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Preparation of high-quality hydrogenated amorphous silicon film with a new microwave electron cyclotron resonance chemical vapour deposition system assisted with hot wire*

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The preparation of high-quality hydrogenated amorphous silicon (a-Si:H) film with a new microwave electron cyclotron resonance-chemical vapour deposition (MWECR-CVD) system assisted with hot wire is presented. In this system the hot wire plays an important role in perfecting the microstructure as well as improving the stability and the optoelectronic properties of the a-Si:H film. The experimental results indicate that in the microstructure of the a-Si:H film, the concentration of dihydride is decreased and a trace of microcrystalline occurs, which is useful to improve its stability, and that in the optoelectronic properties of the a-Si:H film, the deposition rate reaches above 2.0nm/s and the photosensitivity increases up to 4.71×10^5.

Keywords: hydrogenated amorphous silicon (a-Si:H) films, hot wire microstructure, stability, optoelectronic property, deposition rate

PACC: 8115H, 6825, 6220

1. Introduction

As a new functional material, a-Si:H film has been widely applied[1] to semiconductor devices, such as photosensitive devices, solar cells and thin film transistors (TFT), etc. However, due to the light-induced metastable defect or, in other words, Staebler–Wronski effect, the efficiency of the photonic device made from the a-Si:H film is restricted. In this sense, the a-Si:H film cannot be simply used as an inexpensive semiconductor material in the photonic device. So it is important to study the stability of a-Si:H. In recent years, scientists from different countries have made efforts to study its degradation mechanisms and the relevant solitons. And they have made the new progress in theory and preparation techniques.[2]

Microwave electron cyclotron resonance-chemical vapour deposition due to its attractive features has been used for the deposition of the a-Si:H film. However, there still exist some problems in the films prepared by the conventional MWECR-CVD system, such as poor stability, low photosensitivity, etc. So, based on the previous work,[3,4] we develop a new system assisted with hot wire to obtain high-quality a-Si:H film.

2. Experiment

The system used in this study is schematically illustrated in Fig.1. In the system, there are two chambers: the plasma chamber and the deposition chamber. The pumping system consists of a rotary pump and a turbomolecular pump. A background pressure of $\sim10^{-3}$ Pa is achieved by the turbomolecular pump before each deposition. The microwave power is introduced into the plasma chamber through a rectangular waveguide and a ceramic window. The magnetic coil is arranged around the periphery of the plasma chamber and produces a magnetic field for the formation of electron cyclotron resonance (ECR) plasma. The ECR condition is held at a magnetic flux den-

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sity of 875G. The power to sustain the plasma is supplied from a microwave generator, which is modulated by a pulse generator. Based on the above-mentioned system, we introduce a hot wire into the system. A tungsten filament ring with a diameter of 120mm is employed (the cross-sectional diameter of the tungsten filament is 0.5mm), and located 70mm above the sample holder to ensure the minimal radiative heat for the substrate. Both sides of the ring are connected to an AC transformer with an output voltage of 10.6V, producing a light intensity of 80.4mW/cm^2. Temperature rise of the substrate surface is monitored by a thermocouple attached to the substrate.

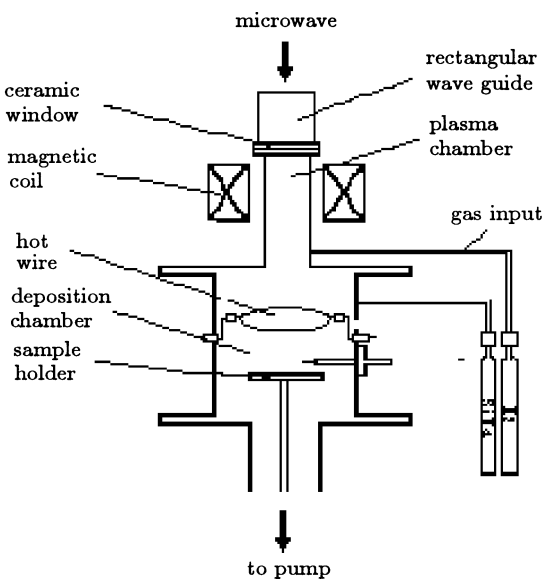


Fig.1. Schematic diagram of the microwave electron cyclotron resonance-chemical vapour deposition apparatus.

