Selected Article

Developing the Standard Sample for the Reticle/Mask Particle Remover
— Particle Remover RP-1 —
レティクル／マスク異物除去装置用標準サンプルの開発
ーパーティクルリムーバー　RP-1ー

Tomoya SHIMIZU

清水 智也

In manufacturing semiconductor devices, removing particles on a pellicle and a glass surface of a reticle has been frequently done by manual air blow or by adhesive substance. In this case, pellicles can be contaminated. To reduce the risk of causing such errors and keep reticles clean over the long term, we developed the Particle Remover RP-1 that automatically removes particles on a pellicle and a glass surface. This time, developing the standard sample allows to measure removal rate and repeat test, which assure performance of RP-1. Moreover, time dependency of the removal rate after attaching particles is reported.

半導体デバイス製造現場では，レティクルのペリクル膜およびガラス面上の異物除去処理は，エアブローまたは粘着剤などを用いて手動で行われることが多い。このとき，ペリクル膜を汚損する問題が発生する場合がある。このような人為的なミスによるペリクル膜の汚損リスクを低下させ，レティクルを清浄な状態で長期に維持するため，ペリクル膜およびガラス面上の異物除去を自動で行う装置パーティクルリムーバーRP-1を開発した。今回，標準サンプルを考案したことによって，除去率の定量化と再現実験が可能となり装置の性能保証を実現した。さらに，標準粒子付着後の除去率経時変化についても考察を加える。

Introduction

Photolithography is a technology that enables the mass production of the semiconductor device by transferring the original pattern printed on the reticle and the mask onto the surface of the wafer. The circuit pattern has become small recently, so particle's size on the reticle surface causing the defect has become small, too. Therefore, the transparent polymer membrane that is called pellicle is mounted on the reticle surface so that particles should not adhere directly on the pattern side of the reticle. The pellicle's thickness has been decreased and pellicle's material has changed from cellulose to fluorine, to adapt short wavelength used in photolithography exposure. We developed an equipment RP-1 that removes particles on the pellicle film or the glass side of the reticle by automatic operation. We thought establishment of a quantitative performance evaluation technique is the most important to develop system. This time, the development of standard samples can make quantification and the repeatability test of the removal rate, and details of experiment are shown. In addition, consideration about a change with the time-dependent change of the removal rate after the particles had adhered is added.

Development Background and Product Concept

Problems are described in the case of adhering particle on the pellicle film and the glass side of the reticle. Even if a minute pattern with the particle adhered on the pellicle film or the glass side is transferred, the image of the particle doesn't make the defect because it is defocused. However, the irregularity of the luminous exposure forms the defect to a minute pattern when the particle is more than certain size. At this time, the size of the particle that causes the defect is different according to the exposure machine and the design of the pattern.

Recently, when the number of particles or the size of particles exceeds the limit, the operator took out the reticle from the case, and removing particles by direct air blow of the pellicle surface, generally.

However, the process has following problems.

1 Pollution of pellicle by the operator's mistake

2 Damaged the reticle pattern by electro discharge when operator touch the reticle

3 Increase in particles adhesion risk by putting reticle in and out from case

For these reasons the expectation for the equipment that automatically and efficiently removes the particles on the pellicle and the glass side has risen. To match these needs, RP-1 automated the removing processes (from opening and shutting of the case of the reticle, transporting the reticle to the stage, removing the particles, and until returning the reticle to the case). The removing particle is characterized in efficiently removing particles on the pellicle film and the glass side on the reticle with a clean dry air. Specification of the removing particle is more than 90% standard particles of 5 μm diameter on the glass side, more than 90% standard particles of 20 μm diameter on the pellicle film. Removing targets are the fallen particles, not particles that grew up on the surface of the reticle.

Product Outline

RP-1 has the mechanism to remove particle, to open and close various reticle cases, and to transport reticle. The removing particle is that taking off particles from the surface with the pressure air from 0.3×10 mm slit and vacuuming these. Figure 1 shows removing prove, the moving part, and the route of the removing particles probe. The particles on the pellicle film and the glass side are efficiently removed by moving the probe through the route shown in the arrow of Figure 1.

