Novel polishing process based on photo-rheological fluids

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Abstract: In float polishing process the entire surface of a workpiece is polished by moving across a lap, larger than the workpiece, that is covered with a slurry containing abrasives. Because of the full aperture processing region, it is considered difficult to control the amount of material removed as function of location across the workpiece surface. To solve this problem, a novel polishing method is proposed that uses a photo-rheological (PR) fluid composed of the azobenzene derivative ACA and the surfactant OHAC. Its viscosity changes reversibly when irradiated with visible and ultraviolet light, thus material removal rate can potentially be locally affected depending on the applied illumination pattern across the contact zone. In this study, viscosity measurements were performed to investigate the influence of various process parameters such as gap and concentration of chemicals. Under strong illuminance (13.2W/cm^2), the viscosity could change within few seconds. Also, the viscosity ratio between UV and visible light increased by selecting appropriate concentrations of the component chemicals, and by using a smaller gap between the tool and the workpiece. On the other hand, the viscosity ratio didn't change much with respect to shear rate. These results will be used to set process parameters in polishing.

Key words: Photo-rheological fluid, viscosity, polishing

1. Introduction

High-precision polishing can be performed by floating a planar workpiece a few microns above a precision lap, as shown in Fig.1[1]. However, because of the full aperture region of processing it is difficult to control the amount of material removed as function of location across the workpiece surface. It is hypothesized here that the polishing rate can be controlled by using Photo-Rheological fluid (PR fluid) [2), 3)] based abrasive slurry, whose viscosity can change reversibly when irradiated with visible light and ultraviolet light. In this report, the PR fluid mainly consists of the acid azobenzene carboxylic acid (ACA) and surfactant oleyl bis(2-hydroxyethyl)methyl ammonium chloride (OHAC). As shown in Fig.2, it is proposed to control the viscosity of PR based slurry by irradiating a pattern of visible and ultraviolet light through the back side of the workpiece. In this report, the process parameters that affect viscosity are investigated.

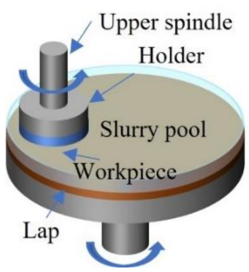

Fig. 1. Schematics of float polishing method.

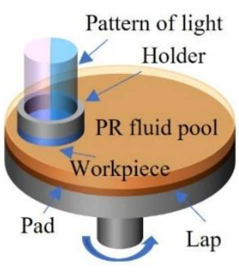

Fig. 2. Schematics of proposed PR polishing.

2. Experimental method of viscosity measurement

PR fluid samples were irradiated sequentially with ultraviolet light (365nm) for 300 s, visible light (445nm) for 300 s, and then ultraviolet light again for 300 s. The viscosity was measured with a rheometer (Anton Paar MCR301) during light irradiation. The viscosity change was evaluated as the ratio of viscosity under ultraviolet light and visible light as shown in Eq. (1).

$$Viscosity\ ratio = \frac{\mu_u}{\mu_v} \tag{1}$$

where μ_u is the average viscosity under ultraviolet light for the intermediate 100 s period, and μ_v is the average viscosity under visible light for the intermediate 100 s period.

In this report, the viscosity ratio was determined as function of the following parameters: (1) the gap between workpiece and lap, (2) the shear rate, (3) the concentration of compounds ACA and OHAC in the PR fluid and (4) time. Table 1 shows the values of the set parameters. Gaps in Subsections 3.2, 3.3, 3.4 was 0.15mm.

Table 1. Measurement parameters.

Gap (mm)	0.05, 0.10, 0.15, 0.20
Shear rate (s^{-1})	400, 566, 800, 1131, 1600
ACA concentration (mM/L)	1, 2, 3, 5, 10, 15, 20
OHAC concentration (mM/L)	3.4, 5, 10, 15, 20, 40

3. Experimental results of viscosity ratio

3.1 Influence of gap between workpiece and pad

Figure 3 shows the relationship between the gap and viscosity ratio. The figure shows that the viscosity change is larger when the gap is smaller. This is because light cannot reach deeply inside the PR fluid when the gap is large. A smaller gap is thus considered suitable for polishing.

