Extended Abstracts of the 20th (1988 International) Conference on Solid State Devices and Materials, Tokyo, 1988, pp. 189-192

C-1-4

Recrystallization Mechanism for Solid Phase Growth of Poly-Si Films on Quartz Substrates

Akira NAKAMURA, Fumiaki EMOTO, Eiji FUJII, Yasuhiro UEMOTO
Atsuya YAMAMOTO, Kohji SENDA, and Gota KANO
Electronics Research Laboratory
Matsushita Electronics Corporation
Takatsuki, Osaka 569, Japan

The recrystallization mechanism for solid phase growth of poly-Si films amorphized by ion implantation on quartz substrates is clarified on the basis of an experimental finding obtained through the TEM observation. It is found that the preferential growth in the <112> directions leads to formation of the dendritic structure. By making use of the above mechanism, large sizes of grains up to 6 μm have been successfully attained leading to the increase of the electron mobility up to 166 $cm^2/v \cdot s$.

1. INTRODUCTION

The poly-Si TFTs (thin film transistors) on quartz substrates have attracted much attention in view of application to TFT integrated circuits that serve as key elements for LCDs, contact image sensors, and thermal printer heads[1)2)].

In order to improve the electron mobility in poly-Si TFTs, attempts to enlarge the grain sizes in the poly-Si films have been made with the use of the solid-phase-growth technology[3)4)]. However, few efforts have been devoted so far to understanding the fundermental mechanism for the recrystallization process of the poly-Si films on quartz substrates.

The purpose of this paper is to demonstrate for the first time the recrystallization mechanism for the solid phase growth of poly-Si films on quartz substrates. This mechanism is clarified from an experimental finding through the TEM observation. It is also shown that the mechanism has been successfully applied to obtain the grian size as large as 6 μm.

2. TEM OBSERVATION OF RECRYSTALLIZATION PROCESS IN SOLID PHASE GROWTH

The poly-Si films were deposited on quartz substrates by the low-pressure chemical vapor deposition at approximatelly 640 °C. The films were amorphized by Si^+ implantation and then annealed in a dry nitrogen atomosphere. Figs.1 (a), (b), (c), and (d) show the TEM micrographs of the Si films after annealing at 600°C for 0 hour, 2 hours, 4 hours, and 6 hours, respectively. In Fig.1 (a), we observe the diffraction pattern of halo shape, showing amorphous structure in the implanted film. In Fig.1 (b), we can find nuclei produced in the amorphous film obtained after annealing for 2 hours. In Fig.1 (c), there have appeared a few elliptical grains containing twin boundaries (arrow) after annealing for 4 hours. In Fig.1 (d), there have appeared dendritic grain after annealing for 6 hours. In the inset of Fig.1 (d), a lot of extra spots are observed in addition to the normal {110} spots, showing the presence of twins. Twin boundaries extend toward the <112>

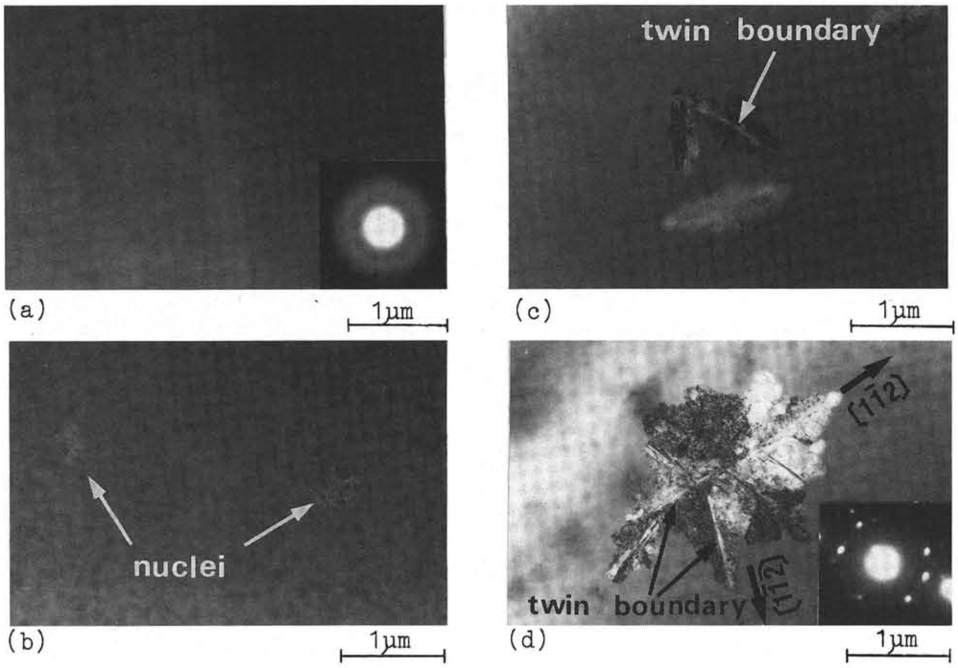

Fig.1 TEM micrographs of poly-Si films implanted and annealed at 600°C for (a) 0h, (b) 2h, (c) 4h, (d) 6h, together with the diffraction patterns in the inset of (a) and (d).

directions with a length of a few micrometers.

