Basic Evaluation of Fully Aromatic Polyimide for CMP Retainer Ring Applications

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1. Introduction

In semiconductor manufacturing, retainer ring wear presents a challenge when it comes to reducing downtime for maintenance, especially in the high-load and chemical-intensive CMP process for compound semiconductor substrates. Materials with superior wear resistance are necessary to mitigate this issue. This study evaluated the potential of fully aromatic polyimides for CMP retainer ring applications due to their excellent wear and heat resistance properties. While many studies have focused on polishing mechanisms of pads[1)], few have evaluated the performance of retainer ring materials. In this study, the wear resistance of small specimens molded from fully aromatic polyimide resin is assessed in comparison to incumbent thermoplastic materials such as PEEK and PPS under different CMP polishing conditions for compound substrates.

2. Materials

The materials examined in this study are Polyether ether ketone (PEEK), crystallized Polyphenylene sulfide (PPS) and fully aromatic Polyimides (PI). All materials are neat polymers with excellent heat resistance and mechanical properties. The specific gravity of PEEK, PPS, PI used in this study was 1.30, 1.36, 1.38, respectively.

3. Methods

Two methods were applied in this study. First, a coin-on-disk wear test was conducted to evaluate the wear resistance of each polymeric material. The sample's average wear rate and maximum temperature of the pads were measured under various combinations of three slurries and two pads. Fig.1 shows the polishing tools and coin samples which were used in this test. Table 1 shows polishing conditions and Table 2 displays the test conditions. The coin-shaped specimens were polished on one side according to these conditions for four hours. Second, a slurry immersing test was performed to verify that the wear rate was not affected by the swelling of the sample due to the slurry or chemical degradation of the resin. In this test, PI was immersed in various slurry solutions for four hours, and its size, weight, and the Vickers surface hardness were measured.

4. Result and discussion

Figure 2 shows the sample wear rate and the maximum pad temperature for each test condition. The results shows that PI has lower wear rates than PEEK for all test conditions. In T1, PI's wear

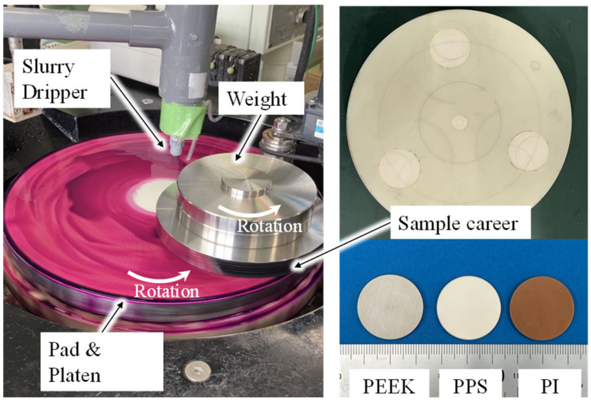

Fig. 1 Polishing tools and samples

Table 1 Polishing conditions

Tool	15-inch single side polishing machine
Polishing Duration	240 min
Sample Fixing Method	Insert template method, 3 pcs per plate
Polish Pressure	460 g/cm^2
Slurry flow rate	4 ml/min
Platen rotation speed	60 rpm
Slurry supply method	By a dripper
Dresser	Metal Bond SD#270
Dress downforce	10 kg
Dress rotation speed	60 rpm
Dress time	10 min
Conditioning type	Ex-Situ (Before polishing)
Chiller temperature	25°C

Table 2 Testing conditions

Test condition	Sample			Slurry			Pad	
	Materials	Size [mm]	Quantity	Type	pH	Target substrate	Pad	Hardness
T1	PEEK, PPS, PI	OD:24.5 THK:2	N=3	Colloidal silica slurry	10	Sapphire	Non-woven fabric (plane)	Asker C 80
T2				$KMnO_4$ based slurry	2	SiC		
T3				$KMnO_4$ based slurry	2	SiC	Micro-porous polyurethane (concentric grooved)	Shore D 52-62
T4				Abrasive grain-less $KMnO_4$ based slurry	2	SiC (finishing)		