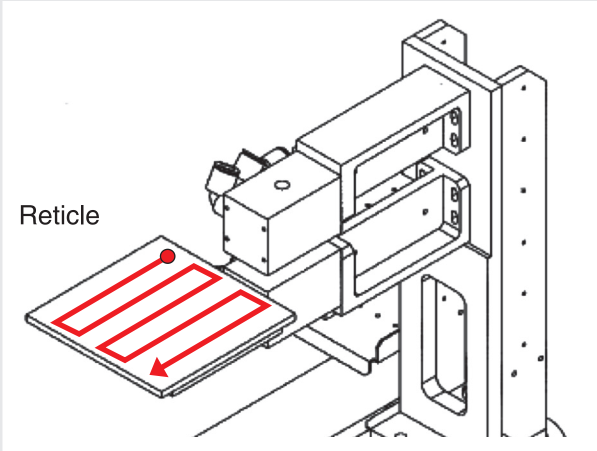


Figure 1 Removing parts of the RP-1

The Evaluation method of Removing Particles Performance Examination for the Evaluation Method

To evaluate the removing particles performance, the sample which adhesion of particle is known is needed. However, the one with thoroughly cohesive both size and shape or the one with deliquescence are included as for the particles actually generated in a clean room. Therefore, it doesn't become a proper indicator because it is difficult to make a repeatability state. Then it is appropriate to the performance assessment of RP-1 using Howe silicic acid glass particle (standard particle) uniformly made.

Air Resistance that Standard Particle Receives

Kinetic characters of a standard particle and no plastic operation foreign body are compared.A standard particle is a spherical particle.*Vs* as for the end gravity subsidence speed of the spherical particle, *Vel* as for the end gravity subsidence speed of the spheroidal particle with the same volume, the ratio η1 of these is shown in Formula (1).

$$\eta_1 = v_{el} / v_s = \beta^{-1/3} \kappa^{-1} \quad \cdots\cdots (1)$$

1/β is an aspect ratio of a spheroid body.

It becomes a perfect sphere by β=1, in the area of a oblate ellipsoid and β<1, in the area of prolate ellipsoid and β>1. κ (kinetic correction factor of no plastic operation particle) is shown in Formula (2).

$$\frac{1}{\kappa} = \frac{1}{3}\left(\frac{1}{\kappa_c} + \frac{2}{\kappa_a}\right) \quad \cdots\cdots (2)$$

κ_c is a rotation axis direction element, κ_a is rotating a radial element, Each one is given by the next Formula.

About prolate sphere (β<1),

$$K_c = \frac{\frac{4}{3}(1-\beta^2)}{\frac{(2-\beta^2)\beta}{\sqrt{1-\beta^2}}\ln\left(\frac{1+\sqrt{1-\beta^2}}{\beta}\right)-\beta} \quad \cdots\cdots (3)$$

$$K_a = \frac{\frac{8}{3}(1-\beta^2)}{\frac{(2-3\beta^2)\beta}{\sqrt{1-\beta^2}}\ln\left(\frac{1+\sqrt{1-\beta^2}}{\beta}\right)+\beta} \quad \cdots\cdots (4)$$

About oblate ellipsoid (β>1)

$$K_c = \frac{\frac{4}{3}(\beta^2-1)}{\frac{\beta(\beta^2-2)}{\sqrt{\beta^2-1}}\arctan\sqrt{\beta^2-1}+\beta} \quad \cdots\cdots (5)$$

$$K_a = \frac{\frac{8}{3}(\beta^2-1)}{\frac{\beta(3\beta^2-2)}{\sqrt{\beta^2-1}}\arctan\sqrt{\beta^2-1}-\beta} \quad \cdots\cdots (6)$$

From Formula (1), The relation between η1 and β is shown in Figure 2.

