euspen's 20th International Conference & Exhibition, Geneva, CH, June 2020

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Best method to achieve high total thickness variance and high flatness in double-sided polishing

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Abstract

Double-sided polishing technique is commonly applied to achieve high total thickness variance (TTV) and high flatness in large silicon wafers, which are used to manufacture Integrated circuit (IC) cards and smartphones. However, a polishing method that realizes both high TTV and high flatness has not been studied in depth theoretically. On the other hand, polishing simulation, based on gap theory, has been developed. It was determined that the simulated results agreed well with the experimental results for single-sided polishing. This paper describes a polishing method to achieve high TTV and high flatness, the values of which were calculated using the new double-sided polishing simulation program. When the flat lower plate and the cone upper plate with the optimum slope are used, the TTV is less than 0.04 µm and the flatness is less than 0.05 µm, the carrier rotation speed is small, and the speed difference between the upper plate rotation and the carrier revolution is equal to that between the lower plate rotation and the carrier revolution. In addition, this study clarifies that higher flatness is obtained by optimally overhanging the workpiece from the inner side of the plate.

Double-sided polishing simulation, Gap theory, High flatness, TTV, Average thickness variation

1. Introduction

Fine patterns of less than 7 nm are exposed using extreme ultraviolet lithography (EUV) to fabricate Integrated circuit (IC) cards and smartphones [1]. Therefore, a flatness of less than 0.1 µm and a total thickness variance (TTV) of less than 0.3 µm, not considering the wafer periphery of 1 mm, are required for 300-mm semiconductor wafers. Such high accuracies can be achieved owing to the progress of the fabrication technique, caused by using the double-sided polishing machine and by accumulating the polishing knowhow. However, this has not been explained in a theoretical manner so far. On the other hand, kinematical analysis of the double-sided machine has been reported [2]. However, double-sided polishing with cone and convex plates has not been investigated thoroughly.

This paper describes the best polishing method to achieve high TTV and high flatness, the values of which were calculated using the new double-sided polishing simulation program developed on the basis of gap theory.

2. Analysis and calculation conditions

Double-sided polishing generates profiles with high flatness and TTV by sandwiching workpieces between an upper plate and a lower plate. If the workpiece is a thin plate with asymmetric sides, it is deformed to achieve almost symmetric sides during polishing, as shown in **Figure 1**. In this case, the bending moment of the workpiece is negligibly small and the distribution of pressure on the top surface is equal to that on the bottom surface. Furthermore, the gap between the workpiece and the upper plate is balanced to that between the workpiece and the lower plate. Based on this supposition, the polishing process was calculated with the double-sided polishing simulation program (CarrierPolish) [3], which was developed by applying the gap theory used in single-sided polishing [4][5].

