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Hydrogenated Amorphous Silicon Nitride Thin Film as ARC for Solar Cell Applications

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Abstract:
Hydrogenated amorphous silicon nitride (a-SiN_x:H) thin films have been deposited using Silane (SiH_4) and Nitrogen (N_2) as source gases by Plasma Enhanced Chemical Vapour Deposition (PECVD). During deposition, Silane flow rate is kept constant at 2 sccm and Nitrogen flow rate is varied from 800 to1200 sccm. Fourier transform Infrared spectroscopy (FTIR) analysis is carried out to identify all the possible modes of vibrations such as Si-N, Si-H and N-H present in the films and the effect of nitrogen flow on these parameters is correlated. The refractive index of the a-SiN_x:H films is calculated using UV-VIS spectroscopy measurements by Swanepoel's method and optical bandgap is calculated using Tauc's equation.

Key words: *a-SiN_x:H, Plasma Enhanced Chemical Vapour Deposition (PECVD), Fourier Transform Infrared Spectroscopy (FTIR)*

1. Introduction

Silicon nitride films have been widely used in the semiconductor device industry because of their good dielectric properties, and provide an excellent barrier against moisture corrosion and mobile ions. Silicon nitride films grown by PECVD have been utilized as antireflection (AR) coating for single-crystalline silicon solar cells as well as amorphous silicon solar cells. The aim of this work is to study the improvements in the performance of silicon solar cells fabricated on glass substrates by using PECVD s antireflective coatings (ARC). There are several materials with refractive index (n) ranging between 1.4 and 2.7 which can be used as AR coatings. These include SiO, SiO_2, Si_3N_4, Al_20_3, Ta_20_5 and TiO_2. The advantage of PECVD grown silicon nitride as AR coating lies in the fact that it can be deposited at very low temperature, i.e. from room temperature to 300 °C, high deposition rate and does not affect other cell parameters such as minority carrier diffusion length. Also, these films can be deposited over metal contacts because the low deposition temperature has negligible deteriorating effect on the quality of the contacts. The actual composition of the films can be varied by adjusting the deposition process parameters. Many researchers have investigated on the structural, optical and electrical properties of silicon nitride films deposited using Silane (SiH_4) and Ammonia (NH_3) as source gases. Much less work has been reported on the deposition of a-SiN_x using Silane and Nitrogen (N_2) as the source gases. The advantages of using nitrogen are, abundantly available at a cheaper cost than ammonia and non-toxic in nature. So in our present investigations, a-SiN_x thin films are deposited by PECVD using Silane and Nitrogen as source gases. Structural properties are investigated using Fourier Transform Infrared Spectroscopy (FTIR) analysis and Optical properties, by UV-VIS spectroscopy analysis.

2. Principle Involved in ARC

In the solar cell, any loss of radiation result in less generation of electron-hole pair which result in the reduction of overall efficiency. The loss of solar radiation due to optical loss is referred to the solar radiation which falls on the solar cell, but does not get absorbed. The loss of radiation could be due to the reflection from the solar cell surface or due to the reflection from the metal contact. The optical loss could be as high as 40 to 50%. This optical loss can be minimized by putting ARC. This ARC is a thin layer of a dielectric material deposited on the surface of the solar cell. It should not absorb a light and should reduce the reflection. The reduction in reflection is based on destructive interference.

In order to obtain the condition of destructive interference, thickness (d_1) and refractive index (n_1) should be properly chosen. The thickness of dielectric ARC should be such that the radiation reflected from AIR-ARC interface and from ARC-Semiconductor interface should have 180^0 phase difference. The out of phase waves will have destructive interference resulting minimum reflected energy. In order to find the optimum thickness of the AR coating one has to choose the wavelength at which solar cell to be coated has maximum quantum efficiency. At this wavelength the product of the refractive index and thickness of the layer are criteria for minimum reflectance. The thickness of the ARC should be quarter of the wavelength i.e.

$$d_1=\lambda_0/4n_1$$

Solar cells are covered with the glass substrate, which affects the reflection from ARC-semiconductor interface and modifies the values of n_1 required for minimum reflection and is given by

$$n_1=\sqrt{n_0 n_2}$$

Where n_0 is the refractive index of the glass, n_1 is the refractive index of ARC material and n_2 is the refractive index of semiconductor material.

