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Simultaneous Mirror Polishing of Workpiece Composed of Various Glasses

Weimin Lin, Toshio Kasai, Kenichiro Horio[1] and Toshiroh Karaki Doy[2]

Graduate School of Science and Technology,
[1]Faculty of Engineering,
[2]Faculty of Education, Saitama University
255 Simo-ohkubo, Urawa, Saitama 338-8570, Japan

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This paper deals with a basic research on the conditions of planarization polishing and the step height difference between simultaneously mirror-polished multimaterials comprising a workpiece surface. Theoretical equations of the step height were introduced, based on several assumptions, as a function of the specific stock removal amount of work materials and specific elastic deformation amount of the polishing pad. The calculated results showed good agreement with the values obtained by the polishing the workpiece composed of four kinds of glasses, carried out under appropriate conditions using cerium oxide powders and polyurethane pads. When the pad was used for a long time, its surface became worn and slippery, resulting in a rather small amount of stock removal. In such a case, brushing and dressing with a diamond wheel was applied to recondition its surface to its original state. However, when the polishing pad was dressed, irregularities on the pad surface incurred unstable conditions, producing relatively large differences in the step height. In order to compare the calculated results of the step height with the experimental data, it was necessary to apply worn-out pad conditions under which the step height difference between materials became stable and constant. Step height showed a tendency to increase when soft pads were used. Moreover, the specific elastic deformation amounts of several pads were obtained from experimental data and equations.

1. Introduction

Polishing is a finishing method to make the surfaces of a glass lens, crystal oscillator, silicon wafer and other planar device materials into an irregularity-free or mirror surface. However, such work materials have various characteristics, some of which create difficulty in making their surface planar. For instance, in the polishing of a polycrystalline material made of small crystal grains having various orientations, the difference in height still remains on the polycrystal due to the stock removal difference among individual crystalline grains, although seemingly finished to a mirror surface. This has been observed when polishing the sliding face of a magnetic head composed of ferrite, ceramic and metal, and also when polishing an expensive crystal with inexpensive dummy materials.

Ten years ago, a chemical mechanical polishing (CMP) method was proposed for introduction into the semiconductor fabrication process to make interlayer dielectric (ILD) materials with presence of topography planar.[1] Forming a glass film produces such an ILD layer by chemical vapor deposition (CVD) on a device wafer surface. Mirror-surface finishing is essential in printing fine wiring circuits, layer-over-layer using a lithographic technique, for which the introduction of CMP has become indispensable in device fabrication. Some of the irregularities form a dense geometry of fine lines and spaces, and their distribution is not balanced. Consequently, the projected areas are not removed uniformly by conventional polishing, leaving step heights because of the difference in the stock removal produced by different forms and locations of the patterns. This phenomenon is similar to that observed in the simultaneous polishing of two kinds of materials.[2,3]

This study covers the simultaneous polishing of various materials and aims to realize ultrasmooth polishing. The generation or distinction of irregularities on a workpiece surface was found to be largely dependent on the conditions and conditioning of the polishing pad surface, and the specific elastic deformation amounts which define the characteristic values of a polishing pad were obtained and are included in this report.

2. Calculation Equation of Step Height Difference between Materials

Fine irregularities left on the polished surface have various factors. The irregularities detected by a surface roughness measuring instrument can be interpreted as an indication of the generation of cutting chips and may be the result of scratching by abrasives or the convex area of the pad and by dust. The smallest of these microirregularities is considered to be of the atomic or molecular order, which is very appropriate for STM imaging. In addition to these irregularities, there are other factors caused by the nonuniformity of a workpiece and the composition of different materials. In this paper, irregularities formed by the step height difference between materials will be explained by applying theoretical equations.

2.1 *Model and theory of step height difference between materials*

In the simultaneous polishing of workpieces composed of n kinds of materials, stock removal is proportional to the relative speed v (m/s) between the workpiece and polishing pad, pressure p (Pa) and time t (s). The proportional constant, i.e., the specific stock removal amount, is assumed to express any j order of n kinds of materials by η_j (μm·m^{-1}/Pa). The whole area S (m^2) is a total of s_j (m^2) (j = 1 to n) and bears additional weight W (N) on work.

