Vol 16 No 11, November 2007
1009-1963/2007/16(11)/3470-05

Chinese Physics

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# Island-growth of SiCGe films on SiC*

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(Received 9 January 2007; revised manuscript received 22 June 2007)

SiCGe ternary alloys have been grown on SiC by hot-wall low-pressure chemical vapour deposition. It has been found that the samples exhibit an island configuration, and the island growth of SiCGe epilayer depends on the processing parameters such as the growth temperature. When the growth temperature is comparatively low, the epilayer has two types of islands: one is spherical island; another is cascading triangular island. With the increase of the growth temperature, the islands change from spherical to cascading triangular mode. The size and density of the islands depend on the growth duration and $GeH_4$ flow-rate. A longer growth time and a larger $GeH_4$ flow-rate can increase the size and density of the island in the initial stage of the epitaxy. In our case, The optimal growth for a high density of uniform islands occurred at a growth temperature of 1100°C for 1-minute growth, with 10 SCCM $GeH_4$, resulting in a narrow size distribution (about 30 nm diameter) and high density (about $3.5 \times 10^{10}$ dots/cm$^2$). The growth follows Stranski–Krastanov mode (2D to 3D mode), both of the islands and the 2D growth layer have face-centred cubic structure, and the critical thickness of the 2D growth layer is only 2.5 nm.

**Keywords:** SiC, SiCGe, island-growth, hot-wall low-pressure chemical vapour deposition
**PACC:** 6150C, 6855

## 1. Introduction

SiC is not sensitive to most of the visible lights and all the near-infrared lights, and essentially sets a limitation to its scope of opto-electronic applications. The ternary alloy SiCGe with an appropriate composition was suggested as the light-sensitive base layer of a SiC-based light-activated Darlington transistor.[1] In comparison with SiGe/Si and SiCGe/Si heterojunctions, the SiCGe/SiC heterojunction structure has been less studied up to now, although a group at the University of Delaware has published an application of Si–C–Ge alloy in SiC hetero-structure bipolar transistors(HBT).[2] However, the Ge content in their Si–C–Ge ternary alloy is only a few percent because of the solution limitation, which may not be enough to reduce the band-gap to meet the need of application in the visible and infrared range. Nevertheless, the feasibility of growing SiCGe alloys with higher Ge content on SiC substrates has been initially confirmed by our recent work.[3]

The island structures have become an interesting subject in fabrication of quantum dots or nanowires in lithography-free nanoscale devices.[4−13] Many observations on island growth of, for example, Ge and rare earth metal silicides on Si have been published.[14,15] In our work, we found that the growth of SiCGe also has an island growth configuration, which depends on the growth temperature, growth time and gas flow-rates. In this paper, we mainly investigate the surface morphology and interior structure of the SiCGe films under different growth conditions.

## 2. Experimental

Three groups of SiCGe islanded samples were prepared by means of hot-wall low pressure chemical vapour deposition. After an appropriate clean procedure, the SiC substrates were immediately loaded into the growth chamber to be pumped down to $1 \times 10^{-3}$ Pa. Before growth, the substrates were treated in $H_2$ atmosphere at a high temperature of 1250°C for 10 min. Afterward, the samples were grown under different growth conditions.

The growth pressure was maintained by a rotary pump during the growth process. In a typical case, the total pressure was 260 Pa with flow-rates of 30, 20, 10 and 1000 sccm for $SiH_4$(10% in $H_2$), $GeH_4$ (5% in $H_2$), $C_3H_8$ (10% in $H_2$) and $H_2$, respectively. The

*Project supported by the National Natural Science Foundation of China (Grant No 60376011) and the Specialized Research Fund for the Doctoral Program of High Education, China (Grant No 20040700001).
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experimental apparatus and the basic growth conditions used in this work has been presented in details in our earlier work.[3]

To investigate the surface morphology and the interior structure, the samples were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and x-ray photoelectron spectroscopy (XPS).

