Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 32-34

Solid-Phase Nucleation Control of Amorphous Si by Step-Structure of Substrate Surface and Local P-Doping

M. Moniwa, K. Kusukawa, M. Ohkura and E. Takeda
Central Research Laboratory, Hitachi Ltd.,
Kokubunji, Tokyo 185, Japan

A novel technique is proposed to control solid-phase nucleation. The technique utilizes a nucleation-enhacement effect obtained from the step-structure of the substrate and local P-doping. This enables the formation of polycrystalline Si (poly-Si) films whose device area consists of a single grain.

1. INTRODUCTION

The performance of the poly-Si thin film transistors (TFT) in on SRAM cell is inferior to that of conventional bulk MOSFETs. This is due to grain boundaries. Thus, it is essential to develop a new technique to form a poly-Si film whose device area consists of a single grain (no boundary) for future high-performance SRAMs.

In this paper, we propose a novel technique for controlling solid-phase nucleation to occur at only one point in a device area as shown in Fig. 1. One-point nucleation leads to single grain formation.

2. NUCLEATION CONTROL METHOD

The concept of this technique is shown in Fig. 2. The conventional random nucleation is shown in Fig. 2(a). The step-structure formation of the substrate confines nucleation in one dimension[1] (Fig. 2(b)), and superposition of a locally doped region confines nucleation in zero dimension, i.e., one-point (Fig. 2(c)).

3. EXPERIMENTAL

Amorphous Si films were deposited by eb-evaporation in an ultra-high-vacuum (~10^{-9} Torr) on Si substrates covered with thermally grown SiO_2. The substrate temperature during the deposition and film thickness were 100°C and 0.4 μm, respectively. Step-structures on the substrate surface were formed by dry-etching with masks prior to the oxidation. Impurity doping was performed by ion implantation under the conditions shown in Table 1. Solid-phase nucleation was induced by annealing at 600°C in dry N_2.

4. RESULTS AND DISCUSSION

A. Nucleation Kinetics

The number of nuclei as a function of annealing time is shown in Fig. 3. Extrapolation to the time axis and the slope of the line give the induction time and nucleation rate, respectively. The step-structure of the substrate decreases the induction time as indicated by "t_0 to t_1" in Fig. 3. This achieves selective nucleation along the step-structure.

P-doping decreases the induction time further (from "t_1 to t_2" in Fig. 3). Thus the most likely location for nucleation is in the locally P-doped region on the step-structure. In addition, P-doping reduces the nucleation rate. The rate reduction increases the controllability to obtain one nucleus since subsequent nucleation may rarely occur under a low nucleation rate.

However, B-doping increases the nucleation rate, although the induction time decreases as for P-doping. The rate increase strongly enhances nucleation making the B-doping-effect dominant and results in no noticeable

enhancement due to step-structure formation. Moreover, the increase means degeneration of the controllability to obtain one nucleus.

These results show that phosphorus should be used for the step-structure/local-doping technique. The doping effects discussed above were observed in all doping conditions in the experiments and larger effects were observed with heavier doses.

The opposite behavior of P- and B-doping on nucleation rate can be interpreted as a change of the minimum nucleus size needed for survival (critical size)[2]. Since nucleation is a thermally activated process, small nucleus formation is frequent and large nucleus formation is rare. P-doping increases the critical size, making it difficult for nucleation to form a nucleus that can survive. B-doping, on the contrary, decreases the critical size, enabling frequent nucleation.

Since B- and P-doping increase the growth rate, nuclei in doped a-Si can grow to the critical size more rapidly than nuclei in undoped a-Si. This corresponds to the induction time decrease observed in the doped a-Si.

B. Controlled Nucleation

Nucleation control is achieved by the superposition of step-structure and local P-doping. The sample geometry is shown in Fig. 4(a). A Nomarski micrograph of a 3-h annealed sample surface is shown in Fig. 4(b). Nuclei are obtained at the cross points of the step-structure and the line-shaped P-doped region. Observation using a transmission electron microscope (TEM) and transmission electron diffraction (TED) proved that the grains shown in Fig. 4(b) consist of only one grain.

The TED additionally shows that the grain has twin-structures. The smooth growth front morphology in the TEM, however, indicates that crystallinity of the grain is superior to that obtained from conventional dendritic growth.

The contact hole shown in Fig. 1 has the step-structure and locally P-doped region. The hole can be used for the proposed nucleation control technique and the utilization is advantageous for process simplicity.

5. CONCLUSION

A solid-phase nucleation control technique was proposed. The technique utilizes superposition of the substrate step-structure and the locally P-doped region. The superposition is obtained at the contact hole connecting the TFT layer and the substrate. This means that the technique is advantageous for process simplicity.

For the basis of the technique, the effect of B- and P-doping on nucleation were investigated. Variations in the nucleation characteristics under the doping can be interpreted with the change of the critical nucleus size and growth enhancement.

ACKNOWLEDGEMENT

The authors wish to acknowledge Mr. A. Nishida for his TEM/TED observation and analysis. They also wish to express their thanks to Dr. T. Nishida and his group for the substrate preparation and Mr. N. Nakamura for the ion implantation, and wish to extend special thanks to Mr. H. Kume for his critical reading and helpful suggestions. All persons acknowledged here are of the Central Research Laboratory, Hitachi Ltd.

REFERENCES

1) M. Moniwa, M. Miyao, R. Tsuchiyama, A. Ishizaka, M. Ichikawa, H. Sunami, and T. Tokuyama, Appl. Phys. Lett., **47**, 113 (1985).
2) G. Shi and J. H. Seinfeld, J. Mater. Res., Vol. 6, 2097 (1991).