As shown in Fig. 1(a), relative to the analysis on the development of step heights, notional polishing begins under the initial condition that the step height difference among all materials is zero. When the relative speed v and the apparent pressure (p) (= W/S) (Pa) are applied, after an initial short period of time Δt, the stock of removal $(\Delta h_j)_1$ (μm) is expressed as:

$$(\Delta h_j)_1 = \eta_j \cdot v \cdot (p) \cdot \Delta t. \tag{1}$$

The stock removal difference among materials is given by η_j of the materials when they are polished only for an initial short period of time Δt. Therefore, the stock of removal polished between $(i-1)\cdot\ \Delta t$ to $t \cdot \Delta t$ is:

$$(\Delta h_j)_i = \eta_j \cdot v \cdot (p_j)_{i-1} \cdot \Delta t, \tag{2}$$

where $(p_j)_{j-1}$ is the pressure of a material of the j order after time $(t-1) \cdot \Delta t$. Hence, $(p_j)_{j-1}$ is:

$$(p_j)_{i-1} = (p) + \frac{1}{\zeta} \cdot \left\{ (i-1) \cdot (\eta) \cdot v \cdot (p) \cdot \Delta t - \sum_{n=1}^{n} (\Delta h_j)_{i-1} \right\}. \tag{3}$$

The 1st term (p) of the right side represents average pressure when the heights of all materials are the same under the initial conditions. The 2nd term is the correction term for pressure change due to varying stock of removal with Δt. ζ is the specific elastic deformation amount of the generating factor of distribution pressure on pads. (η) in the correction term can be defined as the average proportional constant of the different materials.

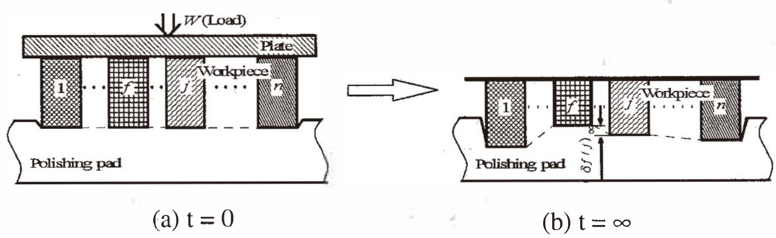


Fig. 1. A simultaneous polishing model using various kinds of materials.

Although step heights between materials are produced on a polished surface, the stock of removal $(\Delta h_j)_\infty$ of any material of j order can be expressed as:

$$(\Delta h_j)_\infty = \eta_j \cdot v \cdot (p_j)_\infty \cdot \Delta t = (\eta) \cdot v \cdot (p) \cdot \Delta t\,, \tag{4}$$

whereas the product of the specific stock removal amount of each material and pressure constitutes a constant value. The relationship between additional weight W, pressure and area of each material is expressed as follows:

$$W = \sum_{n=1}^{n} \{(p_j)_i \cdot s_j\} = \sum_{n=1}^{n} \{(p_j)_\infty \cdot s_j\}. \tag{5}$$

When polishing is performed for a long time, (η) is expressed as follows on the basis of the stock of removal $(h_j)_i$ achieved during the polishing time $i \cdot \Delta t$, the counting of which begins when the step height difference among different materials indicates a constant value:

$$(\eta) = \frac{(h_j)_i}{\{v \cdot (p) \cdot t\}} = \frac{\eta_j \cdot (p_j)_\infty}{(p)}. \tag{6}$$

If $(p_j)_\infty$ is eliminated from eqs. (5) and (6), (η) is expressed as:

$$(\eta) = \frac{W}{(p) \cdot \sum_{n=1}^{n} (s_j / \eta_j)} = \frac{S}{\sum_{n=1}^{n} (s_j / \eta_j)}. \tag{7}$$

Consequently, the first term of the correction term in eq. (3) is an average of specific stock removal amount of all materials achieved during the polishing time $(i\text{–}1) \cdot \Delta t$, and the 2nd term is the total stock of removal of any j order material summed up to time $(i\text{–}1) \cdot \Delta t$. A positive value of the correction term implies that the j order material emerges through the average step height of materials, and the polishing pressure of the area becomes larger than the average one (p) if the amount of specific elastic deformation ζ (μm/Pa) is taken into account.

As described above, although polishing starts from the initial condition that the step heights are identical for different materials, the difference in height occurs, and the polishing pressure of each material becomes reasonable as supporting the additional weight on a workpiece. Based on the above, $i \cdot \Delta t$ after commencement of polishing, the stock of removal $(h_j)_i$ (μm) of a workpiece of the j order can be expressed as:

$$(h_j)_i = \sum_{i=1}^{i} (\Delta h_j)_i = \sum_{i=1}^{i} \{\eta_j \cdot v \cdot (p_j)_{i-1} \cdot \Delta t\}, \tag{8}$$

and the difference $(\delta_{f/j})$ (μm) in the height between materials of f and j orders is given as:

$$(\delta_{f/j})_i = (h_f)_i - (h_j)_i = v \cdot \Delta t \cdot \sum_{i=1}^{i} \{\eta_f \cdot (p_f)_{i-1} - \eta_j \cdot (p_j)_{i-1}\}, \tag{9}$$

where $i = 1$, $(p_j)_{i-1} = (p_f)_{i-1} = (p)$.