## 3. Results and discussion

Figure 1 shows the SEM images of the SiCGe samples grown at different temperatures from 980°C to 1060°C. All the samples were grown for an hour. It is clearly seen from Fig.1(a) that the sample grown at 980°C has two types of island structures: One is spherical island structure; another is cascading triangular island structure. The former, which is dominant in the epilayer, has a regular shape with a diameter of 0.3–1 $\mu$m. The latter is of a small amount, and has two main growth orientations which make a 180° deviation angle between them. The cascading triangular islands rise above the background regions, but are lower than the spherical islands.

As the growth temperature increases to 1030°C (Fig.1(b)), the amount of the spherical island reduces, while that of the cascading triangular island increases. For the growth temperature up to 1060°C, basically a relatively flat two-dimensional (2D) growth front is observed. No formation of spherical island is detected on the sample surface. However, the cascading triangular islands are still observed, which are also oriented like the sample grown at 980°C.

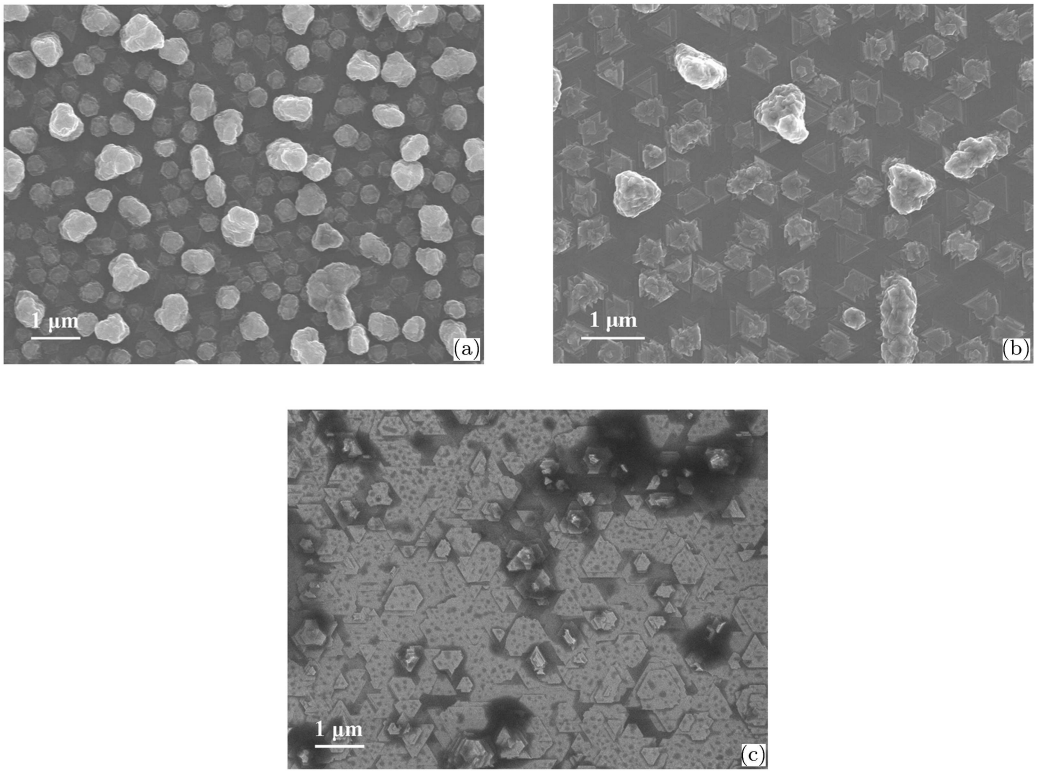



**Fig.1.** SEM images of the SiCGe samples grown at different temperatures. (a)980°C, (b) 1030°C, (c) 1060°C.

As is well known, the spherical 3D island is produced by the great mismatch strain between the substrate and epilayer. When the mismatch strain is relatively small, the growth will change from 3D to 2D. If the mismatch strain still exists in the 2D epilayer, the stacking faults will produce, and the cascading triangular island, i.e. the outcrop of the stacking fault, will also produce. At high temperatures, the SiC phase is more stable than the SiCGe phase, hence the Ge content decreases in the SiCGe epilayer, which reduces the mismatch strain between the epilayer and the substrate, and thus enhances the 2D growth and makes the island mode changing from spherical to cascading triangular island.

