# Silicon Epitaxial Growth by a Fast Wafer Rotating Reactor Using Silane Gas

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An experimental study on the silicon epitaxial growth mechanism was carried out by a fast wafer rotating reactor using $SiH_4$ gas. A three inch wafer was rotated at up to 10800 rpm to control both the gaseous material diffusion rate and the time for the gas phase reactions. High wafer rotation speed notably suppressed the gas phase reactions to prevent silicon particle production through thermal decomposition of $SiH_4$. As a result of such gas phase reaction control, the controlling process for the film growth rate has been clarified, which changes with temperature and the wafer rotating speed. A high growth rate of 40 μm per minute was obtained at a growth temperature of 1000°C.

## 1 Introduction

The use of silane gas for silicon epitaxial growth has advantages over that of silicon chloride gases. One is to reduce the growth temperature below 1000°C and another is that it has a possibility of promoting a growth rate of more than tens of micrometers per minute[1]. The growth rate has usually been, however, only several micrometers per minute in conventional reactors. Furthermore, silicon particle production by gas phase reactions is one of the causes of not only limiting the growth rate but also decreasing the epitaxial film quality. With a view to increasing the growth rate and decreasing the amount of particles, the authors examined the growth rate dependence on the growth conditions by a fast wafer rotating reactor using silane gas. The fast wafer rotating method has effectively suppressed undesirable particle production in the gas phase, and has clarified the growth rate limiting process under a wide range of growth conditions.

## 2 Theory of the fast wafer rotating method

The residence time of the source gas in the boundary layer affects the gas phase reaction, because the gas phase reaction mainly takes place in the boundary layer where the gas temperature is high. It is easy to control the residence time in a fast wafer rotating reactor by adjusting the wafer rotation speed, although it is difficult or almost impossible in a conventional reactor. A theoretical relationship between the residence time and the rotation speed in a fast wafer rotating reactor has been derived from the boundary layer thickness and the diffusion coefficient.

The order of boundary layer thickness, $\delta$, in a fast wafer rotating reactor is theoretically given as;

$$\delta \sim \sqrt{v/\omega}, \tag{1}$$

where $v$ is the kinematic viscosity and $\omega$ is the wafer rotation speed. The diffusion time constant, $\tau$, which is related to the degree of the gas phase reaction is defined as;

$$\tau \sim \delta^2/D, \tag{2}$$

where $\delta$ is the boundary layer thickness and $D$ is the diffusion coefficient. Equations (1) and (2) lead to a relationship between the degree of the gas phase reaction and the rotation speed as;

$$\tau \propto \omega^{-1}. \tag{3}$$

Equation (3) means that a higher rotation speed will suppress the gas phase reactions. Therefore, the wafer rotating method prevents undesirable silicon particle production in the gas phase.

Incidentally, the growth rate under a diffusion controlled condition, in which source material concentration on the wafer surface is negligible compared with that of the feed gas, is also theoretically derived as[2];

$$G.R. = DC\sqrt{\omega/v}\Phi'(0) \propto \sqrt{P\omega}f/Q, \tag{4}$$

where $C$ is the source gas concentration, $\Phi'(0)$ is the dimensionless concentration gradient on the wafer surface, $P$ is the pressure, $f$ is the source gas feed rate, and $Q$ is the total gas flow rate. Equation (4) is effective under the condition that the gas flow in the reactor is

governed by the wafer rotation. Under these conditions, film thickness uniformity within a wafer is obtained by keeping $\sqrt{P\omega}/Q$ a constant optimum value. Therefore, the choice of the growth conditions are flexible in terms of each value of P, $\omega$ and Q, even in the case that a growth rate has to be kept constant. According to Eq.(4), the examination of the growth rate dependence on the growth condition determines whether the growth rate is diffusion controlled.

The fast wafer rotating method has an ability to control both the gas phase reaction and the diffusion rate, as shown in Eqs. (3) and (4). This ability, together with the one-dimensional behavior of the system, is useful to clarify the complex phenomena in a chemical vapor deposition reactor.

