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# Surfactant Epitaxy of Si on Si (111) Activated by Sn

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Surfactant epitaxy of Si on Si(111)7×7 surface covered with a Sn layer is studied. Si grows on the Si(111), which is covered by a Sn monolayer and forms the $\sqrt{3}\times\sqrt{3}$ structure, by the step flow above 330°C, while Si grows on the clean Si(111)7×7 surface by the islanding below 500°C. The Si atoms deposited on the Sn layer are incorporated the bulk Si layer so that the surface is covered always by the Sn layer and the growth by step flow continues as well.

## 1. INTRODUCTION

Copel et al.[1] have reported surfactant epitaxy of Si on Ge or Ge on Si(100), where As(Arsenic) atoms covering the substrate surface change the surface strucutre from the 2×1 dimer structure to a 1×1 structure to promote the epitaxy of the deposit film. The surface active agent, then, works as a mediate layer which control the adsorption, diffusion and nucleation of the deposit atoms. The surfactant epitaxy, therefore, is an useful method to form an epitaxial films of high perfection, similar to the migration enhanced epitaxy[2]. Our issue in the present study is to find if any surfactant can change the islanding to step flow at a lower epitaxial temperature, because the growth by step flow results in an epitaxial layer with the highest perfection.

It is well known that Si(111) surface covered by metal atoms of a monolayer level has a specific surface phases localized at the very surface region[3]. Such surface layers, which are formed even when no alloy phases exist between the metal and Si in the bulk, are more stable than the 7x7 surface, and may act as the surfactants for the epitaxial growths of Si and Ge. We have examined the growth of Si on Si(111) with the surfactant of Sn. Since Sn is reported to form the $\sqrt{3}\times\sqrt{3}$ structure on the Si(111)[4] and is the group VI material of low melting temperature, forming eutectic with Si.

## 2.EXPERIMENTRAL

We have used a high-resolution UHV electorn microscope[5]. The growths of Si on Si(111) with and without surfactant Sn have been observed in-situ by reflection electron microscopy, being recorded on videotapes or on photographic films. Si is evaporated by electron bombardment to keep a constant deposition rate around 0.05ML/min. Sn is evaporated using a tungsten wire by register heating.

## 3. RESULTS and DISCUSSION

A growth sequence of Si on the Si(111)7×7 surface is shown in fig.1, which reveals that step flow occurs at above 500°C of the substrate temperature. The morphology of the surface steps changes as the deposition proceed: Smooth and slightly curved is the each step line of the Si(111)7×7 surface which was cooled gradually from 1200°C(fig.1(a)), while one becomes zigzag and wavy (because each step line consists of segments along ⟨110⟩ directions) after the Si growth(fig.1(b)). At this temperture range Si grows by step flow on the surfaces activated by Sn(fig.2). As seen in fig.2 of reflection electron microscope images of the growth process, the steps of the Sn covered surface of the $\sqrt{3}\times\sqrt{3}$ structure are smoother and less zigzag than the uncovered Si surface(fig.2(a)).

Furthermore the morphology has not changed much after the growth of Si(fig.2(b)), the growth being continued as well. Such step flow has occurred even at 380°C, as shown in fig.3. Thus, the epitaxial temperature for the step flow reduces from 500°C by the surfactant. The most striking result is that the structure of the surface remains to be the same $\sqrt{3}\times\sqrt{3}$ structures as the beginning. The Si atoms deposited on the surface of the $\sqrt{3}\times\sqrt{3}$ structure, therefore, diffuse through the Sn layer to form a Si-on-Si epitaxial layer under the Sn layer (at the step edge) so that the Sn layer locates always at the outer-most surface. The mechanism of the exchange between the Si and Sn atoms remains tobe a very interesting issue.

The epitaxial temperture depends on the step distance (terrace width) and also on deposition rate. We investigated the relationship between step distance, $\lambda$ and the critical substrate temperature $T_C$, above which the island growth turns to the step flow: $T_C$ increases as $\lambda$ increases. As will be reported elsewhere, we have obtained a relation, $\lambda^2 = A\exp(-E/T_C)$. The value of E preliminary derived is 0.75 eV for Si/Si, while 2.99 eV for the Sn activated surface. The large activation energy for the Sn covered surface is the characteristics of the surfactant, and which may be due to the exchange process of Sn and Si atoms deposited.

