# Surface analysis of a-$Si_xC_{1-x}$:H deposited by RF plasma-enhanced CVD

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## Abstract

Thin films of hydrogenated amorphous silicon carbide compounds (a-$Si_xC_{1-x}$:H) of different compositions were deposited on Si substrate by RF plasma-enhanced chemical vapor deposition(PECVD). Experiments were carried out using silane($SiH_4$) and methane($CH_4$) as the gas precursors at 1 Torr and at low substrate temperature(250℃). The gas flow rate was changed with every other parameters(pressure, temperature, RF power) fixed. The substrate was Si(100) wafer and all of the films obtained were amorphous. The bonding structure of a-$Si_xC_{1-x}$:H films deposited was investigated by X-ray photoelectron spectroscopy(XPS) for the film compositions. In addition, the surface morphology of films was investigated by atomic force microscopy(AFM).

# RF plasma-enhanced CVD 법에 의해 증착된 a-$Si_xC_{1x}$:H 의 표면 분석

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## 요 약

RF Plasma 화학 기상 증착법을 이용하여 서로 다른 조성의 비정질 SiC:H 박막을 silicon 기판 위에 증착하였다. Silane($SiH_4$)과 methane($CH_4$) 가스를 이용하여 작업 진공도 1 Torr 와 250℃의 낮은 기판 온도에서 실험이 수행되었으며 다른 공정 조건은 모두 고정하고 가스 유량만을 변화시켰다. 기판은 Si(100)을 사용하였고 모든 박막은 비정질임을 확인하였다. 박막의 결합 구조 및 표면 조도는 각각 XPS, AFM 을 이용하여 분석, 관찰하였다.

## 1. Introduction

The hydrogenated amorphous silicon carbide(a-$Si_xC_{1-x}$:H) films has the useful property that the silicon content can be changed by various conditions, especially the ratio of silane and methane gas mixture. The hydrogenated amorphous silicon carbide(a-$Si_xC_{1-x}$:H) and hydrogenated amorphous silicon (a-Si:H) are important materials for optoelectronic devices such as solar cells[1-5]. a-$Si_xC_{1-x}$:H film attracted attention in recent year because the film is superior to a-Si:H in term of its thermal-and photo-stabillities, and its optical and electrical properties can be varied readily by adjusting the process parameter. The device applications of a-$Si_xC_{1-x}$:H film introduce light-emitting diodes[6], phototransistors[7], photodetectors[8,9] and solar collectors[10]. The films has also been used as wear-resistant coating[11] and X-ray lithography masks[12,13]. It is known that the band gap of a-$Si_xC_{1-x}$:H films grown by PECVD can be varied over 1.9 – 3.2eV by controlling the silicon content in the film.

In this work, a-$Si_xC_{1-x}$:H films which have different compositions were prepared and the sample properties with the compositions of a-$Si_xC_{1-x}$:H films was investigated. The deposited samples have been analyzed by X-ray photoelectron spectroscopy(XPS) and atomic force microscopy(AFM). In particular, the XPS measurements have been utilized to analyze the core-level electrons.

## 2. Experimental procedure

a-$Si_xC_{1-x}$:H films were deposited by PECVD technique, from appropriated gaseous mixtures of silane($SiH_4$) and methane($CH_4$). A schematic of the PECVD equipment is shown in Fig. 1. The reaction system is of the parallel planar discharge system using a rectangular RF electrode(lower) and substrate electrode(upper). The substrate is set on the tray with the surface to be coated facing downward, so that deposition of dust particles and flakes can be minimized. The n-type Si wafers in (100) orientation were used as the substrate. Prior to film deposition, the wafer was dipped in a 10% hydrofluoric acid for about 40s, rinsed in deionized water and acetone, and finally dried in a nitrogen ambient. The base pressure of the chamber is 4 $\times 10^{-5}$ Torr and the source gas was $SiH_4$(10% dilution in $N_2$) and $CH_4$. A typical RF(13.56 ㎒) input power was 150W. The substrate temperature was kept at 250℃, and the pressure during deposition was 1 Torr. The silane gas flow rate(x) was changed from 0.3 to 0.65 in a-$Si_xC_{1-x}$:H.

