B-7-4

P-Doping into Strain-Induced Si<sub>1-y</sub>C<sub>y</sub> Epitaxial Films Grown by Low Temperature Chemical Vapor Deposition

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1. Introduction

The group IV alloys such as Si<sub>1-x-y</sub>Ge<sub>x</sub>C<sub>y</sub> and Si<sub>1-y</sub>C<sub>y</sub> 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 solubility of C in Si.

We have investigated Si<sub>1-y</sub>C<sub>y</sub> 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<sub>1-y</sub>C<sub>y</sub> alloy with high substitutional C composition higher than 3% at a growth temperature of 200°C. Additionally, in-situ P doping was also carried out using PH<sub>3</sub>. This paper reviews structural and electrical characteristics of the Si<sub>1-y</sub>C<sub>y</sub> films.

2. Experimental results and Discussion

Epitaxial Si<sub>1-y</sub>C<sub>y</sub> layers were grown by the plasma-CVD and the mercury sensitized photo-CVD on Si(001) using a gas mixture of SiH<sub>4</sub> and H<sub>2</sub>. The C addition was carried out using C<sub>2</sub>H<sub>2</sub>, CH<sub>4</sub> or SiH<sub>2</sub>(CH<sub>3</sub>)<sub>2</sub>. PH<sub>3</sub> 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 properties were determined by Hall measurement.

Figure 1 shows a SIMS profiles of the H and C concentration 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 different C<sub>2</sub>H<sub>2</sub> addition ratio. It is confirmed that the C content of these films strongly depended on the C<sub>2</sub>H<sub>2</sub>/SiH<sub>4</sub> ratio. However, H incorporation in the as-grown film also increased with increasing C<sub>2</sub>H<sub>2</sub> addition ratio. It suggest that C-H<sub>4</sub> bonds are formed in the film. In order to desorb the H in the films, we carried out thermal annealing.
in N2 atmosphere. By annealing, H concentration could be decreased. On the other 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 Si1-yCy 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 Si1-yCy alloy. Furthermore, we confirmed that the Si1-yCy layer was pseudomorphically grown on Si substrate by X-ray reciprocal lattice mapping.

The fabrication of Si1-yCy films was achieved 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 SiH2(CH3)2 gas.

In-situ P doping was carried out using PH3. C addition was carried out using SiH2(CH3)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 Si1-yCy 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 PH3 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 Si1-yCy films were obtained with carrier concentration up to 1×1019cm^-3.

3. Conclusions
Pseudomorphic Si1-yCy 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 Si1-yCy films with high substitutional C composition of 3.5%. In-situ P doping was carried out by using PH3. P-doped epitaxial Si1-yCy films could be obtained with carrier concentration up to 1×1019cm^-3.

References