

# Grinding Simulation with Diamond Pellets and Optimization of Its Grinding Conditions

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## 1. Introduction

A lapping processing used free abrasive slurry is one method of the abrasive precision processing. The lapping processing has been used frequently for making silicon wafers and optical glass to high precision surface. However, the abrasive precision processing has a tendency to change the method using from free abrasive slurry to the fixed abrasive grains because of the problems such as low processing efficiency, deterioration of the working environment, and disposal of waste slurry having free abrasive processing. According to these problems, the fixed abrasive grain grinding (lapping) using the diamond pellets has advantage high efficient and the clean processing in the surface machining techniques. Therefore, the applied areas of a diamond pellets grinding (DPG) have increased<sup>1)2)</sup>.

The DPG is a surface-machining method of using a DPG plate adhered the many diamond pellets with regularity as shown in Fig.1. In the generality of designing a layout of the many pellets by the DPG plate, the diamond pellets make a figure of circles with the center of the DPG plate for its center.

DPG efficiency depends on a grinding distance between the DPG plate and the work-piece. This is expressed by Preston's equation<sup>3)</sup>. The push for high processing efficiency suggests increasing the grinding distance, and the drive for greater surface accuracy requires decreasing the deviation of that grinding distance. This grinding distance makes a change caused by the layout of the many pellets by the DPG plate. Therefore, we have to examine the grinding conditions from the viewpoint of the grinding distance when we design the layout of the many diamond pellets by the DPG plate. However, in the DPG, there are a few studies on the theoretical and optimized examination in which relates to the optimization problem, though the experimental studies related to the processing characteristics are done<sup>2)</sup>.

This study aims to find the optimum conditions in the DPG. This paper presents the calculation method of the grinding distance. Moreover, this paper discusses the results of processing efficiency and accuracy. Especially, a genetic algorithm is used as the optimization method for decreasing the deviation of the grinding distance at the ground work-piece. This optimized results show that the genetic algorithm can design the layout of the many

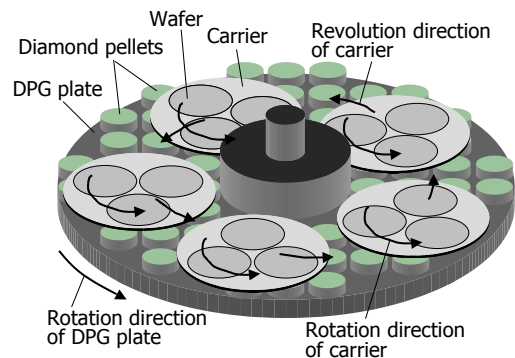


Fig.1 Model of diamond pellets grinding in case of 4-way DPG system

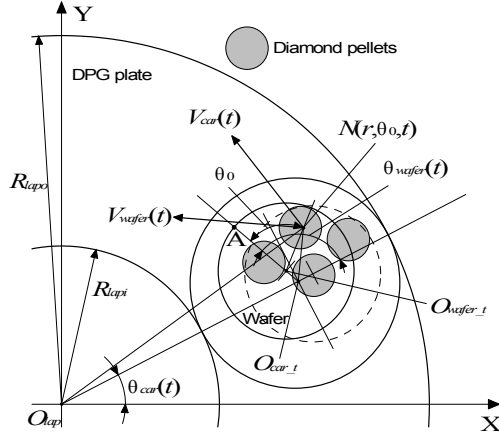
diamond pellets by the DPG plate for which the deviation of the grinding distance is remarkably small.

## 2. Simulation model and method

We use the schematic model as shown in Fig.2 for calculating the grinding distance at the ground work-piece in the 4-way DPG system. This model makes a design for calculating the relative lapping distance between the wafer and the lapping plate at the 4-way wafer lapping system<sup>4)</sup>. This paper describes the simulation method for calculating the grinding distance modified the previous method<sup>4)</sup>. Here, we assume that the grinding quantities are strongly dependent on the grinding distance and the diamond pellets are always flat, and are not worn down in order to simplify our analysis.