XPS measurement was run on a Perkin-Elmer PHI 5700 surface analysis instrument using Mg K$\alpha$ X-rays(1253.6eV) as the photoexcitation source with an electron takeoff angle of 45° from the surface normal.

The morphology of film surface was examined by AFM using the contact mode. In the contact mode, controlling the distance maintains the force exerted by the cantilever

on the surface. For a scanning speed of 1~2 s/line, a surface image consisting of 256 lines requires a time of about 5 min.

## 3. Results and discussion

### 3.1. XPS measurement

The systematic XPS analysis has been performed on a-$Si_xC_{1-x}$:H compounds, which are expected to have rate of compositions within each sample. The photo-emission measurement has been performed on a series of samples before and after removing the surface oxide layer. After the Ar sputter cleaning treatment, oxygen was found to be still present in samples. Curve fitting with mixed Gaussion/Lorentzian functions was performed on unsmoothed data. A detailed analysis of the C1s core level electron is helpful in evaluating the variations of the compound compositions and the oxidation degree of unstable films, as shown Fig. 2. The C1s peak was able to be fitted by C-O-H, C-C and C-Si contribution. Fig. 2(a) and (b) show the results of the charging effect. The charging effect and Si-C peak disappearance was observed for specimen with much oxidation as all of peak energy were shifted. It was observed small shifts with the charging effect in the binding energy depending on the change in oxidation state. The samples oxidized highly have higher binding energies, and emit electrons with lower

kinetic energies. No charging effect was observed in the Fig. 2(c) and (d). The energy of Si-C peak increased with increasing carbon contents and all samples showed a single peak around 283eV with a small shoulder at 284eV, indicating that the films have both Si-C bonds(~282.7eV) and C-C bonds(~283.6eV).

3.2. AFM measurement

Atomically sharp tip interacting with a surface scans the surface features to produce an image[14]. The tip is usually attached to a small cantilever and is used in the contact mode. The tip is always in contact with the surface and in the latter the tip touches the surface only periodically as the cantilever vibrates. Typical AFM images of the surface of a-$Si_xC_{1-x}$:H films are shown in Fig. 3(a)-(d), respectively. Note that the surface is covered with islands of different sizes. Such a microstructure is observed in all fabricated samples while the concentration and the size of islands depend on the deposition condition. At the same time, the result of the diffraction analysis could not detect microcrystals in any samples. The nature of these islands on the surface was clarified using the combined analysis of height and phase images obtained by AFM. We calculated height and diameter for all types of islands on the surface of $4 \times 4$ ㎛.

Samples for Fig. 3(c) and (d) show a lower value of surface roughness as compared to samples for Fig. 3(a) and (b) happened charging effect. The surface roughness for a-

$Si_{0.65}C_{0.35}$:H, a-$Si_{0.45}C_{0.55}$:H, a-$Si_{0.4}C_{0.6}$:H, and a-$Si_{0.3}C_{0.7}$:H are 1.59Å, 1.51Å, 0.92Å, and 0.99Å, respectively. (c)a-$Si_{0.4}C_{0.6}$:H show the lowest value of roughness as compared to other samples. The optimum deposition conditions for the surface roughness found is total gas flows in the range 20-50sccm. This reduction of the surface roughness at a-$Si_{0.4}C_{0.6}$:H is expected to be able to contribute in improving the *p/i* interface in a *p-i-n* solar cell.

## 4. Summary

a-$Si_xC_{1-x}$:H compounds produced by PECVD technique from $SiH_4$+$CH_4$ gas mixtures have been investigated as a function of the compositional gas ratio.

1) Specimen with much oxidation was observed to have charging effect as a shift of energy was observed for Si-C peak to be disappeared. There will be small shifts with the charging effect in the binding energy due to changes in oxidation state. The energy of Si-C peak increased with the decreased silicon contents.
2) The samples for Fig. 3(c) and (d) showed a lower value of surface roughness as compared to the samples for Fig. 3(a) and (b). The sample for Fig. 3(c) a-$Si_{0.4}C_{0.6}$:H showed the lowest value of roughness as compared to other samples.