3. RECRYSTALLIZATION MECHANISM FOR SOLID PHASE GROWTH

Based upon TEM observation of the recrystallization process as shown in Fig.1, we propose the recrystallization mechanism given in Fig.2. In step 1, the {110} textured nucleation occurs at the initial stage of annealing process in the amorphous Si film. During the solid phase growth in step 2, the formation of twins (hatched regions) followed by the growth of elliptical grains occurs. Finally, in step 3 other twins (indicated by A and A′) are also formed and then preperential growth in the <112> directions follows, leading to formation of the dendritic grains.

The behavior of the twin boundary in the preferential growth of the crystal is shown in Fig.3. The TEM micrograph of an

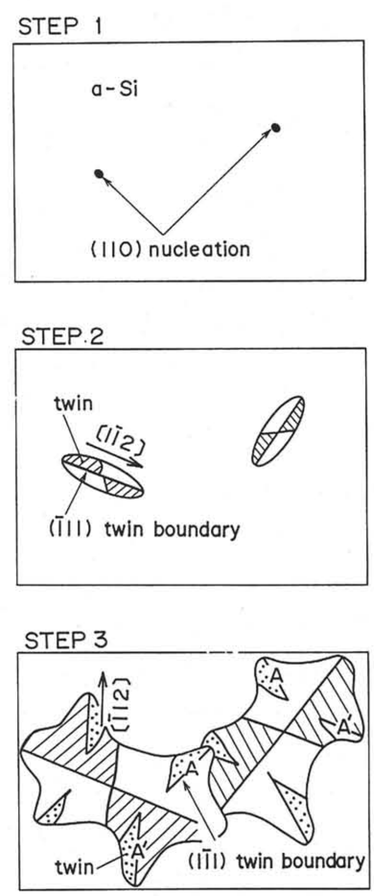

Fig.2 Schematic illustration of the recrystallization mechanism for solid phase growth.

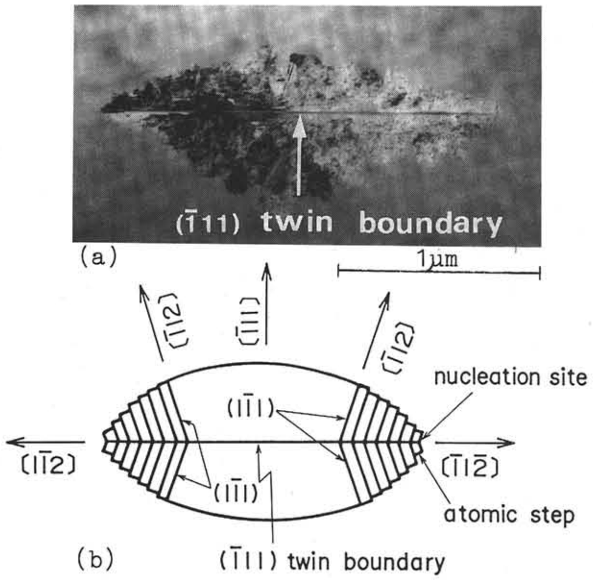

Fig.3 The behavior of the twin boundary in the preferential growth, (a) TEM micrograph of the elliptical grain and (b) schematic illustration of growth of the elliptical grain.

elliptical grain is shown in Fig.3 (a). The elliptical grain in Fig.3 (a) contains a ($\bar{1}$11) twin boundary along <112> directions. The extreme edges of the twin boundary at the crystal surface as shown in Fig.3 (b) can act as nuceation sites for atomic steps[5)6)]. At these nucleation sites, the solid phase growth in the <112> directions is accelerated, leading to production of the grains.

4. FABRICATION OF LARGE GRAIN SIZE POLYSILICON FILMS

According to the above recrystallization mechanism, poly-Si films should be perfectly amorphized to obtain large internuclear distances for enlarging grain sizes. In the conventional method the amorphization of poly-Si films has been performed by one step implantation. A disadvantage of this method is that the obtained films are not perfectly amorphous,

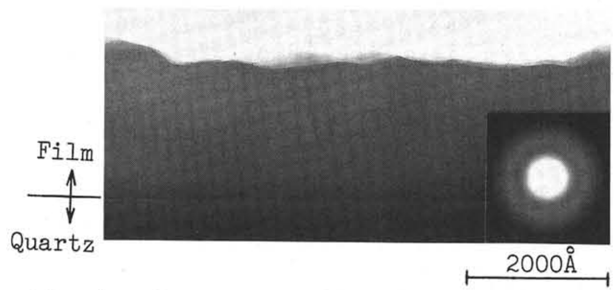

Fig.4 Cross-sectional TEM micrograph of poly-Si film amorphized by two step implantation and its diffraction pattern.

containing still polycrystalline regions near the Si-substrate interface. In view of the above disadvantage, we adopt in this work two step implantation with both high and low acceleration energy given perfectly amorphized poly-Si films throughout the film uniformly. Fig.4 shows the cross-sectional TEM micrograph of the amorphized poly-Si film by two step implantation (130keV and 50keV) and its diffraction pattern consisting of halos. It is seen that the

