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A Methodology for Control of Nucleation and Grain Growth in Amorphous Silicon Films and Its Application to Process Optimization for TFTs

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A new methodology is proposed for fabricating TFTs with the required device characteristics. The device structure and the film fabrication process can be optimized with this methodology. The film fabrication process, such as the doping concentration and the crystallization condition of amorphous silicon films, was investigated and discussed considering kinetic factors. As a typical example, it was predicted that the nucleation and grain growth can be controlled with as low a concentration as applicable to channel doping. It was demonstrated that the ingenious process sequence can be derived, with which TFT characteristics are drastically improved.

1. INTRODUCTION

TFT characteristics not only depend on the device structure, such as channel area and doping concentration, but also on the film structure, such as grain size and its distribution[1-3]. In this paper, a new methodology is proposed, which determines both the device structure and the film fabrication process in order to satisfy the required TFT characteristics. An adequate process can be determined for various TFT applications. A typical example demonstrates that the ingenious process sequence can be derived, with which TFT characteristics are drastically improved.

2. CONCEPT OF THE METHODOLOGY

The concept of the proposed methodology is shown in Fig.1. At the 1st step, TFT characteristics are decided. At the 2nd step, both the device structure and the film structure are specified. At the 3rd step, a process sequence is determined, by which the above mentioned structure specifications can be satisfied. An adequate process sequence has been determined through the device and film processes by this methodology. The dependence of TFT characteristics on the device and film structure has been investigated in advance. Grain size and its distribution can be simulated, using the experimental results on nucleation and regrowth of amorphous silicon films[4].

1st Step: TFT Characteristics Decision.
- Threshold voltage.
- Off current.
- S-factor, etc.

2nd Step: Structure Specification.

Device Structure.
- Channel length and width.
- Doping concentration, etc.

Film Structure.
- Grain size and its distribution.
- Film thickness, etc.

3rd Step: Process Sequence Determination.

Device Process.
- Oxidation temperature and time.
- Channel ion dose, etc.

Film Process.
- Amorphization condition.
- Regrowth temperature and time, etc.

Fig.1 Concept of the proposed methodology.

Impurity effects on the film structure will be described in the following section.

3. RESULTS AND DISCUSSIONS

The impurity effects on the regrowth process for amorphous silicon films were examined by TEM observation. Amorphous silicon films were made by silicon ion implantation into polysilicon films. Figure 2 shows a typical example of a TEM image of a phosphorus-doped regrown film. The nucleation rate and the crystalline fraction were investigated for various regrowth temperatures and phosphorus concentrations. Figure 3 shows an example of crystalline fraction vs. regrowth time. The grain growth rate was derived from the nucleation rate and the crystalline fraction at the early stage[5]. Figure 4 shows the regrowth rate vs. regrowth temperature for various phosphorus concentrations. The regrowth rate increased and the activation energy decreased, as the phosphorus concentration in the amorphous silicon film increased.

Such a phosphorus effect on regrowth behavior can be explained by the change in self-migration coefficient. The decrease in activation energies for both nucleation and grain growth are caused by the increase in self-migration coefficient, due to the increase in defect density[6-8]. Therefore, the incubation time for nucleation was decreased, and the grain growth rate was increased by phosphorus doping, as shown in Figs.3 and 4.

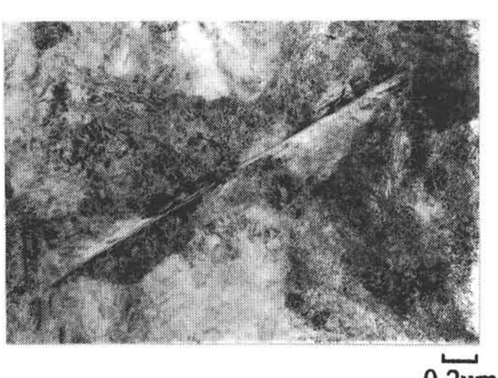

Fig.2 TEM image for films crystallized after phosphorus implantation. (15keV and $1x10^{13}cm^{-2}$) ($600^{o}C$ and 40hours)

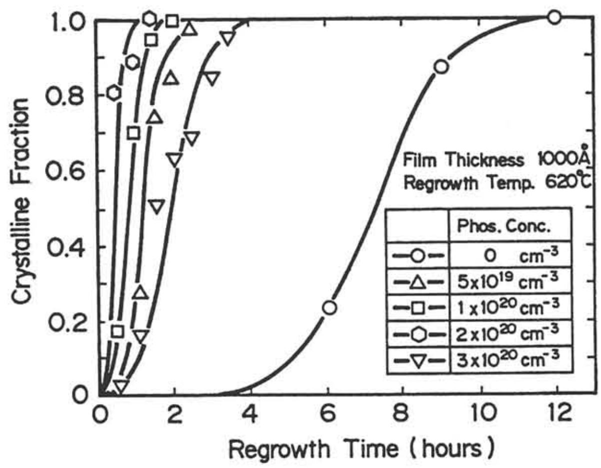

Fig.3 Crystalline fraction vs. annealing time.