**Acknowledgments**

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**List of Figures**

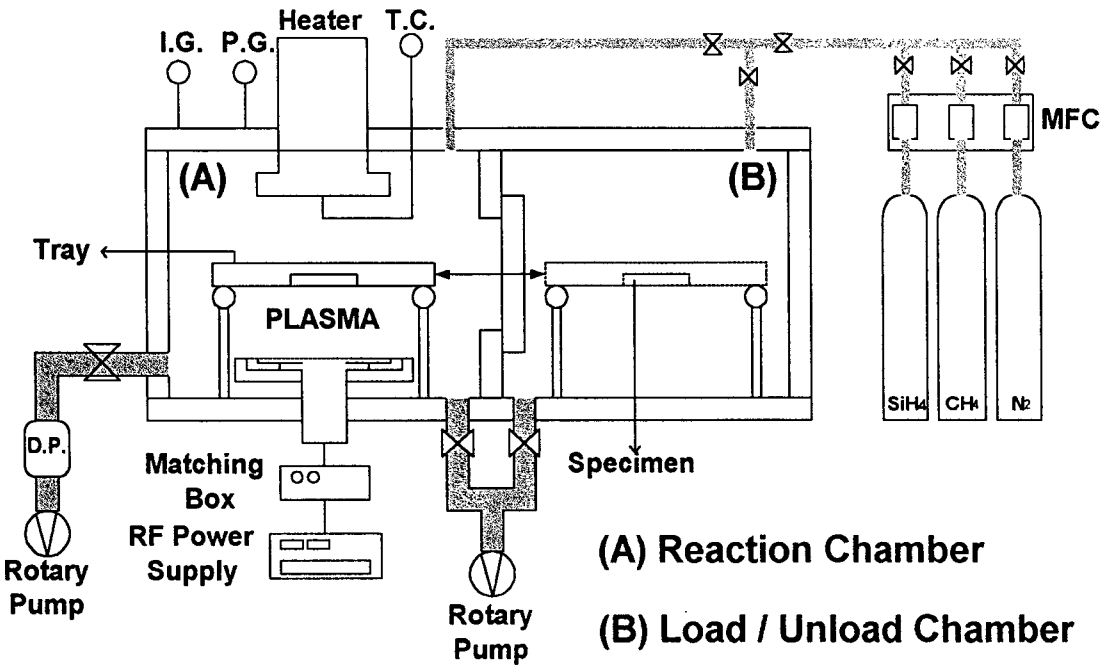
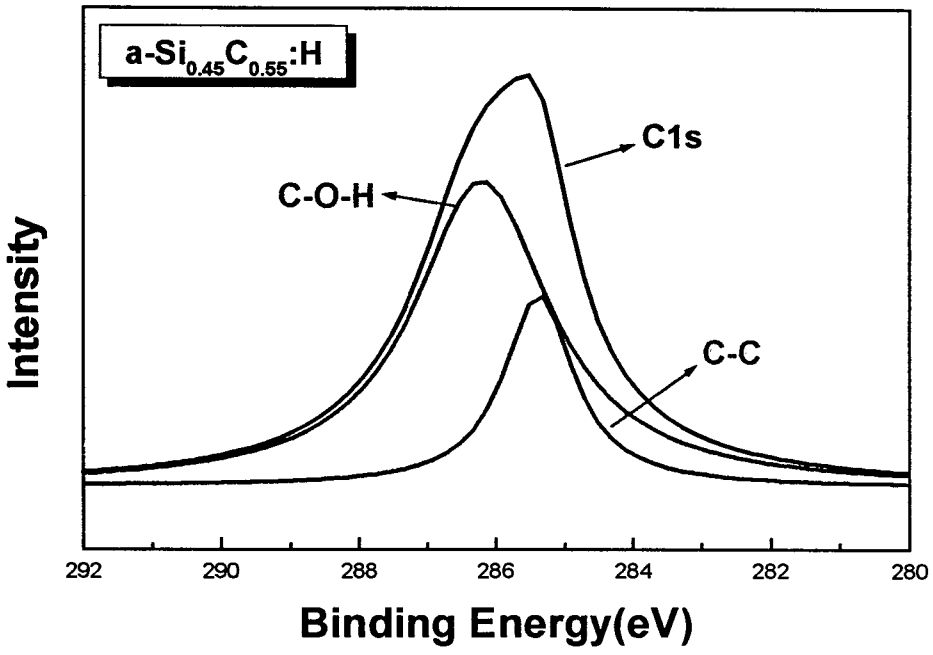
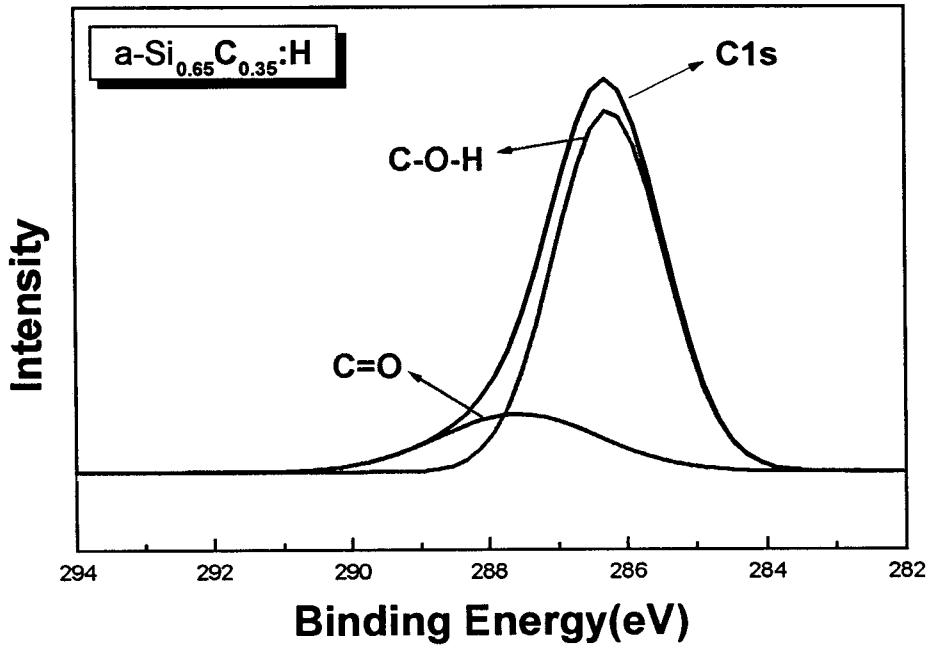

