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# Ge Selective Growth in Micron and Submicron Trenches with UHV-CVD

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## 1. Introduction

Ge is an indispensable material in silicon photonics because its direct bandgap energy corresponds to 1.55μm light and it can be processed with Si-CMOS technology. Recently many Ge optical devices have been reported, such as modulator[1] , detector [2] and laser [3]. These Ge devices were made by selective epitaxial growth (SEG). SEG is an indispensable process for device fabrication. However, Ge-SEG is not well understood compared to III-V compounds[4] or Si [5]. Facet formation and growth species migration occur in SEG of these materials, so the epi-layer height is different from non-SEG layer. In Ge SEG, these phenomena should occur because Ge SEG is similar to Si SEG[6]. From these reasons the purpose of this research is to understand the mechanism of Ge-SEG in narrow areas, focusing on the Ge width and height, such as facet formation and growth species migration.

## 2. Experiments

We used a 4-inch (100) surface p-Si wafer, 525μm thick with 150nm $SiO_2$ layer. Then we made trenches on the $SiO_2$ layer to expose Si with electron beam lithography and reactive ion etching ($CHF_3$). The trench width ranged from 0.5~100μm, along with the <110> direction. At last we grew Ge by ultra-high-vacuum chemical vapor deposition (UHV-CVD) at 600ºC for 110 min. using $GeH_4$ gas. Before the growth, we grew pure Ge at 370℃ as a buffer layer. After the growth we observed the cross-sectional view of Ge by scanning electron microscopy (SEM).

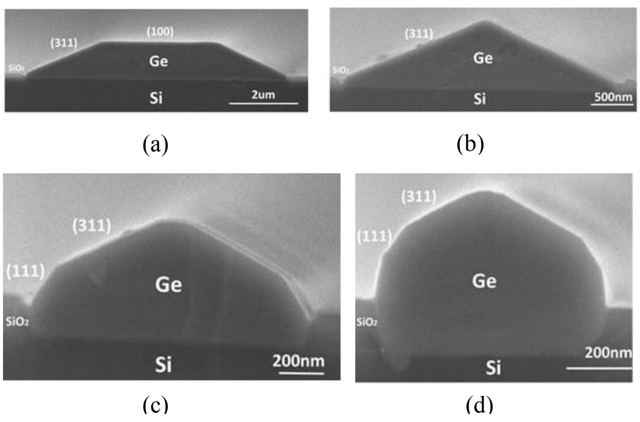


Fig. 1: Cross-sectional view of SEG-Ge by SEM
(a): 7.5μm wide (b): 3.5μm wide (c): 1.0μm wide (d): 0.6μm wide

## 3. Results

Fig. 1 shows that the Ge shape changes from mesa to tetragonal through triangle with narrowing Ge width, and Ge height becomes lower. Fig. 2 shows the Ge height as a function of the Ge width.

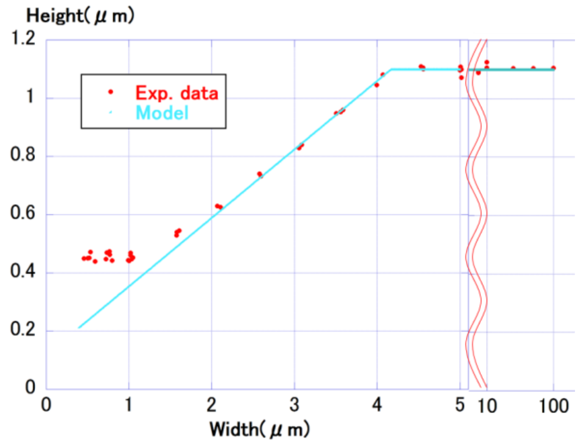


Fig. 2: Ge Width and Height

The Ge height is constant (1.1μm) when the Ge width is wider than 4μm. This is because the Ge shape is mesa in the wider cases and the height is defined by the mesa height. The mesa height is identical to that of the blanket Ge layer.

The Ge height decreases in proportion to the width despite of the same growth time when the Ge width is narrower than 4μm. This is because the (100) plane disappears and the (311) facets dominate Ge height in the narrower cases. The Ge shape is triangle in the narrower cases and the triangle height is proportional to the width. Along with the triangle height, growth on (311) facet is also the factor to determine the Ge height. From the growth mechanism, we made a formula of Ge height.

$$H = \frac{\tan\theta_{311}}{2} \times W + \frac{GR_{311}}{\cos\theta_{311}} \times t. \qquad (1)$$

*H* and *W* mean the Ge height and width respectively. $\theta_{311}$ is 25.2°, i.e., the angle between Si (100) surface and Ge (311) facet. $GR_{311}$ is the growth rate on the (311) facet and *t* means the growth time. The solid line in Fig. 2 shows this formula, assuming 1.0 nm/min as $GR_{311}$. The formula fits the experimental data well when the width is wider than 2μm, but the formula does not fit the data when the width is narrower than 2μm. This is because we assumed that $GR_{311}$ was constant in Eq. (1), but actually $GR_{311}$ is faster in narrower cases.