## 3 Experiment

A schematic of the reactor is shown in Fig.1. A 3" wafer was rotated at up to 10800 rpm and heated by a resistance heater. The source gas and hydrogen gas were fed from the top portion of the reactor and supplied uniformly onto the wafer surface through a porous plate. The wafer temperature was monitored by pyrometers. The growth conditions are shown in Table 1.

## 4 Results and discussion

Figure 2 shows the growth rate dependence on the rotation speed. Two kinds of source gases were used for growths; one was silane at a growth temperature of 1000°C and another was dichlorosilane (DCS) at 1100°C. In both cases, the growth rate should be proportional to the square root of the rotation speed, as shown in Eq.(4), if the growth is diffusion controlled. In the case of DCS, however, the growth rate showed a tendency to saturate with an increase in the rotation speed, which suggests that the growth was surface reaction controlled at a higher growth rate than several micrometers per minute at 1100°C. As for the growth using silane gas at 1000°C, the growth rate was faster than that using DCS, and was almost proportional to the square root of the rotation speed. Consequently, the growth using silane appeared to be diffusion controlled even at a high growth rate of tens of micrometers per minute in spite of the 100 degrees lower growth temperature than when using DCS. This result indicates that silane gas suits silicon epitaxial growth, when a lower growth temperature or a higher growth rate is necessary.

The growth rate dependence on the silane gas feed rate at the rotation speed of 10800 rpm is shown in Fig.3. Polycrystalline films were grown below 900°C. The growth rate was not linear to the source gas feed rate. This result suggests the growth is not diffusion controlled

at a higher source gas feed rate, since the growth rate must be proportional to the silane gas feed rate under the diffusion controlled condition. Two kinds of causes are considered for this phenomenon; one is that the growth rate controlled process may change from diffusion to surface reaction at higher growth rates; the other is that the ratio of conversion of silane gas into silicon particles to the feed gas rate may increase with the feed rate.

The growth rate dependence on the growth temperature is shown in Fig.4. The growth rate increased with the temperature and had a maximum value, then decreased at a higher temperature. From Fig.4, the growth rate controlled process was divided into 3 regimes; first, a reaction controlled regime at a low temperature; second, a diffusion controlled regime at a medium temperature; and third, a particle production regime at a high temperature, where the growth rate is smaller than that under diffusion controlled because of a large amount of particle production in the gas phase. An observation through a view port showed that particles were also produced in the diffusion controlled regime, though they did not appear to affect the growth rate. These regimes depended not only on the growth temperature but also on the rotation speed, because the rotation speed changes both the degree of gas phase reaction and the diffusion rate. The decrease in the growth rate at the particle production regime became smaller with an increase in the rotation speed, since a high rotation speed prevents undesirable silicon particle production as indicated by Eq.(3). Actually, a decrease in silicon particles with the rotation speed was observed through a view port of the reactor.

## 5 Conclusion

The authors have clarified that a fast wafer rotating reactor has an ability to control the gas phase reaction. This ability has been effectively applied to silicon epitaxial growth using silane gas. A wafer rotation effect has been found to suppress undesirable gas phase reaction which produces silicon particles by the thermal decomposition of silane gas, and a high growth rate of 40 μm/min has been obtained. The growth rate limiting process has also been clarified in a wide range of growth conditions.

## 6 References

1) B. Joyce and R. Bradly, J. Electrochem. Soc. 110 (1963) 1235.
2) Y. Sato and T. Ohmine, Extended Abstracts of 1991 International Conference on Solid State Device and Materials, Yokohama, 1991, p.717.