I.G.
P.G.
Heater
T.C.
(A)
(B)
MFC
Tray
PLASMA
SiH4
CH4
N2
D.P.
Matching Box
RF Power Supply
Specimen
Rotary Pump
Rotary Pump
(A) Reaction Chamber
(B) Load / Unload Chamber

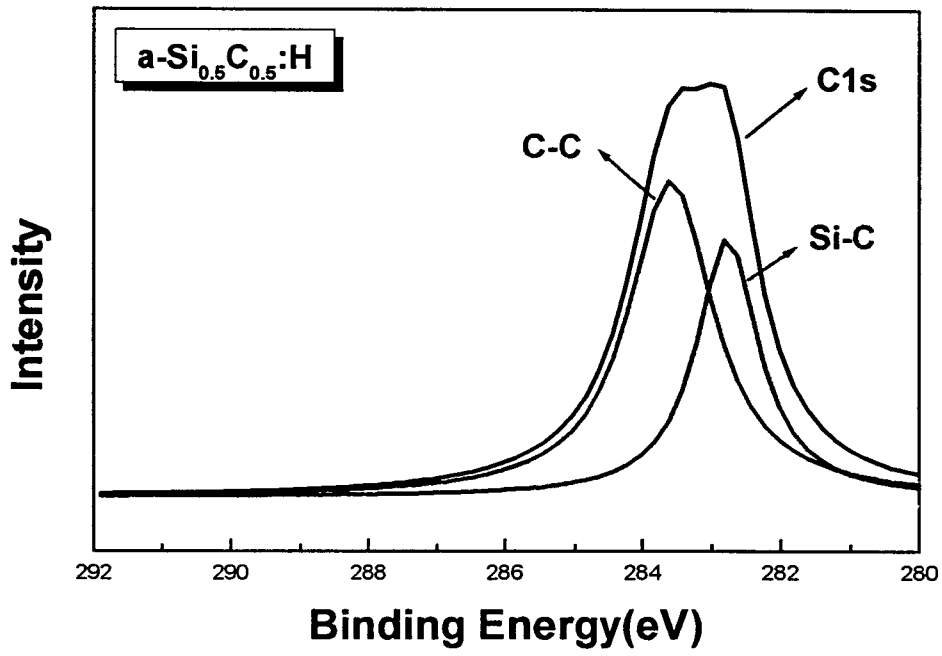
Fig. 1. Y. T. Kim


a-Si0.45C0.55:H
C1s
C-O-H
C-C
Intensity
292
290
288
286
284
282
280
Binding Energy(eV)

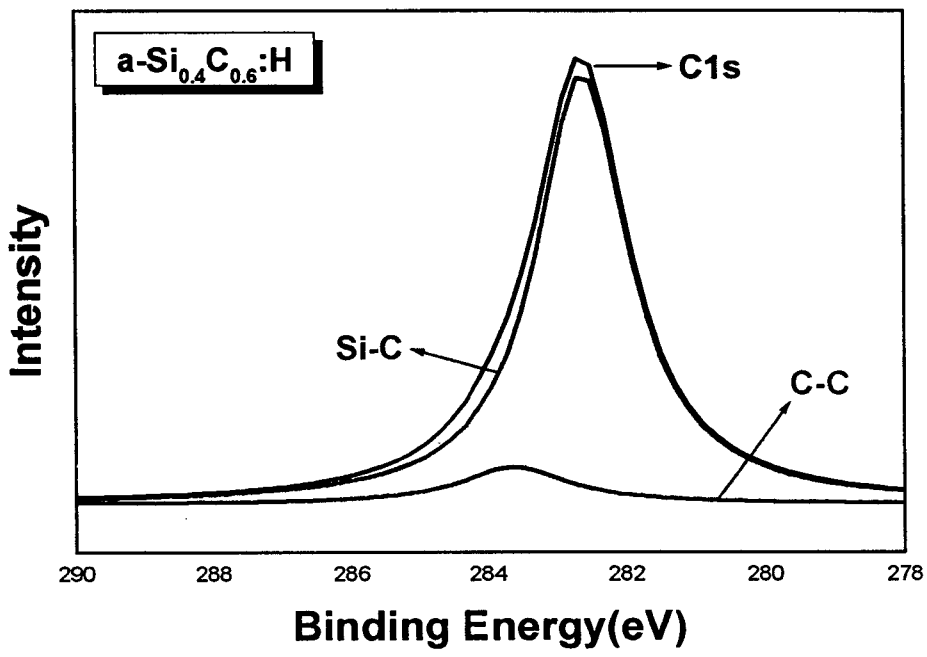
(a)


a-Si0.65C0.35:H
C1s
C-O-H
C=O
Intensity
294
292
290
288
286
284
282
Binding Energy(eV)

(b)

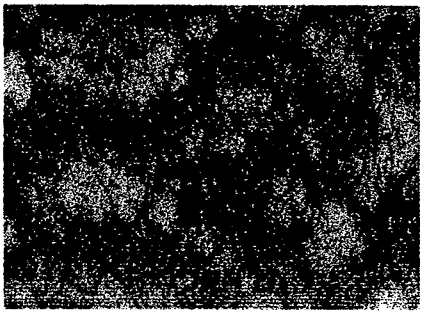

a-Si0.5C0.5:H
C1s
C-C
Si-C
Intensity
292
290
288
286
284
282
280
Binding Energy(eV)

(c)