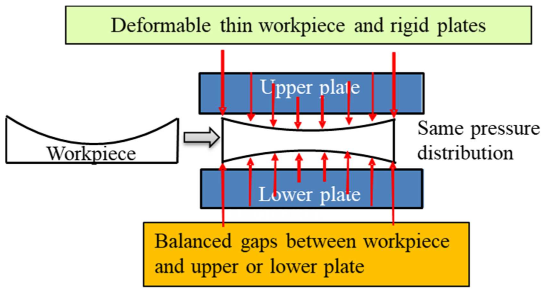


Figure 1 Analysis method in double-sided polishing

Table 1 Calculation conditions

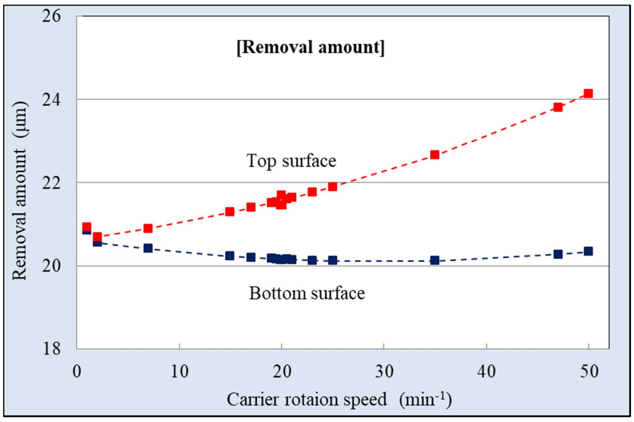
Plate radius (mm)	Inner radius	220 - 250
	Outer radius	670 - 680
Workpiece diameter (mm)		200
Carrier diameter (mm)		500
Carrier planet radius (mm)		450
Center distance between carrier and workpiece (mm)		125
Number of carriers		3
Number of workpieces / carrier		3
Rotation speed (min^{-1})	Upper plate	-10
	Lower plate	50
	Workpiece	0
Carrier speed (min^{-1})	Rotation	1 - 50
	Revolution	20
Pressure (kPa)		10
Relative elastic coefficient (kPa/µm)		0.1
Stock removal rate [(µm/km)/kPa]		7.9
Wear rate [(µm/km)/kPa]		1
Total polishing time (min)		3
Plate material		Cast iron
Abrasive grain		GC#1000
Workpiece material		Quartz glass

Table 1 shows the calculation conditions. The double-sided polishing machine is general-purpose, and the sizes and the rotation speeds for the upper and lower plates can be used widely. Workpieces are made of quartz glass, an abrasive grain is GC#1000, and the plates are made of cast iron.

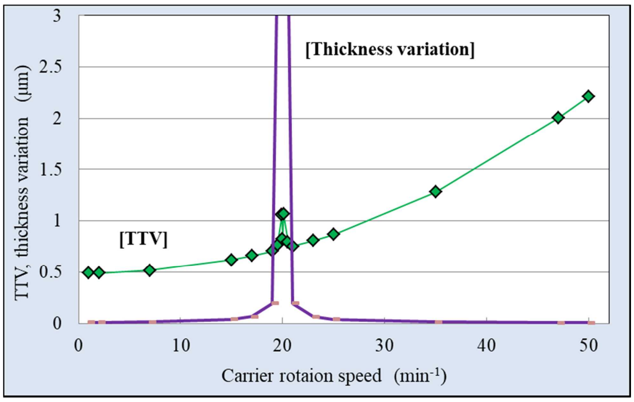
3. Flatness and thickness accuracy

As the carrier rotation speed largely influences the flatness and TTV, the calculation was carried out for a wide range, from 1 to 50 min^{-1}. TTV is defined as the difference between the maximum thickness and the minimum thickness for a workpiece, and the thickness variation is defined as the variation of average thicknesses for all the workpieces as shown in **Figure 2**.

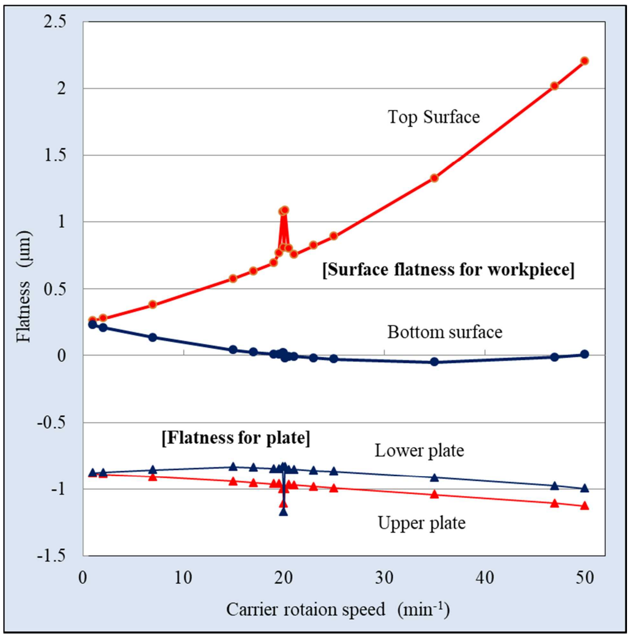
Figure 3 shows the removal amount, flatness, TTV, and thickness variation after 3 min. The removal amount for the top surface of a workpiece increases with the carrier rotation speed and that for the bottom surface is almost constant. This is due to the running distance with the carrier rotation speed as shown in **Figure 4**. Conversely, the removal amount for the bottom surface is almost constant because the running distance does not almost increase with the periphery of the workpiece, which is caused due to the decrease in the speed difference between the carrier and the lower plate.



