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(出版者 / Publisher)
法政大学イオンビーム工学研究所
(雑誌名 / Journal or Publication Title)
PROCEEDINGS OF THE 36th SYMPOSIUM ON MATERIALS SCIENCE AND ENGINEERING RESEARCH CENTER OF ION BEAM TECHNOLOGY HOSEI UNIVERSITY (December 13, 2017)
(巻 / Volume)
36
(開始ページ / Start Page)
83
(終了ページ / End Page)
86
(発行年 / Year)
2018-02
(URL)
https://doi.org/10.15002/00030367

INVESTIGATION OF HOMOEPITAXIAL Si GROWTH DEPOSITED BY ELECTRON BOMBARDMENT ONTO THE Si (100) SUBSTRATE (II)

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Abstract

We have investigated the optimum condition of the two-dimensional epitaxial recrystallization of an amorphous Si layer grown on clean Si (100) substrates aiming at the formation of the patterned silicon-on-insulator structure. The amorphous Si layers were firstly deposited on the clean flat crystalline Si substrates with ~15 nm thick using an electron bombardment evaporator in the ultrahigh vacuum environment at room temperature (RT) to 550°C. The crystallinity of the deposited Si surface was evaluated by a reflection high energy electron diffraction. As a result, the deposited Si layer was fully crystallized during deposition at substrate temperature of 415°C. We then attempted the recrystallization of the RT-deposited samples by ion beam irradiation at substrate temperatures of 300 to 700°C. The crystallinity of the deposited Si layer was measured by a Rutherford backscattering spectrometry and the surface morphology was observed by an atomic force microscope. As a result, The RT-deposited Si layer was recrystallized with about 12 nm by ion beam irradiation at 300 to 700°C. It is supposed that the crystalline grains of (100) orientation were preferentially formed in the amorphous layer by ion beam irradiation.

I. Introduction

Si-on-insulator (SOI) structure consists of a surface crystalline Si (SOI) layer separated from a Si substrate by a buried oxide (BOX) layer. The electric devices fabricated on this structure have the excellent electric properties of high-speed performance, low-energy consumption and high-radiation hardness compared to those on the conventional bulk Si structure.

We aim at forming the patterned SOI substrates that are composed of both SOI (SOI/BOX thicknesses of 10-20 nm) and bulk regions (as shown in Fig. 1). This structure is expected as a high-speed and power-saving random-access-memory by forming trench-capacitor circuits on the bulk region and access-transistor circuits on the SOI region [1, 2]. However, it is difficult to form these hybrid structures using a wafer-bonding SOI process. We then prepared a thin patterned SiO_2 structure formed on Si by photolithographic process substrate in advance and synthesized a thin amorphous Si layer covering the SiO_2 patterns by an electron bombardment (EB) evaporator. Subsequently, we recrystallized the amorphous layer on both the SiO_2 pattern and the bulk crystalline Si by conventional furnace annealing or high-energy ion-beam-irradiation annealing [3, 4] (Fig. 2).

In this study, we investigated the optimum conditions of the two-dimensional epitaxial recrystallization of an amorphous Si layer grown on clean flat Si (100) substrates.

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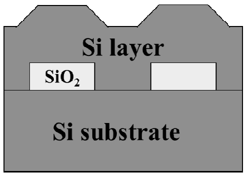

Fig. 1. Schematic image of patterned SOI substrate.

