Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp. 183-186

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Seed Shape Dependence of Si Solid Phase Epitaxy

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A new facet formation mode in Si lateral solid phase epitaxy (L-SPE) of amorphous Si on SiO_2 is presented. This mode occurs in the case of L-SPE using a two-dimensional seed area. Depending on whether the seed shape is convex or concave, a slowly growing {111} facet or a fast growing {110} facet dominates in the case of {100} Si substrate. This phenomenon can be explained using a microscopic model of crystallization. Similar results are obtained for seeds surrounded by an SiO_2 layer and seeds surrounding an SiO_2 island, which have to be taken into consideration in practical device design.

1. Introduction

Si lateral solid phase epitaxy (L-SPE) on SiO_2 film[1,2] is one of the most promising methods for realizing silicon-on-insulator (SOI) structures. The crystallinity of the SOI layer was verified to be suitable for device application by fabricating MOSFET's.[3,4] In addition, L-SPE's high reproducibility and low process temperature are compatible with fabrication processes for sub-micron ULSI's.

Crystal growth mechanism of L-SPE has been investigated, and two types of facet formation have been reported. One is either {110} or {111} facet formation at the SiO_2 edge.[2] and the other is {111} facet formation at the growth front of the L-SPE layers. Facet formation is due to a strong dependence of SPE growth rate on crystalline orientation, which is the most remarkable feature of SPE when compared with other epitaxial growth methods.

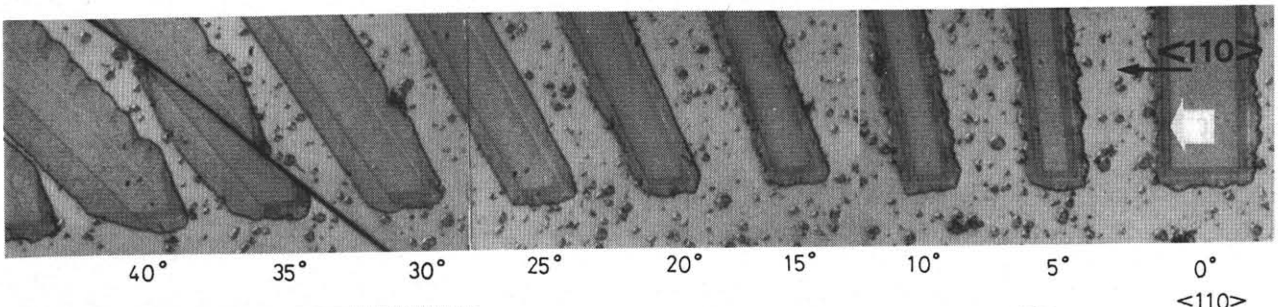
These orientation dependences are well explained by the microscopic SPE model proposed by Drosd and Washburn (D-W).[5] Kunii et al.[2] also explained facet formation at the SiO_2 edge based on this model.

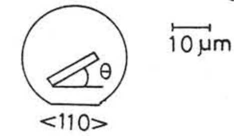
In the present work, the third mode of facet formation in L-SPE is presented, which is observed in the case of L-SPE using a two-dimensional seed area[6]. Studies on L-SPE using a two-dimensional seed provide useful information for practical device design. Furthermore, the facet formation mechanism is discussed in relation to the D-W model.

2. Experimental

Cz-grown {100} oriented Si wafers were utilized for substrates. SiO_2 was thermally grown to a thickness of 25nm for the planar type and 140nm for the LOCOS type. Various seed shapes were patterned on the SiO_2 layer. i. e. stripe seeds with various patterning directions from <100> to <110>, convex or concave seeds, seeds surrounded by an SiO_2 layer (window-shaped seed) or seeds surrounding an SiO_2 island (sea-shaped seed).

Base pressure in the vacuum chamber was about 10^{-8}Pa (Ulta High Vacuum:UHV). The substrate surface was cleaned by Ar beam sputtering and then annealed at 680℃ for





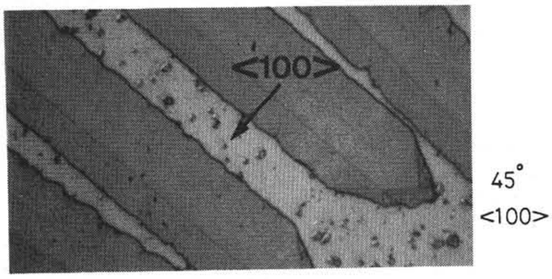


Fig. 1 Growth direction dependence of L-SPE. White arrow indicates {111} facet-grown part in V-SPE layer.

1hr in UHV. Amorphous Si (a-Si) was deposited at a substrate temperature of 100℃ at 10^{-7}Pa. Typical thickness of the a-Si was 1-4 μm to clearly observe crystal growth. Deposited a-Si was annealed at 450℃ for 1hr in UHV for densification and then annealed for SPE at 600℃ in a nitrogen atmosphere. The samples were Wright-etched[7], and then observed by Nomarski interference optical microscopy.

