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Nucleation Controlled Poly-Si TFT by Selective Doping

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Crystallization process of amorphous silicon (a-Si) has been investigated. Nucleation rate of a-Si is found to be enhanced by heavy ion-doping, so that nucleation site could be controlled onto doping region by selective ion doping. And, during subsequent annealing, grain growth continues to propagate over them. It is also demonstrated that the device characteristic of MOSFET's formed on this film is improved, especially in small geometry devices.

1. Introduction

Poly-Si transistors are attracting for high density memories and large-area devices due to its simple fabrication process. The electrical characteristics of poly-Si transistors are, however, inferior to that of bulk Si. This is due to the grain boundaries in poly-Si films. Consequently, the large-grain poly-Si film, by laser-annealing or solid-phase crystallization of amorphous Si (a-Si), has been extensively studied. However, as the device size gets close to the grain size, it becomes the possibility of degrading device uniformity whether each device contains a grain boundary. If nucleation site of a-Si can be controlled, the uniformity of electrical characteristics in poly-Si transistors will be much improved. Thus several technology [1)-3)], selective implantation and surface step method, have been developed.

In this report, the new method for the control of nucleation sites and grain boundaries in poly-Si transistors will be demonstrated. And the device characteristics will be also presented.

2. Concept of nucleation control

As the annealing of a-Si film proceeds, first nuclei generated in the films and the growth of nuclei to grains follows. This nucleation may be affected by a-Si itself, impurities and interface structure (films underneath). In order to control the nucleation rate, we choose the ion doping [4)]. It is well known that impurities, such as phosphorous and boron, has the effect of increase Si self-diffusion.

The concept of this technique is represented in fig.1. First, a-Si film deposited on insulated substrate is doped by

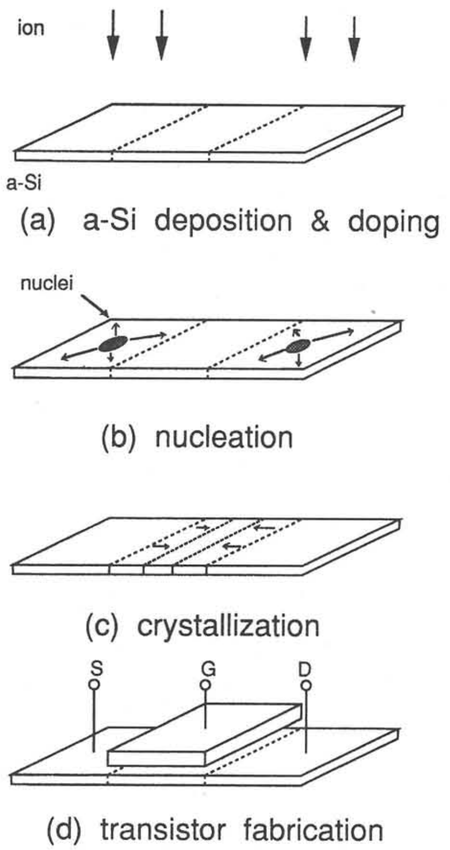

Fig.1 Concept of nucleation controlled Poly-Si TFT.

selective ion implantation. During subsequent annealing for solid-phase crystallization, nucleation is first appeared in the selective doping region, which has a high nucleation rate. Then, the crystallization in non-doping regions is propagated over entire a-Si film from the doping regions. At the next step, poly-Si transistors are fabricated using poly-Si gate. The selective doping regions are to be source and drain regions. In this configuration, channel region has only one grain boundary. Therefore, not only the device performance but also the uniformity will be improved. And the process steps are not increased because only two steps, crystallization step and source/drain formation step, are exchanged.

It is essential for this method that the difference of crystallization velocity between doping and non-doping regions become large. So we have examined the nucleation rates and crystallization velocities of doping and non-doping a-Si films.