Although the island growth mode was observed in SiCGe ternary films, the idiographic growth state is still unclear. The nucleation and initial growth are the important stages of the island growth, and are also the important periods to investigate the growth mode and the interior structure, therefore the growth time is reduced to less than 10 min to observe the epitaxial situation of the starting of growth.

As shown in Fig.2, the growth durations of these four samples are 40 s, 50 s, 3 min, 10 min, respectively. Islands are present in all the growth layers except the one grown for 40 s. Note that as the duration increases, the islands become larger gradually (from 400 nm to 5 $\mu$m). Meanwhile, the island density increases rapidly till the islands begin to coalesce.

The sample grown for 40 s has no island on the inhomogeneous surface, as shown in Fig.2(a). When the growth time extends to 50 s (Fig.2(b)), islands can be observed but the size of them is under 500 nm. Comparing this two images, we see that the nucleation stage of the self-organized island is fugacious, which is about 10 s. As the growth time is much longer, the islands are large enough, they then coalesce and the island density decreases obviously. It can be clearly seen that coalescence of the neighbouring islands has taken place in the sample grown for 10 min.

It is obvious that the island sizes are different, as shown in Figs.2(b) and 2(c). We believe that these islands of different sizes are produced in different growth stages. The smaller ones with a diameter of 500 nm are in the nucleation stage, while the greater ones have finished the nucleation stage and continue to grow up.

Because the presence of Ge in the SiCGe films can change the epitaxial state, it is important to discuss the influence of the $GeH_4$ flow-rate on the properties of SiCGe ternary alloys. Therefore, we change the $GeH_4$ flow-rate from 0 to 20 sccm while keeping the other growth parameters unchanged.

All the four samples grown at different $GeH_4$ flow-rates demonstrate the island growth configuration, as shown in Fig.3. When $GeH_4$ is not incorporated in or the flow-rate is as low as 5 sccm, both the island size and density are very small. As the $GeH_4$ flow-rate increases to 10 sccm, the sample has the highest island density (about $3.5 \times 10^{10}$ dots/cm$^2$), the smallest island size (about 30 nm in diameter) and the best uniformity in size. But when the $GeH_4$ flow-rate increases again, the density of islands drops and the size of islands increases rapidly, as shown in Fig.3(d).

