Fixed Abrasive Flat Lapping with 3M™ Trizact™ Diamond Tile Abrasive Pads

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Keywords: lapping, diamond, abrasive, silicon, optical substrates, fixed abrasive, structured abrasive, coolant

1. INTRODUCTION

Lapping is an important dimensioning and finishing technology that is used in many different industries including metal, electronic, and optical component fabrication, as well as silicon wafer production. In each of these applications lapping is used to produce flat substrates of a controlled thickness, flatness, and surface roughness. Lapping can be performed in either a single-sided or double-sided operation.[1] Conventional lapping technology can be divided into two basic categories: loose abrasive grinding (slurry lapping) or fixed abrasive lapping. In slurry lapping the abrasive is in the form of an aqueous slurry of abrasive minerals (typically alumina or silicon carbide) and the lapping surface is the machine platen (typically cast iron).[1] Conventional fixed abrasive lapping is also called "pellet lapping. In this process the abrasive (typically diamond) is incorporated into small pellets (metal, vitreous, or resin bond) which are attached to cast iron machine platens. The lapping surface during pellet lapping is formed by the top surfaces of all of the pellets. Here we report on a structured abrasive lapping technology developed by 3M. The structured abrasive pad consists of an organic (polymeric binder) – inorganic (abrasive mineral, i.e., diamond) composite and is used with coolant. Typical lapping coolants including deionized water are used as lubricants without the addition of any free abrasive mineral. Table 1 shows a comparison between conventional loose abrasive, pellet, and 3M fixed abrasive lapping technology.

Table 1: Lapping Technology Comparison

Lapping Operation	**Abrasive Type**	**Abrasive Material**	**Liquid**	**Lapping Platen / Pad**
Loose abrasive grinding	***Loose*** (slurry)	alumina, SiC, diamond	abrasive slurry with corrosion protection and suspension additives	Cast Iron Platen (possibly serrated with grooves)
Pellet Lapping	***Fixed*** (metal, vitreous, or resin bonded)	diamond	machining coolant with corrosion protection	Cast Iron plates with pellets bonded to surface
3M Trizact™ Diamond Tile Lapping	***Structured*** (resin/diamond composite pad)	diamond	DI Water or machining coolant with corrosion protection	Any flat or serrated plate with 3M Trizact™ Diamond Tile pad bonded to the surface

3M Trizact™ Diamond Tile abrasive pads can be used to lap a variety of brittle substrates including optical glasses (BK7, Borofloat™ optical glass, Pyrex™ optical glass), fused quartz/fused silica, soda-lime glass, memory-glass substrates (aluminosilicate glasses), silicon, AlTiC, lithium niobate, crystalline quartz, & sapphire. Both single-sided and double-sided lapping operations are possible with this technology.

2. EXPERIMENTAL METHODS AND MATERIALS

2.1. 3M Trizact ™ Diamond Tile pads

The 3M Trizact™ Diamond Tile pads are produced using 3M's microreplication technology which has been used to produced a wide variety of innovative products including Frensel lenses for overhead projectors, retroflective sheeting for road signage, brightness enhancement film for notebook computers, and 3M Trizact™ fixed abrasives. The 3M pad materials consist of vitreous diamond agglomerates contained in a cross-linked resin matrix. Diamond grades (micron sizes of diamond) 3, 6, and 9 micron are currently available. Development efforts continue to produce pads

Presented at Optifab 2003, Rochester, New York, May 2003.

using finer grades. The micron grade is chosen based on the hardness of the substrate to be lapped along with the desired removal rate and surface finish.

2.2 Pad mounting, machine set-up, and run conditions

3M™ Trizact™ Diamond Tile pads were mounted to the machine plates using a Pressure Sensitive Adhesive (PSA) that is provided on the backside of each pad. After the machine plates were thoroughly cleaned, the pads were mounted by removing the release liner from the backside adhesive and incrementally rolling the pad onto the plate. For most double-sided lapping machines, cleaning and mounting of 3M Trizact™ Diamond Tile pads can be accomplished in under 1 hour.

Pre-conditioning of 3M Trizact™ Diamond Tile pads is not necessary for most medium-to-medium hard glass and ceramic substrates. Substrates with a Mohs hardness of 5-8, including most optical glasses, fused quartz, glass ceramic, and polycrystalline alumina will satisfactorily self condition a new 3M Trizact™ Diamond Tile pad. Initial conditioning of new 3M Trizact™ Diamond Tile pads may be required for semiconductor and compound semiconductor substrates (Si, InGaAs, GaAs, InP) and thin substrates (crystalline quartz for piezoelectric applications). For results reported in this paper, conditioning of 3M Trizact™ Diamond Tile was accomplished by applying 3M Trizact™ 268XA alumina abrasive pads to solid part carriers and running under normal lapping conditions for 5-15 minutes. Periodic conditioning cycles to maintain stable material removal rates are not required for substrates softer than Mohs 8. Harder substrates such as sapphire and silicon carbide may require periodic conditioning to maintain stable material removal rates.