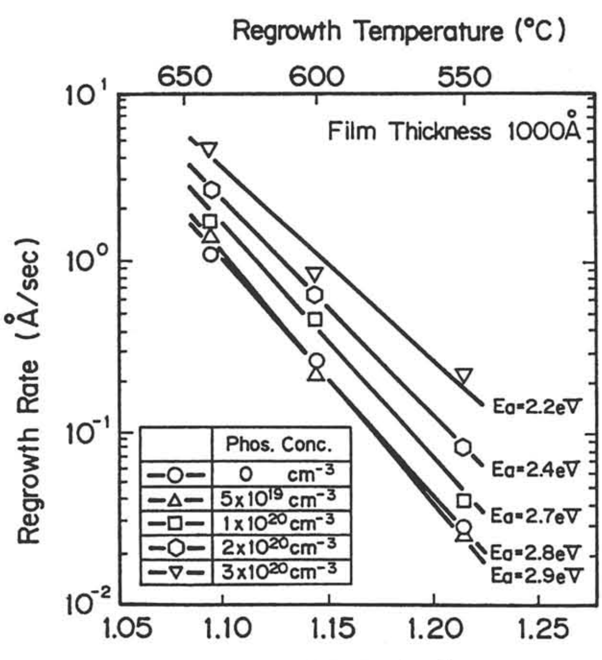

Fig.4 Regrowth rate vs. annealing temperature. Activation energies are also shown.

The activation energy of nucleation differs from that for grain growth by the free energy difference between amorphous and crystalline phase[9]. This means that nucleation and grain growth can be controlled independently by phosphorus concentration and regrowth temperature. Some examples are shown in Fig.5, which simulate the regrowth behaviors. Figure 5(a) shows the simulated result, where it is assumed that the regrowth temperature is 640^{o}C, and that the phosphorus concentration is $2x10^{20}cm^{-3}$. Figure 5(b) shows the simulated result for 640^{o}C and $5x10^{18}cm^{-3}$. Figure 5(c) shows the result for 600^{o}C and $5x10^{18}cm^{-3}$. As the simulated patterns show, the grain sizes for individual films are predicted as being 3um, 2um and 3um, respectively. This suggests that the doping effect on grain growth appears, even if the doping concentration is as low as applicable to channel doping.

Figure 6 shows the experimental results obtained regarding the final grain size of regrown films. Considerable effect on the increase in the grain size by phosphorus doping was not observed, when the regrowth temperature was 640^{o}C. However, even at low phosphorus concentration, the grain size can be increased by decreasing the regrowth temperature and by increaseing the regrowth time, which is predicted by the proposed methodology as shown in Fig.5.

Figure 7(a) shows the TFT characteristics fabricated on the film, which was doped with phosphorus for channel ion implantation before regrowth at 600^{o}C. The acceleration energy and dose of phosphorus ion implantation were 15keV and $1x10^{13}cm^{-2}$, respectively. This condition corresponds to that shown in Fig.2. The characteristics for a TFT, fabricated on the film which was doped with phosphorus after regrowth, are shown as Fig.7(b). Figure 7 indicates that TFT characteristics can be drastically improved by the optimization of process sequence. Similar improvement on TFT characteristics was obtained for boron doped films.

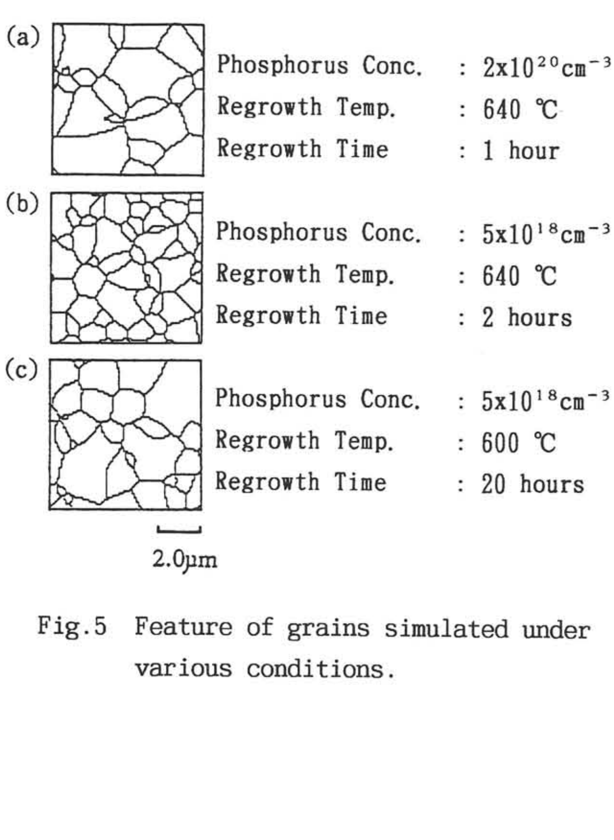

Fig.5 Feature of grains simulated under various conditions.

