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In-situ Doped Si Selective Epitaxial Growth for Raised Source/Drain Extension CMOSFET

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1. Abstract

In-situ doped selective epitaxial Si with high B and As concentrations was grown for PMOSFET and NMOSFET, respectively. The characteristic features of the growth were interpreted on the basis of HCl etching and surface segregation of As.

2. Introduction

Suppression of the short channel effect is a critical issue due to CMOS device scaling. An attractive solution to this problem is to reduce the extension junction depth. A raised source drain extension structure by in-situ doped Si selective epitaxial growth (SEG) has been developed as a promising technique, because an SEG film has an abrupt dopant profile.[1] However, the growth mechanism is unknown because of the complex surface reaction. In this paper, we discuss the growth mechanism for in-situ B- and As-doped Si SEG. We also demonstrate growth of the films with a high dopant concentration.

3. Experimental Procedure

The substrate crystals were CZ Si(100) wafers. SiH_2Cl_2 and HCl were used as reaction gases, and B_2H_6 and AsH_3 were employed as dopant gases. The total pressure was controlled using a conductance valve which was mounted between the chemical vapor deposition chamber and the vacuum pump. The films were analyzed by SIMS, AFM, and XPS.

4. Results and Discussion

Figure 1 shows the B and As concentrations as functions of the B_2H_6 and AsH_3 flow rates under low pressure (LP) and atmospheric pressure (AP), respectively. The B and As concentration increased with an increase in the flow rate of the dopant gases. However, B concentration under LP was higher than under AP, while As concentration under AP was higher than under LP.

Fig. 2 shows the growth rates as functions of the flow rate of the dopant gases. The growth rates of the B-doped films increased with increasing B_2H_6 flow rate under both LP and AP. However, the growth rate of the As-doped films decreased under LP and increased under AP with an increase in the AsH_3 flow rate. Furthermore, the growth rate under LP was higher than that under AP for B-doped SEG, while the growth rate under AP was higher than that under LP for As-doped SEG.

As the growth rate under AP is lower than that under LP by the effects of HCl etching for undoped Si SEG, the B and As concentrations and the growth rates are plotted in Fig. 3 as functions of the HCl flow rate, respectively. The B and As concentrations decreased with increasing HCl flow rate. This indicates that B and As atoms are preferentially etched compared to Si atoms. These results explain the phenomena for the B-doped SEG well, wherein the B concentration and the growth rate under LP are higher than those under AP.

We should take surface segregation into account in order to understand the phenomena for As-doped SEG. Figure 4 shows the depth profiles of the B and As concentration incorporated into the undoped Si layers grown on the doped layer, respectively. The B concentration was under the detection limit, while the As concentration was about 5×10^{17} atoms/cm^3. This is caused by strong surface segregation of As atoms during the growth.

AFM images of the surfaces of the Si layers with B and As concentrations of 5×10^{19} atoms/cm^3 are shown in Figs. 5(a) and (b), respectively. The surface of the B-doped layer is smooth, whereas it is rough for the As-doped layer. Based on analysis of the As-doped films using angle resolved XPS, as shown in Fig. 6, the As concentration on the surface is more than 1%. This indicates that the surface roughness of the As-doped layer is due to surface segregation of As atoms. It is understood that a high As concentration at a high growth rate under AP, as shown in Figs. 1 and 2, is caused by suppression of As surface segregation due to the strong etching effect of HCl under AP. [2-3]

In order to reduce surface segregation of As atoms, the effects of the growth rate and temperature were investigated. Figure 7 shows the dopant concentration and the growth rates as functions of the SiH_2Cl_2 flow rate. The B concentration increased as the SiH_2Cl_2 flow rate decreased, while the As concentration increased as the SiH_2Cl_2 flow rate increased. This is due to suppression of surface segregation of As caused by the high growth rate. Figure 8 shows the dopant concentration and the growth rates as functions of the temperature. The B concentration increased as temperature increased. However, the As concentration decreased with increasing temperature. We speculate that this is due to desorption of surface As atoms.[4] This indicates the suppression of the surface segregation of As.

By the optimization of the growth rate and temperature, we achieved Si layers with high B and As concentrations of 2.3×10^{20} and 7.5×10^{19} atoms/cm^3, respectively.

5. Conclusions

We investigated the characteristics of in-situ doped Si SEG. The growth mechanism was discussed in terms of the etching effect and the surface segregation of As. By optimizing the growth conditions based on these interpretations, we achieved high B and As concentrations of 2.3×10^{20} and 7.5×10^{19} atoms/cm^3, respectively.

References

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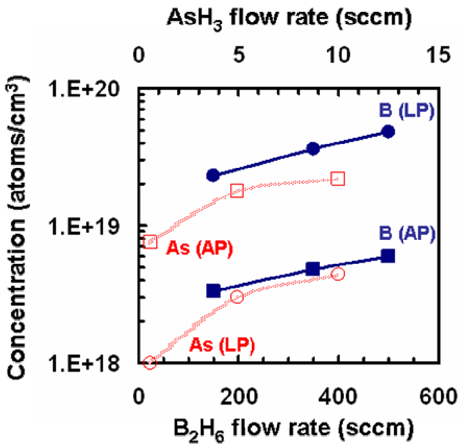

Fig. 1 B and As concentration as functions of the B_2H_6 and AsH_3 flow rate under LP and AP, respectively.

