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Mirror-polishing of rough surface glass by soothing of abrasive layer

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Abstract
We propose a pore-filled media abrasive tool (with a spiral wire structure) using the smoothing effect of a filler layer and the elastic effect of media particles. When the proposed tool was applied to the mirror polishing of rough-surface glass, the following results were obtained. (1) The media abrasive layer composed of Ni and ceria particles is effective as an electrodeposited layer that supports the filler layer, and its strength is a more important factor than its elasticity. (2) The smoothing effect of the filler layer is more effective for suppressing the effect of the variation in the diameter of abrasive grains than that of the electrodeposited layer. The polishing force can be dispersed by this smoothing effect. The surface roughness *Ra* of the polished surface was 4nm for a tool feed rate of 3µm/s. (3) The rough surface of chemical-resistant borosilicate glass was successfully polished to a mirror finish using only the proposed tool with the filler that exhibited mechanical and chemical effects. Thus, the proposed tool showed the potential to become an alternative to mechanical polishing.

Keywords: rough surface glass, media abrasive, composite plating, spiral structure, pore-filling, smoothing

1. Introduction

The planarization process for sliced wafers, such as single-crystal SiC wafers, generally consists of two steps: (1) mechanical lapping and polishing and (2) chemical mechanical polishing (CMP). This is because it is difficult to reduce the swell, warpage, and surface roughness of a sliced wafer and remove the processing strain in a single step. One problem in the mechanical polishing of glass is the generation of scratches due to abrasive grains of various diameters [1]. Because these scratches contain latent scratches, it is necessary to suppress the effect of the variation in the diameter of such abrasive grains. We propose a pore-filled media abrasive tool (with a spiral wire structure) using the smoothing effect of a filler layer and the elastic effect of media particles.

2. Fabrication of pore-filled media abrasive tool and concept of tool

A total of three combinations of abrasive grains and media particles were adopted to fabricate media abrasive tools (Table 1). Table 2 shows the methods of fabricating and fixing the media abrasives as well as the composition of the filler. For Tools 1 and 2, the abrasive grains were embedded into the media particles using a stirrer and the obtained media abrasive was fixed onto a spiral wire by Ni electrodeposition. For Tool 3, only Ni particles were first electrodeposited and ceria particles were subsequently electrodeposited on the Ni particles. The filler with the composition shown in Table 2 was packed into the pores and baked at 260^{o}C. Figure 1(a) shows a schematic of a media abrasive tool prepared by embedding the abrasive grains into the (elastic) media particles and fixing them by electrodeposition. The effect of the variation in the diameter of abrasive grains is suppressed because the force applied to the tool during polishing is dispersed by the elastic deformation of the resin. However, pores are randomly formed in the

Table 1. Specification of media abrasive.

Tool	Media grain	Media particle	Abrasive grain size
1	Media particle + Conductive diamond	Silicone ϕ10-30μm	Conductive diamond ϕ5-12μm
2	Media particle + Ceria		Ceria ϕ2μm
3	Media Ni + Ceria	Ni ϕ10-20μm	

Table 2. Media abrasive manufactures and fixing method.

Tool	Fabrication of media grain	Fixation of media grain	Filler (Baking: 260degree, 1h)
1	Embedding by stirrer	Electrodeposition (dispersion)	Water-soluble PTFE resin + Ion-water (1:1) + Diamond (1g, ϕ4-6μm) + Ceria (2g, ϕ2μm)
2		Electrodeposition (non-dispersion)	
3	First: Ni electrodeposition (non-dispersion) Second : Ceria electrodeposition (non-dispersion)		Above filler + epoxy

electrodeposited layer and cause the loading of swarf. Therefore, all the pores should be filled with a filler such as the resin [Fig. 1(b)]. Porous resin-bonded wheels have also been used [Fig. 2(b)]. Although pores are randomly formed in these wheels during baking to induce the elastic effect and suppress the effect of the variation in the diameter of abrasive grains, the pores are gradually loading with swarf. The abrasive grains present in the pores easily become detached to cause the generation of scratches. For the proposed pore-filled media abrasive tool [Fig. 1(b)], the effect of the variation in the diameter of abrasive grains is suppressed by the smoothing effect of the filler layer and the dispersion of the force locally applied to the tool during polishing. In addition, the strength of

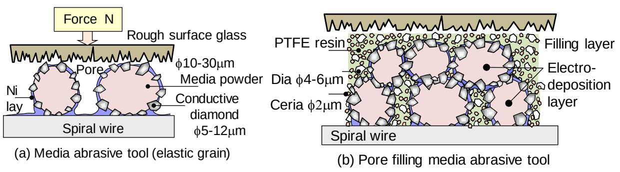
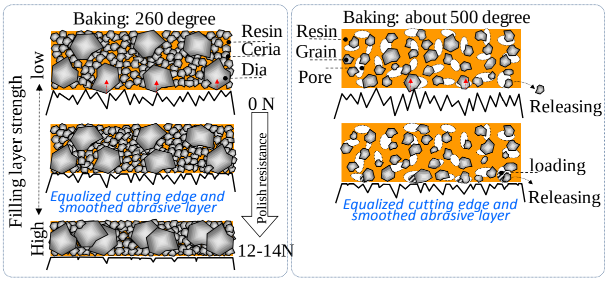


Figure 1. Concept of pore-filled media abrasive tool.

the filler layer increases with the polishing force, preventing the detachment of abrasive grains unlike, in contrast to the case of using resin-bonded wheels [Fig. 2(a)].



