

## Low Pressure Silicon Epitaxy Using $\text{Si}_2\text{H}_6$

Fumitake MIENO, Yuji FURUMURA, and Mamoru MAEDA

Process Engineering Dept. Semiconductors Group Fujitsu Ltd.

1015, Kamikodanaka Nakahara-ku, Kawasaki, 211, Japan

It is found that the epitaxial growth temperature can be reduced to 700 °C or below by using a low pressure  $\text{Si}_2\text{H}_6/\text{H}_2$  system, resulting in very small autodoping of impurities from highly doped substrates. In addition, selective epitaxial growth (SEG) is also realized by the same system at temperatures below 950 °C. A new technique of selective polysilicon deposition is also achieved by using a  $\text{Si}_2\text{H}_6/\text{N}_2$  system at the same temperature range.

As the device feature sizes become scaled down to submicron levels, heavy emphasis is placed on the development of low-temperature processes. In particular, a low-temperature process for silicon epitaxial growth is necessary to minimize autodoping and solid-state diffusion effects. Autodoping in silicon epitaxy was first discovered in 1961 and numerous studies have been performed for the purpose of minimizing the autodoping [1]-[6]. In order to reduce the autodoping, various processes such as molecular beam epitaxy, ion beam epitaxy, solid phase epitaxy, plasma-enhanced epitaxy, and low pressure epitaxy (LPE) have been developed [7][8]. Of the processes, only the LPE satisfies manufacturing requirements such as high throughput and low cost.

On the other hand, selective epitaxial growth (SEG) is known as a technique having a high potential in fabricating submicron devices. Numerous studies on SEG using silicon chlorides have been reported [9]-[12]. However, only a few studies have been reported describing SEG using silanes ( $\text{SiH}_4$ ) [13][14].

We have achieved that the epitaxial growth temperature can be reduced to 700 °C or below by using a low-pressure  $\text{Si}_2\text{H}_6/\text{H}_2$  system, resulting in very small autodoping of impurities from highly doped substrate. In addition, SEG is also possible by the same system at temperatures below 950 °C. A new technique of selective polysilicon deposition is also achieved by using a  $\text{Si}_2\text{H}_6/\text{N}_2$  system in the same temperature range.

### EXPERIMENTAL

A schematic of the low pressure CVD reactor equipped with M.B. and R.P. is shown in fig. 1. The pressure was controlled by ballasting  $\text{N}_2$ . A 4-inch silicon wafer was placed on the graphite susceptor which was electrically heated by an auto-voltage regulator. Disilane ( $\text{Si}_2\text{H}_6$ ) was used as a Si source gas.  $\text{H}_2$  or  $\text{N}_2$  was used as a carrier gas. The gas flow rate was controlled by a mass flow controller. The typical growth sequence is shown in fig. 2. The evaluation of autodoping was done as follows: Undoped epi-layers were grown over heavily doped substrates. Boron, arsenic, and antimony were used as dopant elements. The autodoping is estimated from the carrier concentration-depth profile obtained by a spreading resistance measurement. For the evaluation of SEG, silicon wafers with 0.5  $\mu\text{m}$ -thick thermal  $\text{SiO}_2$  stripe masks on their surfaces were prepared as substrates. Stripe masks of  $\text{SiO}_2$  were fabricated by a usual anisotropical etching. SEG was performed under the various conditions. A nomarski microscope and an SEM were used to observe the surface features and evaluate the selectivity.

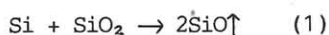
### RESULTS AND DISCUSSION

#### 1) Low-Temperature Epitaxial Growth

The effect of growth pressure on the epitaxial temperature was examined. Following the sequence shown in fig. 2, epitaxial layers were grown on the substrates at growth pressures of 450 Pa and 8130 Pa and at different temperatures. The nomarski micro-

scope photographs of the obtained surfaces are shown in fig. 3. It is apparent from the photographs that the epitaxial temperature is decreased as the growth pressure decreases. Arrhenius plots of the growth rate vs. temperature at pressures of 450 Pa and 8130 Pa are shown in fig. 4. There is little difference between the plots for the two pressures.

