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P-Doping into Strain-Induced $Si_{1-y}C_y$ Epitaxial Films Grown by Low Temperature Chemical Vapor Deposition

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1.Introduction

The group IV alloys such as $Si_{1-x-y}Ge_xC_y$ and $Si_{1-y}C_y$ are very promising materials for band-gap engineering in Si technology. However the growth of C-containing epitaxial alloy is difficult because of the very low solid solbility of C in Si.

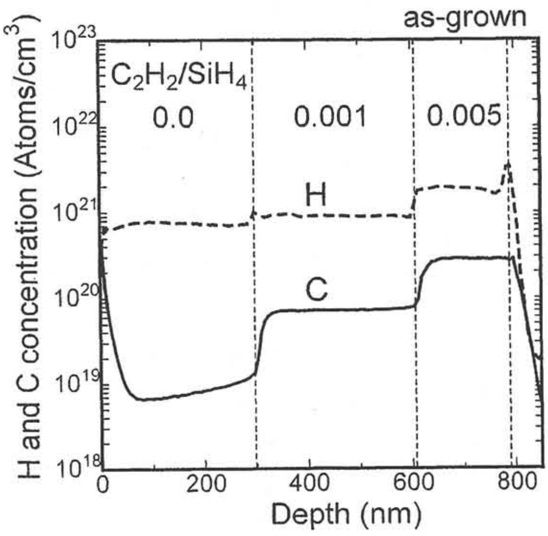
We have investigated $Si_{1-y}C_y$ alloy by using plasma-enhanced chemical vapor deposition (plasma-CVD) and mercury sensitized photo chemical vapor deposition (photo-CVD)[1]. Since the epitaxial growth by these methods proceeds under non-thermal equilibrium conditions, highly C containing alloy can be realized without solid solubility limitation. In this paper, we have obtained the epitaxial $Si_{1-y}C_y$ alloy with high substitutonal C composition higher than 3% at a growth temperature of 200°C. Additionally, *in-situ* P doping was also carried out using PH_3. This paper reviews structual and electrical characteristics of the $Si_{1-y}C_y$ films.

2.Experimental results and Discussion

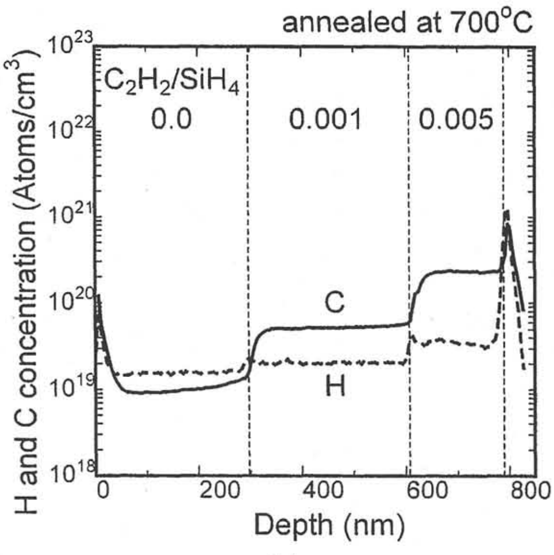
Epitaxial $Si_{1-y}C_y$ layers were grown by the plasma-CVD and the mercury sensitized photo-CVD on Si(001) using a gas mixture of SiH_4 and H_2. The C addition was carried out using C_2H_2, CH_4 or $SiH_2(CH_3)_2$. PH_3 was used as doping gas. The substrate temperature was about 210°C. The growth pressure was maintained at 0.5 Torr.

The epitaxial growth was confirmed by reflection high-energy electron diffraction (RHEED). The structural properties were measured by high-resolution X-ray diffractometry (HRXRD). The distribution of the elements within the films was characterized by secondary ion mass spectroscopy (SIMS). Electrical propaties were determined by Hall mesurement.

Figure 1 shows a SIMS profiles of the H and C concentraton in the undoped epitaxial films. The samples were (a)as-grown and (b)annealed at 700°C. The film was grown by the plasma-CVD and each layer has defferent C_2H_2 addition ratio. It is confirmed that the C content of these films strongly depended on the C_2H_2/SiH_4 ratio. However, H incorporation in the as-grown film also increased with increasing C_2H_2 addition ratio. It suggest that C–H_n bonds are formed in the film. In order to desorb the H in the films, we carried out thermal annealing



(a)



(b)

Figure 1: SIMS profile of the epitaxial film containing three layers. The samples were (a)as-grown and (b)annealed at 700°C.