(a) Filled layer (b) Porous resin bonded wheel

Figure 2. Differential of filler layer and porous resin wheel.

3. Effect of filler and polishing mechanism

The major roles of the resin used as the filler are the suppression of loading and the dispersion of the force due to the elastic effect. Moreover, the abrasive grains added to the resin are expected to exhibit mechanical and chemical effects during the mirror polishing of rough-surface glass depending on their material and diameter. As shown in Figs. 1(b) and 2(a), diamond particles of ϕ4–6μm are used to truncate the pearskin surface of the glass and ceria particles of ϕ2μm promote the chemical reaction to improve the surface roughness. At the same time, the filler layer is smoothed and the effect of the variation in the diameter of the abrasive grains is suppressed. The polishing force is dispersed as the filler layer is smoothed. Therefore, even abrasive grains of various diameters can be used to polish glass to a mirror finish.

When the filler layer of the proposed media abrasive tool consists of resin and diamond particles, the amount of polishing is large at the pearskin surface but decreases with the improvement of surface roughness (Fig.3). If the polishing force is excessively increased, the strength of the filler layer increases and the risk of crack generation also increases. Therefore, ion water or a catalyst should be added to the newly formed active surface to chemically form a softened layer. Figure4 shows the polishing mechanism of chemical-resistant borosilicate glass. The Na_2O in borosilicate glass (Na_2O-B_2O_3-SiO_2) is dissolved in water by heat during polishing to form 2NaOH. SiO_2 reacts with alkali NaOH to become Na_2SiO_3. In this reaction, a softening layer called liquid glass, which is softer than the original material, is considered to be formed on the newly formed surface in the presence of water and heat during polishing. In addition, the CeO_2 in the filler reacts with SiO_2, the main component of the glass, as a catalyst to form Ce-O-Si bonds that react with water [2]. The two interactions promote the polishing process.

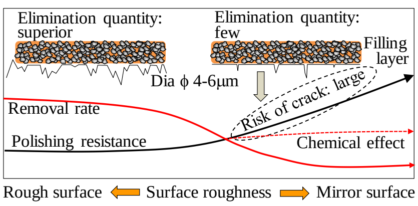


Figure 3. Surface roughness and removal rate.

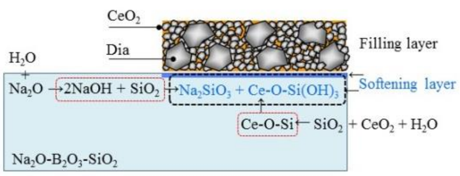
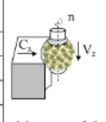


Figure 4. Polishing mechanism of borosilicate glass.

4. Mirror polishing of rough-surface glass

Using the thus-obtained Tool 3, the pearskin surface of borosilicate glass was polished under the conditions summarized in Table 3. The depth of cut was controlled to maintain the polishing force at 12–14N. Polishing was repeated at a tool feed rate of 100μm/s. Figure 5(a) shows the pearskin surface before polishing and Fig. 5(b) shows the glass surface completely polished to a mirror finish. When the tool feed rate was 3μm/s, *Ra* was 4nm. The pearskin surface was truncated by the diamond particles of ϕ4–6μm added to the filler, and the filler layer was smoothed as the surface roughness improved (Fig. 6).

Table 3. Manufacturing condition.

Substrate and wire	ϕ10-SUS, ϕ0.6mm-copper	Media abrasive tool
Tool form and revolution (curvature radius 10mm)	Strawberry form, n1000rpm	
Workpiece	Borosilicate glass	
Feed V_z	100μm/s and 3μm/s	
Cutting depth C_x	1μm	
Polish resistance	12-14N	Macro model
Mist	Ion-water (semidry)	

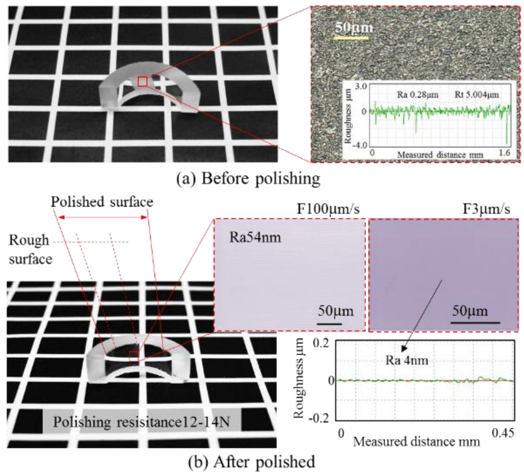
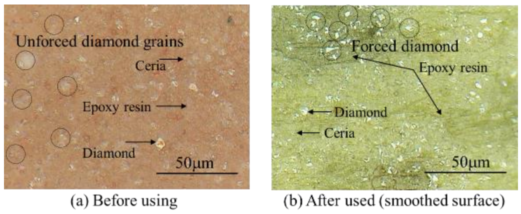


Figure 5. Mirror finish of rough surface glass.



(a) Before using (b) After used (smoothed surface)

Figure 6. Microscopic image of tool surface.

5. Conclusions

(1) The smoothing of the filler layer is effective for suppressing the effect of the variation in the diameter of abrasive grains. The polishing force can be dispersed by the smoothing effect. The surface roughness of the polished glass, *Ra*, was 4nm for a tool feed rate of 3μm/s.

(2) When the diamond and ceria filler that exhibits mechanical and chemical effects is used for the proposed tool, the rough surface of chemical-resistant borosilicate glass can be polished to a mirror finish by one chuck.

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