Particle Deposition Mechanism onto Si Wafer

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The mechanism of particle deposition was studied both theoretically and experimentally. Particle deposition is described by particle deffusion model. There are stationary and non-stationary state deposition and the former depends on ionic strength in solution, particle surface electric potential, particle size and diffusion layer thickness. It's important for LSI technology that small particles less than $0.1\,\mu$m are very liable to adhere to Si wafer.

1. INTRODUCTION

Semiconductor devices have been manufactured more finely with year, and now even very small particles prevent high production yield and device performances. In the case of 16M DRAM particles more than 0.05 μm in diameter would affect the yield. But the behavior of such small particles, especially deposition mechanism onto the wafer, has been scarcely elucidated.

In this paper we would like to introduce a model to explain particle deposition mechanism.

2. THEORETICAL

The model of particle deposition, we devised, is based on diffusion theory. Particles move along the flow in solution and deposit by particle diffusion (Fig. 1). The main
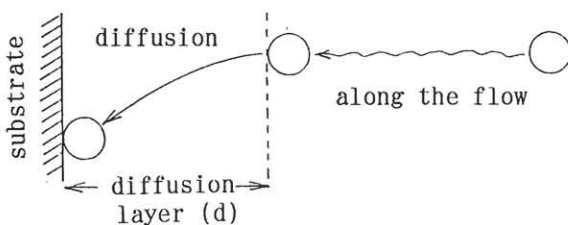
force working in the particles adjacent to the wafer surface are Van der Waals force and repulsion of electric double layers between particle and surface. The potentials of Van der Waals force and electric double layers are

$$V_a = -\frac{Ham}{6}\left\{ \frac{2a(x+a)}{x(x+2a)} - \ln\frac{x+2a}{x} \right\}$$

$$V_r = \frac{\varepsilon a}{4}\left\{ (\phi^2+\phi_s^2)\ln\frac{\exp(2\kappa x)-1}{\exp(2\kappa x)} \right.$$
$$\left. +2\phi\phi_s\ln\frac{\exp(\kappa x)+1}{\exp(\kappa x)-1} \right\}$$

V_a:potential of Van der Waals force

V_r:potential of electric double layers

ϕ_s:surface electric potential of wafer

ϕ :surface electric potential of particle

κ :Debye constant

a:radius of particle

V_a and V_r depend on parameters such as ionic strength in solution, particle size etc. We considered both stationary and non-stationary state.

Fig. 1 Model of particle deposition

2.1 Stationary state

The diffusion equation is (considered in one dimension)

$$j = -D \frac{dn}{dx} + vn$$

$\quad$ j:flux of particles
$\quad$ D:diffusion constant
$\quad$ n:density of particle number
$\quad$ v:velocity of particles

The flux j consists of diffusion part and drift part. The drift part is modified as

$$v = -\frac{1}{\rho_v} \frac{dw}{dx}$$

$\quad \rho_v$:frictional constant
$\quad W = V_a + V_r$

and from the Einstein relation.

$$D\rho_v = kT$$

$\quad$ k:Boltzman constant
$\quad$ T:absolute temperature

Therefore

$$\frac{dn}{dx} + \frac{1}{kT} \frac{dw}{dx} n + \frac{j}{D} = 0$$

is obtained.

The boundary conditions are

$\quad$ n=0 at x=0

$\quad$ n=n_d at x=d

$\quad$ d:diffusion layer thickness
$\quad$ n_d:particle density at x=d

We consider n_d is equal to particle density in the water bath.

The solution under these boundary conditions is

$$j = n_d \cdot D \cdot \frac{1}{\int_0^d \exp\left(\frac{w}{kT}\right)dx} \quad ---(1)$$

j corresponds to the particle deposition rate. The integral can't be solved analytically, so we calculated it numerically by HITACHI M-680H.

2.2 Non-stationary state

The diffusion equation is

$$\frac{\partial n}{\partial t} = \frac{\partial j}{\partial x}$$

It was calculated using Crank-Nikolson method.

In this paper stationary state was mainly discussed. The results were compared with the experiments mentioned in next chapter.