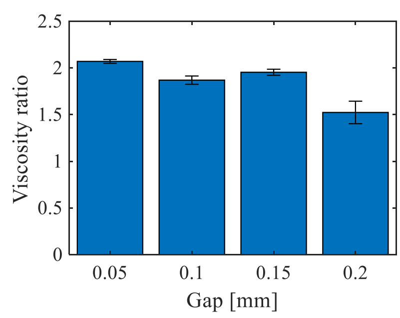

Fig. 3. Viscosity ratio as function of gap height

3.2 Influence of shear rate

Figure 4 shows the relationship between shear rate and viscosity ratio. The figure shows that the viscosity ratio increases slightly when the shear rate is high until becoming approximately constant. The structure created by the surfactant at high viscosity may be slightly more easily broken by shear forces than the structure created by the surfactant at low viscosity In general, it is known that the material removal rate increases when shear rate is high. On the other hand, when shear rate is high the absolute value of viscosity was found to decrease as shown in the Fig.5, which would negatively impact the expected material removal rate. The shear rate will thus need to be selected by taking these competing factors into consideration.

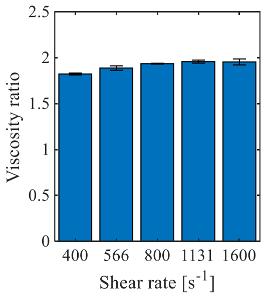

Fig. 4. Viscosity ratio as function of shear rate

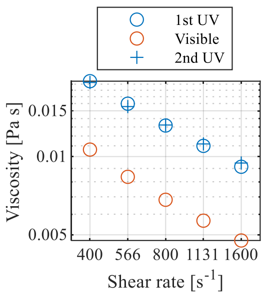

Fig. 5. Viscosity as function of shear rate

3.3 Influence of ACA/OHAC concentration

Figure 6 shows the viscosity ratio as function of ACA and OHAC concentration. It reaches a maximum of approximately 2.5 when the OHAC concentration is 3.4 mM/L and the ACA concentration is 3 mM/L. On the other hand, when the OHAC concentration is 10 mM/L and the ACA concentration is 5 mM/L, the viscosity ratio is about 0.15, which is the lowest. A viscosity ratio lower than 1 means that the viscosity increases under visible light irradiation. This may be caused by changes in the amount and molecular structure of ACA entering the structure created by the surfactant OHAC At this concentration, the change in viscosity is also large. The two conditions with the largest and smallest viscosity ratios are suitable for the proposed polishing method.

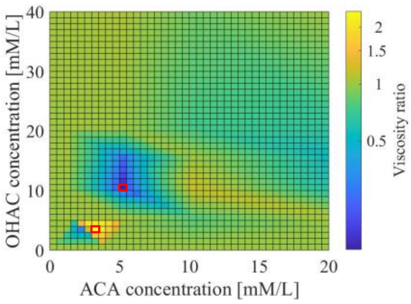

Fig. 6. Viscosity ratio as function of ACA/OHAC concentration

3.4 Influence of irradiation time

Figure 7 shows the relationship between the absolute value of viscosity and time. The blue line indicates viscosity under strong light irradiation (UV light: 13.2 W/cm^2 Visible light: 15.0 W/cm^2) and red line indicates viscosity under weak light irradiation (UV light: 2.5 W/cm^2 Visible light: 2.5 W/cm^2). When irradiated with strong light, the viscosity changes quickly and viscosity reaches a steady state. The proposed polishing method should allow for quick viscosity changes and will therefore require strong light irradiation.

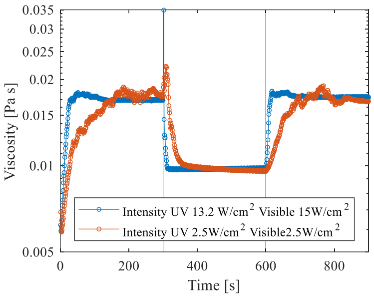

Fig. 7. Viscosity as function of irradiation time

4. Conclusion

A novel polishing method using PR fluid based slurry has been proposed. It was shown in this report that fluid viscosity ratio can be maximized by reducing the workpiece/pad gap, selecting an appropriate compound concentration, and maximizing the irradiation intensity. On the other hand, the optimal processing shear rate will need to be determined according to the absolute value of viscosity as well as the viscosity ratio.

5. Future research

PR fluid polishing should be performed in contactless condition. The small gap requires micron level flatness of the pad. A pad dressing system was designed for this purpose, as shown in Fig.8. Next, the polishing experiment will be conducted to study relationship between the removal rate and viscosity ratio. Finally, polishing parameters will be set based on the results of this study to investigate how the polishing rate varies in response to changes in the viscosity of slurry.

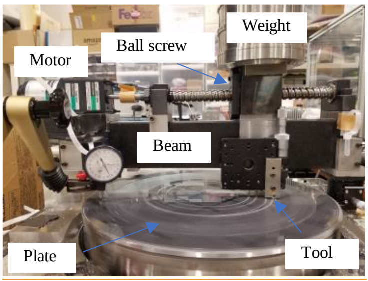

Fig. 8. Dressing system to planarize the polishing pad

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