The reason why the epitaxial temperature is lowered as the growth pressure decreases can be as follows. Prior to the epitaxial growth, native oxide remaining on the substrate surface must be removed. At the first stage of pre-baking, the reaction(1) is taken place.



This reaction is enhanced at lower pressures. As a result, the epitaxial temperature is lowered with the pressure decreases. It is known that a chemical treatment to remove the native oxide is effective to realize a lower epitaxial temperature. Therefore, the combination of a chemical treatment and a low pressure is interesting to obtain a lower epitaxial temperature. Just before the growth, the substrate was treated with 10% HF aq. solution to remove the native oxide. And, the silicon epitaxial growth was performed at 450Pa, at a H<sub>2</sub> flow rate of 10.0 l/min and a Si<sub>2</sub>H<sub>6</sub> flow rate of 3.0 cc/min. The growth temperature was varied as a parameter. The nomarski microscope photographs of the surface features of the grown layers are shown in fig. 5. Even in the low temperature of 690 °C, an epitaxial growth was achieved.

## 2)Autodoping

The effects of the pre-bake temperature, the pre-bake pressure, the growth temperature, and the growth pressure on boron autodoping profiles were examined. The obtained profiles are shown in fig. 6, 7,8, and 9. The transition widths in boron autodoping profiles are not affected within an experimental error by the changes in the pressure below 7980 Pa in both a H<sub>2</sub> pre-bake step and an epitaxial growth step (fig. 8 and 9 ). The transition width of about 0.1 μm is derived from the data.

On the contrary, the transition width is affected by the growth temperatures. The transition width of 0.15 μm at the growth temperature of 920 °C is reduced to 0.09 μm at 810 °C (fig. 7), indicating that the autodoping is remarkably reduced as the growth temperature decreases. The transition width of about 0.1 μm is obtained for boron, arsenic, or

antimony when the epitaxial growth is done at a temperature of 810 °C and a pressure of 450 Pa (fig. 10 ). There is not a significant difference in transition width among these dopants.

## 3)SEG and Selective Polysilicon Growth

An SEM picture of SEG using a Si<sub>2</sub>H<sub>6</sub>/H<sub>2</sub> system under the conditions of growth temperature of 920 °C, growth pressure of 450 Pa, and flow velocity figure of 640 cm/sec is shown in fig. 11. The flow velocity figure is a value simply calculated from the diameter of reactor tube, a pressure, and a total gas flow rate. The selectivity was enhanced under a higher temperature and a higher flow velocity. Study on SEG using SiH<sub>4</sub> under a growth temperature over 1175 °C and an atmospheric pressure was reported [13][14]. In these papers the following reactions (1), (2), and the surface migration of Si on SiO<sub>2</sub> mask are considered as factors to prevent the growth of Si on SiO<sub>2</sub> mask.



In order to investigate the relation between the reaction (2) and the selectivity, SEG using N<sub>2</sub> instead of H<sub>2</sub> as a carrier gas was examined under the same conditions. The results are shown in fig. 12. Poly Si was deposited only on the Si surface without any Si nuclei on SiO<sub>2</sub> masks, indicating that a new technique of selective poly Si deposition is achieved. The relation between the selectivity and the growth conditions of temperature and flow velocity was the same as those of SEG. A higher temperature and a higher flow velocity produced a good selectivity. These results indicate that there is not an important relation between the reaction (2) and the selectivity. It might be said that the reaction (1) and/or migration of Si on the surface are much more likely than the reaction (2) and could be utilized to prevent the growth on SiO<sub>2</sub> masks. For further detailed analysis of the selectivity, studies on contributing species and the other Si source gases such as Si<sub>3</sub>H<sub>8</sub>, SiH<sub>2</sub>F<sub>2</sub> etc. must be carried out.

## SUMMARY

It is found that the epitaxial growth temperature can be reduced to 700 °C or below by using a low pressure Si<sub>2</sub>H<sub>6</sub>/H<sub>2</sub> system, resulting in very small autodoping of impurities from highly doped substrates.

The SEG is performed at a growth temperature of

920 °C with a pressure of 450 Pa. Selective poly-silicon deposition is also realized when the carrier gas is replaced from H<sub>2</sub> to N<sub>2</sub>. The selectivity of Si growth was enhanced under higher temperatures and higher gas flow velocity.