3. Experimental

A 50-nm thick a-Si film was deposited onto Si wafer with 100-nm thick thermal oxide by LP-CVD using Si_2H_6 at typically 450°C. Then selective ion doping was performed by 60-keV BF_2 ion implantation. Implantation dosage were varied from $1.5x10^{14}$ to $3.0x10^{15}$ ions/cm^2. Solid-phase crystallization was performed by annealing at 600°C in dry nitrogen. Nucleation stage was examined by optical microscope and transmission electron microscope (TEM).

In order to evaluate electrical characteristics, poly-Si transistors were fabricated over 6-inch wafers. CVD silicon oxide film of 40-nm thick was formed onto bottom poly-Si gate. Nucleation controlled poly-Si

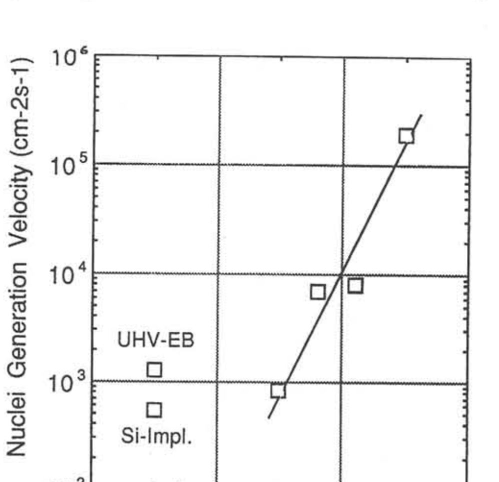

Fig.2 Dependence of nucleation rate on deposition temperature.

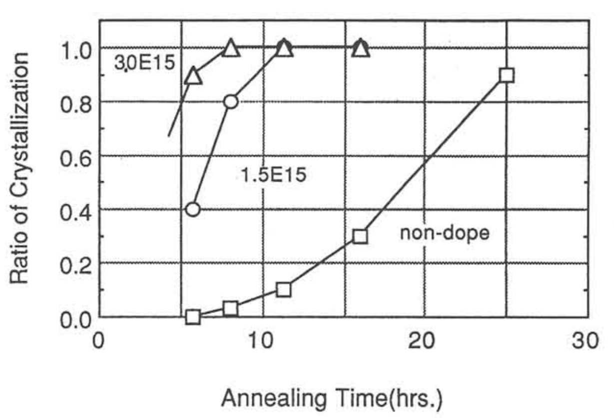

Fig.3 Crystallization of a-Si as a parameter of BF_2 ion implantation dose.

films were formed by the method described above. Source and drain regions were of selectively doped regions. Then, metallization and SiN passivation were performed. For comparison, conventional device was also fabricated. The fabricated devices have a channel length of 1.2 μm but channel width were varied from 0.6 μm to 10 μm.

4. Results and discussion

a) Nucleation control

For decreasing the nucleation rate, we adopted the low temperature deposition of a-Si using Si_2H_6. Figure 2 shows the relationship between deposition temperature and nucleation rate of a-Si. The nucleation rate is decreased as the deposition temperature decreased. The nucleation rate of $8.4x10^2$ $cm^{-2}s^{-1}$ is obtained at 450°C. This value is the same as in self-implanted a-Si and evaporated a-Si.

We examined the effect of ion doping on crystallization velocity, which is shown in fig.3. Crystallization of non-doping a-Si film is not yet completed after 25-hours annealing. However, full crystallization become faster as doping level increased, and it can be achieved in 5.7 hours annealing with $3x10^{15}$ ion/cm^2 doping.

These doping effect on crystallization can be explained by the increase of Si self-diffusion coefficient. Such effect is known to be more enhanced by phosphorous than by boron. However, P-type MOSFET is required for the application of SRAM-cell load transistors, so in this experiment boron was chosen.