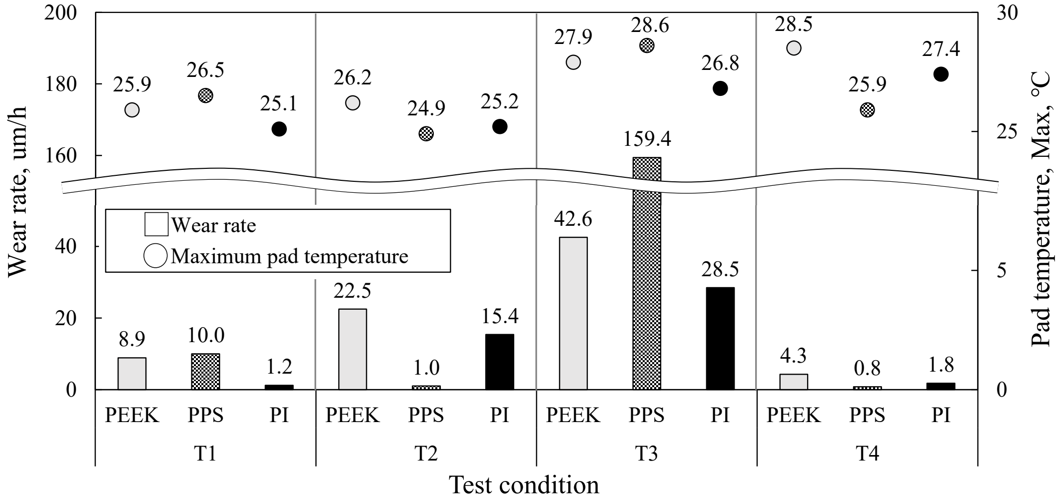

Fig. 2　Wear rate of the samples and maximum of the pad temperature under the individual test conditions

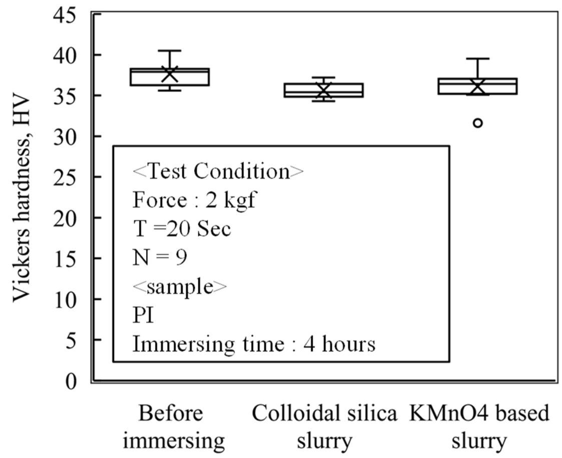

Fig. 3　Vickers hardness of PI before and after immersing

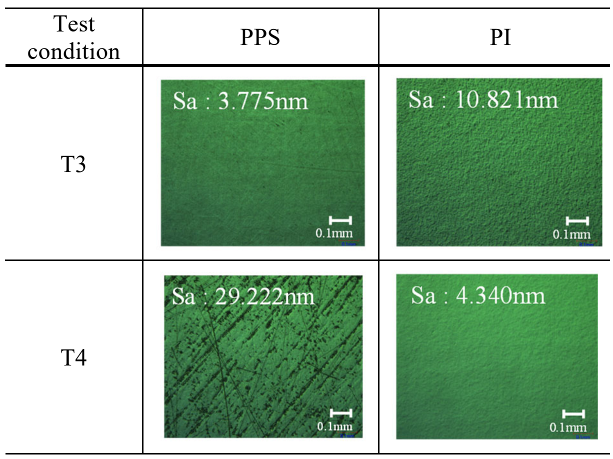

Fig. 4　Sample surface image and roughness (Sa) after test

rate was approximately 83% lower than PEEK and 82% lower than PPS. In T3, its wear rate was 34% lower than PEEK and 82% lower than PPS. This demonstrates that PI exhibits high wear resistance in both the colloidal silica slurry with nonwoven pads used for alkali-based sapphire polishing and the $KMnO_4$-based slurry with polyurethane pads used for SiC acidic polishing. Furthermore, the study also showed that the wear resistance of the retainer ring depends on the chemical composition of the slurry and the presence of abrasive particles. Furthermore, no dimensional changes were observed following the immersion tests. A potential swelling of the test specimen due to the slurry had no effect on the wear rate nor did the surface hardness decrease significantly, see Fig.3.

Higher pad temperatures correlated with higher wear rates, but a proportional relationship between temperature and wear rate was not demonstrated for PI at T3 and T4. This can be attributed to the fact that the temperature of the pad is influenced by both frictional heat and chemical reaction heat.

Finally, the surface image taken with confocal laser microscope and the surface roughness of PPS and PI at T3 and T4 are shown in Fig.4. PPS showed lower wear rates but higher surface roughness due to the remaining polishing marks. Although PI exhibited significantly lower wear in T4 than in T3, the T4 surface was smoother than T3. The wear rate value indicates that the resistance to mechanical grinding was relatively low in PPS, while PI has a strong resistance to both chemical and mechanical grinding.

5. Conclusion

In this study, basic wear tests were performed with various slurries and pads used in CMP processes of compound semiconductors. The results revealed that PI exhibited higher wear resistance than PEEK under all test conditions and demonstrated superior wear resistance to PPS with colloidal silica-based slurries and non-woven fabric pads for Sapphire CMP processes and $KMnO_4$-based slurries and polyurethane pads for SiC CMP process. Further investigations and analysis on the wear mechanism involving more complex factors are required.

References

1) S. Chiba：Diamond Polishing Technique for Advanced Crystal Substrates Using Resin Pads (in Japanese), Tribology, 36, 11(2022) 43.