(a) Removal amount for the top and bottom surfaces of a workpiece



(b) TTV and thickness variation for a workpiece



(c) Flatness for a workpiece and a plate

Figure 3 Removal amount, TTV, thickness variation, and flatness calculated for a workpiece made of quartz glass and a plate made of cast iron polished with GC#1000 after 3 min when carrier rotation speed changes from 1 to 50 min^{-1}.

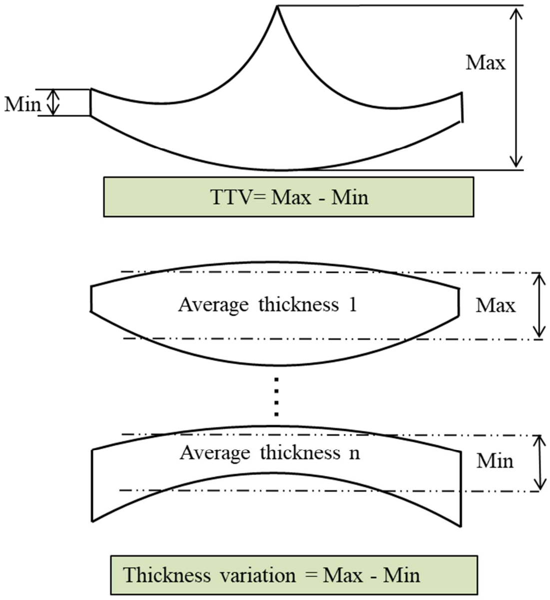


Figure 2 Definitions of TTV and thickness variation

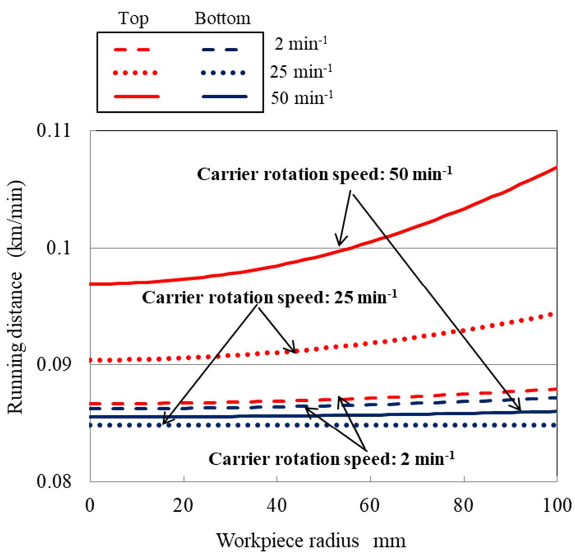


Figure 4 Total running distances of a workpiece at the carrier rotation speed of 2, 25 and 50 min^{-1}.

The flatness of the upper or the lower plate is approximately -1 µm (minus indicates concave), and it deteriorates with an increase in the carrier rotation speed. The flatness of the top surface of the workpiece increases with the carrier rotation speed and becomes a convex profile of more than 2 µm at the carrier rotation speed of 50 min^{-1}. The profile for the bottom surface of the workpiece changes from convex to concave at the speed of 20 min^{-1}. As the relative velocity between the bottom surface of the workpiece and the lower plate becomes uniform, at the speed of 50 min^{-1}, the flatness of the bottom surface of the workpiece approximately becomes zero. Thus, the flatness of the bottom surface of the workpiece does not exceed 0.3 µm at any speed more than 20 min^{-1}. This is attributed to the fact that when the concave shape of the lower plate increases by a huge amount due to wearing, the average pressure in the periphery of the workpiece increases with the carrier rotation speed. Conversely, the running distance reduces.