3. EXPERIMETAL

0.9 μm polystyrene particles (Dow chemical) and n-type Si wafers (Shinetsu Kagaku) were used. The particles were dispersed in ultra clean water. HCl and NaCl were used in order to control the ionic strength.

Deposition experiment was made in two ways.

(1) Wafers were put on the rotating disk in particles dispersed water and rotated at certain velocity (Fig. 2).

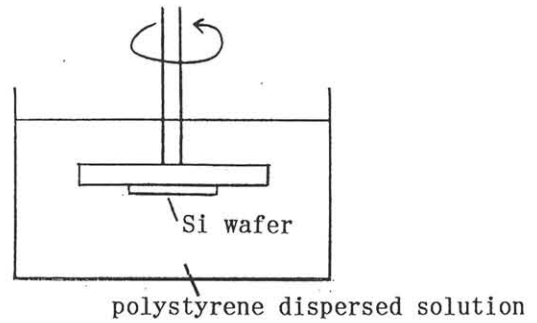(2) Wafers were dipped into the paricles dispersed water (Fig. 3).

polystyrene dispersed solution

Fig. 2 Particle deposition experiment
(rotating disk)

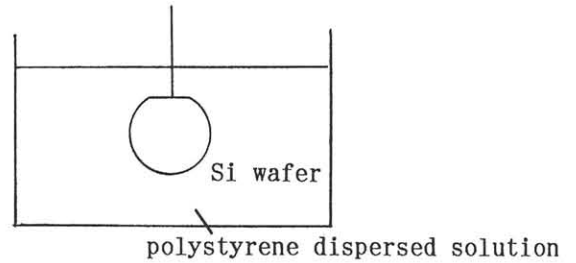

polystyrene dispersed solution

Fig. 3 Particle deposition experiment
(dipping)

In both cases Si wafers were immersed for a certain minutes and pulled up. After drying, particles deposited on the wafer were observed by optical microscope.

4. RESULTS AND DISCUSSION

4.1 Under laminar flow

Rotating disk was used in order to define the thickness of laminar sub-layer. Fig. 4 shows the relation between immersing time and particle deposition under two rotating rates. Diffusion layer thickness d can be calculated

by laminar sub-layer thickness. Thus we can compare the theoretical value of formula (1) and the slopes in Fig. 4, which correspond to the deposition rates (Table 1). Both are almost coincident.
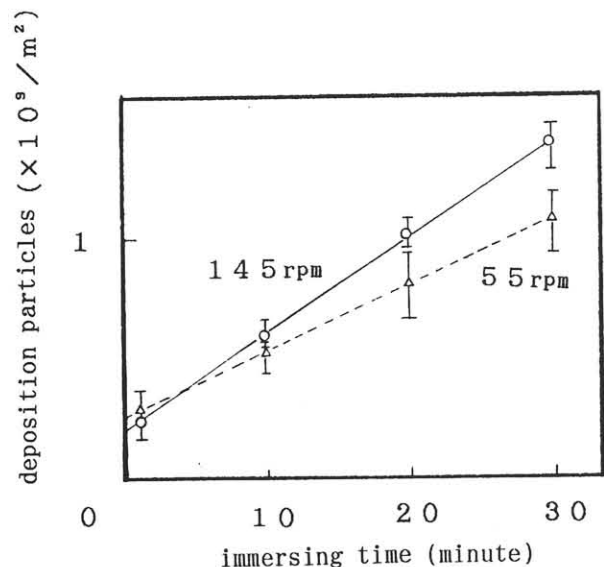