The substrate used in the experiment is Corning 7059 glass which is for measuring thickness, optical gap and conductance of the film, and also highly resistive crystalline silicon wafer which is for estimating bonded hydrogen. The thickness of the film is measured by using a step apparatus. The photoconductivity and the dark conductivity are measured by the KEITHLEY 6517 Electrometer/High Resistance System. The optical gap is obtained from a Tauc plot[5] calculated from transmission and reflection spectra in the visible wavelength region using SHIMADZU-3101PC Scanning spectrophotometer.

3. Results

3.1. Influence of the hot wire on the microstructure of a-Si:H film

Table 1 lists the deposition condition of the a-Si:H film in the experiment. The substrate temperature is set at 120°C, but actually reaches ~200°C due to the contribution of the heat supplied by the hot wire. The Fourier transform infrared (FTIR) spectra of the a-Si:H film growing at 120°C are shown in Fig.2. From the peak at 640cm^{-1} we can see that with the assistance of the hot wire, H content decreases obviously, and meanwhile, with the decrease of the double peaks at the wave numbers of 840–890cm^{-1} and with the peak shift of 2090cm^{-1} to 2000cm^{-1}, there exist very few polyhydride and dihydride bonds compared to those deposited without hot wire, which is beneficial to decreasing the defect density of the a-Si:H film. Figure 3 illustrates the x-ray diffraction (XRD) patterns of the a-Si:H films. It can be clearly seen from the figure that when the temperatures of the hot wire and the substrate are 1450°C and 200°C, respectively, there appears a trace of microcrystalline and with the increase of the temperatures the content of the microcrystalline is further increased, which is useful to improve the stability of the a-Si:H films.

Table 1. Deposition condition of a-Si:H film.

Background pressure/Pa	1.5×10^{-3}
Flux of SiH_4diluted by H_2 (20%)/ sccm	30
Deposition pressure/Pa	2
Substrate temperature/°C	Room temperature, 120,150,200,250
Microwave power/W	450
Distance from hot wire to substrate/mm	70
Hot wire temperature/°C	1350,1450,1600,1700
Substrate	glass, single crystalline silicon wafer
Distance from substrate to microwave window/mm	130

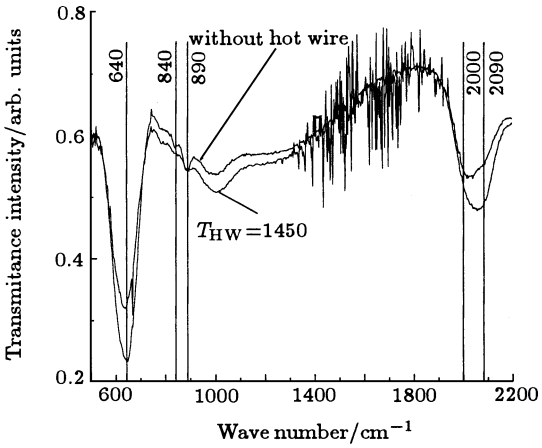


Fig.2. FTIR spectra of a-Si:H films growing at T_P=120°C.

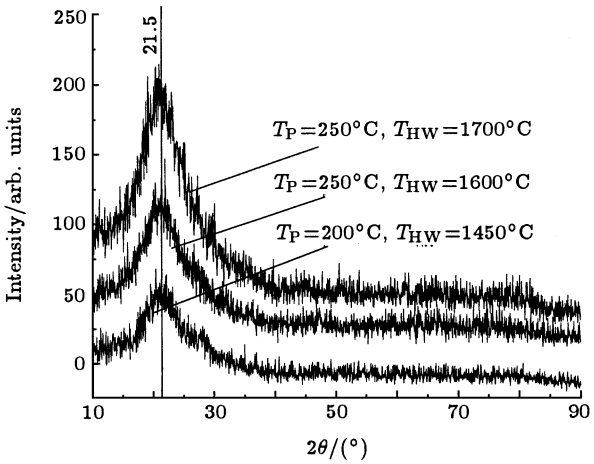


Fig.3. XRD patterns of a-Si:H films with the different temperature combinations.