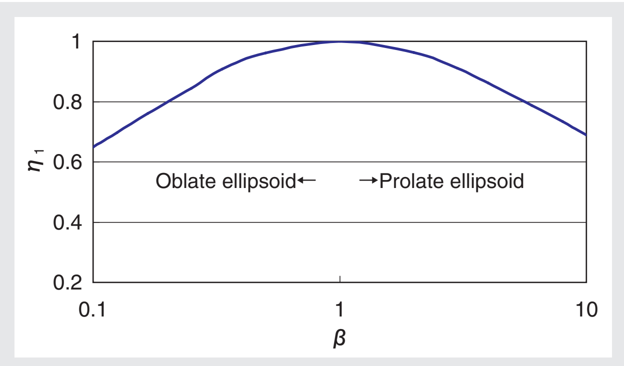


Figure 2 The Ratio at the Gravity Subsidence Speed in a Spheroid Body

From Figure 2, the ratio at the gravity subsidence speed in a spheroid body with the same volume is smaller than perfect sphere. There is because the aerodynamic diameter of a spheroid body is larger than that of sphere. General particles having more complex form than spheroid bodies are easy to receive the wind drag because they have bigger projected areas comparing with isometric sphere. Therefore, it is thought that a standard particle is not easily removed comparing to a general particle. Please note the particles having adhesion or deliquescence are not considered here. Formula and Figure 2 of this chapter are quoted from reference.[1]

Method of Making Standard Sample

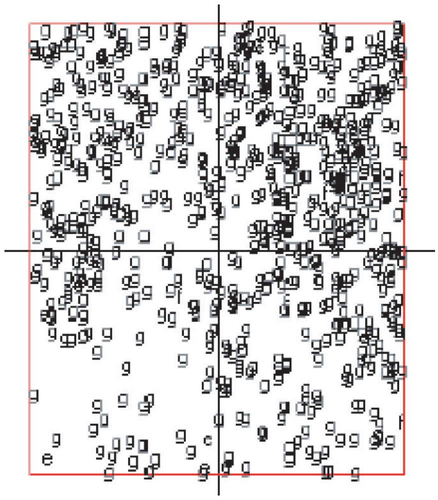
Our particle detection Equipment PR-PD3 (henceforth PD3) is used for the evaluation of the standard sample for RP-1. PD3 has the particle detection sensitivity of diameter 0.5 µm or bigger by the laser scattering. The detected particles can be mapped and observed by the microscope. Next, the method of uniformly distributing standard particles to the surface of the reticle is described as follow. Generally, the standard sample for the particles inspection equipment is made by sprinkling in the mist containing the particles on the clean reticle, thoroughly distributing, and evaporation drying up. In the standard sample for the PD series, the liquid drop that contains the particle of certain density is dropped partially on the surface of the reticle, and it is dried up. However, this way is unsuitable for the evaluation of RP-1 because the water stain might enter between a standard particle and the surface of the reticle and it adhere by strong power in the above-mentioned method. Then, making the correlation sample was tried by uniformly distributing a dry standard particle to the surface of the reticle. It is made by the DukeScientific company silicic acid glass particle, and grain diameter 5~40 µm that uses. Next, the making way of the 20 µm and 40 µm standard sample is described, so 20 µm and 40 µm standard sample are difficult to make comparing other size of standard particles.

Results are shown in the Figure 3, that 20 µm and 40 µm standard particle are freely fallen and distributed on the glass surface of reticle from height of 800 mm. This work was done in a clean space where there is no air flow in a clean room.

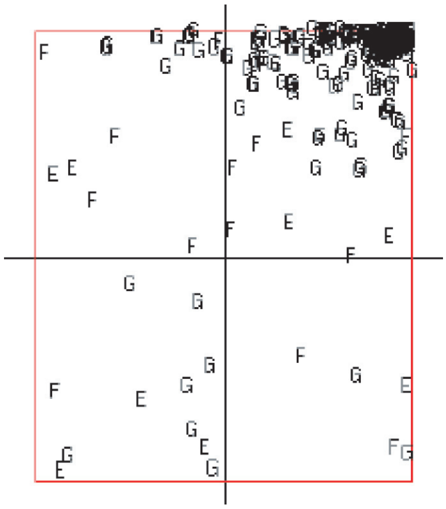
In Figure 3, the area enclosed in red lines is inspection area (120×100 mm) on the surface of the reticle, that show the part where the scattering light was detected. 20 µm standard particles have been uniformly distributed over the reticle as shown in Figure 3 (a). On the other hand, 40 µm standard particles have been extremely dense as shown in Figure 3 (b) in the top of the reticle. Because the particles reached the surface of the reticle before distributing enough as the sinking velocity of the particle was too fast. The terminal velocity in the air is shown in Formula (8).