The surfactant epitaxy, thus, enables us to controll the epitaxy, and to copy the morphology of the substrate. The structure and defects of the epitaxial layer can be well defined because of the nature of the growth process, and may applicable for the formation of a well-defined and defect-less inteface layer of a homogeneous thickness.

## REFERENCES


1) M.Copel, M.C.Renter, Efthimios Kaxiras and R.M.Tromp. Phys. Rev. Lett. 63(1989) 632.

2) Y.Horikoshi, M.Kawashima and H.Yamaguchi. Jpn. J. Appl. Phys. 25(1986) L868.

3) K.Takayanagi, Y.Tanishiro, T.Ishitsuka and K.Akiyama. Appl. Surface Sci. 41/42(1989) 337.

4) T.Ichikawa. Surface Sci. 140(1984) 37.

5) K.Takayanagi, Y.Tanishiro, K.Kobayashi, K.Akiyama and K.Yagi. Jpn. J. Appl. Phys. 26(1987) L957.


a

b

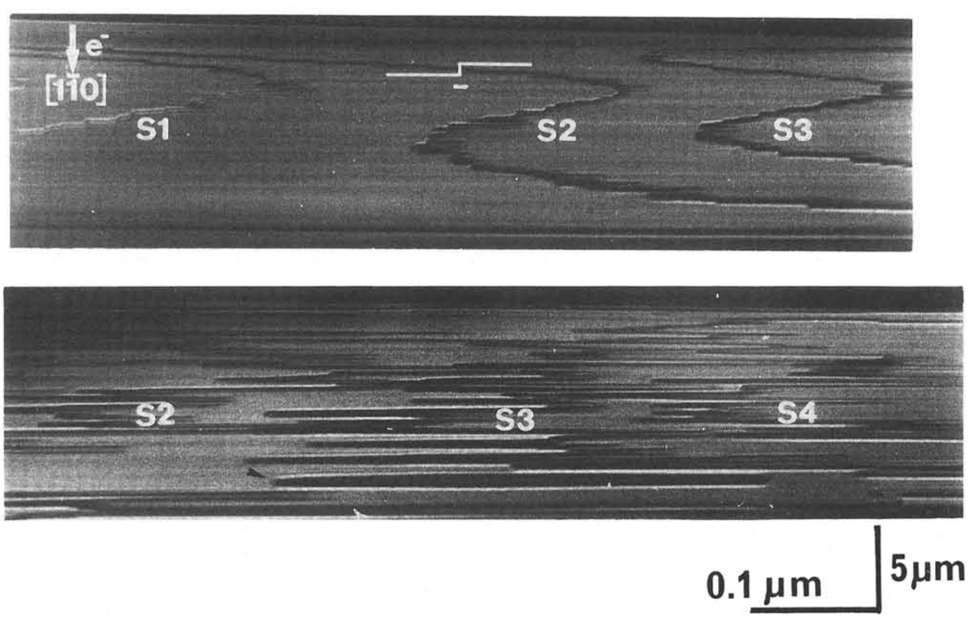


**Fig.1** Growth of Si on the clean Si(111)7×7 surface at 500°C, (a) before the deposition and (b) after the deposition. Note step flow.