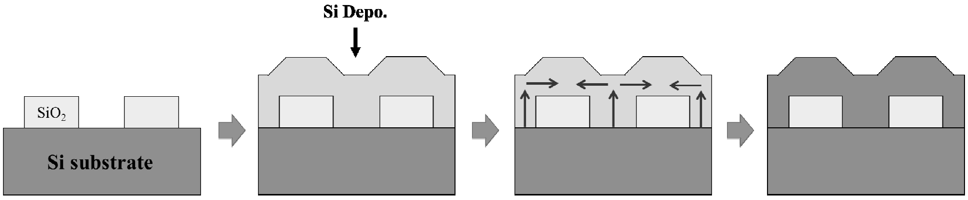

Fig. 2. Formation method of patterned SOI structure

II. Experiment

We prepared the clean Si(100) surface by a typical Shiraki method as follows. We first chemically treated the Si(100) surface terminated by a thin oxide layer by the modified RCA method and immediately introduced it into an ultrahigh vacuum (UHV) chamber. The sample was heated at 890°C for 80 sec in order to eliminate the thin chemical oxide. The reflection high energy electron diffraction (RHEED) pattern showed a clean Si(100)-(2×1) structure, which is well known as one of the clean Si(100) surfaces. Next, an amorphous Si layer was deposited on the clean surface with ~15 nm thick using the EB evaporator in UHV environment at the substrate temperatures of room temperature (RT), 350, 415 and 550°C. The crystallinity of the deposited Si surface was evaluated by RHEED. We then attempted the recrystallization of the RT-deposited sample using an ion beam irradiation by 180 keV Ar^+ ions with a fluence of 5×10^{15} ions cm^{-2} at the substrate temperatures of 300, 500 and 700°C. Finally, the crystallinity of the deposited Si layer was measured by a Rutherford backscattering spectrometry (RBS) and the surface morphology was observed by an atomic force microscope (AFM).

III. Results and discussion

Figure 3 shows the RHEED patterns for the samples on which the thin Si layer was deposited at the substrate temperature of (a)350, (b)415, and (c)550℃. The pattern of the 350℃-deposited sample depicted in Fig. 3 (a) shows a hallow pattern corresponding to amorphous structure. On the other hand, the single-crystal Si pattern was observed from the 415℃- and 550℃-deposited samples (Figs. 5 (b) and (c)). It is indicated that the homoepitaxial growth took place at 415℃ or higher temperatures. In addition, the two-dimensional single-crystal Si pattern was confirmed on the 415℃-deposited surface (Fig. 3 (b)); however, the diffraction pattern in Fig. 3 (c) changed to a transmission diffraction pattern. It is indicated that the higher temperature deposition significantly promotes an island like growth.

Figure 4 shows the minute surface morphology of the 415°C-deposited sample by AFM. The average roughness was estimated to be about 0.6 nm, indicating that the sample surface is found to be very flat. Figure 5 shows RBS spectra for the RT- and 415°C-deposited samples. From the spectrum observed for the 415°C-deposited sample, we confirmed that the deposited Si layer was almost crystallized comparable to the bare Si substrate. Consequently, we decided the optimum deposition condition for two-dimensional crystallization to be the substrate temperature of 415°C.

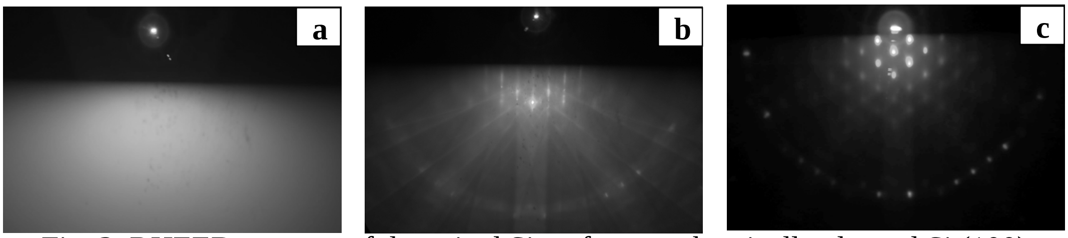

Fig. 3. RHEED patterns of deposited Si surface on chemically cleaned Si (100)
[Substrate temperature (a) 350℃, (b) 415℃, (c) 550℃]

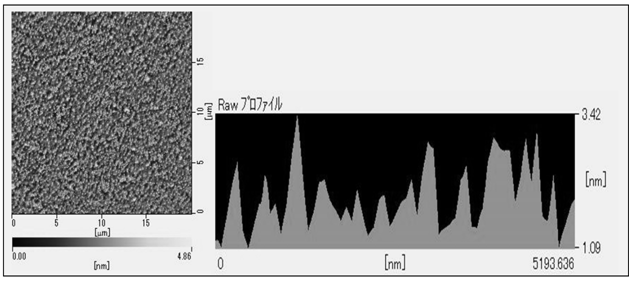

Fig. 4. Surface morphology of the 415℃-deposited sample observed by AFM.