$$v_s = \frac{2(\rho_p-\rho)}{9\mu}a^2 g \quad \cdots\cdots (8)$$

$\rho_p=2.5\times10^3$ kg/m^3 (density of the Howe silicic acid glass), $\rho=1.2$ kg/m^3 (density of air 20 °C), and $g=9.8$ m/s^2



(a) 20 μm standard particles



(b) 40 μm standard particles

Figure 3 Mapping image of inspected standard particles on the reticle
Using the reticle having the grids Blow : Vacuume = 6 : 10 (L/min)

(gravitational acceleration) and $\mu=1.8\times10^{-5}$ Pa/s (viscosity of air 20 °C). The gravity subsidence speed of 20 μm standard particle is 0.03 m/s from Formula (8). The gravity subsidence speed of 40 μm standard particle is 0.12 m/s. The gravity subsidence speed of 40 μm is 4 times larger than one of 20 μm standard particle. If to get uniformly distribution of 40 μm particles as well as one of 20 μm particles is need 4 times higher height for dropping. It is difficult to drop a standard particle from the height of 3 m or more on the reticle in a clean room. Then, generating moderate disturbed flow at the same time of 40 μm standard particles falling, made uniform decentralization as well as 20 μm standard particles

Next, the result of examining the existence ratio whether the standard particle distributed on the reticle is a multi grain body or it is a single grain body is shown in Table 1. Air resistance of the multi particle is more intense than that of the single particle, so the same standard is not applied. Judgment whether it is single particle or multi particle is confirmed by microscope observation when the reticle is detected with PD3.
From Table 1, 10 um standard particle's ratio of single particle was 80% over, and 5 um standard particle' s one was 70% over. The length between 5 um standard particles is so short that the ratio of multi particle is increase by electrostatic force.

Table 1 Ratio of the single or multi standard particle of each standard particle size*.

Size (μm)	5	10	20	40
Number (pices)	684	827	798	900
multi +single (pices)	989	990	980	900
single rate (%)	70.1	85.5	81.4	100.0

*DukeScientific 9005, 9010, 9020, 9040

The error margin of the elimination factor because of the difference of single particle rate can be presumed as follows.
it is assumed that there are 350 single particles, and multi 150 particles (single particle rate 70%) when a standard particle is distributed on the reticle, and 10 single standard particles remained after processing the removal. Removal rate for single particle is 97.1%(=340/350×100), removal rate for multi particle is 98.0% (=490/500×100), so 0.9% error margin is generated in the case of removal rate of only single particle. The confirming of single particle or multi particle at every time is difficult when getting removal rate, so it is supposed that all standard particle are single particle.
Therefore, the removal rate contains the above-mentioned error. If the number of standard particles would be little, the error margin increases, so it is decided that number of standard particles are more over 500 particles to minimize error margin.

Evaluation and Consideration of Standard Particle Removal Performance

Change in Removal Rate by each Blow Condition.

Chapter 5 shows the evaluation result for the particle on the pellicle. A clean reticle is prepared and the presence of the particle adhesion is confirmed with PD3. If there were already adhesion particles, those are recorded to distinguish from standard particles. The reticle having the grid is easy to distinguish standard particle or not. A standard particle is put by the method of the description in Chapter 4 and they are measured by PD3. The removal rate is calculated by comparing the numbers of before removed standard particles to the number of after the removed particles.

Figure 4 shows the change of the standard particle removal rate at changing the flowing volume of blow. Figure 4 shows that the removal rate has improved by increasing the flowing volume of blow. However, there is a possibility to damage the pellicle when flowing quantity is increased too much.

Flowing quantity in various pellicles (For i line, g line, KrF, and ArF etc.) with the risk of damage was separately examined, and it was confirmed no damage in 6 L/min.

The target specification of RP-1 removal rate is 90% or more in 20 μm standard particle on the pellicle. The removal rate of 20 μm standard particle can be about 99%, and the target specification of RP-1 is achieved in blow condition 6 L/min. So following experiments ware done in this conditions of flow rate.

