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Novel Highly Conductive Polycrystalline Silicon Films Reducing Processing Temperature Down to 650°C

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In-situ doped polycrystalline silicon films were deposited at temperatures below 550℃ using Si_2H_6 and PH_3. For the first time, conductivity values no less than the conventional values were obtained after annealing at low temperatures of 650℃. Moreover, the resistivity did not change at elevated temperatures. From Hall effect measurements and transmission electron microscopy, we found that these novel properties result from the amorphous structure of the as-deposited films, which lead to the growth of large grains at low temperatures.

INTRODUCTION

Low-pressure chemical vapor deposited (LPCVD) polycrystalline silicon (poly-Si) is widely used for electrodes and wiring in Si LSIs. Because as-deposited poly-Si films are highly resistive, they are afterwards doped through ion implantation or phosphorous diffusion to reduce resistivity[1]. These doping processes usually require temperatures of 900℃ or higher[2].

The increasing integration of LSIs, in which smaller devices are fabricated at lower temperatures, poses new problems for poly-Si. For example, reducing both processing temperature and impurity concentration, without increasing resistivity, is key to fabricating shallow junctions at poly-Si/substrate contacts.

In this paper, we report a novel method of forming highly conductiv poly-Si films processed at temperatures as low as 650℃. We used Si_2H_6 and PH_3 as source gases and deposited films in an amorphous state. In the past, some authors have reported the formation of amorphous Si films by LPCVD using SiH_4[3-5]. However, those depositions were not performed below 560℃ because of the slow growth of Si films. Si_2H_6 enabled us to form Si films at much lower temperatures with a practical growth rate. We found that the novel properties emerged for the first time when the films were deposited below 550℃.

EXPERIMENTAL

Si films 200nm thick were deposited on thermally oxidized Si wafers in a conventional LPCVD reactor. Phosphorous was in-situ doped by mixing PH_3 with Si_2H_6 as a source gas. Flow rates of Si_2H_6 and PH_3 were fixed at 50sccm and 0.75sccm, respectively. Total pressure in the reactor was 30Pa and deposition temperature was 475℃-630℃. Isochronal annealing was subsequently performed for 20 minutes in a dry N_2 atmosphere.

Resistivity of the films was measured by the 4-point-probe method. Carrier concentration and mobility were calculated from Hall effect measurements using the van der Pauw method [6].

The grains in the films were observed by transmission electron microscopy (TEM).

RESULTS AND DISCUSSION

The films deposited below 600℃ showed little conductivity as made, although they were in-situ doped.

Film resistivity after annealing is shown in Fig. 1. Resistivity was almost equal among all samples investigated after 1000℃ annealing. However, it differed at lower temperatures. Resistivity of the films deposited above 550℃ decreased with increasing annealing temperature. Temperatures as high as 1000℃ were necessary to get sufficient conductivity. This result is similar to that for conventional films, which were deposited in polycrystalline state and doped afterwards [2]. By contrast, the resistivity of the films deposited at lower temperatures was fully reduced through annealing at temperatures as low as 650℃. Annealing at elevated temperatures had no effect on reducing the resistivity. This is surprising when compared with conventional films.

To further investigate these films, Hall mobility and carrier concentration in the films were measured. The results are shown in Figs. 2 and 3. The carrier