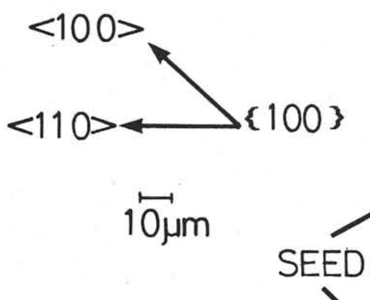
3. Results and Discussions

The effect of seed shape on L-SPE growth is discussed, including L-SPE using stripe seeds, convex or concave seeds, and window-shaped or sea-shaped seeds.

3. 1 L-SPE using stripe seeds having various patterning directions

The plain view of a sample after annealing for SPE at 600℃ for 4hr are shown in Fig. 1, where a large growth direction dependence of L-SPE is observed. The black lines on the specimen are stress-induced cracks caused by the large Si thickness (about 4μm).

The extent of L-SPE growth using a <110> oriented seed was only 2μm, and revealed a poor crystallinity. Wright etching for about 10sec, which removes Si layer of about 0.2μm thick, clearly revealed differences in the L-SPE



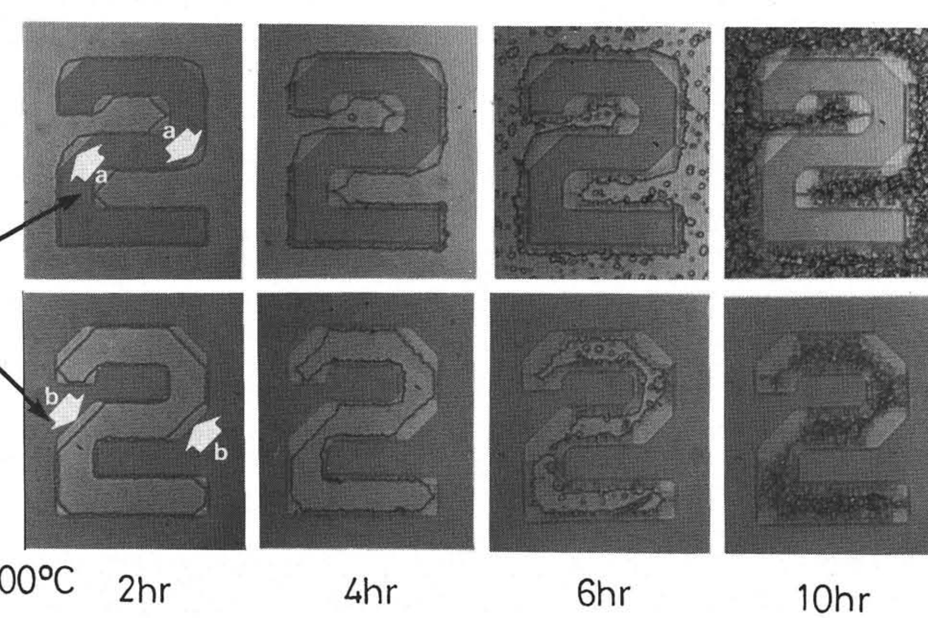


Fig. 2 L-SPE growth using a two-dimensional seed.

(a) convex seeds

(b) concave seeds

crystallinity. The poor crystallinity and narrow SOI layer is explained by the appearance of the {111} facet and microtwin formation on this facet[8]. Because of the thick SPE Si layer, it was possible to verify the appearance of the {111} facet during the vertical growth stage (V-SPE), as indicated by the white arrow in Fig. 1.

On the other hand, L-SPE using a <100> oriented seed realizes a broad (8μm-wide) SOI layer and relatively good crystallinity. This can be attributed to {110} facet growth.

For L-SPE between <110> and <100> directions, a large change in crystallinity occurs at an angle of $\theta=20$, which is defined as shown in Fig. 1.

3.2 Facet formation in L-SPE with convex and concave seeds

L-SPE growth was carried out using the seed pattern shown in Fig. 2. The Si film thickness was 1.3μm. In the top row of the figure, the seed pattern is surrounded by an SiO_2 background. In the bottom row of the figure, the seed/background relation is reversed. The seed patterns are made by <100> and <110> patterning, and exhibit convex parts (indicated by "a") and concave parts (indicated by "b"). L-SPE behavior is totally different, depending on whether the seed is convex or concave. For the convex seed, slow <110> L-SPE growth is dominant, while for the concave seed, fast <100> L-SPE growth is dominant. In other words, the {111} and {110} facets become enlarged and are extended in the case of convex and concave seeds, respectively. As shown in Fig. 3(a), a clearer picture could be obtained using the thicker film (about 4μm-thick).