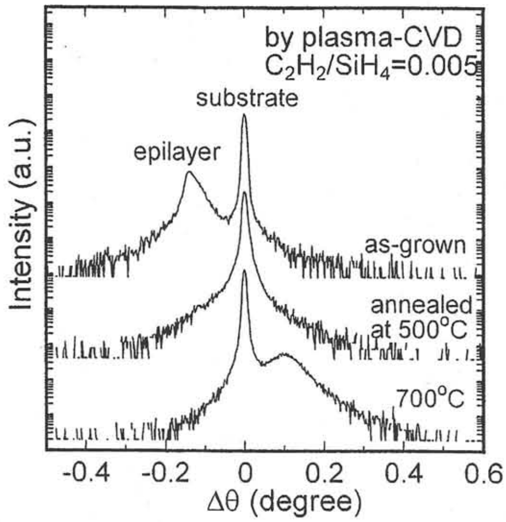


Figure 2: XRD(004) results for as-grown and annealed $Si_{1-y}C_y$ films.

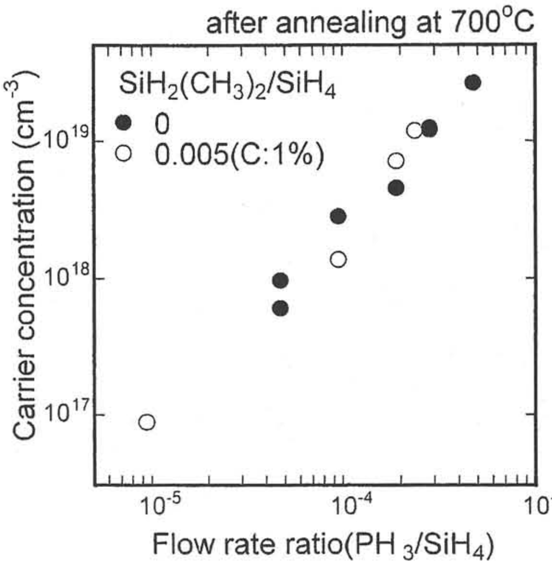


Figure 3: Dependence of the carrier concentration on the PH_3/SiH_4 ratio.

Table I: Maximum C compositions

Source gas	Photo-CVD	plasma-CVD
C_2H_2	2.3%	2.7%
$SiH_2(CH_3)_2$	0.7%	3.5%
CH_4	-	0.4%

in N_2 atmosphere. By annealing, H concentration could be decreased. On the othe hand, there is little difference in the C profiles between the as-grown and the annealed sample.

The XRD(004) patterns are shown in Fig.2. It is expected that the C incorporation into the Si layer should decrease the lattice constant. However, the XRD peak of the epitaxial $Si_{1-y}C_y$ films was shifted to a lower degree compared to the peak of the substrate. This is due to H incorporation into the films[2]. The XRD pattern of the layer annealed at 700°C revealed that the lattice constant was smaller than that of Si. This indicates the formation of $Si_{1-y}C_y$ alloy. Furthermore, we confirmed that the $Si_{1-y}C_y$ layer was pseudomorphically grown on Si substrate by X-ray reciprocal lattice mapping.

The fabrication of $Si_{1-y}C_y$ films was acheaved using several C source gases. Table I shows maximum substitutional C compositions of the obtained films for each combination of C source gases and growth methods. The substitutional C compositions were calculated considering the strain in the films by Vegard's law, which is based on the lattice constants of Si and 3C-SiC. The maximum substitutional C composition of about 3.5 at.% was obtained by plasma-CVD using $SiH_2(CH_3)_2$ gas.

In-situ P doping was carried out using PH_3. C addition was carried out using $SiH_2(CH_3)_2$. In the as-grown films, the carrier concentration of the C-added films were lower than that of Si films. However, after annealing at 700°C, the values of the $Si_{1-y}C_y$ films became the same level of the Si films as shown in Fig.3 which shows the dependence of the carrier concentration of the annealed samples on the PH_3 doping ratio. The open circles and the closed circles indicate the films with and without C addition, respectively. These results suggest the formation of the P, C and H including complexes and suppress a dopant activation by the complex. The P-doped epitaxial $Si_{1-y}C_y$ films were obtained with carrier concentration up to $1\times10^{19}cm^{-3}$.

3. conclusions

Pseudomorphic $Si_{1-y}C_y$ alloy layers were grown on Si by plasma-CVD and mercury sensitized photo-CVD. By deposition at very low substrate temperature of 200°C, we have successfully obtained the epitaxial $Si_{1-y}C_y$ films with high substitutional C composition of 3.5%. *In-situ* P doping was carried out by using PH_3. P-doped epitaxial $Si_{1-y}C_y$ films could be obtained with carrier concentration up to $1\times10^{19}cm^{-3}$.

References

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[2] K. Abe, T. Watahiki, A. Yamada and M. Konagai, Jpn. J. Appl. Phys. 37(1998)1202