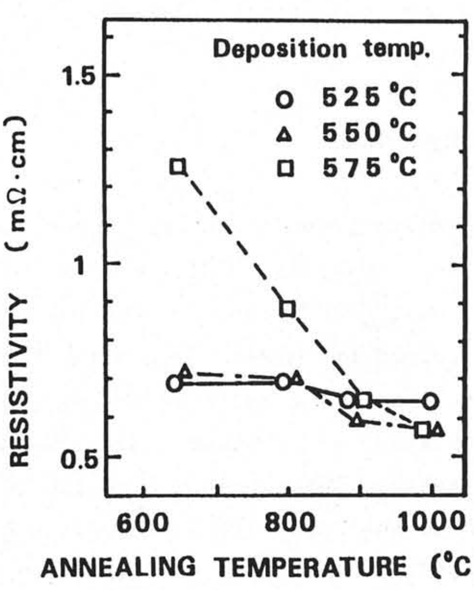


Fig. 1. Resistivity vs. annealing temperature

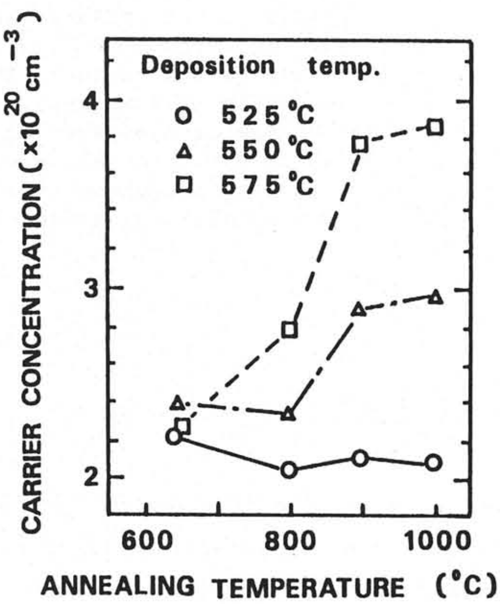


Fig. 2. Carrier concentration vs. annealing temperature

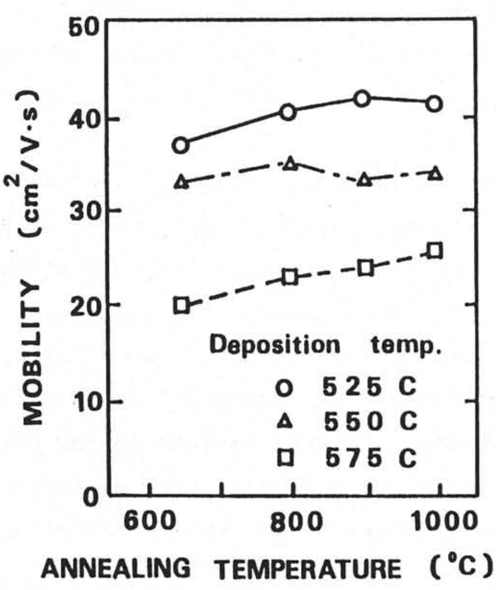


Fig. 3. Mobility vs. annealing temperature

concentration increased with annealing temperature in the films deposited above 550℃. On the other hand, it was constant at all annealing temperatures for lower temperature deposition.

The mobility was almost independent of annealing temperature for all deposition temperatures investigated. It is noteworthy that the mobility of the films deposited at 525℃ is 40% larger than that of the films deposited at 575℃.

Mobility and carrier concentration reflect the grain structures in poly-Si films. Fig. 4 shows the TEM micrographs of the films deposited at 575℃ (upper) and 525℃ (lower). Polycrystalline and amorphous phases coexisted in the films deposited at 575℃ as made. After annealing, columnar grains grew, and their size increased with annealing temperature. The grain size after 1000℃ annealing remained about 0.3μm. The results are similar to those for conventional P-doped poly-Si films[2]. By contrast, the films deposited at 525℃ were amorphous as formed. They showed dendritic structures with 1-2μm grains after annealing at 650℃. Grain growth saturated at this temperature, as did electrical properties.

These results indicate that the followings result from growing large grains at low temperatures: high conductivity after annealing at 650℃, large mobility, and electrical properties which are independent from annealing temperature.

The enhanced grain growth in conventional poly-Si has so far been attributed to the existence of dopant atoms, such as phosphorous or arsenic, in the films[2]. In order to clarify the the cotribution from dopants in the present films, Si films were deposited at 525℃ without PH_3 and compared with in-situ doped films. The results are shown in Fig. 5. The films were amorphous as deposited and large grains with 1-2μm long grew at temperatures of 650℃. These result are quite similar to those of in-situ doped films, although there