According to the D-W model, SPE occurs when Si atoms (single atoms or atom clusters) in a-Si form two undistorted bonds

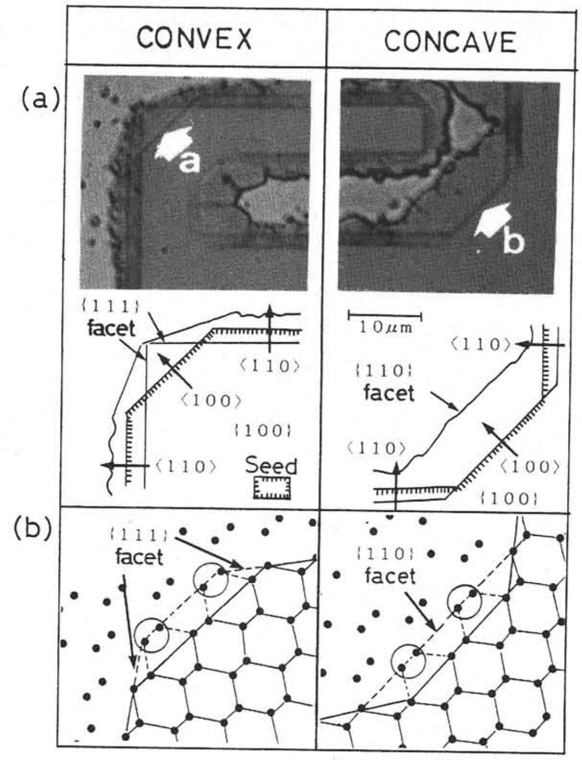


Fig. 3 Facet formation in L-SPE using convex and concave seeds.

with those in c(crystalline)-Si on the a-Si/c-Si interface. Applying this rule to the present case, two-atom clusters on {110} facet depicted in circles in Fig. 3(b) satisfy this condition. Because of the

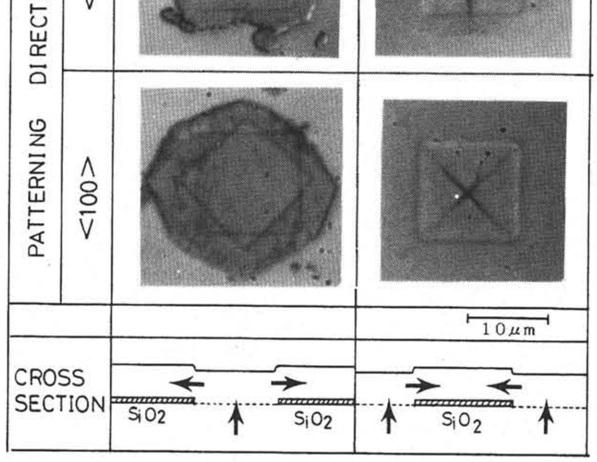


Fig. 4 L-SPE using window-shaped and sea-shaped seeds.

difference in boundary conditions between convex and concave seeds, this mechanism results in {111} and {110} facet enlargement, respectively.

3. 3 L-SPE using window-shaped and sea-shaped seeds

Window-shaped seeds are preferable for practical SOI device applications [9] due to small seed area. An attempt to use sea-shaped seeds has also been reported.[6]

L-SPE using these seeds are shown in Fig. 4, where the SiO_2 patterning direction is either <100> or <110>.

A {111} facet-grown SOI layer was obtained in the case of window-shaped seeds for <110> patterning. For <100> patterning, the expected fast growth of the {110} facets was restricted by {111} facets growing from the corners. The boundary between {110}- and {111}-grown layer can be clearly visualized by Wright etching. The appearance of the {111} facet is probably due to microscopic insufficiency of patterning, i. e. <110> patterning occurs microscopically at the corners of <100> defined square pattern. As a result, the window-shaped case corresponds to the convex seed case in section 3. 2.

The {110} facets are enlarged in the sea-shaped seed case on both the <100> and <110> patterning directions. These facets grow from the corners for <110> patterning. The concave seed case described in section 3. 2 corresponds to this case. In addition, crystal defects, which are probably due to phase mismatch of the facets, appeared in the SOI layer. These defects in SOI layer must degrade performance of fabricated devices.

4. Conclusion

A new facet formation mode is described in L-SPE using a two-dimensional seed area on {100} Si wafer. {111} facets are enlarged in the case of convex seeds. In contrast, {110} facets are enlarged in the case of concave seeds. These results can be explained within the context of the Drosd-Washburn model for SPE. Window-shaped and sea-shaped seeds have inherent problems such as the formation of crystal defects due to {111} facet growth and the occurrence of phase mismatches, respectively. This seed shape dependence has to be taken into consideration in practical device design.

Acknowledgements

The authors are grateful to Prof. Takashi Tokuyama, Dr. Masao Tamura, and Mr. Nobuyoshi Natsuaki for their fruitful discussions during the course of this work.

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