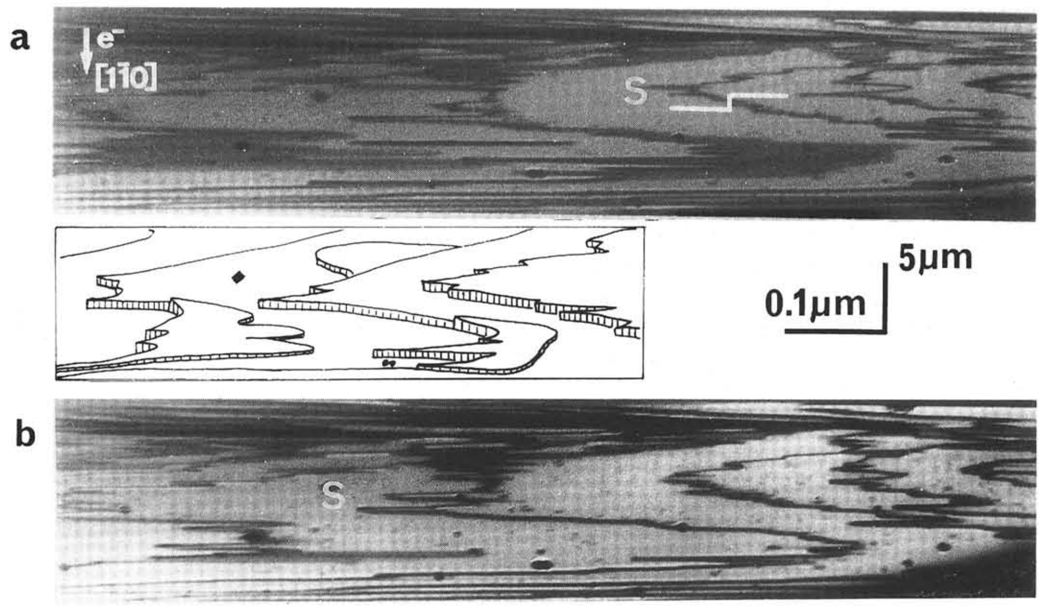


**Fig.2** Growth of Si on a Sn covered Si(111) surface at 500°C, (a) before the deposition and (b) after the deposition. Note step flow.

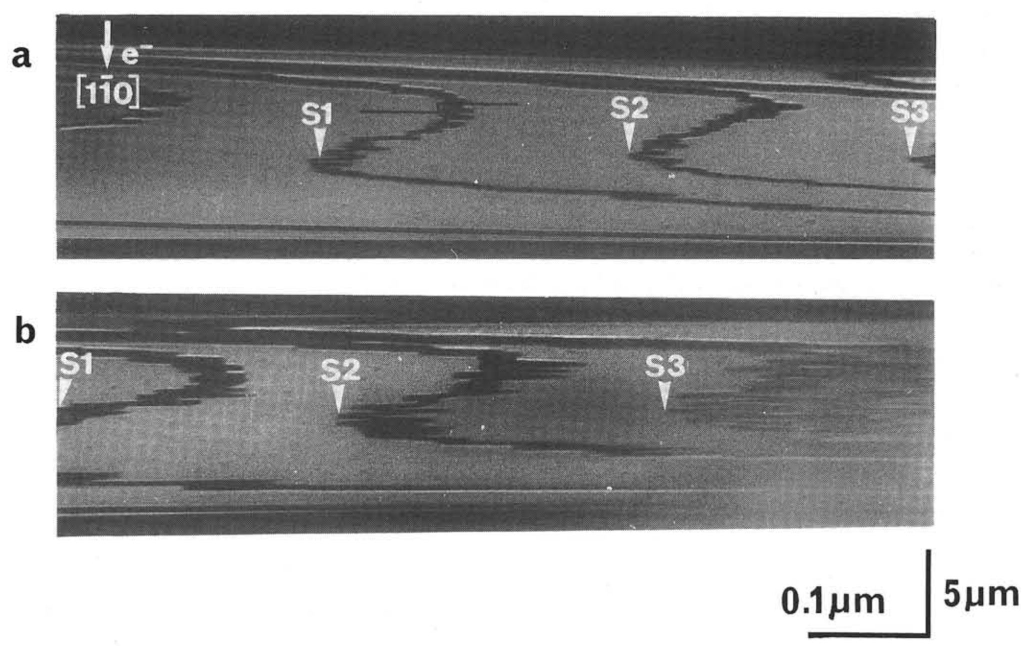


**Fig.3** Growth of Si on a Sn covered Si(111) surface at 380 °C,(a)before and (b) after the deposition. Note that no nucleation has occurred on the terraces.