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Influence of total gas flow rate on microcrystalline silicon films prepared by VHF-PECVD*

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Hydrogenated microcrystalline silicon (μc-Si:H) films are fabricated by very high frequency plasma enhanced chemical vapour deposition (VHF-PECVD) at a silane concentration of 7% and a varying total gas flow rate (H_2+SiH_4). Relations between the total gas flow rate and the electrical and structural properties as well as deposition rate of the films are studied. The results indicate that with the total gas flow rate increasing the photosensitivity and deposition rate increase, but the crystalline volume fraction (X_c) and dark conductivity decrease. And the intensity of (220) peak first increases then decreases with the increase of the total gas flow rate. The cause for the changes in the structure and deposition rate of the films with the total gas flow rate is investigated using optical emission spectroscopy (OES).

Keywords: very high frequency plasma enhanced chemical vapour deposition, intrinsic microcrystalline silicon, gas flow rate

PACC: 8115H, 7360F

1. Introduction

Microcrystalline silicon solar cells with high conversion efficiency and almost no Stabler–Wronski effect (SWE) compared with amorphous silicon solar cells have become a hot research subject.[1−4] At present, there have been several methods of preparing microcrystalline silicon films, such as radio frequency plasma enhanced chemical vapour deposition (RF-PECVD), hot-wire chemical vapour deposition (HW-CVD) and very high frequency plasma enhanced chemical vapour deposition (VHF-PECVD). Among them, the fabrication of microcrystalline silicon films by VHF-PECVD has received much attention, because of their higher quality and higher deposition rate.[5,6] To fabricate device-quality microcrystalline silicon films, influences of deposition pressure, discharge power, silane concentration and substrate temperature on the characteristics of microcrystalline silicon films are widely studied.[7−10] Although some researches focus on the influence of gas flow rate on the properties of microcrystalline silicon films,[11,12] few studies are devoted to the influence of total gas flow rate at a fixed silane concentration on the performances of microcrystalline silicon films. In this paper, a series of films is prepared at different total gas flow rates. The present study emphasizes the structural and electrical properties of the films of this kind.

2. Experiment

All films under investigation were fabricated by the cluster CVD system. The films were deposited on the corning 7059 glass, which had been etched in HF acid (5%) for 5 minutes prior to deposition. The deposition was carried out at a silane concentration of 7%, a pressure of 160 Pa and a discharge power of 50W. The total gas flow rate was changed from 50 sccm to 150 sccm.

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Raman spectrum was measured by MKI Renishaw 2000, which used a 632 nm He–Ne excitation source. The X_c of a film was calculated by the following equation:[13]

$$X_c = (I_{510} + I_{520})/(I_{480} + I_{510} + I_{520}).$$

X-ray diffraction was obtained by D/max-2500X at a wavelength of 0.1504 nm. OES measurement was carried out by PR650 spectrometer at a position near the substrate surface.

3. Results and discussion

3.1. Electrical and structural characteristics

Figure 1 shows that photosensitivity of the films increases, but dark conductivity decreases with the increase of total gas flow rate. Variation of electrical characteristics of films results from the structural variation. In general, Raman spectra can partly give the information about the film structure.[14,15] Figure 2 shows that the peak of Raman spectrum shifts from the position of 520 cm^{-1} to 480 cm^{-1} with the increase of the total gas flow rate, which is a feature of transverse optical (TO) of α-Si:H. The value of X_c decreases with the increase of the total gas flow rate (see the inset in Fig.2), namely the structure of silicon in the films changes from microcrystalline to amorphous. So, the dark conductivity decreases but the photosensitivity increases with the increase of the total gas flow rate, as shown in Fig.1.

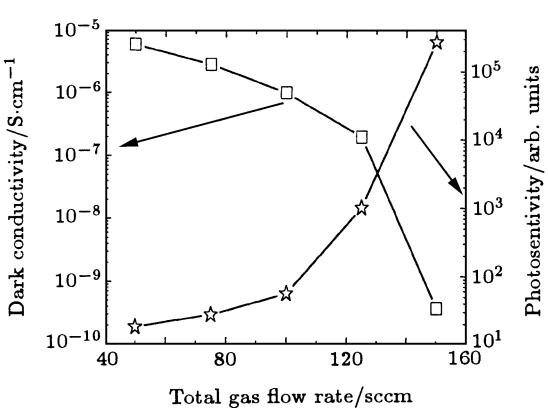


Fig.1. Photosensitivity and dark conductivity of samples varying with the total gas flow rate.