As shown above, the step height difference $(\delta_{f/j})_i$ between the materials composing a workpiece was calculated. The difference varies in relation to the polishing time under the initial conditions without a difference in the step heights.

As seen in eq. (4), when the difference in the step height becomes constant, the pressure $(p_j)_\infty$ is given by the amount of deformation of the pad, as indicated in Fig. 1(b), and obtained from eq. (5). The step height difference between materials of f and j orders is:

$$\begin{aligned}(\delta_{f/j})_\infty &= \zeta \cdot \{(p_f)_\infty - (p_j)_\infty\} \\ &= \zeta \cdot (p) \cdot (\eta) \cdot \left\{\left(\frac{1}{\eta_f}\right) - \left(\frac{1}{\eta_j}\right)\right\} = \zeta \cdot (p) \cdot (\eta) \cdot \left(\frac{1}{\eta_f}\right) \cdot (1-\kappa),\end{aligned} \tag{10}$$

whereas $\eta_f / \eta_j = \kappa$. When $\kappa < 1$, the relationship between p_f, p_j, η_f and η_j is $p_f > p_j$, $\eta_f < \eta_j$, and becomes $(\delta_{f/j})_\infty = 0$, which means that the material of the f order is more prominent than that of the j order.

Figure 2 shows the step height difference $(\delta_{f/j})_\infty$ when κ is changed from 1 or 2 to 10 while keeping η_f constant, and Fig. 3 shows the calculated results of the relationship between polishing pressure and step height difference $(\delta_{f/j})_\infty$. As expected, $(\delta_{f/j})_\infty$ is proportional to the polishing pressure and becomes minimum when $\kappa = 1$, and as κ advances, it increases. Experimental data that will be mentioned in section 4.5 show good agreement with the calculated results.

The specific elastic deformation amount ζ of the pad can be obtained from eqs. (7) and (10);

$$\zeta = \frac{(\delta_{f/j})_\infty \cdot \eta_f}{(p) \cdot (\eta) \cdot (1-\kappa)} = \frac{(\delta_{f/j})_\infty \cdot \sum_{n-1}^{n} (s_j / \eta_j)}{W \cdot (1/\eta_f) \cdot (1-\kappa)} \tag{11}$$

2.2 *Abnormal generation of step height differences between materials*

An equation for obtaining the step height difference between materials, which is based on the stock of removal that is proportional to the relative speed, pressure and time, has been introduced. Preston described such a proportional relation in glass polishing with a

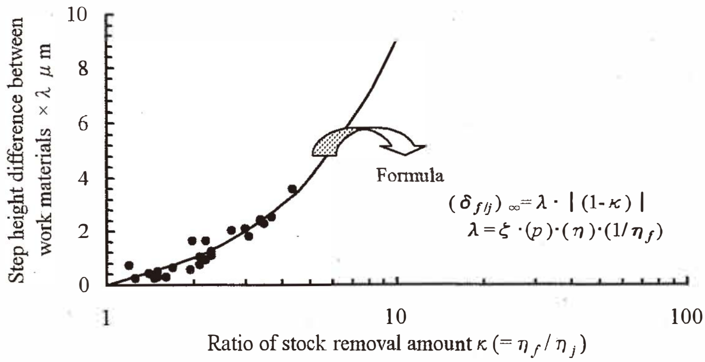


Fig. 2. Calculated results of the relationship between step height difference and specific stock removal amount of each material. Dots represent experimental data. Abrasives: cerium oxide powders (CeO_2) [a] and [b]. Polishing speed: 0.34 m/s. Polishing pressure: 11 kPa. Polishing time: > 10 h.

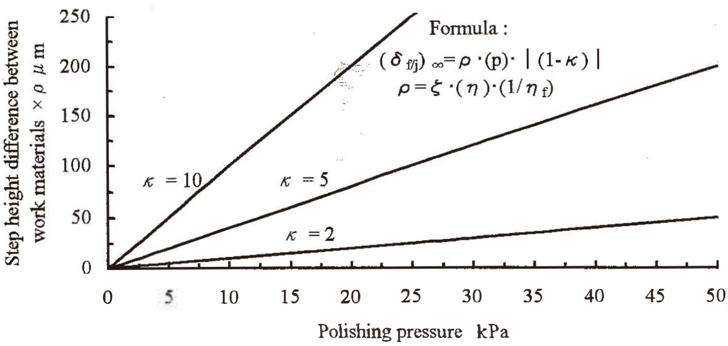


Fig. 3. Calculated results of relationship between step height difference and polishing pressure.