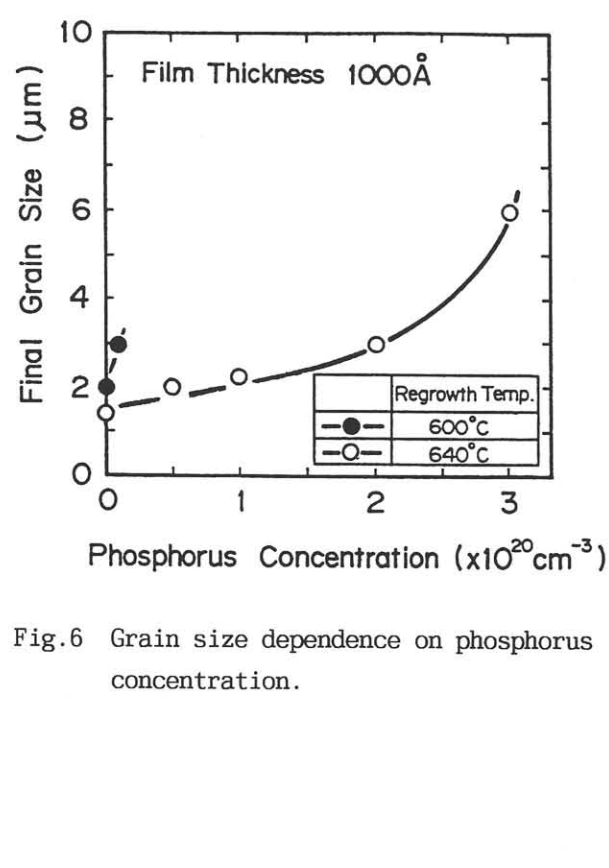

Fig.6 Grain size dependence on phosphorus concentration.

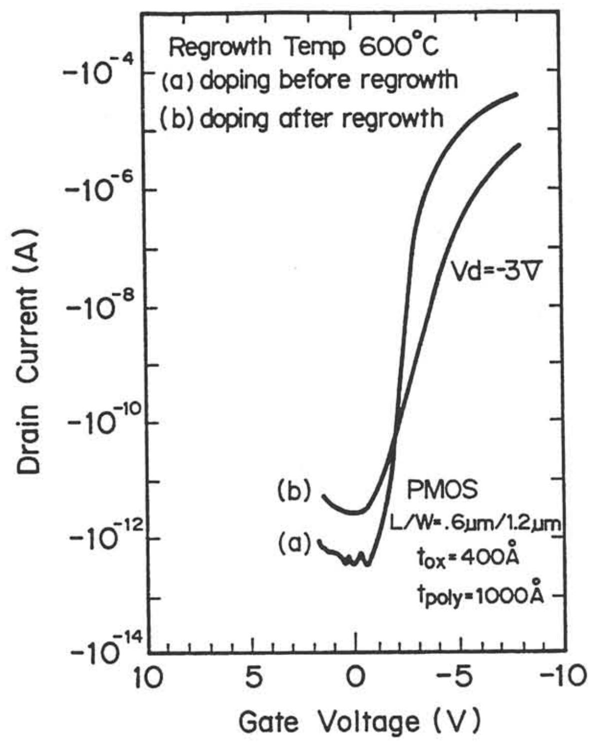

Fig.7 TFT characteristics.
(a) P implantation before regrowth.
(b) P implantation after regrowth.
(15keV and $1x10^{13}cm^{-2}$)

4. CONCLUSION

A methodology was proposed for fabricating TFTs with the required characteristics. The fabrication process for films and devices was investigated, such as the doping concentration, the crystallization condition and so on. Based on the experimental results, an optimized TFT process sequence could be determined by this methodology. As a typical example, it was predicted that the nucleation and grain growth could be controlled with as low a concentration as that applicable to channel doping. It was demonstrated that the TFT characteristics were drastically improved with the derived process sequence.

This methodology can be applied to the improvement in ultra thin film properties, such as grain size, or to the control of the grain boundary in doped polysilicon film, which is used as gate material for small MOS devices.

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