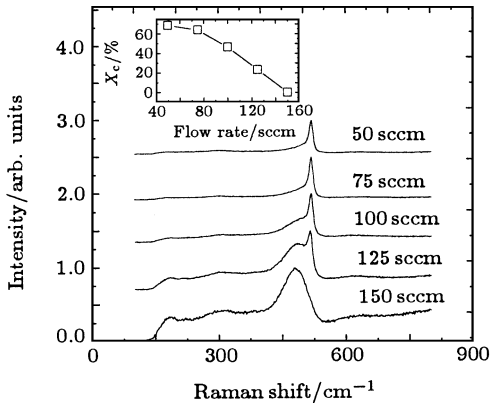


Fig.2. Raman spectra of sample varying with the total gas flow rate.

In order to obtain more information about the crystalline orientation in the films, x-ray diffraction was used to investigate the film structure, as shown in Fig.3, where it can be seen that the intensity of (111) peak monotonously decreases with the increase of total gas flow rate. However the intensities of (220) and (311) peaks first increase and then decrease. The intensity of diffraction peak is the strongest at a total flow rate of 75 sccm (The details can be seen in Fig.4). Comparing Fig.4 with the inset in Fig.2, it can be concluded that the relation between the X_c and the intensity of (220) peak is nonlinear.

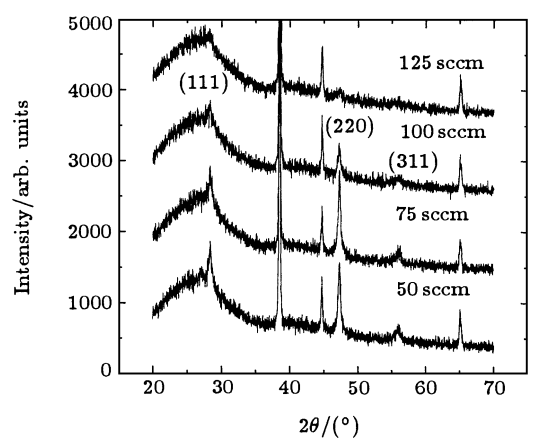


Fig.3. The x-Ray diffraction varying with the total gas flow rate.

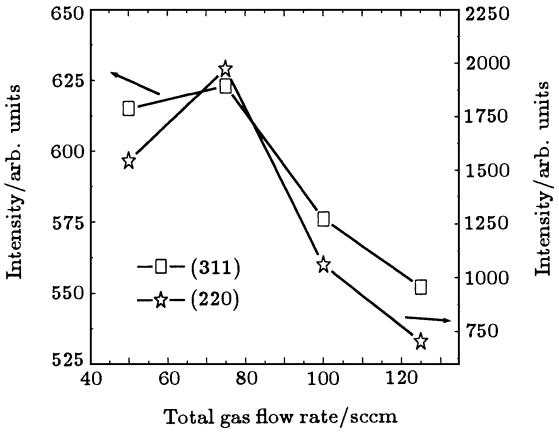


Fig.4. The intensities of (220) and (311) peak varying with the total gas flow rate.

3.2. Optical emission spectroscopy

The properties of microcrystalline silicon in the films are also strongly correlated with the plasma conditions during deposition. OES can obtain some valuable information about plasma states occurring in the reactive gas, especially about the silane plasma.[16,17] The plasma detected by PR650 can be used to obtain the precursor information such as SiH^* at a wavelength of 412 nm, H^*_β at 486nm, H^* at 602 nm, and H^*_α at 656 nm, respectively. Figure 5 shows that the intensities of optical emissions for H^*, H^*_α, H^*_β and SiH^* increase with the total gas flow rate increasing, which maybe stems from the fact that the probabilities of collisions between electron and SiH_4 and between electron and H_2 are enhanced with the increase of the total gas flow rate. In general, the variation of SiH^* intensity can reflect the variation of the deposition rate[18] to some extent. Our results also confirm the regular variation, as shown in Fig.5 and Fig.6.