felt-polishing pad in 1927;[4] its proportionality constant is similar to the amount of specific wear in friction and wear.[5] Also, in the practical conditions of lapping and polishing, one of the authors proved that a similar proportional relationship could be expected not only with workpieces but also with laps and pads. Units such as μm, m and Pa or kgf/cm^2 for stock of removal, distance traveled and pressure, respectively, were left in this proportional constant η without elimination, which was then called specific stock removal amount, specific pad or lap wear amount.[6] The proportional constant η varies with the processing conditions such as polishing characteristics of a workpiece, kind and size of abrasives, property of tool materials or type of slurry, and, coupled with the specific elastic deformation amount ζ of the pad, has been considered important in establishing polishing conditions theoretically.[7]

Taking the above into consideration, we studied the step height difference in a workpiece composed of different kinds of materials from a theoretical point of view. However, it is difficult to determine the step height difference in actual polishing. For example, although dressing is performed to recondition the pad surface at each polishing cycle, the pad surface changes since its features become worn as polishing advances. This implies that η and ζ change with time or pressure, resulting in the occurrence of some abnormalities in the step height difference between materials.

Such an abnormal occurrence of step height difference is a problem in planarization polishing of semiconductor device wafers; therefore, adequate pad dressing conditions are required. It is necessary to understand where the step height differences become constant and from where they start varying.

3. Experimental Methods and Conditions

The experimental conditions shown in Table 1 were applied to the polishing to investigate the step height differences between materials composed of different glasses.

In preparing an experimental workpiece, four kinds of glasses were polished to 1 mm thickness each, bonded together and cut into 5×11 mm blocks, as shown in Fig. 4. Each of the three glass plates was put in between fused silica glasses. Six blocks were waxed on a plane parallel glass jig of $\phi\,60 \times$ t 15 mm at regular intervals near the edge.

To measure specific stock removal amount η, glasses of the same shape and size were prepared for polishing. Four different types of pads (A, B, C and D) were used, two of which were polyethyleneterephthalate felt fibers, and the other two were polyurethane foam,[8] under a wide variety of surface conditions including wearing, loading, dressing and brush cleaning. Dressing or brush clearing were applied to recover from worn surfaces or loaded surfaces, respectively.

CeO_2 abrasive powders [a] and [b] dispersed in pure water were used as slurry. These powders were classified into the processing efficiency and low processing efficiency groups for the barrel processing of glass balls.[9]

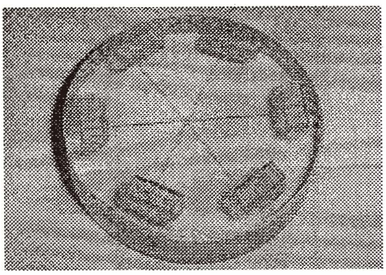
The polishing machine used was a conditioning ring type of machine shown in Fig. 5, whose outer and inner diameters are $\phi\,180 \times 30$ mm. The inner and outer diameters of the conditioning ring are $\phi\,60 \times 90$ mm. The parallel jig mounting workpiece is set in a conditioning ring and polished under a suitable loading, relative speed to polishing pad and slurry supply.

The dressing wheel for reconditioning the pad surface was a nickel-plated bond wheel made of #400 diamond grains with the same form and size as the conditioning ring. Brushing of the polishing pad surface is applied to recover the loaded pad with abrasives. The brush is a plastic wire scrubbing brush.

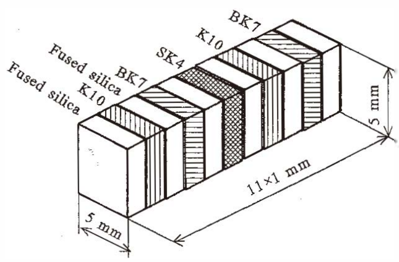
To measure the step height difference between materials induced by polishing, an optical-type surface roughness measuring instrument (New View 100, Zygo Co.) and a stylus-type-measuring instrument (SE-3C, Kosaka Lab. Co.) were used.

Table 1
Polishing conditions.