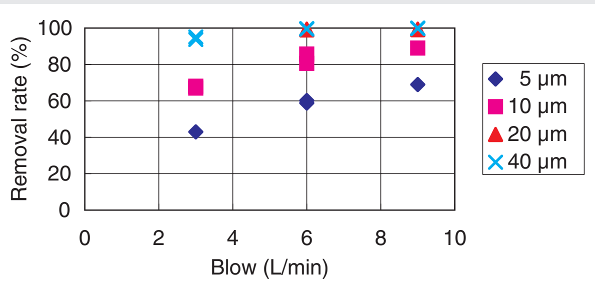


Figure 4 Change of the removal rate by Blow volume
Vacuume 10 (L/min)

Difference of Elimination Factor According to Standard each Particle Diameter.

Figure 5 shows the difference of the removal rate according to the standard particle diameter of 5~40 μm. From Figure 5, it is understood that the removal rate has decreased with the grain diameter is small. It is thought that this the aerodynamic diameter became small because the grain diameter becomes small.

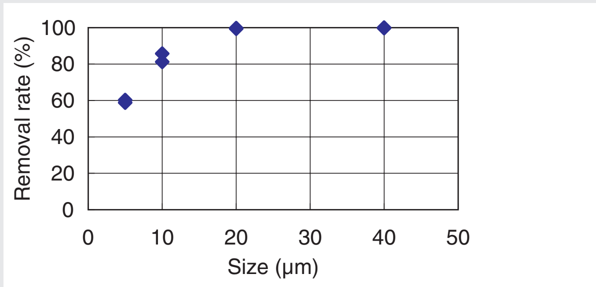


Figure 5 Difference of the removal rate by standard particles size
Blow : vacuume = 6 : 10 (L/min)

Reproducibility of the Removal Rate

Figure 6 shows the result of a measurement immediately after the adhesion of standard particles and the PD3 measurement result (mapping image) after the removal process. 20 μm standard particle was selected here as a representative case.

It is understood that a lot of standard particles were removed from Figure 6.

We observed the detection particles after the removal

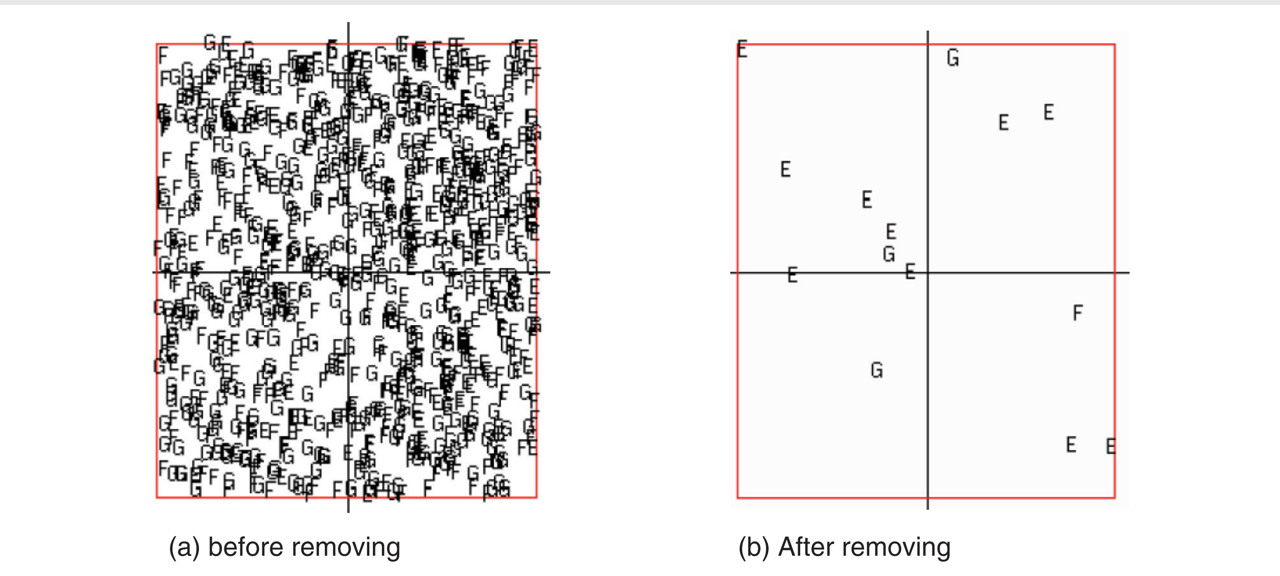


Figure 6 Mapping image of inspected standard particles before and after removing
Blow : vacuume = 6 : 10 (L/min)

process. The detection particles were 14 pieces. 9 particles were standard particles. Table 2 shows the result of the repeatability of the standard particle detection result and the removal rate.