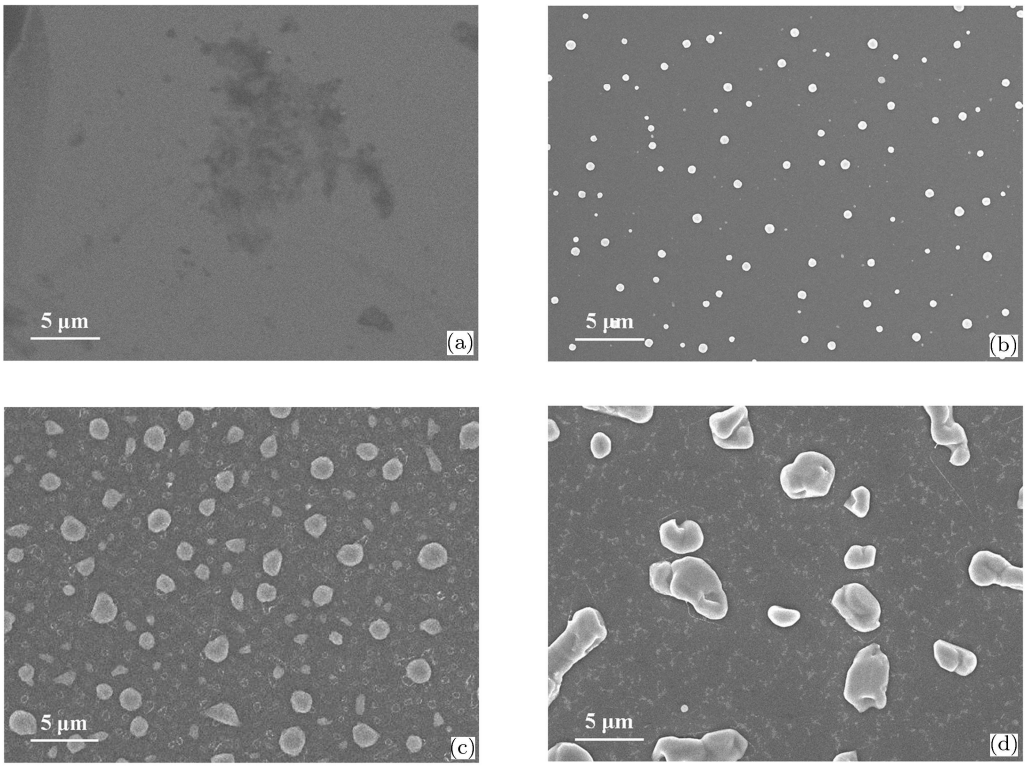



**Fig.2.** SEM images of the samples grown for different times. (a) 40 s, (b) 50 s, (c) 3 min, (d) 10 min.

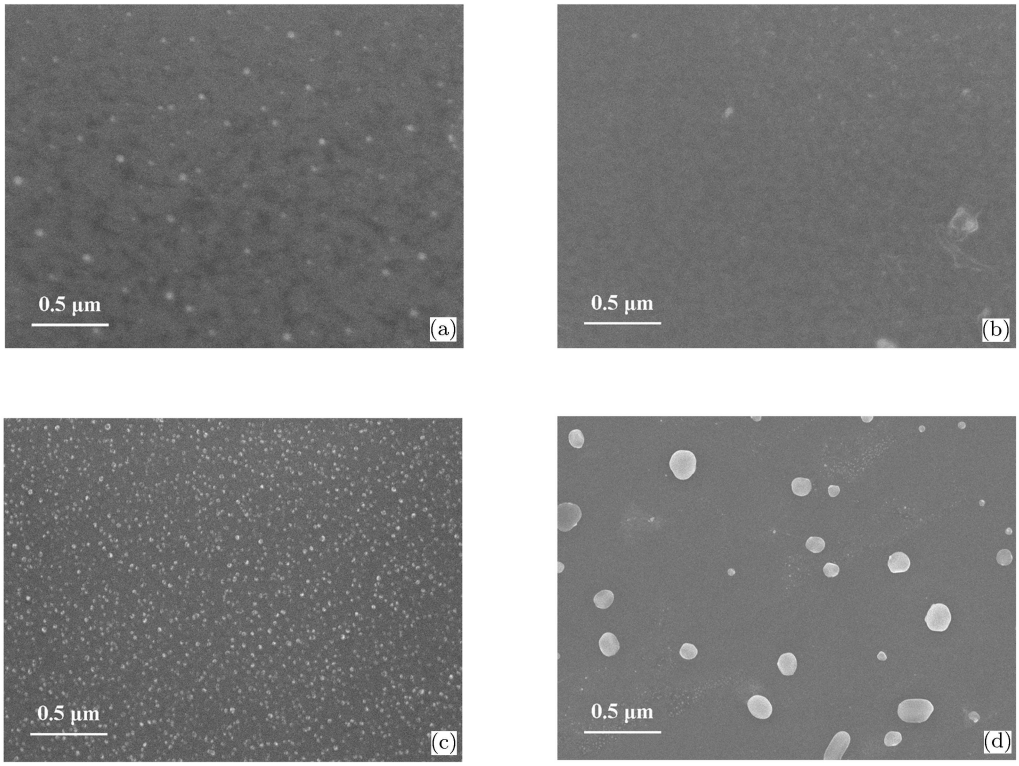



**Fig.3.** SEM images of the samples grown at different $GeH_4$ flow-rates. (a) 0 sccm, (b) 5 sccm, (c) 10 sccm, (d) 20 sccm.

It seems that the surface morphology of the epilayer grown without $GeH_4$ is similar to that of the one grown at 5 sccm $GeH_4$. In the growth, the $GeH_4$ cannot thermally decompose completely, and only part of the decomposition-released Ge atoms can be adsorbed onto the SiC substrate and take part in the epitaxy. Therefore, as the $GeH_4$ flow-rate is very low, the part of $GeH_4$ that participates in the growth is much less. The small content of Ge cannot affect the growth effectively, so there is no obvious difference in the SEM images of these two samples. This is also confirmed by the XPS measurement, the Ge content in the sample grown with 5 sccm $GeH_4$ is only 0.3%, which is too small to influence the epitaxy, as shown in Table 1.