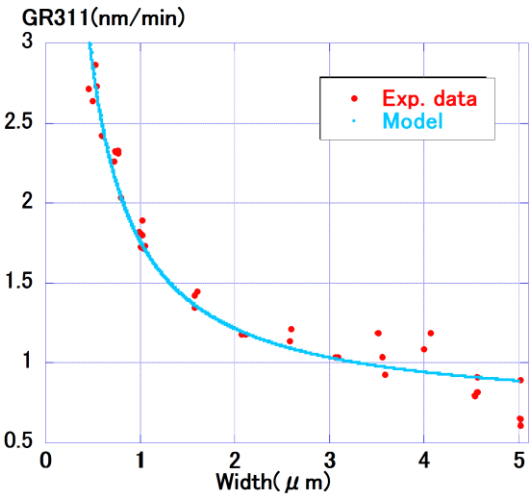


Fig. 3: Ge width and $GR_{311}$

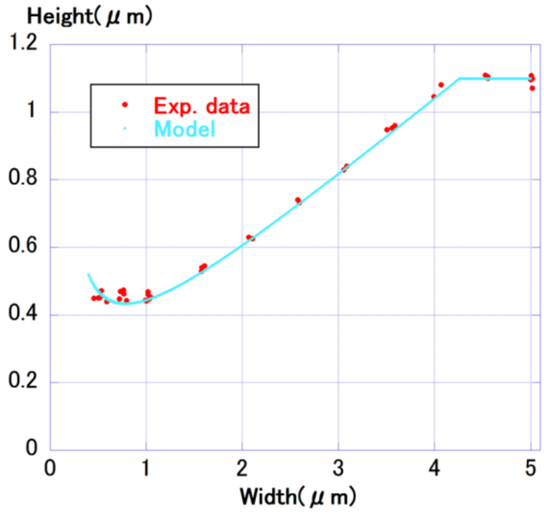


Fig.4: Final model of Ge height

Fig. 3 shows the Ge width and $GR_{311}$. We calculated $GR_{311}$ by dividing Ge thickness on (311) by growth time. This suggests that $GR_{311}$ would be inversely proportional to Ge width. Generally in CVD growth, growth rate is the same in all cases because chamber flux is constant. To explain Fig. 3, we made a model that Ge atoms or $GeH_x$ migrated from $SiO_2$ in addition to the chamber flux. The trench in this model is 1cm long and $W$ cm wide. We assumed that the $SiO_2$ height did not affect growth rate. In this experiment, the gap between trenches is 100μm so that it is much wider than trench width. Thus we assumed that the number of Ge atoms migrating from $SiO_2$ into the trench is constant ($Ge_{SiO2}$). Since the trench area is $W$ cm$^2$ and the chamber flux is $F_{chamber}$ cm$^{-2}$, total Ge atoms ($Ge_{all}$) are

$$Ge_{all} = F_{chamber} \times W + Ge_{SiO_2}. \quad (2)$$

By dividing total Ge atoms by trench area ($W$ cm$^2$), we obtain the number of Ge atoms per width ($Ge^{\circ}$) as below.

$$Ge^{\circ} = F_{chamber} + \frac{Ge_{SiO2}}{W}. \quad (3)$$

In a high vacuum condition, $GR_{311}$ is proportional to $GeH_4$ pressure [7]. Thus we assumed that $GR_{311}$ is proportional to the number of Ge atoms on (311). From this assumption, we fit Eq. (3) to the experimental data and obtain $GR_{311}$ as below.

$$GR_{311(nm/\min)} = 0.67 + \frac{1.09}{W}. \quad (4)$$

The solid line in Fig. 3 shows Eq. (4). This good fitting strongly suggests that the Ge migration model is right. We applied Eq. (4) to Eq. (1) , and the final model is as Fig. 4.

## 4. Discussion

In Eq. (4), the first term corresponds to the chamber flux and the second term corresponds to Ge atoms from SiO2. If the width is 0.8μm, the ratio is 1:2.

This means that Ge atoms migrating from $SiO_2$ contribute to growth twice more than chamber flux in a 0.8μm trench. Thus we can say Ge from $SiO_2$ should not be negligible in submicron wide Ge-SEG with UHV-CVD. Since we need submicron scale Ge to fabricate single mode optical devices, we have to know the behavior of Ge on $SiO_2$.

In [8] the ratio of $GR_{100}$ : $GR_{311}$ is reported1:0.58, but in our growth system the ratio is 1:0.1~0.3. We considered this is because the pressure of $GeH_4$ is lower than [8].

## 5. Conclusion

We have studied Ge SEG with UHV-CVD using $SiO_2$ mask. Ge height is lower in narrower trenches because of facet formation. In narrower trenches Ge height is higher than our prediction due to Ge migrating from $SiO_2$. The Ge migration model strongly suggests that Ge migrating from $SiO_2$ should not be negligible in submicron wide Ge-SEG with UHV-CVD. This is very important to fabricate submicron scale Ge devices.

## Acknowledgement

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