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Selective Doping of P Atoms in Lateral Solid Phase Epitaxy of Si Films

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A selective doping method of P atoms is proposed in lateral solid phase epitaxy (L-SPE) of Si films, in which L-SPE mainly proceeds along the P-doped regions and active devices are fabricated in the undoped regions. This method was successfully applied to fabrication of MOSFETs in which the P-doped region was used as the source and drain regions and the undoped region was used as a channel between them.

1. Introduction

Lateral solid phase epitaxy (L-SPE) of amorphous Si (a-Si) films deposited on Si substrates with SiO_2 patterns is one of the most promising techniques to form silicon-on-insulator (SOI) structures suitable for 3-dimensional integrated circuits, since the growth temperature of L-SPE is as low as 600°C[1-7]. In this technique, it has been found that incorporation of P atoms in a-Si films is effective to increase the polycrystallization time as well as to enhance the L-SPE growth rate[4]. Thus, the maximum L-SPE length from the pattern edge has been reported to be as long as 50 μm in P-doped samples[6]. This value is longer than that in undoped samples by factors 5 to 10.

However, since P concentration necessary to improve the L-SPE characteristics is as high as $3x10^{20}cm^{-3}$, it is generally impossible to fabricate active devices in the films. So, in this paper, we propose a selective doping method of P atoms in L-SPE, in which the L-SPE proceeds efficiently through P-doped regions, while active devices are fabricated in undoped regions. A typical doping profile is shown in Fig.1, in which P atoms are incorporated in both seed and SOI regions except a part of the SOI region. In this structure, it is expected that the L-SPE characteristics are not so affected by the undoped region if the width of the undoped region is narrow enough, and that the region can be used as a channel region of an MOSFET.

2. Growth Procedure

In the experiment, SiO_2 films about 200nm thick were partially grown on Si(100) wafers using LOCOS (local oxidation of silicon) process. The pattern edge was directed to the <010> axis of the substrate so that L-SPE proceeded to the <001> direction. The wafers were then chemically cleaned using RCA solution and mounted in an ultra-high vacuum chamber with base pressure of about $1x10^{-8}$ Pa. After thermal cleaning at 800°C for 30 min, Si films about 220 nm thick were deposited on the wafers at substrate temperatures around 500°C by electron beam evaporation of undoped Si source. The deposited Si films were single crystalline on the seed regions, while they were polycrystalline on the SiO_2 patterns.

These films were then uniformly amorphized by Si ion implantation at room temperature. The resultant dense a-Si films showed much better L-SPE characteristics than room-temperature-deposited porous a-Si films. In order to incorporate P atoms selectively, P ions were implanted using photore-

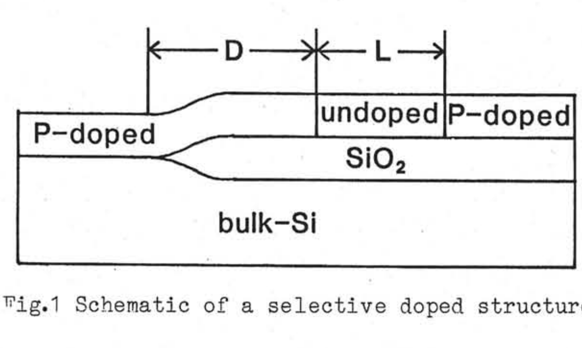

Fig.1 Schematic of a selective doped structure

sist masks. The implantation energies and doses were so chosen that the maximum P concentration is nearly equal to $3x10^{20}cm^{-3}$. The implantation processes are shown in Fig.2. Finally, the samples were furnace-annealed in N_2 atmosphere at 600°C and the growth areas were observed by a Nomarski optical microscope after Wright etching.