Fig. 4 Relation between immersing time and particle deposition

As shown in Fig. 4 the y-intercept is not 0. This means that there must be fast deposition within one minutes. It's explained by non-stationary state deposition. Fig. 5 shows the result of non-stationary state calculation. The total non-stationary deposition particles which are calculated coincide with the y-intercept in Fig. 4(Table 2).
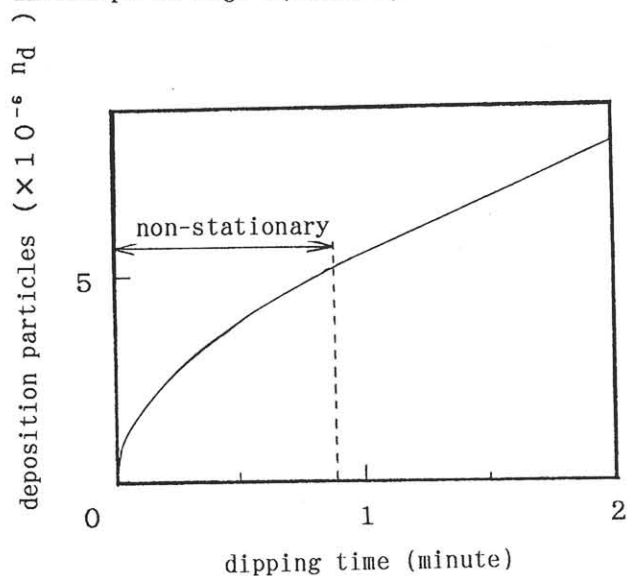

Fig. 5 Relation between immersing time and particle deposition (solution of non-stationary equation)

Table 1 Comparison of experimental and theoretical

	theoretical	experimental
5 5 rpm	3.9×10^5	4.9×10^5
1 4 5 rpm	5.9×10^5	6.6×10^5

$(/m^2 sec)$

Table 2 Total deposition particles of non-stationary state

	theoretical	experimental
5 5 rpm	1.1×10^8	1.6×10^8
1 4 5 rpm	7.2×10^7	1.1×10^8

$(/m^2)$

4.2 Dipping

In the case of dipping we can't define the laminar sub-layer. But the diffusion layer is finite, because there would be any flow in the water bath by the convection etc.

Figure 6 shows the relation between dipping time and particle deposition. Three particle densities were selected. In each density the deposition particles increase linearly with the dipping time. And the slope increases in proportion to the density of particle number. These agree with the formula (1) basically.
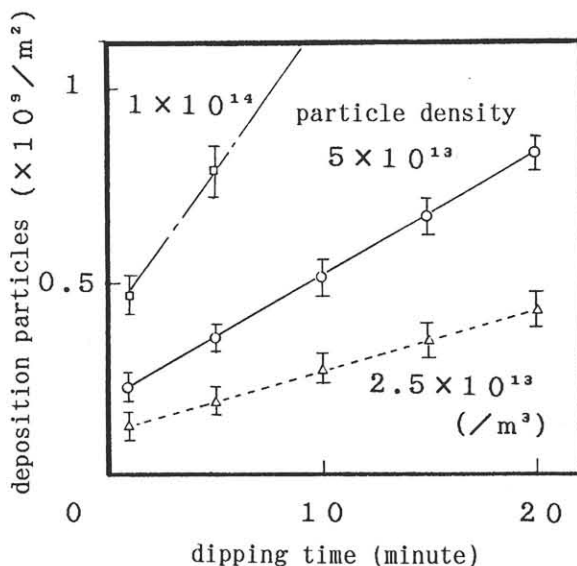

Fig. 6 Relation between dipping time and particle deposition

In the next part relations between parameters and particle deposition are discussed.

(a) Ionic strength in solution

Figure 7 shows the relation between ionic strength and particle deposition. Ionic strength was controlled by HCl or NaCl. At low ionic strength, for example in ultra clean water, particles scarcely adhered to the wafer. But at the concentration above 10^{-3} mol/l, particles abruptly turned into adhere to the wafer.
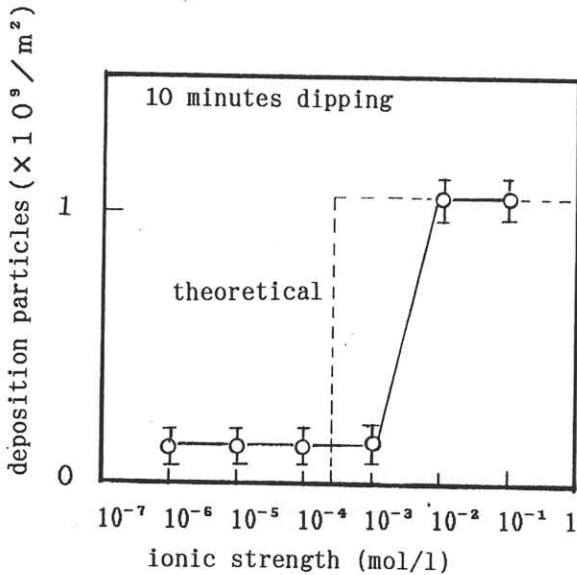