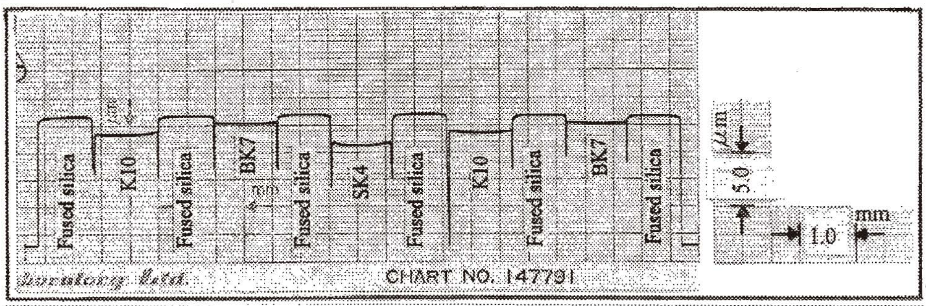
Work material	Fused silica glass (Hardness H_k 9,400 MPa) BK7 glass (Hardness H_k 6,500 MPa) K10 glass (Hardness H_k 7,900 MPa) SK4 glass (Hardness H_k 7,100 MPa)
Polishing pad	A: Polyethyleneterephthalate felt fibers sheet (Suba400) B: Polyethyleneterephthalate felt fibers sheet (Suba800) C: Polyurethane foam type sheet (IC1000) D: Polyurethane foam type sheet (MH-N24A-13)
Dressing wheel	Ni bond type of #400 diamond
Brushing	Plastic wire brush
Polishing liquid	Pure water
Abrasive	Cerium oxide powder (CeO_2) [a] and [b]
Polishing machine	Conditioning ring type of polishing machine
Polishing speed	61 r.p.m. (0.34 m/s)
Polishing pressure	3.5 – 33 kPa (36 – 340 gf/cm^2)
Step height measurement	Surface roughness measuring instrument



(a)



(b)



(c)

Fig.4. Workpiece model and step height difference on a workpiece. (a) Photograph of workpiece. (b) Schematic of workpiece composed of four kinds of glasses. (c) An example of measured step height difference on a workpiece.

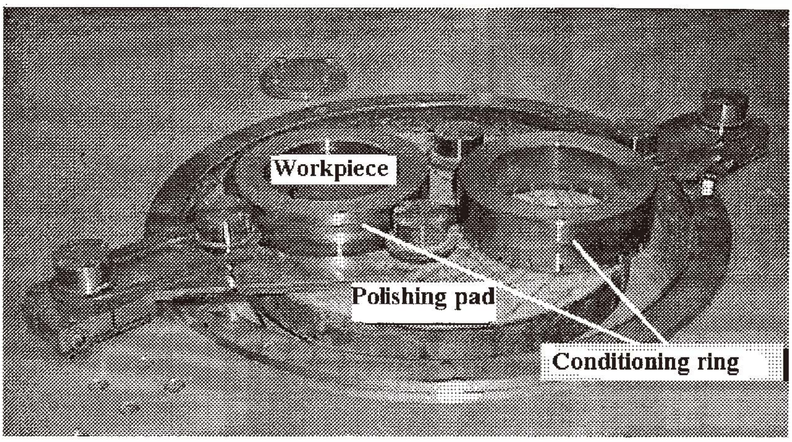


Fig. 5. Photograph of conditioning ring type of polishing machine.

4. Experimental Results and Discussion

In the preparation process prior to polishing, a lapping method was applied to make the surface of workpiece composed of different glasses planar. However, in this process, step height differences were already produced, depending on the differences in the lapping characteristics of the materials; it was impossible to make the step height difference nil before shifting to the polishing process. For example, the step height difference between fused silica glass and SK4 glass was 0.6 μm at a pressure of 3.5 kPa using Al_2O_3 #1000 abrasives and a cast iron lap.

Below are the results of the polishing experiments and discussion based on the theoretical analysis.

4.1 *Variations of step height difference between different glasses during polishing*

An example of the step height difference between the glass materials comprising the polished workpiece is shown in Fig. 4(c). The surface roughness-measuring instrument took the profile of the step height difference. The fused silica glasses have a round convex shape, while SK4 glass, K10 glass and BK7 glass interposed by fused silica glasses have a concave shape. The step height difference is indicated by the difference between the minimum value of the recessed glass height and the maximum value of the adjacent fused silica glass height.

When this workpieces are polished for a long time, the step height difference varies widely. Figure 6 shows the change in the step height difference between fused silica glass and SK4 glass 15 h or more after polishing started under a pressure of 11 kPa, using the softest pad A and CeO_2 [a] powders. During polishing, the conditions of the pad surface

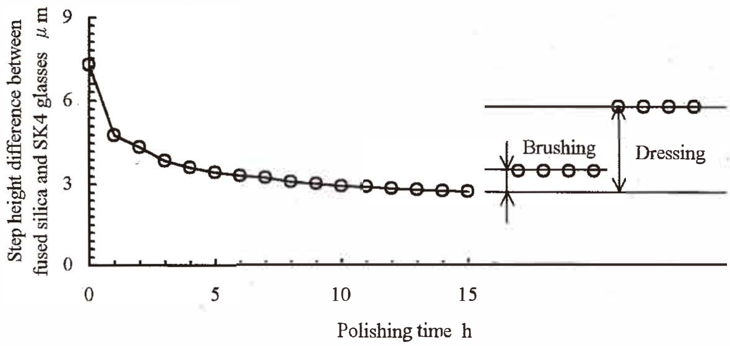


Fig. 6. Variations of step height difference as polishing advances, adopting dressing and brushing. Pad: polyethyleneterephthalate fibers felt sheet A (Suba400). Abrasives: cerium oxide powder (CeO_2) [a]. Polishing speed: 0.34 m/s. Polishing pressure: 11 kPa.

showed various changes, and the surface was subjected to brushing or dressing as required.