The TTV is 0.5 µm below a carrier rotation speed of 2 min^{-1} and becomes higher with an increase in the carrier rotation speed. It exceeds 2 µm at a carrier rotation speed of 50 min^{-1}. The thickness variation is less than 0.1 µm outside the range of 20$\pm$2 min^{-1}, but the maximum value exceeds 10 µm inside the range. The TTV and flatness also deteriorate inside this range.

Accordingly, a good flatness and TTV are obtained under the following polishing conditions: the speed difference between the upper plate rotation and the carrier revolution is nearly equal to that between the lower plate rotation and the carrier revolution, and the carrier rotation speed is small. In addition, it is necessary to avoid the condition in which the carrier rotation speed corresponds to the carrier revolution speed within 10 %.

Figure 5 shows the thickness variation with respect to the polishing time. The carrier rotation speeds are 2, 51, and 101 min^{-1}. When the rotation speed is slower, the amplitudes and periods are larger. The period does not change with the polishing time, but the amplitude reduces slightly with the polishing time. This period corresponds to a period of the change in the distance between the plate center and the specimen center. This change influences the running distance and the removal amount, and eventually leads to deterioration in the thickness variation. The carrier rotation speed must be increased to reduce the thickness variation, as is clear from Figure 5. The thickness variation decreases rapidly with an increase in the carrier rotation speed. The value of the thickness variation becomes less than 0.01 µm at 101 min^{-}1 and is 1/10 of that value at 2 min^{-1}. Subsequently, the thickness variation is smaller than the flatness. Thus, the thickness variation can easily be reduced by increasing the carrier rotation speed. However, this method deteriorates the flatness and TTV, as previously mentioned.

Figure 6 shows the periods of the TTV variation and the thickness variation with respect to the polishing time. The TTV variation in Figure 6(a) was calculated by removing the slope amount from the TTV. As the carrier rotation speed comes close to the carrier revolution speed of 20 min^{-1}, the amplitude and the period of the TTV variation increase rapidly. The thickness variation in Figure 6(b) reaches 14 µm at the carrier rotation speed of 19.9 min^{-1}. Accordingly, the carrier rotation speed near the revolution speed should avoid using, because the condition deteriorates largely the TTV variation and the thickness variation.

4. Improvement of flatness and TTV

It is impossible to improve the flatness and the TTV to be less than 0.1 µm by optimizing only the carrier rotation speed. Therefore, a polishing technique using a flat lower plate and a conical upper plate is proposed.

Figure 7 shows calculated results of the flatness and the TTV. Upper plates with slopes of 50, 70 and 80 µm/250 mm were used. Both the top and bottom surfaces of a workpiece are convex for the slope of 50 µm and they become convex and concave for the slope of 70 and 80 µm. The flatness is less than 0.04 µm for the slopes of 70 µm. The TTV is more than 0.15 µm for the slope of 50 µm after 3 min, but it is less than 0.03 µm for the slope of 70 µm. This simulation result clarifies that it is possible to achieve flatness below 0.05 µm for both the top and bottom surfaces of the workpiece and a TTV below 0.04 µm by using the cone plate to adjust the slope.