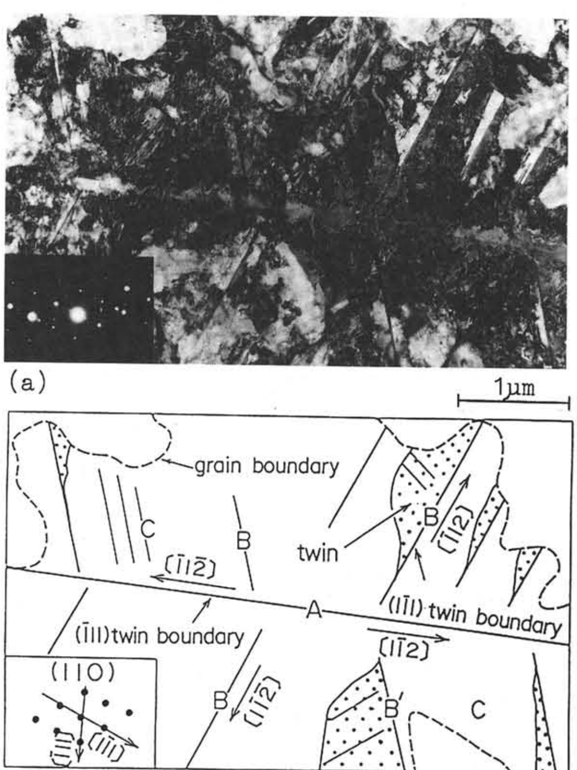

Fig.5 (a) TEM micrograph of the grain growth in solid phase.
(b) Schematic illustration of the TEM micrograph.

poly-Si film has been perfectly amorphized. The TEM micrograph of dendritic grains such films by the solid phase growth and its schematic illustration are shown in Figs.5 (a) and (b), respectively. In these figures dendritic grains as large as 6 μm are seen. The large grain size attained is direct result of the perfect amorphization achieved by the two step implantation. In fact, many {111} twin boundaries are seen to extended toward the <112> directions in Fig.5, as pointed out in step 3 of Fig.2.

5. DEVICE PERFORMANCE

After the solid phase growth, p- and n-channel TFTs were fabricated on the recrystallized poly-Si films by using the conventional CMOS process. The typical subthreshold characteristics of the fabricated p- and n-channel TFTs are shown in Fig.6. Both of the length and width of the channel are 10 μm. A thickness of the gate oxide is 1300 Å. The threshold voltages for p- and n-channel were -5.6V and 2.9V, respectively. The hole mobility and the electron mobility calcurated from the I-V characteristics were 88 $cm^2/v\cdot s$ and 166 $cm^2/v\cdot s$, respectively. It is apparent that the increase of mobilities is due to the enlarged grain sizes.

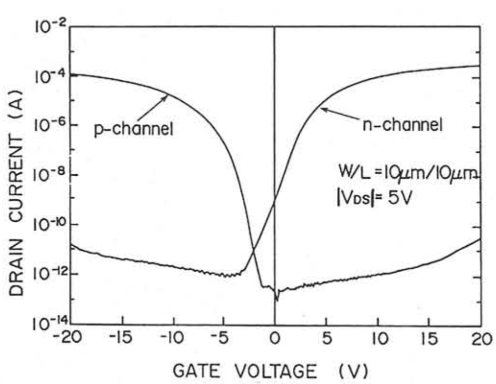

Fig.6 Subthreshold characteristics of the p- and n-channel TFTs of size of W/L=10 μm/10 μm under |VDS| =5V.

6. SUMMARY

The recrystallization mechanism of the solid phase growth has been clarified. Annealing causes the {110} textured nucleation in an amorphous Si film followed by the preferential growth in the <112> directions, leading finally to formation of the dendritic structure. Based on this mechanism we have successfully attained large grain sizes up to 6 μm. On these recrystallized poly-Si films, p- and n-channel TFTs have been fabricated, showing the field-effect electron mobility elevated up to 166 $cm^2/v\cdot s$.

ACKNOWLEGEMENTS

The authors would like to thank Dr.I.Teramoto and Dr.M.Takeshima for valuable discussion and encouragement. They also thank Mr.T.Kouzaki of Matsushita Technoresearch for TEM observation.

REFERENCES

1) S.Morozumi, K.Oguchi, S,Yazawa, T.Kodaira, H.Ohshima, and T.Mano; SID 83 digest of technical papers (1983) 156.
2) Y.Hayashi, H.Hayashi, M.Negishi, T.Matsushita; ISSCC digest of technical papers (1988) 266.
3) T.Ohshima, T.Noguchi, and H.Hayashi; Jpn. J.Appl.Phys. 25 (1986) L291.
4) H.Ishiwara, A.Tamba, and S.Furukawa; Appl.Phys.Lett. 48 (1986) 773.
5) R.Drosd and J.Washburon; J.Appl.Phys. 53 (1985) 5169.
6) D.R.Hamilton and R.G.Seidensticker; J.Appl.Phys. 31 (1960) 1165.