3.2. Influence of the hot wire on the optoelectronic properties of a-Si:H films

The measurements for the optoelectronic properties of the a-Si:H films are listed in Table 2 with the different combinations of the hot wire and substrate temperatures. From Table 2 we can obtain the following results. Firstly, the deposition rate can reach up to more than 2.0nm/s, higher than that of radio frequency plasma enhanced chemical vapour deposition (RF-PECVD). Secondly, the photosensitivity of the a-Si:H film achieves the highest value under these experimental conditions when the temperatures of the hot wire and substrate are 1350°C and 120°C, respectively. Thirdly, the optical gap of the a-Si:H film trends to decrease gradually with the increase of the temperature.

Table 2. Properties of a-Si:H films with the different combinations of the hot wire and substrate temperatures.

No.	Growth condition	Growth rate/(nm/s)	Photosensitivity	Optical gap/eV
T1	without hot wire	2.7	3.57E2	1.80
H1	T_{HW}=1350°C, T_P=20°C	2.7	7.79E3	1.76
H2	T_{HW}=1350°C, T_P=120°C	2.7	4.71E5	1.75
H3	T_{HW}=1450°C, T_P=120°C	2.3	1.54E5	1.71
H4	T_{HW}=1450°C, T_P=140°C	2.6	2.19E4	1.59
H5	T_{HW}=1500°C, T_P=200°C	2.5	1.30E3	1.50

3.3. Influence of the hot wire on the light-induced effect

Figure 4 illustrates the influence of the hot wire on the light-induced effect of the a-Si:H film. Obviously we can see that with the prolongation of soaking time, the photoconductivity of the sample obtained under hot wire trends to decrease slowly compared with that obtained without hot wire.

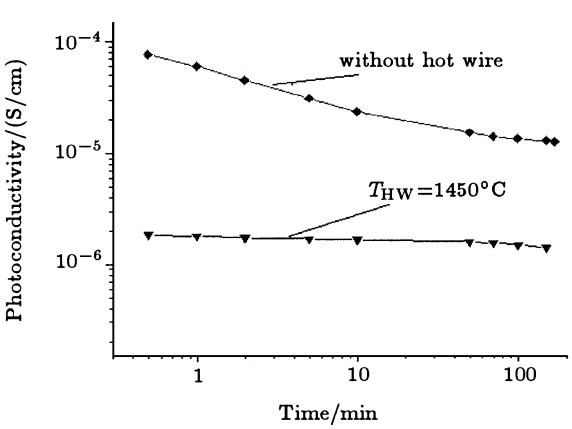


Fig.4. Dependence of the photoconductivity on light-soaking time in a-Si:H films.

4. Discussion

In this MWECR-CVD system assisted with hot wire, the microstructure, the optoelectronic properties and the stability of a-Si:H film have been improved remarkably. This is attributed to the effect of the added hot wire. The main role played by the hot wire is to supply thermal radiation needed to improve the temperature of plasma. According to Ref.[6], when the temperature reaches an equilibrium state, the relationship between ionization degree and ionization condition can be expressed in the Saha equation:

$$\alpha^2/\left(1-\alpha^2\right) = \left(2\pi m_{\mathrm{e}}/h^2\right)^{3/2} \times \left[(kT)^{5/2}/p\right] \times \exp\left(-ev_i/kT\right)$$

where α is the ionization degree, m_{e} is the electron mass, h is the Planck constant, p is the pressure, K is the Boltzmann constant, T is the temperature, e is the electron charge and v_{i} denotes the ionization potential of the gas.

By analysing this equation we can see that the improvement of the plasma temperature inevitably causes the value of α to increase. So it is easy to imagine that with the increase of α, the decomposition of reaction gas is enhanced, thereby the low-hydrogen radicals increase and the higher silicon reactive species which are critical to the light-induced degradation of a-Si:H film are restrained; in addition, the thermal radiation of the hot wire also functions as a supplemental heat supplier to the growing surface of the a-Si:H film, which is beneficial to strengthening the activation of the surface and enhancing the diffusion of hydrogen atoms, so that the microstructure and the optoelectronic properties of the a-Si:H film can be improved.

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