The pad was dressed and polishing started from a step height difference of 7.3 μm. The change in step height difference was measured every hour. The step height difference between the two glasses decreased drastically at the start of polishing, and then the decrease slowed down. At 15 h, the step height difference became 2.8 μm and showed a tendency to become constant. Under such conditions, the pad surface seemed to be covered and loaded with abrasives, and was worn out and slippery. Then, brushing and dressing were conducted in an attempt to recover the original state of the pad surface. As a result, the step height difference increased to 3.4 μm by brushing and to 5.5 μm by dressing.

The experiments have revealed that the pad surface is scratched by the diamond-dressing wheel or by brushing, and such an irregular pad surface tends to enlarge the step height differences between glasses. The step height differences between glasses are related to the irregularities of the pad surface. It is also true that such irregularities are worn out, crushed and loaded with abrasives, which makes the step height difference smaller as polishing advances. Floating of the workpiece due to the hydroplaning is also anticipated. It is also expected that the projections of the pad surface are pushed into recessed areas. Elastic deformation, plastic deformation or wear causes variations of the pad surface irregularities. The irregularities of some pads having the possibility of elastic recovery cause the generation of minute polishing pressure, by the product of its elastic deformation amount and specific elastic deformation amount ζ, when the workpiece surface is pressed or polished. The step height difference between glasses is formed by such polishing pressure and specific stock removal amount η of each glass materials. This can be presumed from the fact that when the irregularities become small after polishing for a long time, the step height difference between glasses likewise becomes small. Here lies the cause of the abnormality, irregularity or uncertainty in the generation of the step height difference, which varies as polishing advances.

In the CMP method for semiconductor devices, it is necessary to finish wafers having many grooves to an even surface, which are a few μm or smaller in width and 0.5 μm in depth. In such cases, the projections of the pad surface after just dressing will act not only as a bank, but also as the bottom of grooves regrettably, if being able to respond elastically to the uneven movement of the work surface. This is an undesirable phenomenon. In this experiment, the lateral surfaces of rather thickly layered glass plates used as a workpiece are polished, in order to obtain basic data to support the CMP method. The projections of the pad surface compensate for the step height difference of the workpiece by attacking a part having larger specific stock removal amount.

In order to compare theoretical analysis and experimental results reliably, the step height difference between materials under constant, stable conditions, when the pad surface has small irregularities of similar height with abrasives adequately loaded as polishing advances, should be discussed.

4.2 *Step height difference between glass materials using different polishing pads*

The step height difference between materials varies depending on the type of pad and dressing conditions. Pad surfaces subjected to only dressing were the most unstable, and it takes a considerable amount of time for them to become stable. According to Fig. 6, 8–10 h are needed. As the pad surface continues to be unstable, the specific elastic deformation amount ζ, which represents the strength of the pad, varies constantly, and as a matter of course, it can be assumed that specific stock removal amount η also has changeable characteristics values depending on the topography. The specific stock removal amount η in a stable condition of the step height between materials can be obtained easily and will be described later. However, regarding unstable conditions of the step height, development of new studies based on the quantitative data of polishing pad surfaces may be needed.

Figure 7 shows the step height difference between glass materials using four kinds of polyurethane pads (A, B, C and D), showing values measured on the step height differences when the differences became constant and stable after being fully polished.

The hardness of the pads is in the order of A < B < C < D according to the manufacturer's indications.[8] The softest pad, A, exhibited the largest step height difference, followed by B, C and D.

4.3 *Influence of polishing pressure*

From eq. (10), it is shown in Fig. 2 that the step height difference between materials is proportional to the polishing pressure. Figure 8 shows the results of polishing using pad A and CeO_2 [a] powders, while changing the polishing pressure under stable conditions. The step height difference between materials is found to be proportional to the polishing pressure in accordance with the theoretical equation.