3. Experimental Results

3.1 Growth characteristics

The L-SPE growth characteristics of uniformly doped, selectively doped, and undoped samples were measured at 600°C using optical microscopy. A typical result for P-doped samples is shown in Fig.3, in which the growth length from the SiO_2 pattern edge is plotted with the annealing time at 600°C. In the selectively doped samples, the width L of the undoped regions was changed in 1, 2, 3, and 20 μm, while the distance D between the pattern edge and the undoped region was fixed at 2 μm. The 6 lines in the figure represent, in descending order, the L-SPE characteristics in the uniformly doped, selectively doped (L=1,2,3 and 20 μm) and undoped samples. We can see from this figure that the L-SPE proceeds beyond the undoped region and the saturated growth rate in the second P-doped region is equal to the rate in the uniformly doped sample. We can also see in the selectively doped sample with L = 20 μm that the saturated growth rate in the undoped region is the same as that in the undoped sample.

Whereas, the L-SPE characteristics in the selectively doped samples with L = 1, 2, and 3 μm were a little complicated. Since L is changed linearly in these samples, it is expected that the upper 4 lines in the figure are equally separated, if the L-SPE growth rate in the undoped region is constant. However, the experimental results show that the separation between the adjacent lines are larger for the wider undoped region. The deviation from the equal separation is too large to be explained by the error of the pattern size. Thus, in order to explain this phenomenon, the initial growth rate in the undoped region is necessary to be enhanced compared to the saturated growth rate in the undoped sample. Among various possibilities to enhance the growth rate, the following two seem to be most important; one is the impurity effect of P atoms which were redistributed from the doped region by the thermal diffusion or the snow plow