The results of selectively doped a-Si films are shown in fig.4. Each doping area has 1.0 μm square in size and 7.0 μm in distance and is doped with $3x10^{15}$ ion/cm^2. After 5.7-hour annealing, only doped regions are crystallized. The crystallization proceeds from the selectively doped regions with annealing time, and each grain coalesces after 16-hour annealing while a-Si regions still remain in non-doped regions. These results represent the control of nucleation sites and grain boundaries.

b) Device characteristics

We assessed the device characteristics formed on these films. Figure 5 presents the device performance formed on these films. Drain current on these films are always larger than that of conventionally crystallized films by a factor of 2-3. This ratio becomes large when device size get small. This result indicates that, in a small size device, the channel regions are crystallized laterally from a fewer nucleation sites formed in source and drain areas. For the precise nucleation control, the size and the distance of doping regions need to be optimized.

5. Conclusion

We have demonstrated the control of nucleation site and grain boundary in crystallized a-Si using selective doping. The doping with boron of 3×10^{15} ion/cm^2 dose enhanced nucleation rate and the grain growth continued to propagate over them. It has also confirmed that the device characteristics was improved by this method, especially in small geometry devices. This method does not need additional steps and so is suitable for the device applications.

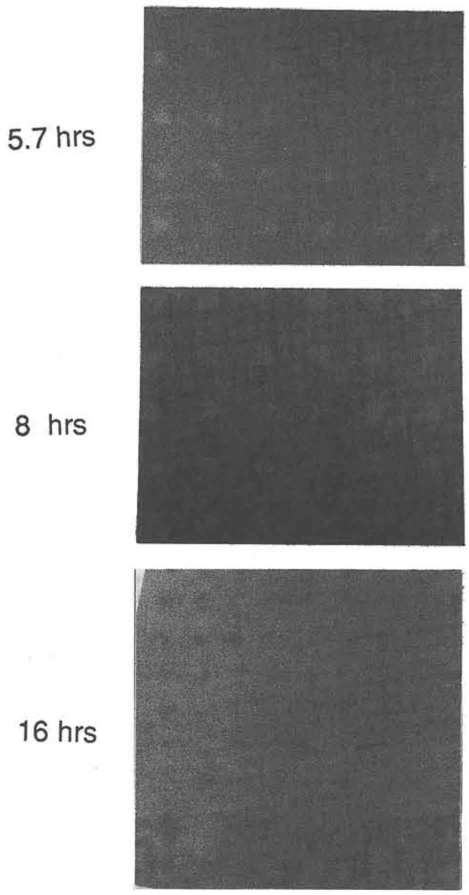

Fig.4 Crystallization behaviour by selective ion doping.

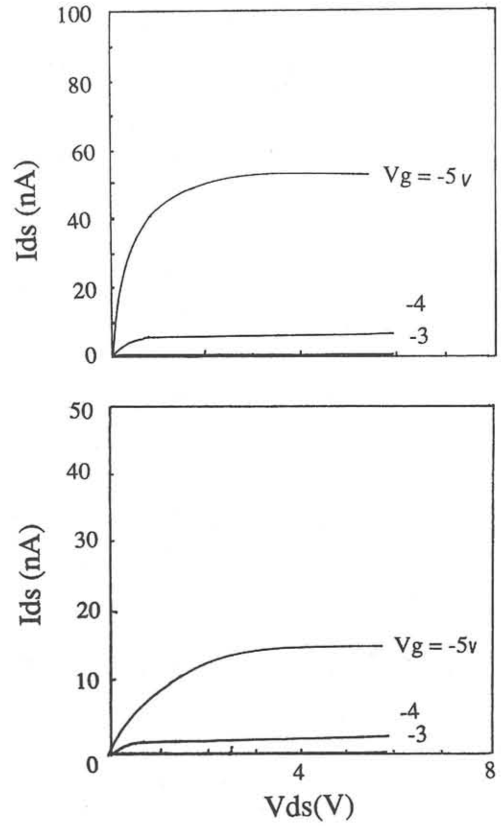

Fig.5 I-V characteristics of poly-Si transistors formed on the film by; (a) this method, (b) conventional method.

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