Figure 8 shows the removal amount or the profile for the top

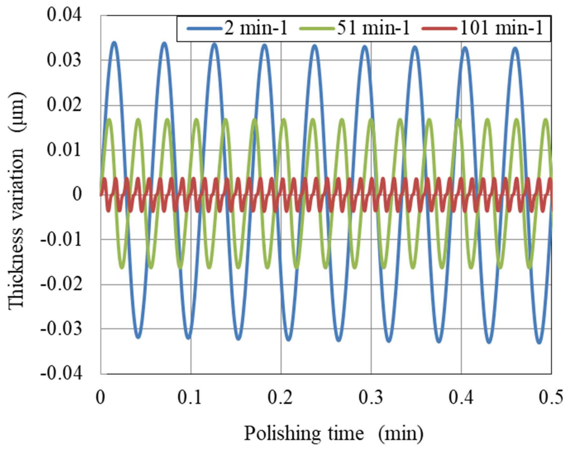
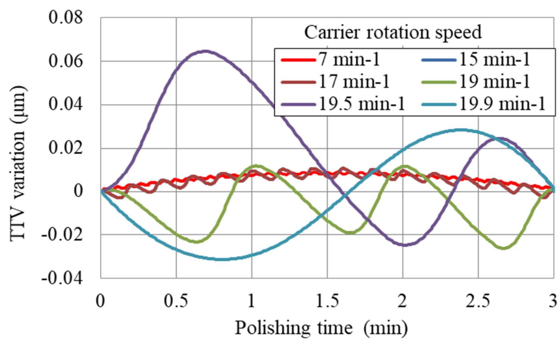
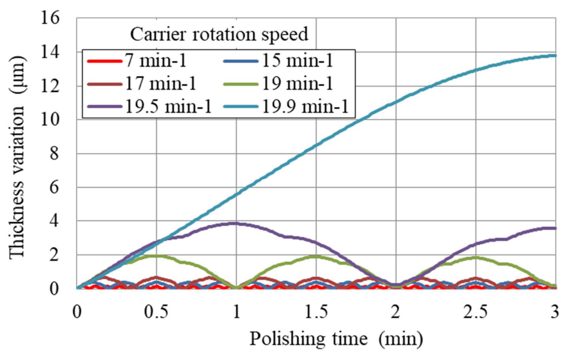


Figure 5 Thickness variations of a workpiece in various carrier rotation speeds with respect to polishing time.



(a) TTV variation of a workpiece

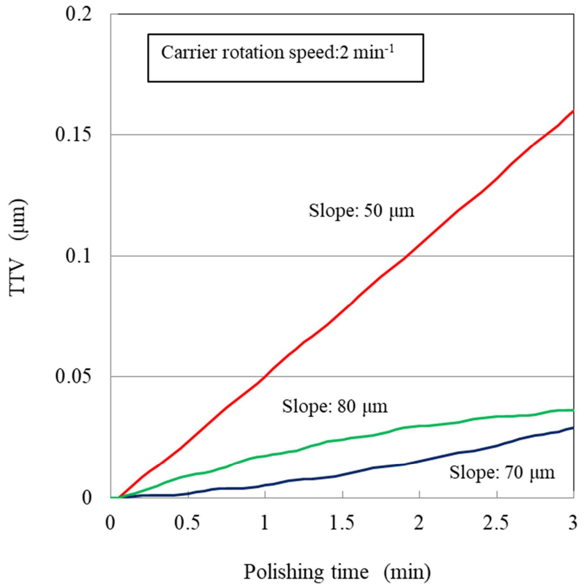


(b) Thickness variation of a workpiece

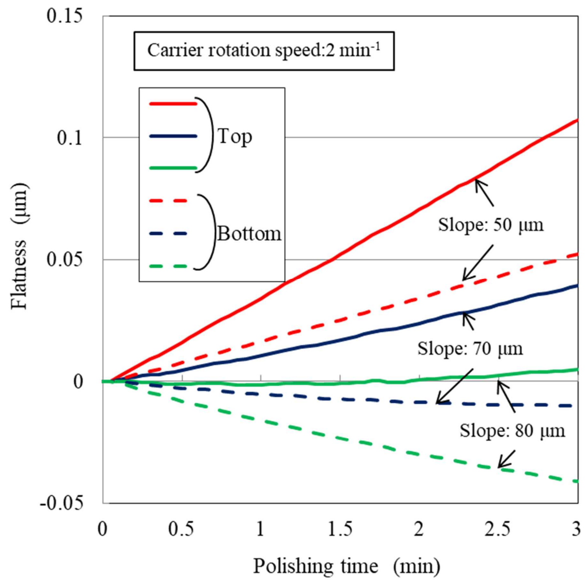
Figure 6 TTV variation and thickness variation of a workpiece in various carrier rotation speeds with respect to polishing time.