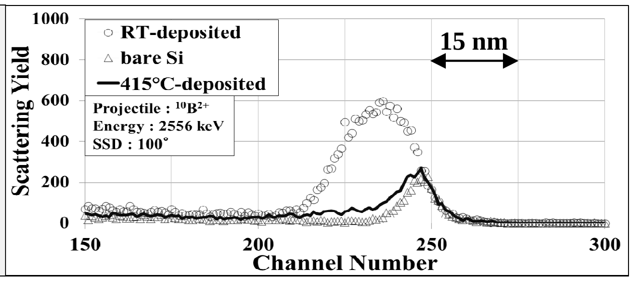

Fig. 5. RBS spectra of the 415℃-deposited sample.

Figure 6 shows RBS spectra for the RT-deposited substrates followed by annealing at 300, 500, and 700℃ with or without Ar^+ ion irradiation. Figs. 6 (a), (b) and (c) show RBS spectra with the ion irradiation, and Figs. 6 (d), (e) and (f) do those without irradiation. It is found that the recrystallization of the deposited Si layers followed by the ion irradiation occurred at all substrate temperatures from 300 to 700℃. From these spectra, we obtained the recrystallization thickness of ~12 nm and the recrystallization rate of 0.8 Å/min in all samples.

We discuss the reason why the similar recrystallization thickness and rate were observed in all irradiated samples. The interface of the deposited Si/substrate moved towards the surface with about 12 nm. In addition, the scattering yields around the plateau region significantly decrease with respect to the as-deposited sample (see Figs. 6(b) and (c)). It is supposed that the crystal grains of the (100) orientation were likely to be formed in the deposited layers by the Ar^+ ion irradiation.

From the above considerations, the recrystallization process by the ion beam irradiation should be different from that by the heat-treatment. In the ion beam irradiation process, the crystal grains having the (100) orientation were preferentially formed along the Ar^+ ion direction. With increasing the fluence, the volumes of those domains fairly grow larger and three-dimensionally and then laterally connect with neighboring grains.

In order to validate the evidence of radiation effect, we also tried thermal annealing without ion beam irradiation under the same conditions of temperature and duration in the ion beam irradiation treatment. Figs. 6(d),(e),(f) show the RBS-channeling spectra observed for the Si-deposited samples on cleaned surfaces before and after thermal annealing at 300-700°C in vacuum (~10^{-6} Pa), which corresponds to the same condition in the ion beam irradiation treatment. It is clearly seen that the deposited Si layer was not recrystallized at 300°C, whereas the deposited Si layers were recrystallized over 500°C.
These recrystallization rates were 0.4 Å/min and 0.8Å/min, 500℃ and 700℃, respectively.
It is indicated that the recrystallization rate depends on the substrate temperature.