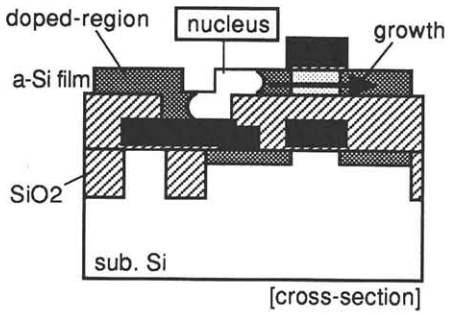

Fig. 1 Single-grain poly-Si film formation for an SRAM cell by controlling solid-phase nucleation and growth.

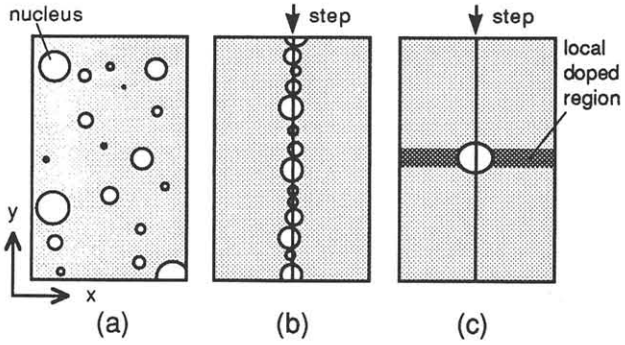

Fig. 2 Concept of solid-phase nucleation control technique. (a) random nucleation (conventional), (b) selectivity in x-direction by step-structure formatin, and (c) selectivity in y-direction by local doping.

Table 1 Ion-implantation conditions.

Sample Name	Dopant	Energy (keV)	Dose (x 10^{15} cm^{-2})
BD1	B	55	1.78
BD2			3.29
BD3			6.05
PD1	P	140	2.7
PD2			5.0
PD3			9.2

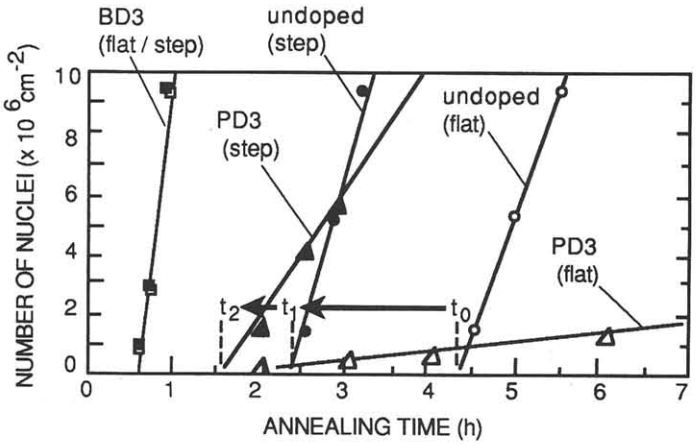

Fig. 3 Number of nuclei as a function of annealing time.

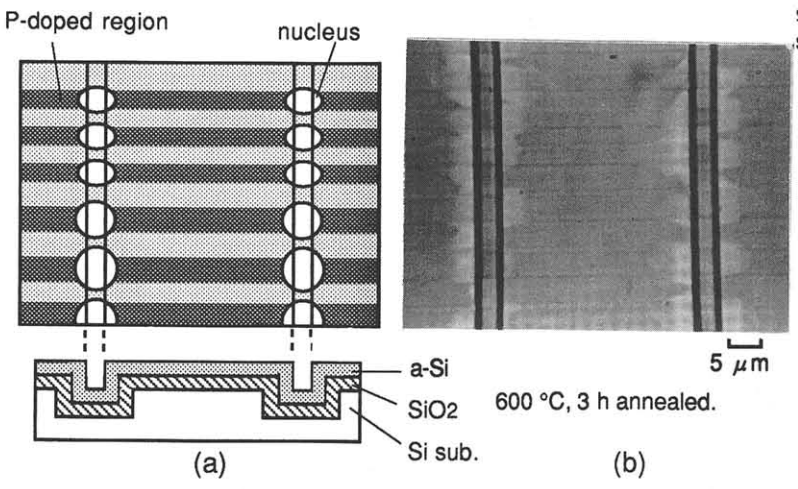

Fig. 4 Preferential nucleation induced at cross point of local P-doping region and step-structure of substrate surface. (a) sample geometry and (b) Nomarski micrograph.

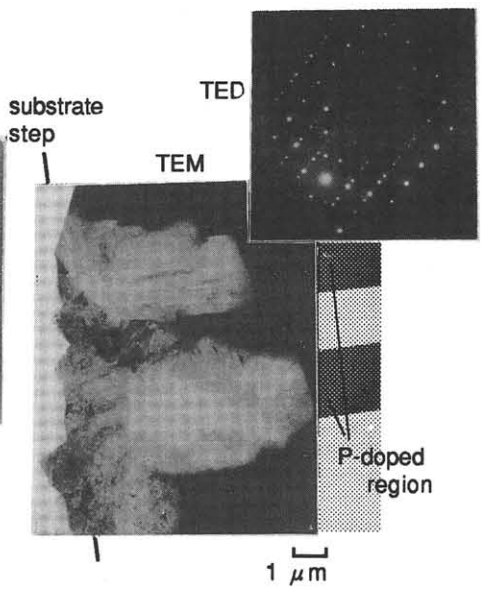

Fig. 5 TEM micrograph of nuclei shown in Fig. 4. The inset is a TED pattern of a nucleus at a cross point of the local P-doped region and the step-structure on the substrate surface.