In this simulation,  $R_{lapi}$ ,  $R_{lapo}$  and  $R_{wafer}$  are the inner and outer radius of DPG plate, and work-piece (wafer) radius, respectively. Moreover,  $\omega_{lap}$ ,  $\omega_{car}$  and  $\omega_{wafer}$  are the rotating angular velocity of DPG plate, carrier and work-piece, respectively. The directions of each angular velocity define the counter clockwise from the X-axis at the positive value. Therefore, the central angle  $\theta_{car}(r, \theta_0, t)$  and  $\theta_{wafer}(r, \theta_0, t)$  are values in the counter clockwise from the X-axis.  $x_o$  is the eccentricity of the center  $O_{wafer}(t)$  of work-piece from the center  $O_{lap-t}$  of the carrier.

Consider the point  $N(r, \theta_0, t)$ , which locates in radius  $r$  of the ground work-piece at time  $t$  in Fig.2, where  $r$  changes from 0 to  $R_{wafer}$ . For time  $t$  from 0 to  $T$ , the relative grinding distance  $L_{relative}(r, \theta_0)$  at radius  $r$  can be expressed as follows,



**Fig.2** Schematic illustration of DPG for calculating grinding distance

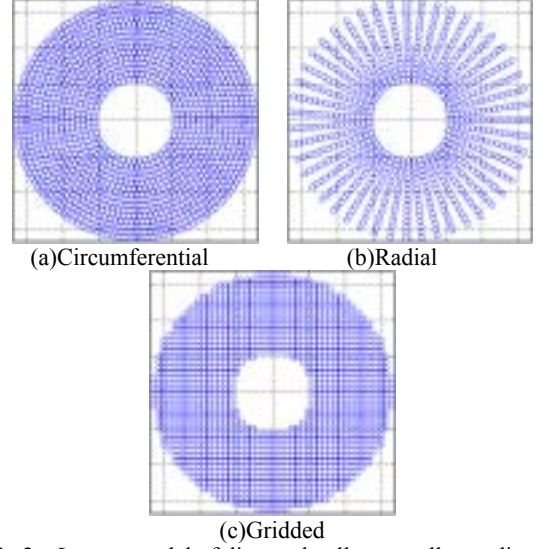
**Table 1** Main simulation conditions

Inner radius of DPG plate $R_{lapi}$ :	211.67/2mm
Outer radius of DPG plate $R_{lapo}$ :	668.87/2mm
Radius of wafer $R_{wafer}$ :	50 mm, $(R_o - R_i)/2$
Eccentricity of wafer $x_o$ :	60 mm
Radius of diamond pellet $R_p$ :	6, 7.5, 20mm
Rotation angular velocity of DPG plate $\omega_{lap}$ :	-3.33rpm
Revolution angular velocity of carrier $\omega_{car}$ :	3.3rpm
Rotation angular velocity of carrier $\omega_{wafer}$ :	2.5rpm
Calculated time $T$ :	$2*(2\pi/\omega_{wafer})$

$$L_{relative}(r, \theta_0) = \int_0^T V_{relative}(r, \theta_0, t) dt \quad (1)$$

where  $V_{relative}(r, \theta_0, t)$  is the relative grinding velocity at time  $t$ , and  $T$  is processing time. In this simulation,  $T$  was given in  $2*(2\pi/\omega_{wafer})$  which means the work-piece two rotating time at all calculated conditions. Here, Eq.(1) can be applied in case of used the lapping plate without grooves.

However, in the DPG, the relative grinding velocity at the ground work-piece passing in time  $t$  has to be considered on these two patterns. Hence, the pattern (a) is the case that the point  $N(r, \theta_0, t)$  contacts with any pellets each other, and the the pattern (b) is the case that the point  $N(r, \theta_0, t)$  does not contact with any pellets each other. In the case of pattern (a), the relative grinding velocity is the equal of the lapping velocity calculated



**Fig.3** Layout model of diamond pellets at pellets radius  $R_p$  of 7.5mm

the 4-way wafer lapping system. In the case of pattern (b), the relative grinding velocity is the equal of zero. Therefore, if Eq.(2) at the work-piece passing in time  $t$  establishes, this case means pattern (a).