ACKNOWLEDGEMENT

We would like to acknowledge O. Hideshima, and S. Nakamura for their support in S.R. measurement, H. Ishikawa for many useful discussions, K. Yanagida for providing an environment which made all this work possible, and H. Ino for encouraging directions.

REFERENCE

[1] G. R. Srinivasan, J. Electrochem. Soc., 127, 1334 (1980).  
 [2] G. R. Srinivasan, J. Electrochem. Soc., 125, 146 (1978).  
 [3] G. R. Srinivasan, J. Electrochem. Soc., 127, 2305 (1980).  
 [4] S. B. Kulkarni and A. A. Kozul, Electrochem. Soc. Extended Abstracts, 80-2, 1351 (1980).  
 [5] V. J. Silvestri and G. R. Srinivasan, J. Electrochem. Soc., 131, 877 (1984).  
 [6] Hsueh-Rong Chang, Electrochem. Soc. Extended Abstracts, 83-2, 550 (1983).  
 [7] T. J. Donahue and R. Reif, J. Appl. Phys., 57 (8), 2757 (1985).  
 [8] M. L. Hammond, Solid State Technology, 22, 61 (1979).  
 [9] D. M. Jackson, Jr., Trans. Metall. Soc., AIME, 233 596 (1965).  
 [10] E. G. Alexander and W. R. Runyan, Tans. Metall. Soc., AIME, 236 284 (1966).  
 [11] D. D. Rathman, D. J. Silversmith and J. A. Burns, J. Electrochem. Soc., 129 2303 (1982).  
 [12] L. Jastrzebski, J. F. Corboy and R. Pagliaro, Jr., J. Electrochem. Soc., 129 2645 (1982).  
 [13] D. J. Dumin, J. Crystal Growth, 8, 33 (1971).  
 [14] P. Rai-Choudhury and D. K. Schroder, J. Electrochem. Soc., 118, 107 (1971).

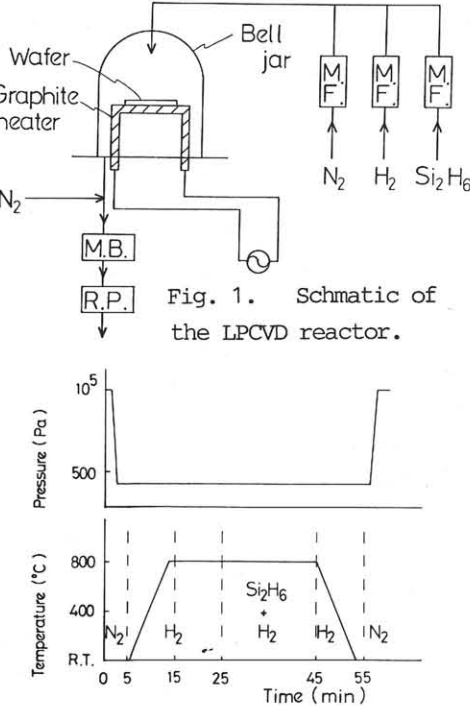


Fig. 2. Typical growth sequence.

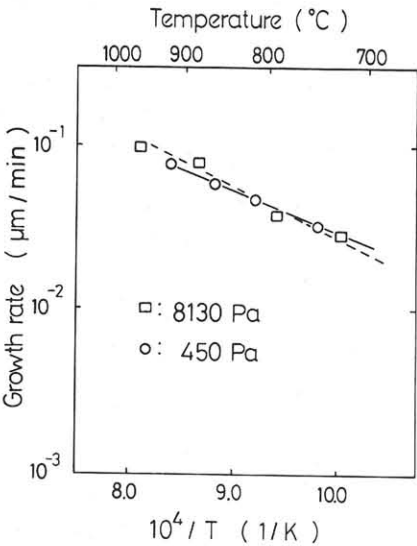


Fig. 4. Arrhenius plots of the growth rate vs. the temperature.

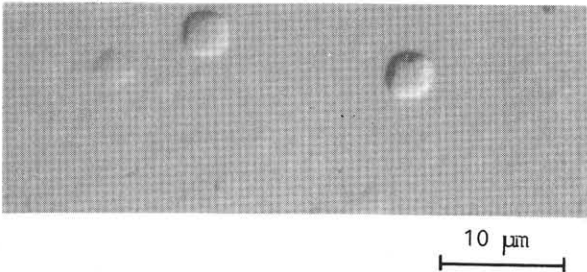


Fig. 5. The nomarski microscope photograph of the epitaxial layer, which was grown at a temperature of 690 °C.