4.4 *Measurement of specific stock removal amount of glass materials*

Various CeO_2 powders as abrasives of polishing slurry are commercially available. In this experiment, two kinds of cerium oxide powders CeO_2 [a] and CeO_2 [b] were adopted, which had been classified by the stock of removal in the barrel finishing of glass balls. The

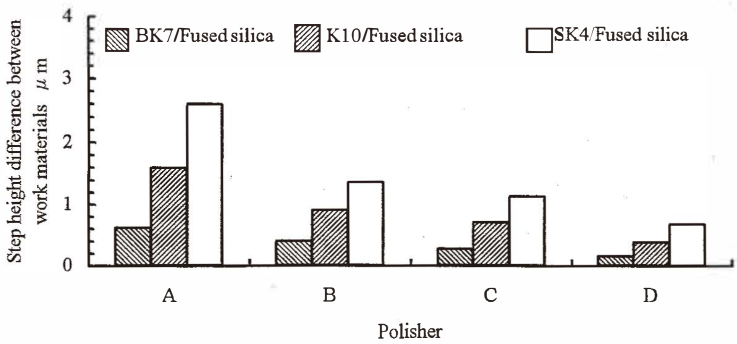


Fig. 7. Step height difference using four kinds of polyurethane polishing pads. Pads: A, B, C and D sheet. Abrasives: cerium oxide powder (CeO_2) [a]. Polishing speed: 0.34 m/s. Polishing pressure: 11 kPa. Polishing time: > 10 h.

stock of removal of the former was one-half the latter. There was, however, no major difference in polishing between the two types of powders. Processing conditions are clearly different between barrel finishing and plane polishing of the present experiment. In the case of barrel finishing, processing is carried out in a plastic container, bringing about a considerable temperature increase.

In general, abrasive polishing powders are attached to work materials as if they were compatible with each other, which is probably similar to pad materials. In such a case, an abnormal specific stock removal amount of a workpiece will probably come out. It is difficult to clarify the relationship between polishing slurry and step height difference between materials.

Concerning the step height difference between various glass materials, as shown in Figs. 6, 7 and 8, the heights of three kinds of multicomponent glasses compared with that of fused silica glass as a basis were measured. The step height differences were found to follow the order of fused silica glass/SK4 glass > fused silica glass/K10 glass > fused silica glass/BK10 glass.

One of the factors that affect such a step height difference between materials is the specific stock removal amount which can be obtained easily from the stock of removal, relative speed, pressure and actual polishing time. Figure 9 shows the specific stock removal amount η of different glass materials, pads and abrasives under the condition that the step height difference reached a constant, stable region. The specific stock removal amount shows the following order: fused silica glass < BK7 glass < K10 glass < SK4 glass, and does not contradict the step height difference. Regarding abrasive powders, the specific stock removal amount was CeO_2 [a] < CeO_2 [b] in continuous foam-type polyurethane pads, A and B. On the other hand, in the independent foam-type pads, C and D, the inverse tendency of CeO_2 [a] > CeO_2 [b] was observed. Hardness of the pads follows the order A < B < C < D, as mentioned previously. The softer the pad is, the smaller the specific stock removal amount seems to be using CeO_2 [a] powders as opposed to CeO_2 [b].

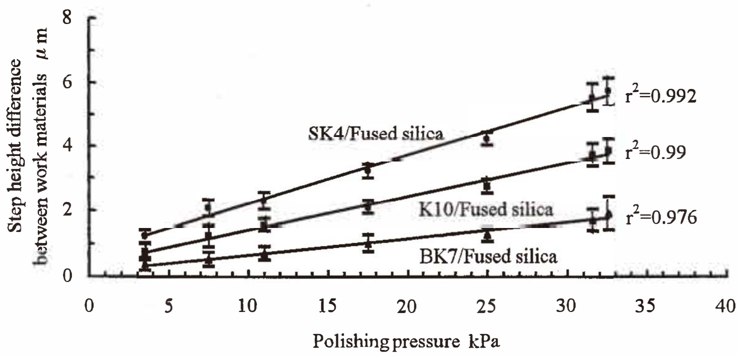


Fig. 8. Step height difference in polishing under various pressure conditions. Pad: polyethyleneterephthalate fibers felt sheet A (Suba400). Abrasives: cerium oxide powder (CeO_2) [a]. Polishing speed: 0.34 m/s. Polishing time: > 10 h.