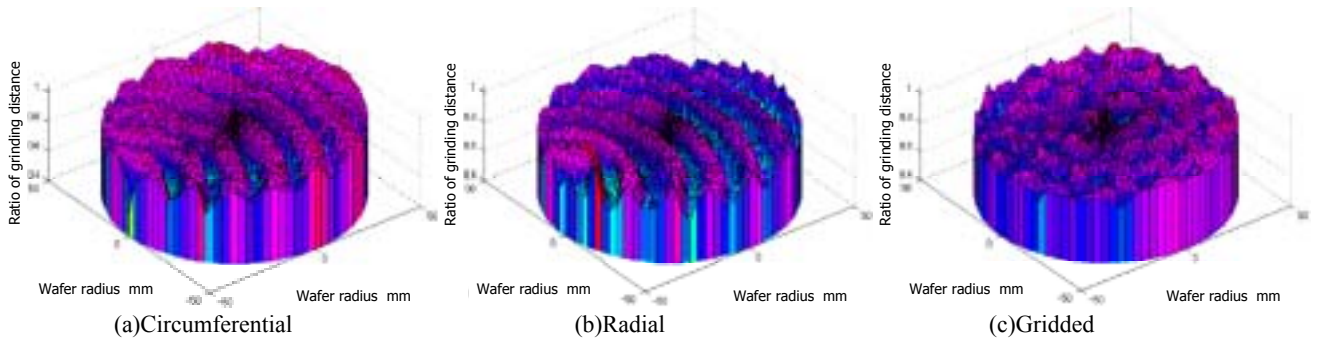
$$\min \left| \sqrt{(X_w(t) - X_{pm})^2 + (Y_w(t) - Y_{pm})^2} \right|_{m=1 \sim M} \leq R_p \quad (2)$$

where,  $(X_{pm}, Y_{pm})$  is the center coordinates of each pellets and  $(X_w(t), Y_w(t))$  is the coordinates of the point  $N(r, \theta_0, t)$ .  $R_p$  stands for the radius of pellets.  $m$  is the natural number from 1 to  $M$ , and  $M$  is the number of pellets.

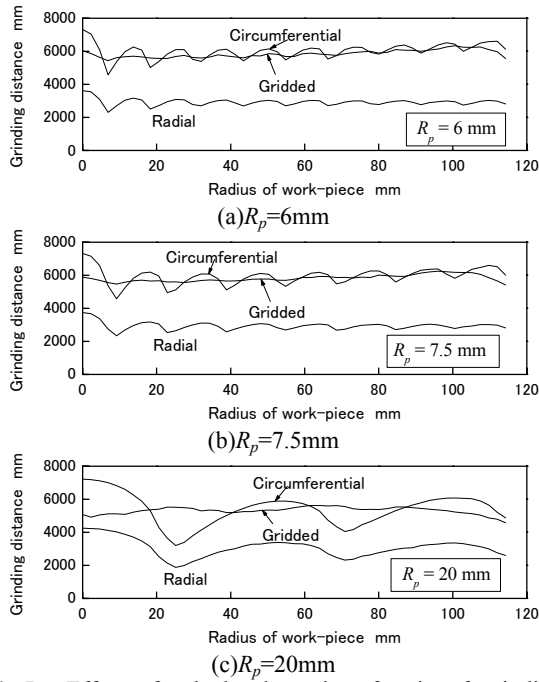
Figure 3 shows the general layout methods of pellets. Figs.3-(a), (b) and (c) show circumferential, radial and gridded, respectively. This paper discusses effect of the layout method and the pellets radius on the grinding distance characteristics. The main experimental conditions are as shown in Table 1.

### 3. Computer simulation and consideration

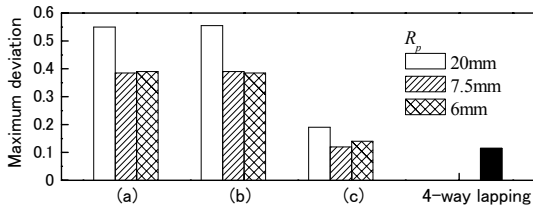
Figure 4 shows the non-dimensional grinding distance for specific cases at pellets radius  $R_p$  of 7.5 mm. Figs. 4-(a), (b) and (c) are the results of circumferential, radial and gridded respectively. The ratio of the grinding distance compares the maximum grinding distance at