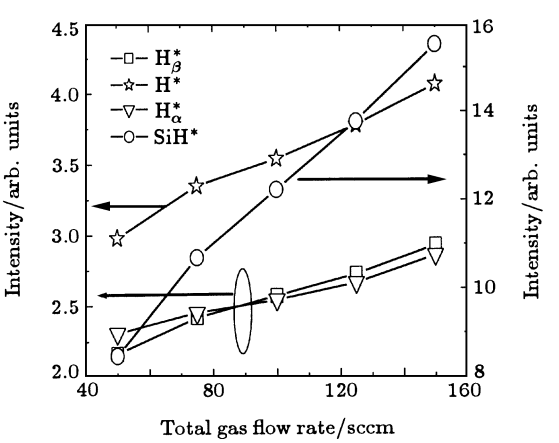


Fig.5. The intensities of H^*, H^*_α, H^*_β and SiH^* varying with the total gas flow rate.

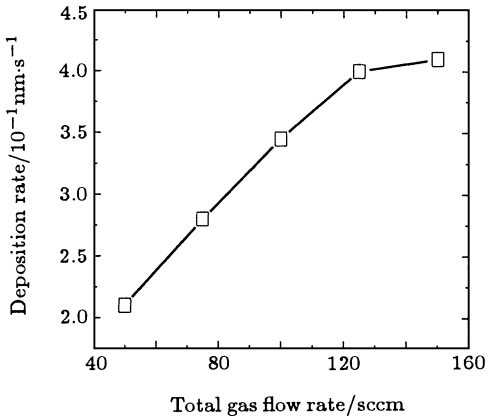


Fig.6. Deposition rate varying with the total gas flow rate.

Figure 7 shows the decrease in $I_{H^*_\alpha}/I_{SiH^*}$ ratio with the total gas flow rate increasing. In combination with the results of X_c shown in Fig.2, $I_{H^*_\alpha}/I_{SiH^*}$ ratio can be used as a measure of the crystallinity in films,[18] which is very important for shortening the fabrication time of high-quality silicon thin films. Figure 7 also shows the variation of $I_{H^*_\beta}/I_{H^*_\alpha}$ with the total gas flow rate, which provides the information about the electron temperature[19] of hydrogen plasma. As can be seen, $I_{H^*_\beta}/I_{H^*_\alpha}$ increases with the increase of gas flow rate. So the electron temperature increases with the increase of the total gas flow rate.

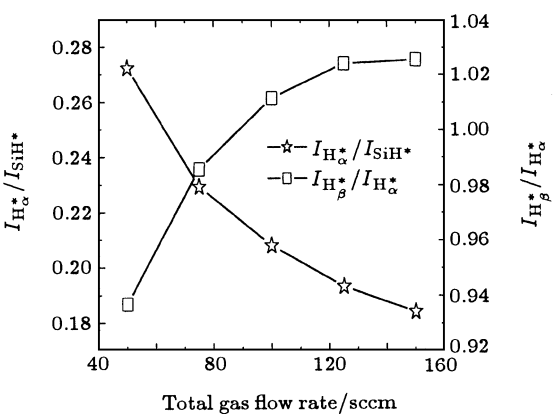


Fig.7. $I_{H^*_\alpha}/I_{SiH^*}$ and $I_{H^*_\beta}/I_{H^*_\alpha}$ ratio varying with the total gas flow rate.

4. Conclusions

Microcrystalline silicon (μc-Si:H) films are prepared by VHF–PECVD at a varying total gas flow rate. The results indicate that with the increase of the total gas flow rate, the deposition rate and photosensitivity increase, whereas the dark conductivity and X_c decrease. The intensity of (220) peak first increases and then decreases, which shows a different variation

tendency compared with the intensity of (111) peak. Optical emission intensities of SiH^*, H^*, H^*_α and H^*_β increase with the increase of the total gas flow rate in the experimental range. The $I_{H^*_\beta}/I_{H^*_\alpha}$ ratios also indicate that the electron temperature changes with the total gas flow rate varying.

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