3. Experimental

The a-SiN_x:H layer is deposited using Silane (SiH_4) and Nitrogen (N_2) as reactant gases. By varying the Nitrogen flow rate, band gap and refractive index can be varied over a wide range. This hydrogenated amorphous silicon nitride thin film is deposited on the glass substrate by conventional parallel plate 13.56 MHz PECVD deposition system. Before the deposition, the glass substrate is first cleaned with soap solution and then with acetone in order to remove the organic impurities. The process parameters are tabulated in table 1.

Sample Number	**SiH_4 (sccm)**	**N_2 (sccm)**	**Deposition Time (min.)**
SiN 1	2	800	12
SiN 2	2	900	12
SiN 3	2	1000	12
SiN 4	2	1100	12
SiN 5	2	1200	12

Table 1: Process Parameters of deposition of a-SiN_x:H films.

During the deposition process, the silane flow is kept constant at 2 sccm and nitrogen flow is varied from 800 to 1200 sccm. During the deposition, power density, process pressure and deposition time is kept constant at 31 mW/cm^2, 600 mTorr and 200 ºC respectively. Optical absorption spectra were recorded using UV-VIS spectrometer (Perklin Elmr Lambda 35) in the wavelength range of 300-1100 nm. Thickness (d) and absorption coefficient (α) of the film were calculated using the Swanepoel's method and the optical band gap (E_g) was calculated from Tauc's equation. Fourier Transform Infrared (FTIR; Bruker Alpha T) spectroscopy studies have been carried out in the wave number range 400 - 4000 cm^{-1} in order to identify various chemical bonding occurring between Nitrogen, Silicon and Hydrogen.

4. Results and Discussion

A.Optical Properties

Optical transmission spectra of a-SiN_x:H films have been recorded in the wavelength range of 300-1100 nm. The transmission spectra of SiN 3, SiN 4 and SiN 5 are as shown in fig. 1a, 1b and 1c. The refractive index (η) of the deposited films was calculated using Swanepoel's method, which is based on the parabolic fitting procedure of adjacent maximum T_M and minimum T_m of the transmission spectra. The refractive index (η), and the absorption coefficient of the film depends on the wavelength.

The refractive index (η) of the film has been calculated as a function of wavelength using expression given below which is deduced from the maximum (T_M) and minimum (T_m) values of transmission spectra.

$$N = \left[N + (N^2 - S^2)^{1/2}\right]^{1/2}$$

Where,

$$N = 2s\left(\frac{T_M - T_m}{T_M T_m}\right) + \left(\frac{(s^2 + 1)}{2}\right)$$

Where S is the refractive index of the glass substrate, S=1.50. The refractive index values are calculated for SiN 3, SIN 4 and SiN 5 using above mentioned Swanepoel's method at λ=700 nm and the values are 1.82, 1.88 and 1.80 respectively.

The bandgap (E_g) of the film were calculated using Tauc's equation which gives the relation between absorption coefficient and optical bandgap and is given by