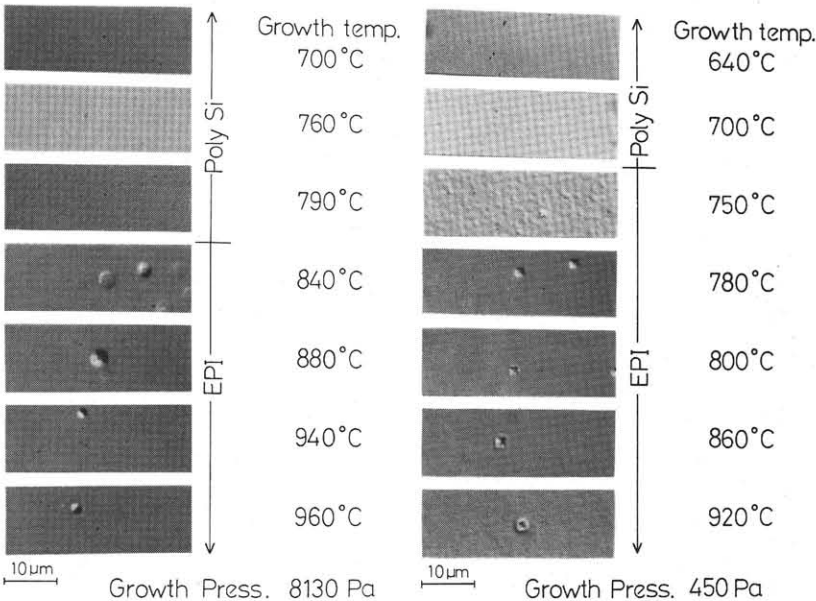


Fig. 3. The nomarski microscope photographs of the film surfaces.

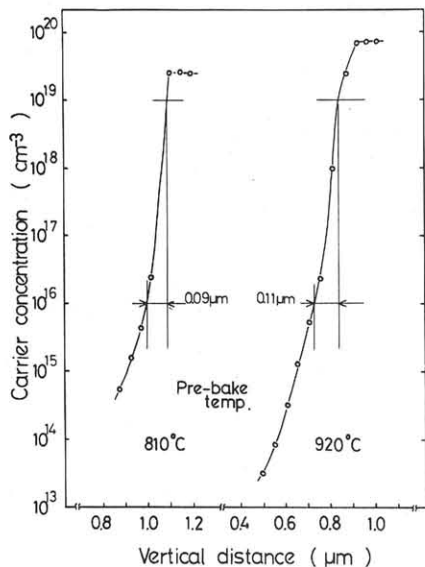


Fig. 6. Carrier concentration profiles for boron autodoping. The growth temperature is 810 °C and the pressure is 450 Pa.

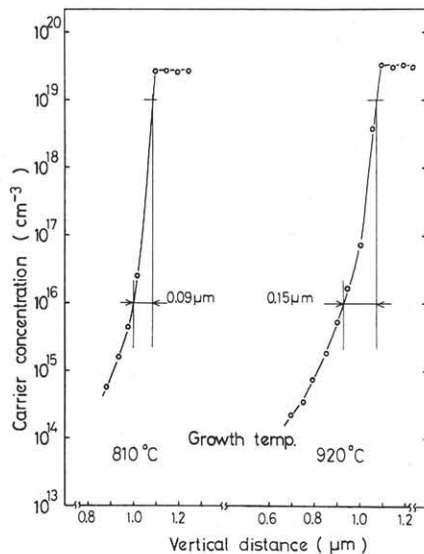


Fig. 7. Carrier concentration profiles for boron autodoping. The pre-bake temperature is 810 °C and the pressure is 450 Pa.