The samples grown at the $GeH_4$ flow-rates of 10 and 20 sccm have different island morphologies, as shown in Figs.3(c) and 3(d). The islands of the sample grown at 10 sccm $GeH_4$ have a small size and a high spatial density, while the sample grown at 20 sccm $GeH_4$ has the results contrary to the former. We find that the island density increases as the $GeH_4$ flow-rate increases at a relatively low flow-rate; while the island density decreases with increasing $GeH_4$ flow-rate when the $GeH_4$ flow-rate is high. It is thus concluded that more Ge atoms from the decomposition of $GeH_4$ can participate in the epitaxy as the $GeH_4$ flow-rate increases when it is comparatively low; and the Ge atoms adsorbed can induce mismatch stress, enhance 3D island formation and increase the island density rapidly. As more Ge atoms take part in the growth, the island size becomes large and the islands coalesce, and then the island density decreases accordingly.

**Table 1.** XPS results of the composition of samples grown at different $GeH_4$ flow rates. (a) 0 sccm, (b) 5 sccm.

| (a) | Element | wt% | At% | (b) | Element | wt% | At% |
|---|---|---|---|---|---|---|---|
| | C | 31.91 | 48.59 | | C | 33.78 | 50.88 |
| | Si | 53.74 | 35.00 | | Si | 50.74 | 32.69 |
| | Ge | 0.00 | 0.00 | | Ge | 1.21 | 0.30 |
| | O | 14.35 | 16.41 | | O | 14.27 | 16.13 |

Figure 4 shows the high-resolution transmission electron microscopic (HRTEM) image of the sample grown at 10 sccm $GeH_4$. It is confirmed that the growth of SiCGe film on SiC follows the Stranski–Krastanov mode (2D to 3D mode) and the self-organized island will form when the epilayer thickness exceeds a few monolayers. This sample has smooth and sharp interface between the SiC substrate and

the SiCGe epilayer. The 2D growth layer has good epitaxial connection with the substrate, whose critical thickness is only 2.5 nm. Both the islands and the 2D growth layer have face-centred cubic structure. There is a 45°-deviation angle between the islands and the 2D growth layer in the epitaxial orientation.

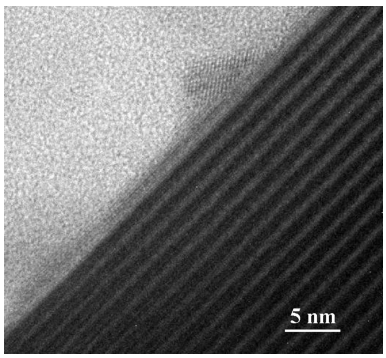



**Fig.4.** HRTEM image of the sample grown at 10 sccm $GeH_4$ flow-rate.

## 4. Conclusions

SiCGe ternary alloys have been grown on SiC by hot-wall low-pressure chemical vapour deposition. It has been found that the samples obtained exhibit an island configuration. When the growth temperature is comparatively low, the epilayer has two types of islands: one is spherical island, another is cascading triangular island. With the increase of the growth temperature, the amount of the spherical islands reduces, while that of the cascading triangular islands increases. When the growth temperature increases to 1060°C only cascading triangular islands are observed on the surface of the epilayer. The size and density of the islands depend on the growth duration and $GeH_4$ flow-rate. As the growth time increases, the islands become larger gradually; meanwhile, the island density increases rapidly till the islands begin to coalesce. When the $GeH_4$ flow-rate increases at a relatively low $GeH_4$ flow-rate, the island density increases; while the island density decreases with increasing $GeH_4$ flow-rate for the high $GeH_4$ flow-rate. The growth follows Stranski–Krastanov mode (2D to 3D mode), both of the islands and the 2D growth layer have face-centred cubic structure.

## Acknowledgments

The authors would like to thank Dr Wang Ning at the Hong Kong University of Science and Technology, Mr. Liu Shou-Zhi, Lu Zheng-Xin, Chen Di-Chun and Li Ying at Xi'an University of Technology for their assistances in material characterization.

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