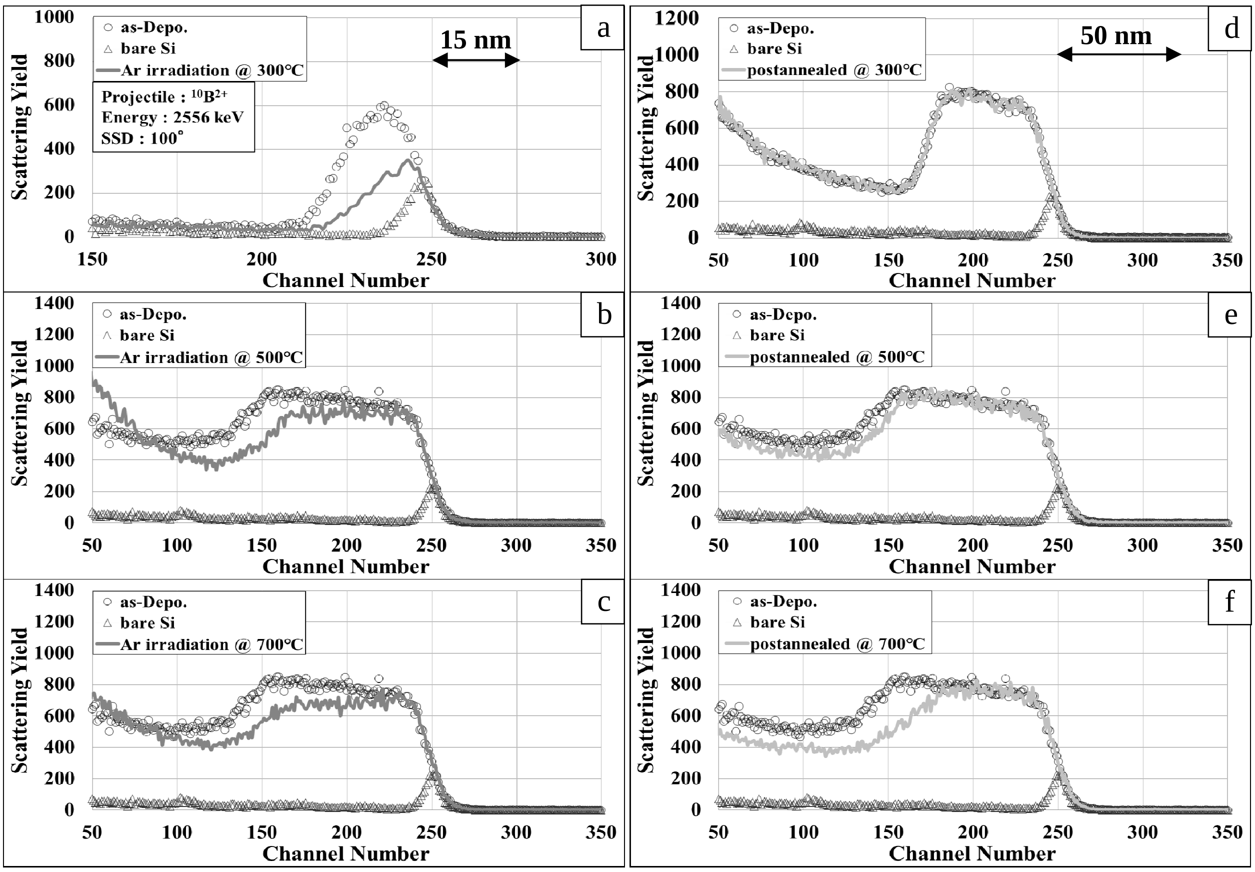

Fig. 6. RBS spectra of the irradiated samples ((a)(b)(c)) , and the non-irradiated samples((d)(e)(f)). [sample temperature (a)(d) 300℃, (b)(e) 500℃, (c)(f) 700℃]

IV. Conclusions

In this study, we investigated the optimum condition of the two-dimensional epitaxial recrystallization of Si grown on flat clean Si (100) substrates. As a result, the deposited Si layer at substrate temperature of 415℃ was two-dimensionally crystallized. On the other hand, the RT-deposited samples were more or less recrystallized at all substrate temperatures from 300 to 700℃. However, the recrystallization thickness was about 12 nm in all irradiated samples. It is supposed that the crystal grains of (100) orientation were preferentially formed in the amorphous layer by ion beam irradiation.

Acknowledgements

We express our sincere thanks to the members of Nakata and Mizuno laboratories for their helpful suggestions and discussions.

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