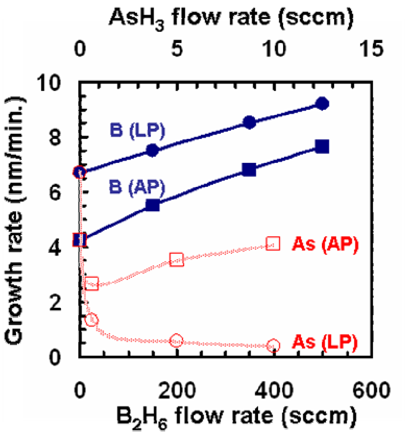

Fig. 2 The growth rates as functions of the B_2H_6 and AsH_3 flow rates under LP and AP, respectively.

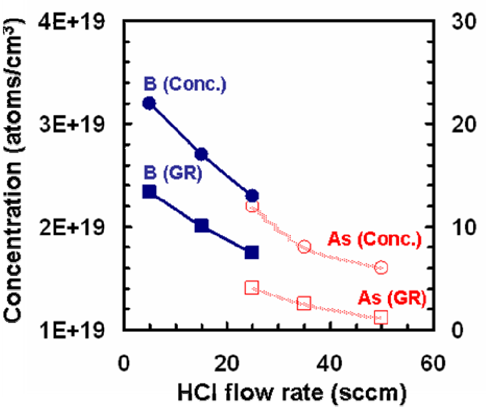

Fig. 3 B and As concentration and growth rates as functions of the HCl flow rate, respectively.

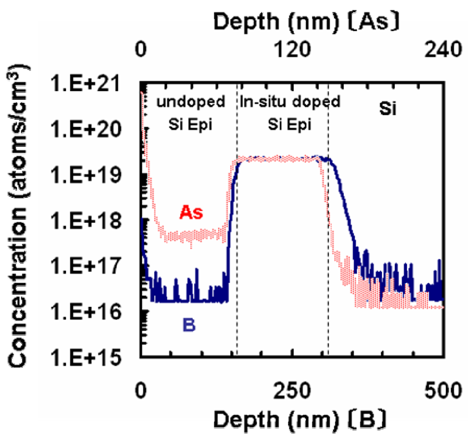

Fig. 4 Depth profiles of the B and As concentration incorporated into the undoped Si layers grown on the doped layer, respectively.

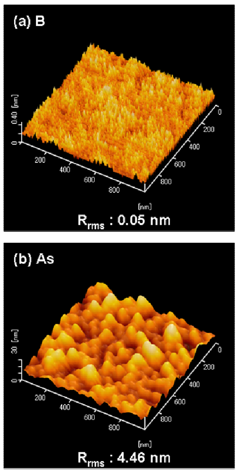

Fig. 5 AFM images of the surfaces of Si layers with (a) B and (b) As concentration of 5×10^{19} atoms/cm^3.

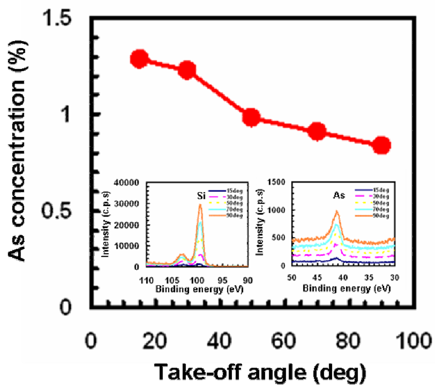

Fig. 6 Angle resolved XPS of the As-doped films.

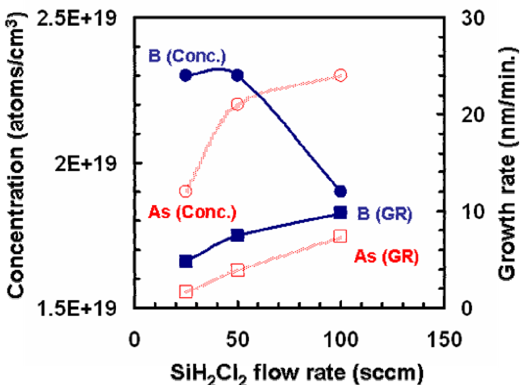

Fig. 7 B and As concentration and growth rates, respectively, as functions of the SiH_2Cl_2 flow rate.

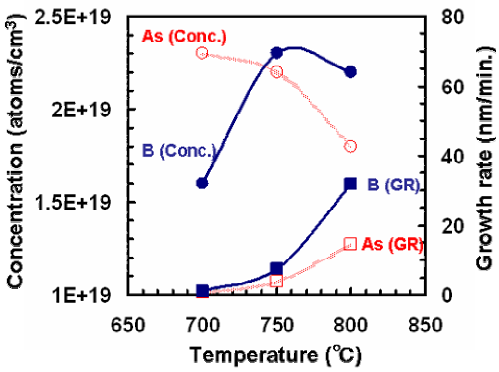

Fig. 8 B and As concentration and growth rates, respectively, as functions of temperature.