**Fig.4** Calculated results of ratio of relative grinding distance in work-piece surface at pellets radius  $R_p$  of 7.5mm



**Fig.5** Effect of calculated results of ratio of grinding distance in work-piece radius direction on pellets radius and layout methods

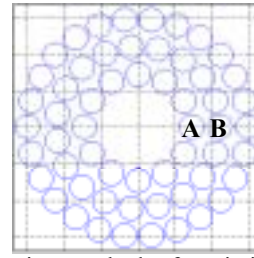


**Fig.6** Effect of maximum deviation at work-piece grinding distance on pellets radius and layout methods ((a)Circumferential, (b)Radial, (c)Gridded)

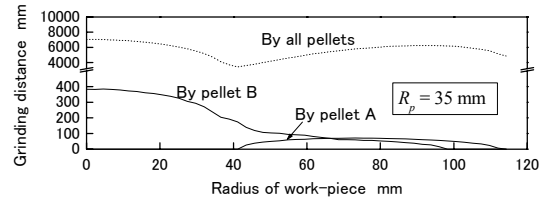
work-piece surface. The figures show the results of circumferential and radial have the regular ruggedness, and the result of gridded does not have that ruggedness.

Figure 5 shows the dimensional grinding distance at the radius direction of work-piece surface when the work-piece diameter is the equals of the width of DPG plate given by subtracting  $R_{lapi}$  from  $R_{lapo}$ . Figs. 5-(a), (b) and (c) are the results of circumferential, radial and gridded respectively. The figures (a), (b) show the regular ruggedness, and also the width of ruggedness is almost equal to the pellets diameter. On the other hand, the figure (c) does not show such as ruggedness.

Figure 6 shows the result of the maximum deviations when the layout method and pellets radius  $R_p$  are changed. This figure shows the maximum deviation in case with the gridded layout method is the smallest, and the maximum deviations decrease as the decreasing pellets radius. Moreover, compared decreasing effect of the maximum deviation with the layout method and pellets radius, effect of the layout method is greater than that of the pellets radius. In addition, the maximum deviation in case with the gridded is almost equal to that in case with the 4-way lapping used ungrooved



**Fig.7** Examination method of optimization of pellets layout method (Example of circumferential layout method of  $R_p$  at 35mm)



**Fig.8** Calculated results of grinding distance at layout method of Fig.7 and effect of grinding distance on pellets A and B

lapping plate as shown black rod.

Summarizing, it should be desirable to adopt the gridded layout method. However, it is difficult to perfectly satisfy the demands for the maximum deviation approaches to zero. Therefore, thinning layout method in the DPG plate will be considered to obtain the high accuracy while decreasing the maximum deviation of the grinding distance. In this paper, the thinning layout method in the DPG plate will be especially optimized using a genetic algorithm.

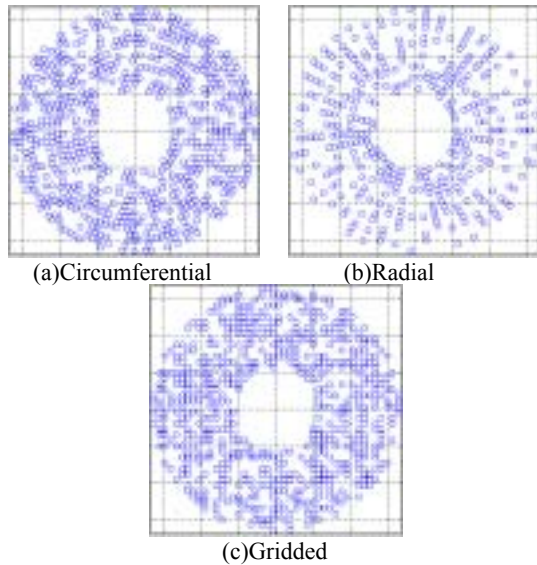
## 4. Optimization of thinning layout method using genetic algorithm

### 4.1 Examination of the application method

The goal of a genetic algorithm<sup>5)6)</sup> is to find a set of parameters that minimizes the output of a fitness function using the latent ability of realizing the solution in which mutation and natural selection are optimum in the evolution theory of the organism.