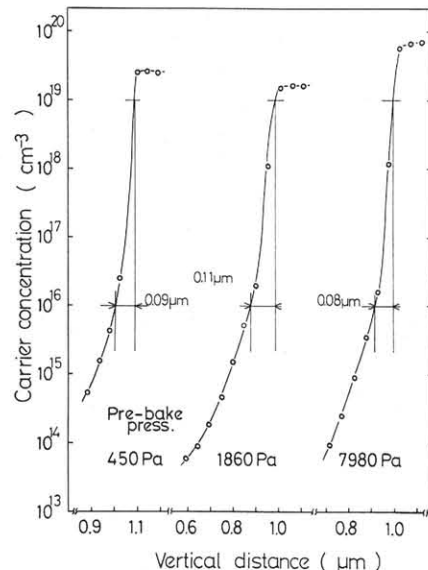


Fig. 8. Carrier concentration profiles for boron autodoping. The growth pressure is 450 Pa and the temperature is 810 °C.

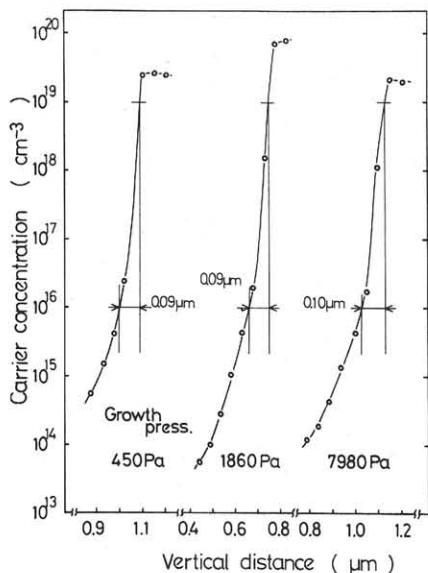


Fig. 9. Carrier concentration profiles for boron autodoping. The pre-bake pressure is 450 Pa and the temperature is 810 °C.

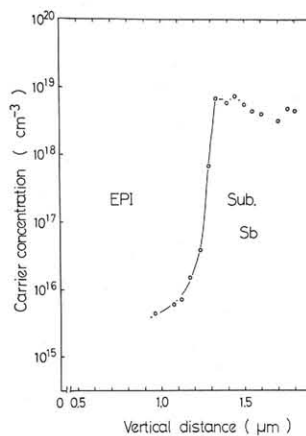


Fig. 10. Carrier concentration profiles for arsenic autodoping and antimony autodoping.

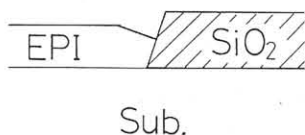
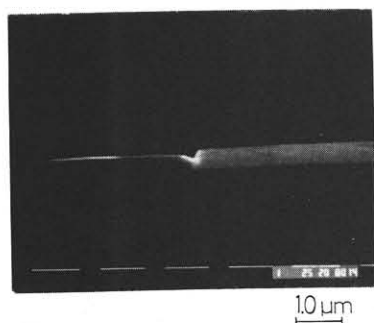
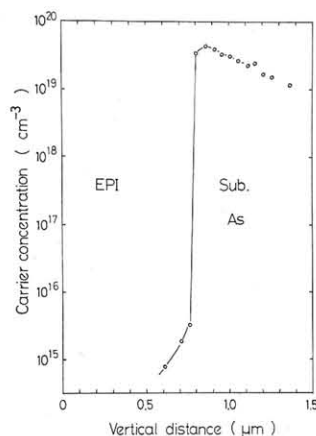


Fig. 11. A cross-sectional SEM picture of the sample on which SEG was performed.

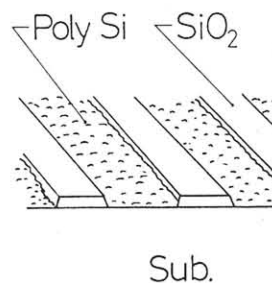
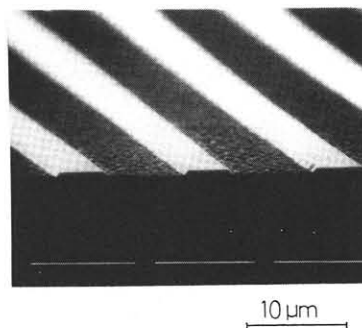


Fig. 12. An SEM picture of the sample on which selective polysilicon deposition was performed using a  $\text{Si}_2\text{H}_6/\text{N}_2$  system.