$$(\alpha E)^{1/2} = B(E - E_g)$$

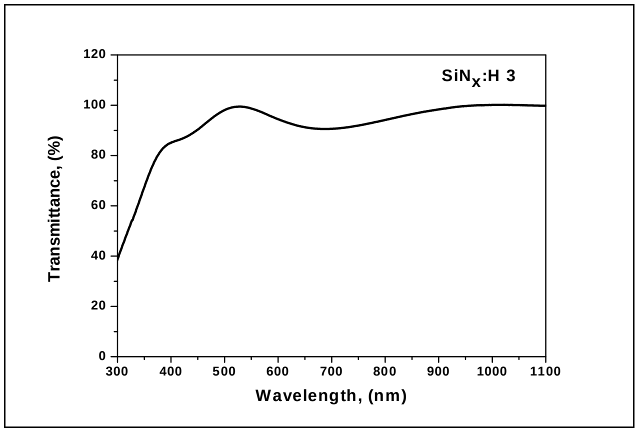

Figure 1: Transmission Spectra of Sin 3 Film

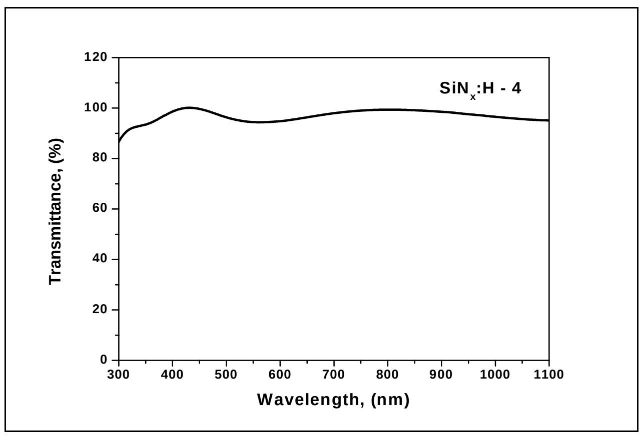

Figure 2: Transmission Spectra of Sin 4 Film

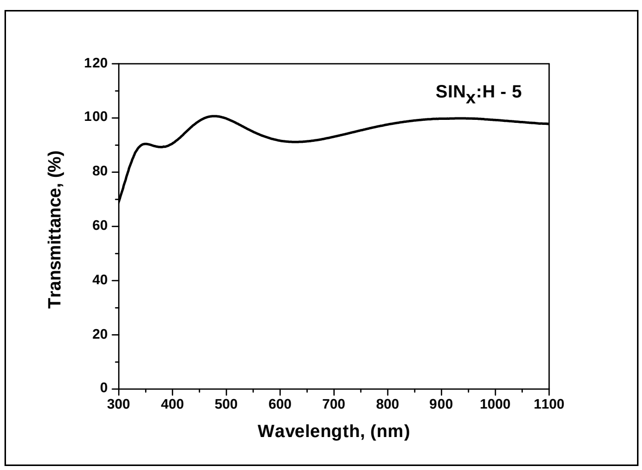

Figure 3: Transmission Spectra of Sin 5 Film

From the equation, B is a constant which is almost independent of the chemical composition of the semi-conductor; E is the photon energy and Eg is the optical band gap. Therefore, the bandgap of the films SiN 3, SiN 4 and SiN 5 are 2.5, 2.9 and 3.05 respectively. The bandgap increases with an increase in the nitrogen content in the film.

B.Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR analysis is a non-destructive versatile tool in identification of various vibrational modes occurs in the materials and in determining the nature of chemical bonds present in the material. Fig 4 shows the FTIR analysis of various a-SiN_x films deposited using PECVD at different nitrogen concentrations. Generally, in silicon nitride films three groups of bonds can be observed like Si-N, N-H and Si-H. In the range from 2000 to 2200 cm^{-1} various vibrational modes like H−Si−Si3, H−Si−HSi2, H−Si−NSi2, H−Si−SiN2, H−Si−H and H−Si−N3 will exist in a-SiN_x films. Si-N vibrational mode is observed around 780-800 cm^{-1} whereas around 1130-1160 cm-1 N-H wagging mode is observed. All the possible modes of vibrations present in the a-SiN_x films are tabulated in the table.2

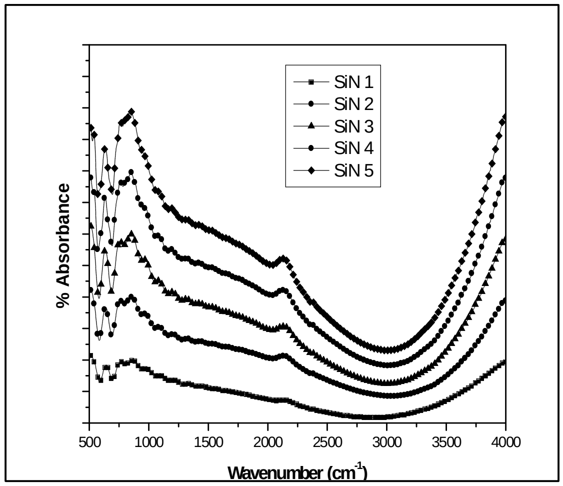

Figure 4: FTIR Spectra of A-Sin_x Films

5. Conclusion

Hydrogenated amorphous silicon nitride films are deposited by PECVD technique using Nitrogen and Silane as source gases. Optical transmission spectra are recorded in order to calculate the refractive index of the deposited films. Refractive index values are calculated using Swanepoel's method For a-SiN_x:H thin films to be applied as ARC in a-Si:H solar cells, it should match the refractive index of glass and amorphous silicon i.e., in between 1.7-1.9. The PECVD process parameters are optimized for a-SiN_x:H thin films with a refractive index of 1.80. FTIR analysis is carried out to identify various vibrational modes present in the deposited films.

S. No.	Modes of vibration			
	Si-H stretching	Si-N stretching	N-H wagging	Si-H wagging
SiN 1	2046	783	1148	705
SiN 2	2035	785	1151	688
SiN 3	2029	788	1145	670
SiN 4	2031	794	1148	684
SiN 5	2033	800	1160	699

Table 2: Modes of Vibration of A-Sin_x:H Films

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