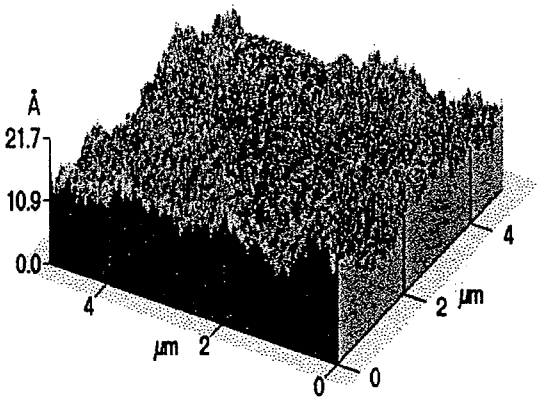

a-Si0.4C0.6:H
C1s
Si-C
C-C
Intensity
290
288
286
284
282
280
278
Binding Energy(eV)

(d)

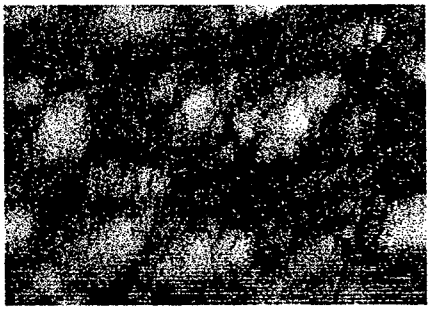
Fig. 2. Y. T. Kim



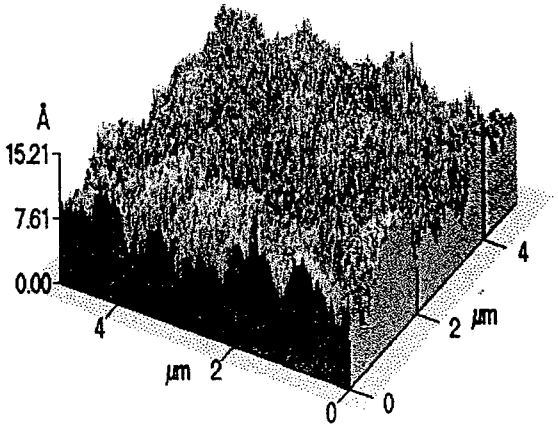
**Average roughness – 1.59 Å**




(a)

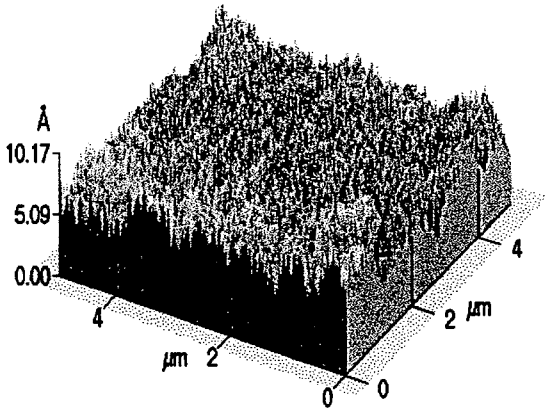


**Average roughness – 1.51 Å**



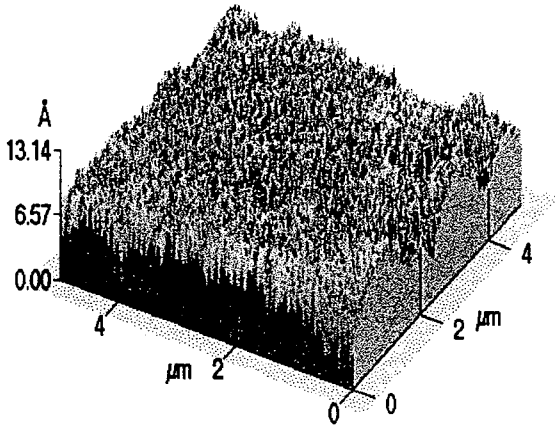

(b)

**Average roughness – 0.92 Å**




(c)

**Average roughness - .099 Å**




(d)

Fig. 3. Y. T. Kim