Fig. 7 Relation between ionic strength and particle deposition

(b) Surface electric potential

The surface electric potential of the particle can't be measured, so we measured the zeta potential by electrophoresis. Zeta potential is thought almost equal to surface electric potential.

Figure 8 shows the relation between zeta potential of particles and particle deposition. As shown in Fig. 7, polystyrene particles don't adhere to the wafer at low ionic strength. But materials such as HF-treated Si or Al_2O_3, whose zeta potential is more than -10 mV, adhere to the wafer even at low ionic strength. This agrees with the calculation.
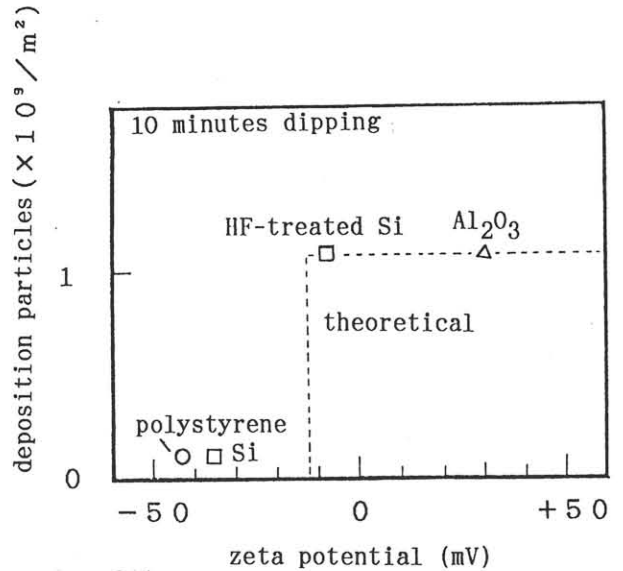

Fig. 8 Relation between zeta potential and particle deposition

(c) Particle size

Figure 9 shows the relation between particle size and particle deposition. As shown in Fig. 7, 0.9 μm polystyrene particles don't adhere to the wafer at low ionic strength. But Fig. 8 shows particles below 0.1μm adhere even at low ionic strength.
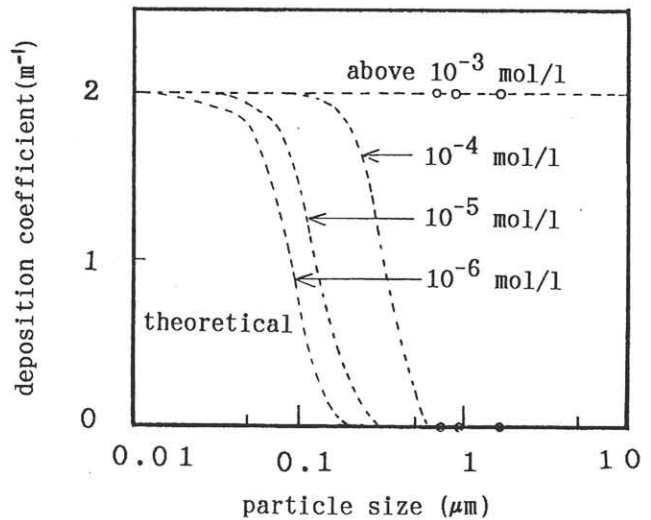

Fig. 9 Relation between particle size and particle deposition

deposition coefficient : $\dfrac{1}{\int_0^d \exp \left(\frac{w}{kT}\right) dx}$

As is mentioned above, it is valid to describe the particle deposition by the diffusion model and we basically elucidated the small particle deposition behavior.