Table 2 Repeatability of the removal rate for 20 µm standard particles blow : vacuume = 6 : 10 (L/min)

Times	1	2	3
Number of before removing (pices)	897	966	977
Number of after removing (pices)	7	9	5
removal rate (%)	99.1	99.0	99.4

The removal rate was 99% over in the three cases, and high repeatability was obtained.

Time-Dependency of theRemoval Rate.

Time-dependency of the removal rate after the particle adhesion becomes a key indicator to keep reticles clean. Standard particles ware put on the reticle, and they ware preserved during the fixed time in reticle case. After that time, removal process was done by RP-1. The graph of Figure 7 shows the relation between the preservation time and the removal rate. The result of 10 L/min that the difference of the removal rate in each blow condition is big is shown here as an example of the representative.

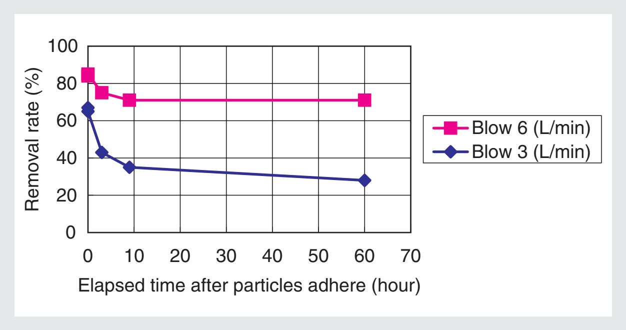


Figure 7 Change of the removal rate by Elapsed time
Vacuume 10 (L/min)
10 µm standard particle
Preserving state : In the reticle case

Figure 7 shows that the removal rate has decreased promptly within 10 hours after standard particles adhere. In blow condition 3 L/min, the removal rate decreases after 10 hours or more pass. In condition 6 L/min, the change of removal rate was small, however it though that the removal rate was continued to the gradual decreasing tendency. Therefore, it was understood that the removal rate decreases even the simple form particle made of the Howe silicic acid glass with small ground contact area of the reticle surface, when having left it for a long term after it adheres to the reticle surface. A general particle having more complex shape than a standard particle is thought to show more remarkable tendency. That is, it is preferable to remove the particles immediately after the particle adheres. Removing particle immediately after the use of the reticle is effective to keep the reticle clean in the photolithography process.

Conclusion

In the examination using the standard sample made for this time, the repeatability of the removal rate was obtained. We showed that the examination using the standard sample was an appropriate technique to the performance assessment of the removing particle device. In time-dependent change of the removal rate, it has decreased remarkably from the first stage to 10 hours as the preservation time increases. In addition, it confirmed that the decreasing of removal rate continued at passing over 10 hours or more. For this matter, removing particle immediately after use of the reticle is necessary for a long term to keep it cleanly. The evaluation of the removal performance with dart particles (non standard particles) is difficult because repeatability is not obtained like standard particles. To obtain the general consequence, we thought that the getting more results of removing particle is only way. It is necessary to discuss the removal performance with the shape and so on. about several thousand actual particles or more.

Recently, the reticle price rises along with a further process minute, so it is thought that needs of the automaticaly removing particle process increase more and more. To meet these needs, we hope to develop the technique and the evaluation method which effectively removes smaller particles and the cohesive particles.

Reference

[1] K, Takahashi. Chapter of Japanese aerosol society, Base of aerosol study, Morikita publication Ltd. (2003)

Tomoya SHIMIZU
清水 智也
Semiconductor Instrument Development Dept.
Application Development Center
HORIBA Ltd.