and bottom surfaces of the workpiece, improved by overhanging a workpiece from the plate. The profile for the top surface is almost same as that of the bottom surface. The carrier rotation speed is 1 min^{-1}. The overhang amount for the inner and outer sides is shown in parentheses. Overhang (0, 5) shows that the overhang amount is 0 mm for the inner side and 5 mm for the outer side.

The improvement due to the overhanging is greater in the inner side than the outer side. The flatness of the top surface or the bottom surface was improved from 0.27 µm to 0.15 µm or from 0.23 to 0.16 µm, respectively, by the inner overhanging of 25 mm or 23 mm. The TTV were improved from 0.5 to 0.3 µm,



(a) TTV for a workpiece



(b) Flatness for the top and bottom surfaces of a workpiece

Figure 7 TTV and flatness of a workpiece improved by using flat lower plate and cone upper plate with various slopes.

5. Conclusion

The best polishing method under certain polishing conditions was determined with the new double-sided polishing simulation program, which was developed on the basis of gap theory. It was determined that it is necessary to reduce the speed difference between the carrier revolution and the upper plate rotation to the speed difference between the carrier revolution and the lower plate rotation and to have a small carrier rotation speed. In addition, the only solution to improve the TTV to less than 0.1 µm is to use a combination of flat plates and cone plates with adjusted slopes.

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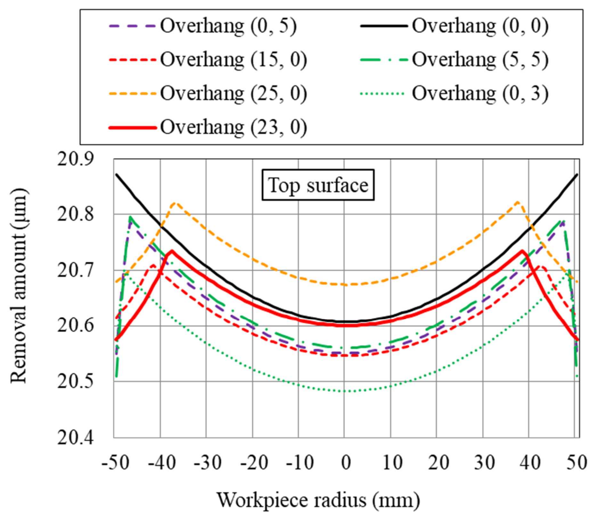
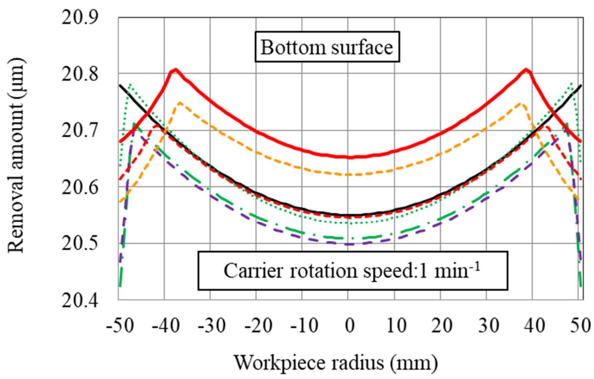


(a) Flatness for the top surface of a workpiece



(b) Flatness for the bottom surface of a workpiece

Figure 8 Top and bottom surface profiles of a workpiece improved by overhanging from a plate at the carrier rotation speed of 1 min^{-1}.