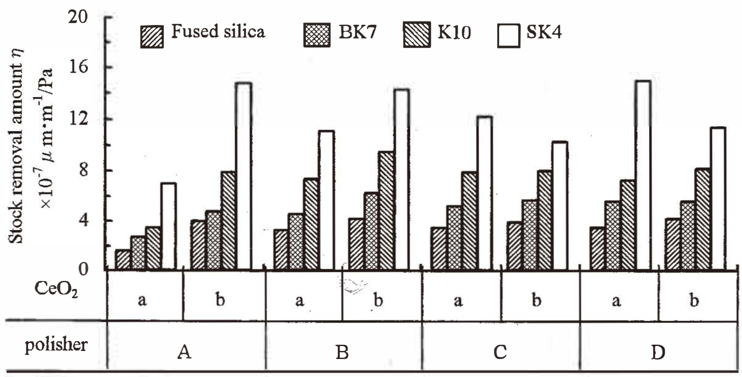


Fig. 9. Specific stock removal amounts of four kinds of glasses. Pad: A, B, C and D sheet. Abrasives: cerium oxide powder (CeO_2) [a] and [b]. Polishing speed: 0.34 m/s. Polishing pressure: 11 kPa. Polishing time: > 2 h.

Abnormal specific stock removal amount was calculated in a similar manner from the stock removal after polishing for only one hour, after the pad is dressed or brushed. Compared with the specific stock removal amount in stable conditions, it was 1/5 ~ 1/10 in the case of the softest pad A, while pads B, C and D show no large difference among them. Polishing for one hour may be too long for these estimations. No convincing explanation of the above results is available. From the viewpoint of a large stock of removal, several reasons can be listed such as (1) large diameter of the abrasive, (2) hardness of abrasives, (3) large number of working abrasives, and (4) probable chemical reactions by abrasives.

We can also presume that some of the differences that have arisen between CeO_2 [a] and CeO_2 [b] powders are attributable to the existence of compatibility, to some degree, between abrasives and each pad. Research on this is under way, covering also several CeO_2 abrasive powders.

4.5 *Specific elastic deformation constant of various pads*

The specific elastic deformation amount ζ is obtained from eq. (11), which is related to the step height difference between materials and shown in Fig. 10. Rheological interpretations for pads were investigated a long time ago. However, the numerical indication related directly to polishing accuracies has not been established yet. Presently, some measurement methods, such as simple penetration and rubber hardness measurement, have been proposed and applied to the classification of pads ranging from soft to hard ones. In the present experiments, the specific elastic deformation amounts ζ of each pad at work were obtained.

Considerable agreement between calculations and experimental results of step height differences, as shown in Fig. 2, was found. The specific elastic deformation amounts obtained are the actual values of the pad at work and relevant to the matter in step height difference between materials. These results are considered to contribute to the future study of the mechanical characteristics of pads and their novel measurement method.

5. Conclusion

Theoretical and experimental studies have been conducted in relation to the generation of the step height difference between materials in the polishing of workpieces composed of several different glass materials.

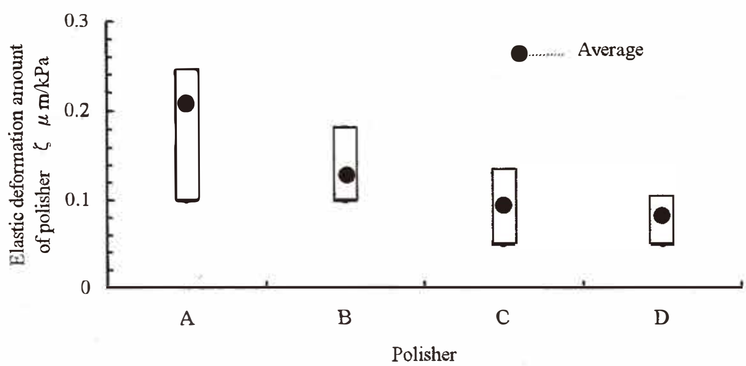


Fig. 10. Specific elastic deformation amounts of polyurethane polishing pad. Pad: A, B, C and D sheet. Abrasives: cerium oxide powders (CeO_2) [a] and [b]. Polishing speed: 0.34 m/s. Polishing pressure: 11 kPa. Polishing time: > 10 h.

(1) Theoretical equations for the step height difference between materials were introduced based on several assumptions, as a function of the specific stock removal amount of work materials and the specific elastic deformation amount of a polishing pad.
(2) In the experiments, workpieces composed of four kinds of glasses such as fused silica, SK4, K10 and BK7 glasses were polished, using four kinds of polyurethane pads and two kinds of CeO_2 abrasive powders. Step height differences were generated between the glasses, which revealed various differences in the formation of gap heights, under various pad surface conditions.
(3) The calculated results showed good agreement with the values obtained by polishing under specific conditions, in which the step height differences between constituent materials became stable and constant.
(4) The step height difference between materials became stable, constant and small, showing a tendency to increase when soft pads were used.
(5) Specific stock removal amounts η of four different glasses were obtained from polishing experiments. Based on the results and the step height differences between materials, the specific elastic deformation amount ζ of each pad was obtained.

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