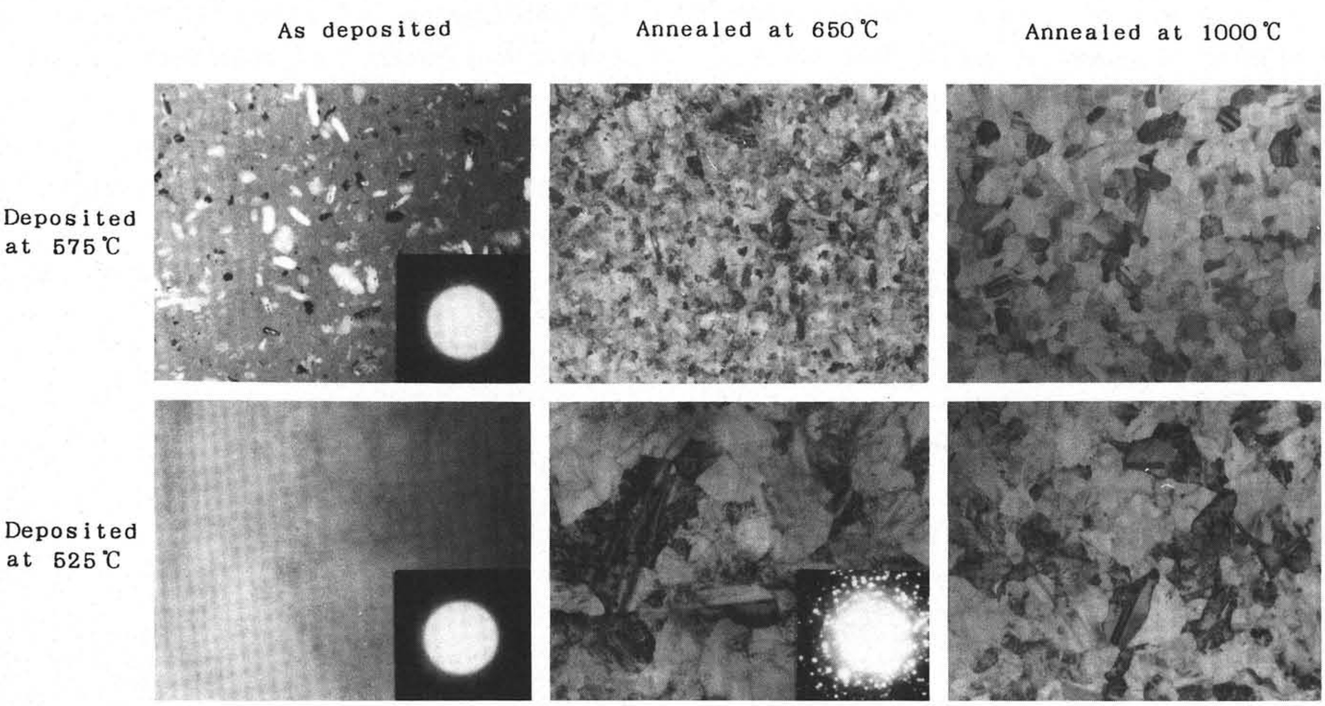
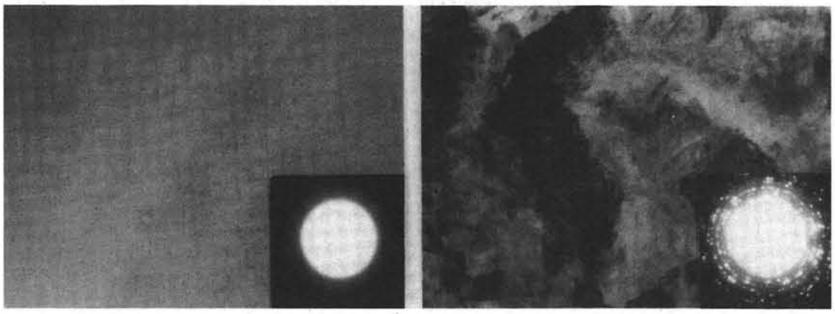


Fig. 4. TEM micrographs of the in-situ doped films deposited at 575℃ and 525℃



As deposited　　Annealed at 650℃　　1 μm

Fig. 5. TEM micrographs of the undoped films deposited at 525℃

were no dopants in the films. Therefore, it is clear that the growth of large grains in in-situ doped Si films results from the amorphous as-deposited structure, and not from the existence of dopants.

SUMMARY

In-situ doped Si films were deposited in an amorphous state at temperatures below 550℃ using Si_2H_6 and PH_3. For the first time, conductivity values no less than conventional values were seen in these films after annealing at low temperatures of 650℃. Moreover, these conductivity characteristics showed no change at elevated temperatures. These novel properties are closely related to the existence of large grains which grew at low temperatures. Contrary to the conventional model, this grain growth was found to be enhanced by the amorphous structure of the as-deposited films, as opposed to the existence of dopant atoms. Using these films, processing temperature of poly-Si electrodes and wiring can be lowered from 900℃ to 650℃. Thus these films will be the key to fabricating shallow junctions for deep-submicron LSIs.

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