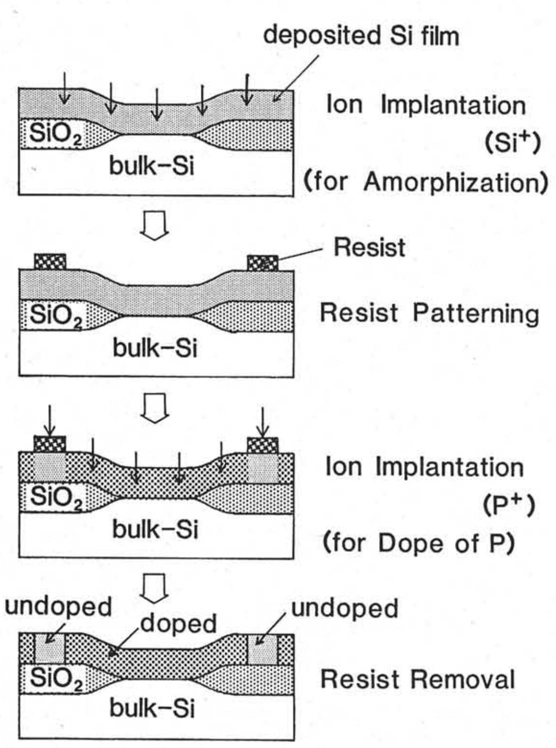

Fig.2 Ion implantation procedure in selective doping

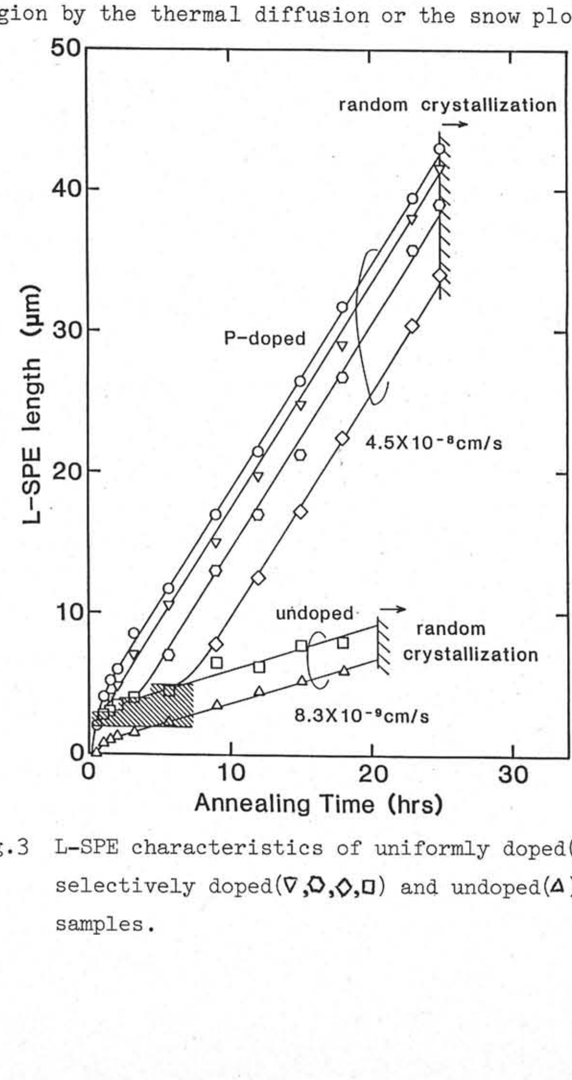

Fig.3 L-SPE characteristics of uniformly doped(○), selectively doped(▽,⬡,◇,□) and undoped(△) samples.

effect, and the other is an intrinsic effect that the (111) facet is not formed at the growth front in the early stage of L-SPE.

In this sample structure, redistribution of P atoms during L-SPE is most serious , since the undoped region is so designed that its width is equal to the width of the active region. Therefore, the origin of the enhanced growth rate was further investigated. In the first experiment, the L-SPE characteristics were measured in the samples with different D values and it was found that the growth rate was enhanced only when the undoped region was located near the seed region, which strongly suggests that this phenomenon is closely related to the (111) facet formation[5]. In the second experiment, P atom profiles in the films were measured by electron probe microanalyzer (EPMA). Figure 4 shows a typical result from a grown sample with an undoped region 3 μm wide. We can see from the figure that the redistribution of P atoms is less than the system resolution and the impurity level in the undoped region is close to the detection limit. We conclude from these results that the initial enhancement of the growth rate is not due to the impurity effect of P atoms, but due to the intrinsic effect that the (111) facet is not formed at the growth front.

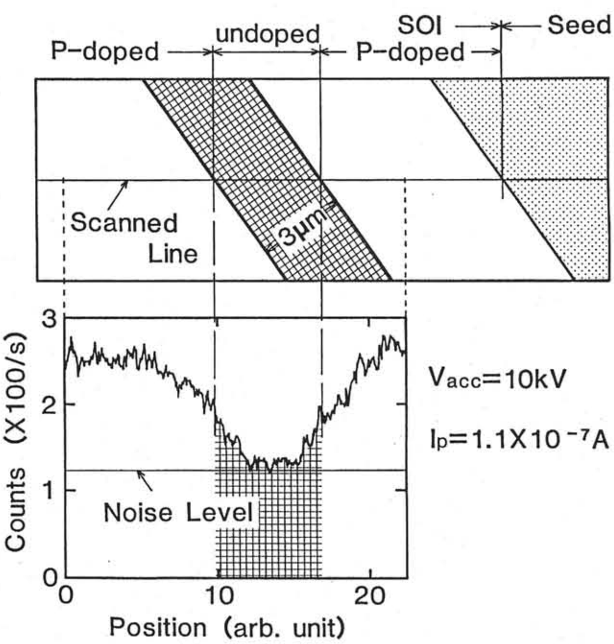

Fig.4 P atom profile in a selectively doped sample by EPMA

3.2 Fabrication of MOSFETs

In order to characterize the electrical properties of the undoped region, Al-gate n-channel MOSFETs were fabricated in the L-SPE film. The fabrication processes are schematically shown in Fig.5. The P-doped regions were used as the source and drain regions and the undoped region was used as the channel region of MOSFET. After formation of Si islands, the gate oxide 200nm thick was deposited using plasma-CVD at 400°C. Then, contact holes for the source and drain regions were made

