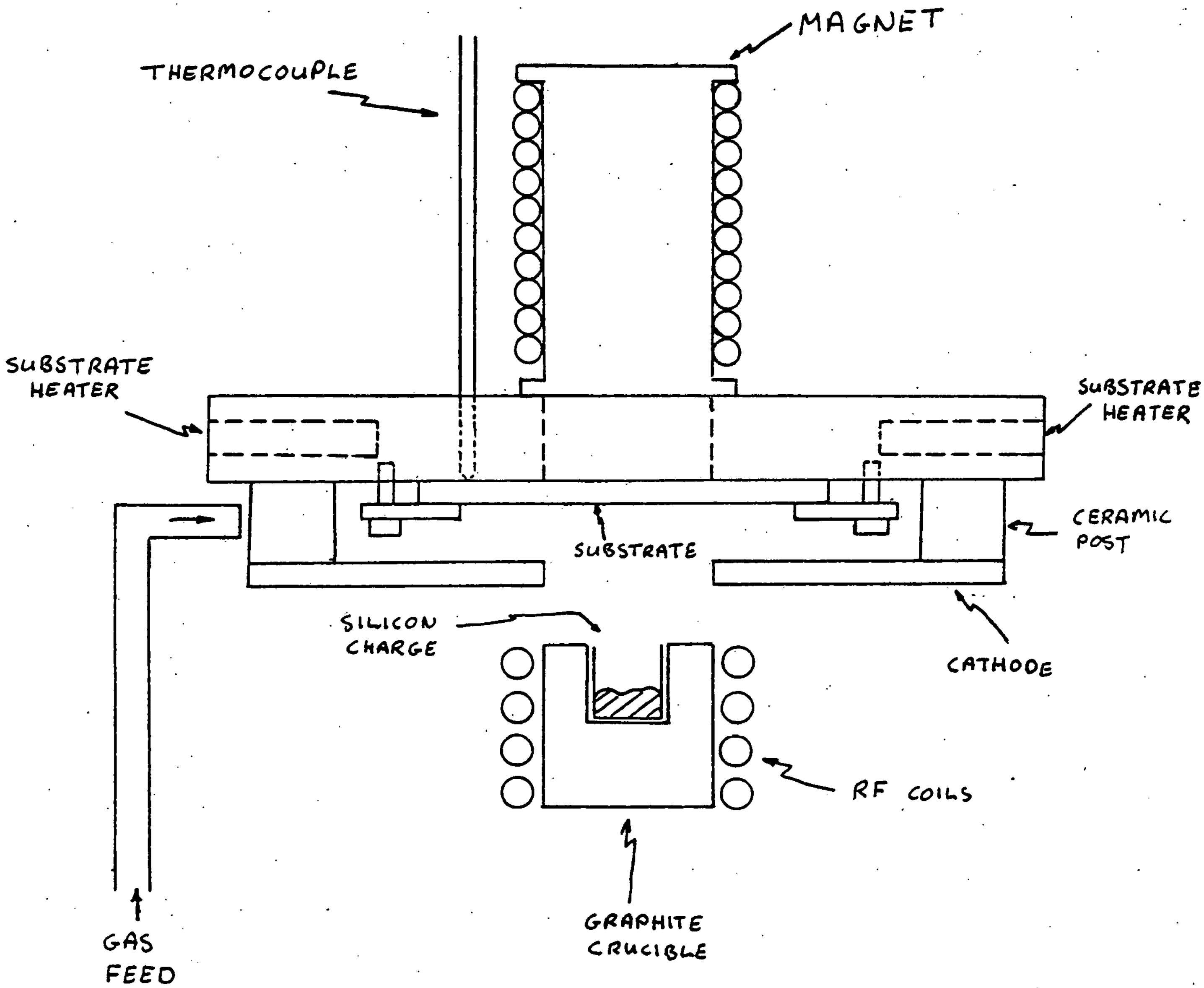

Figure 1. Substrate holder for ion-plating apparatus. The region of magnetic field glow confinement occurs just below the substrate.