## Table 1. Growth conditions

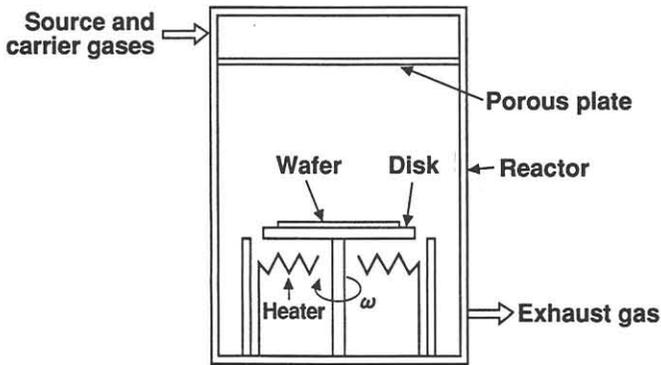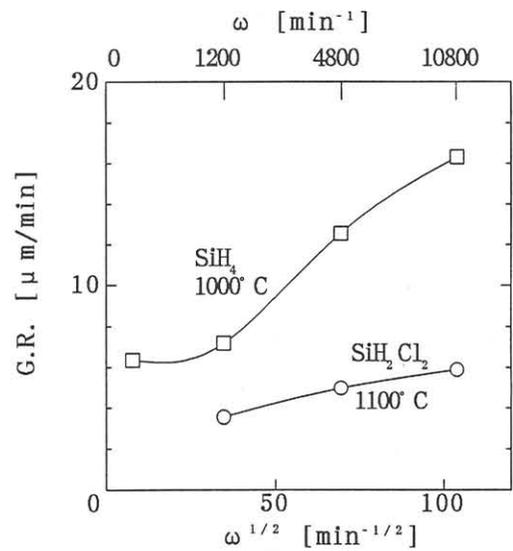| Source gas | $SiH_4$, $SiH_2Cl_2$ |
|---|---|
| Source gas flow rate | 1 l/min |
| Carrier gas | $H_2$ |
| Carrier gas flow rate | 15 l/min |
| Temperature | 800 - 1200°C |
| Pressure | 38 Torr |
| Wafer rotation speed | 60 - 10800 rpm |
| Wafer | 3" Si (111) |



Fig.1 Rotating disk reactor diagram



Fig.2 Growth rate dependence on rotation speed
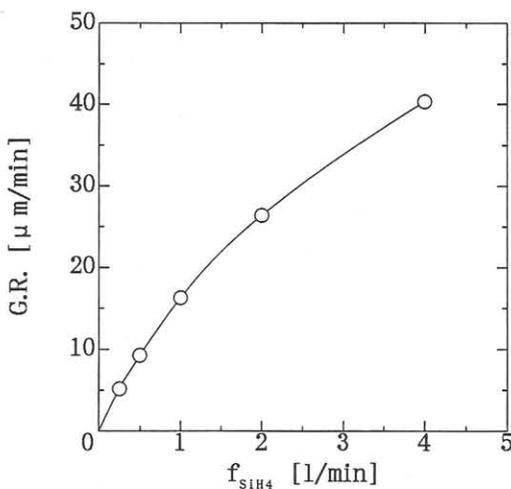P=38 Torr, $H_2$=15 l/min, $SiH_4$,DCS=1 l/min



Fig.3 Growth rate dependence on silane gas flow rate
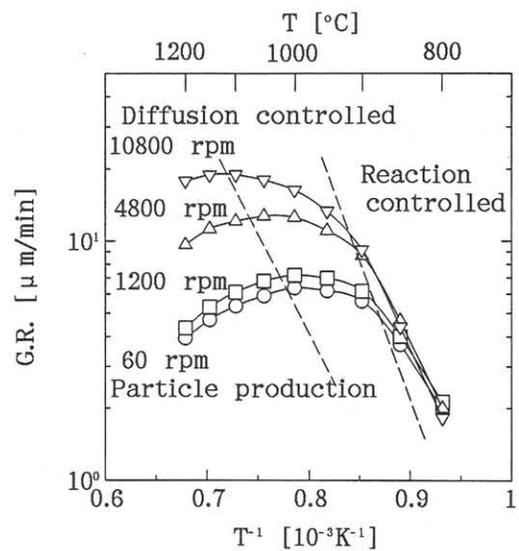T=1000° C, P=38 Torr, $H_2$=15 l/min, $\omega$ =10800 rpm



Fig.4 Growth rate dependence on temperature
P=38 Torr, $H_2$=15 l/min, $SiH_4$=1 l/min