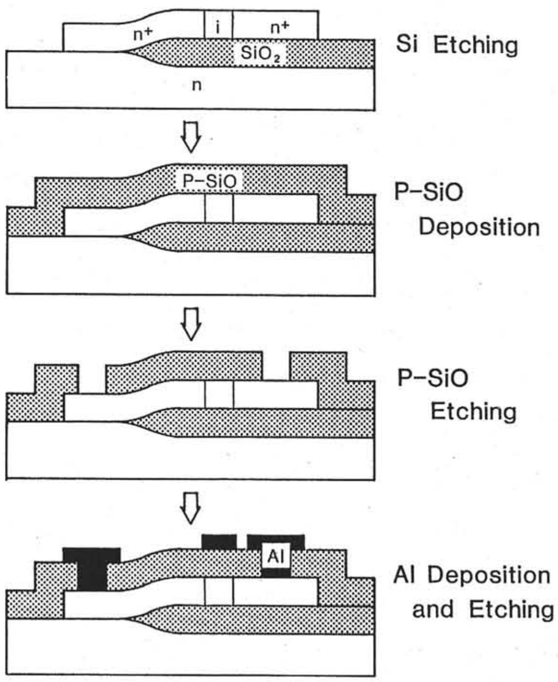

Fig.5 Fabrication process of MOSFETs

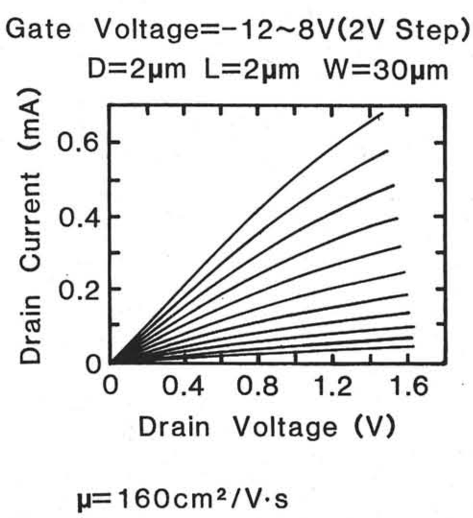

Fig.6 I_D-V_D characteristics of a MOSFET fabricated in a selectively doped L-SPE film and an Al film was deposited for formation of the electrodes. The pattern sizes of the undoped region were changed from 1 to 5 μm and the channel width was 30 μm. The distance D between the undoped region and the SiO_2 pattern edge was also changed from 2 to 20 μm. The minimum channel length of the MOSFET was about 0.8 μm and the device still showed the transistor operation. Typical I_D-V_D characteristics for an FET with L = 2 μm, W = 30 μm, and D = 2 μm are shown in Fig.6. The electron mobility calculated from this figure is about 160 cm^2/Vs. This value will be improved by optimization of fabrication process of the gate insulator.

4. Summary

We investigated the L-SPE characteristics of a-Si films in selectively P-doped samples. The main results obtained are summarized as follows.

1. In a doping profile, in which P atoms are incorporated in both seed and SOI regions except a part of the SOI region, the L-SPE proceeds beyond the undoped region and the saturated growth rate in the second P-doped region is equal to that in the uniformly doped sample.
2. Redistribution of P atoms due to thermal diffusion or snow plow effect during L-SPE is negligible.
3. L-SPE growth rate in the undoped region is enhanced when the region is close to the seed region. This phenomenon originates from a fact that the (111) facet is not formed at the growth front in the early stage of L-SPE.
4. Al-gate n-channel MOSFETs were fabricated in the L-SPE film, in which the P doped regions were used as source and drain regions and the undoped region was used as a channel between them. The maximum electron mobility of an MOS FET with the channel length of 2 μm was about 160 cm^2/Vs.

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