Consider  $N$  chromosomes having  $M$  genes in one generation, which iteratively change with selection, crossover, and mutation. In the following discussion  $p_c$  and  $p_m$  will be used for the crossover probability and the mutation probability, respectively.  $M$  is the number of pellets in each generally layout method.

It is necessary to calculate the grinding distance in each pellet because of comparing with the total grinding distance. For example, considered the DPG plate at the pellets radius of 35mm and at the layout method of circumferential as shown in Fig.7. Figure 8 shows the results of the grinding distance by each pellet A and B in Fig.7. The total grinding distance as shown the dotted line is given by adding grinding distance by use of each pellet. Therefore, the generally genetic algorithm can apply this optimized problem with binary code. Thus, one binary digit represents the pellet state as "on" = 1 or "off" = 0 in DPG plate.



**Fig.9** Optimized thinning layout model of diamond pellets at  $R_p$  of 7.5mm by GA

#### 4.2 Optimum results

The previous section gave an overview of the optimized method for making thinning layout method in DPG plate using the genetic algorithm. This section describes the application results.

Figure 9 shows the designed result of thinning layout method of each generally layout method when the genetic algorithm applies in this optimized problem. In this paper,  $N$ ,  $p_c$  and  $p_m$  are 50, 0.6, and 0.1 respectively. The genetic operation is carried out to 100 generations.

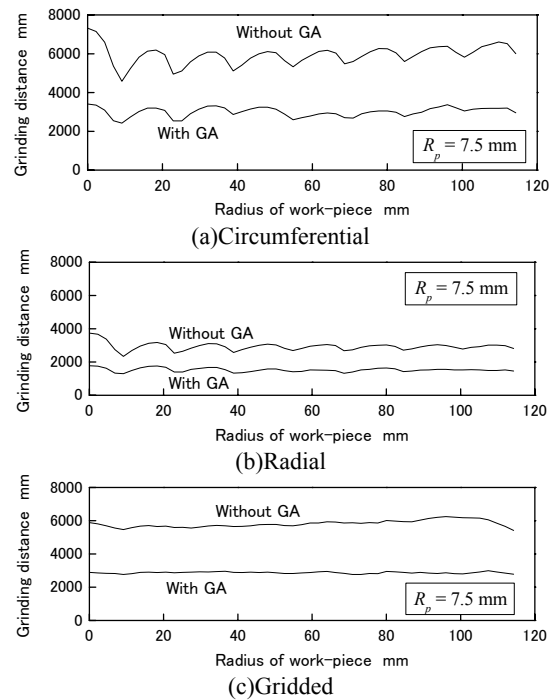
Figure 10 shows the results of the dimensional grinding distance at the radius direction of work-piece surface with/without genetic algorithm. Figure 11 shows the result of maximum deviation for the thinning layout method and pellets radius with genetic algorithm compared with Fig.6. These results show that the genetic algorithm can design thinning layout method for which the maximum deviation of grinding distance is remarkably small.

### 5. Conclusions

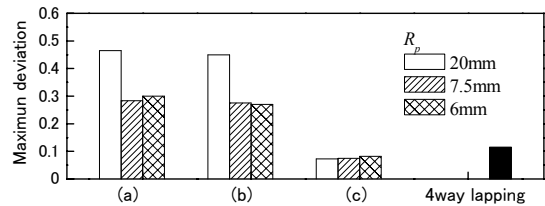
This paper describes effect of the pellets layout method on the grinding distance between DPG plate and work-piece at the 4-way DPG system. And also, this paper especially introduced the use of a genetic algorithm for optimizing the selection thinning layout method in a DPG plate to make the deviation of grinding distance small.

As a result, the following areas are clarified.

- (1) The deviation of grinding distance in case with gridded layout method is smaller than that in cases with circumferential and radial layout methods.
- (2) The genetic algorithm can design the optimized thinning layout method.
- (3) Effect of the genetic algorithm in case with gridded layout method is greater than that in cases with circumferential and radial layout methods.



**Fig.10** Calculated results of ratio of grinding distance in wafer radius direction on optimized layout methods at  $R_p$  of 7.5mm



**Fig.11** Effect of maximum deviation at wafer grinding distance on pellets radius and optimized layout methods by GA ((a)Circumferential, (b)Radial, (c)Gridded)

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