An aqueous lubricant/coolant is recommended for use with all 3M Trizact™ Diamond Tile products. However, for some substrates (Si for example) de-ionized (DI) water also works as a coolant. Several commercially available coolants were used in this study. Recycling/re-use of coolants was not performed for this study, but is commonly done in larger operations. Because there is very little abrasive in the used coolant, simple filtering and handling techniques can allow the coolant to be used for several weeks. Lapping tests were performed on a Peter Wolters AC 500 double-sided lapping machine. Specific running conditions will be noted with each data set.

2.3 Substrate metrology

Material removal rates were calculated by measuring the substrate weight loss after lapping. Surface finish was measured by contact profilometry using a Tencor P2 Long Scan Profilometer. Part flatness was measured using interferometry on a Corning-Tropel Flatmaster™ 200.

Table 2: Average Glass Removal Rate and Surface Roughness* during Double Sided Lapping (*SSD = Sub Surface Damage)*

3M Trizact™ Diamond Tile Pad Performance on Glass				
Average Material Removal and Finish				
Grade	**Borofloat™ Glass**	**Pyrex™ Glass**	**BK7 Glass**	**Window Glass**
3um	58 µm/min *Ra = 1575 Å* *Rt = 1.408 µm* *SSD = 3 µm*	55 µm/min *Ra = 1625 Å* *Rt = 1.545 µm* *SSD = 2.25 µm*	22 µm/min *Ra = 1629 Å* *Rt = 1.455 µm* *SSD = 2.5*	N/A
6um	105 µm/min *Ra =2352 Å* *Rt = 2.169 µm* *SSD = 3.75 µm*	115 µm/min *Ra = 2495 Å* *Rt = 2.316 µm* *SSD = 3.75 µm*	76 µm/min *Ra = 2531 Å* *Rt = 2.284 µm* *SSD = 3.75 µm*	43 µm/min ** *Ra = 2814 Å* *Rt = 2.503 µm* *SSD = 3.0 µm*
9um	181 µm/min *Ra = 3035 Å* *Rt = 2.580 µm* *SSD = 4.0 µm*	165 µm/min *Ra = 3152 Å* *Rt = 2.827 µm* *SSD = 4.0 µm*	105 µm/min *Ra = 38425 Å* *Rt = 3.429 µm* *SSD = 4.5 µm*	72 µm/min ** *Ra = 3499 Å* *Rt = 3.061 µm* *SSD = 5 µm*
2 psi, 96 rpm, 200 ml/min flow rate, 5% Sabrelube™ 9016 in water				
5 minute cycles, ten 65 mm diameter substrates				
* - Data is an average of four 1.1 mm scan with a 0.25 µm tip radius and 250 µm cut off				
** - 10% Sabrelube™ 9016 in water				

3. RESULTS AND DISCUSSION

Double-sided lapping tests were performed on the following glass substrates sold under trade-names: Borofloat™, BK7, Pyrex™, and window glass (soda-lime float glass) using 3, 6, & 9 micron 3M™ Trizact™ Diamond Tile pads. Table 2 shows the average removal rate and surface roughness for each abrasive / substrate combination. As expected the roughness increases with the diamond grade (size) of abrasive used. However, in all cases after the first 5 minutes, significant reduction in subsurface damage and improvement in finish were observed. This feature is an advantage of the 3M pad over currently available lapping techniques.

3M Trizact™ Diamond Tile pads can also be used to lap silicon wafers. Tests were carried out using 100 mm Silicon wafers (1,0,0 orientation) supplied by Lattice Materials Corporation. Lapping of silicon was carried out on an AC 500 Peter Wolters fine lapping machine at 85 rpm and applied force of 1.38 psi. Five silicon wafers were lapped per batch at a process time of 6 minutes. Deionized water (flow rate of 200 mL/min) and several commercially available lubricants, were used to measure the performance of the 3M Trizact™ Diamond Tile pads.

Figure 1 shows the cut-rates observed using a 3 μm 3M Trizact™ Diamond Tile pad in deionized water and other commercially available lubricants. The behavior of the silicon cut-rate data using DI water is consistent with those observed for other substrates. The initial cut-rate of a rough, as cut wafer is higher than those observed for subsequent cycles where the incoming wafers have become smooth from the previous cycle. Therefore, the observed data has variance that is dependent on the roughness of the substrate being lapped. An increase in cut-rate is consistently observed when a new, as cut wafer is introduced. Thus, there is no requirement to recondition the pad as the rough surface of an as cut wafer will serve to expose a fresh diamond surface. Further improvements in cut-rate were observed when using commercially available lubricants in very small quantities (1% by volume in DI water). Reduction of lubricant level is possible without compromising the cut-rate significantly. Significant differences in cut-rates were observed using various lubricants. In all lubricants, however, the cut-rates observed in the first 1 – 2 batches are always lower because of the time needed to wet and saturate the pad with the desired lubricant. The best cut-rate was observed when using Sabrelube™ 9016 coolant. In addition to the increased cut-rate observed when using lubricants instead of DI water, the cut-rate remains stable even when using smooth wafers as the incoming wafers. Thus, the 3M Trizact™ Diamond Tile pads are robust and can be used with different lubricants to yield an appropriate combination of cut-rate and finish. As shown in Table 3, correlating with the increased cut-rate, the wafers processed using Sabrelube™ 9016 as the coolant had a rougher finish than those observed using DI water. Furthermore, in all cases improvement in finish and flatness was observed within the first 6 minutes.

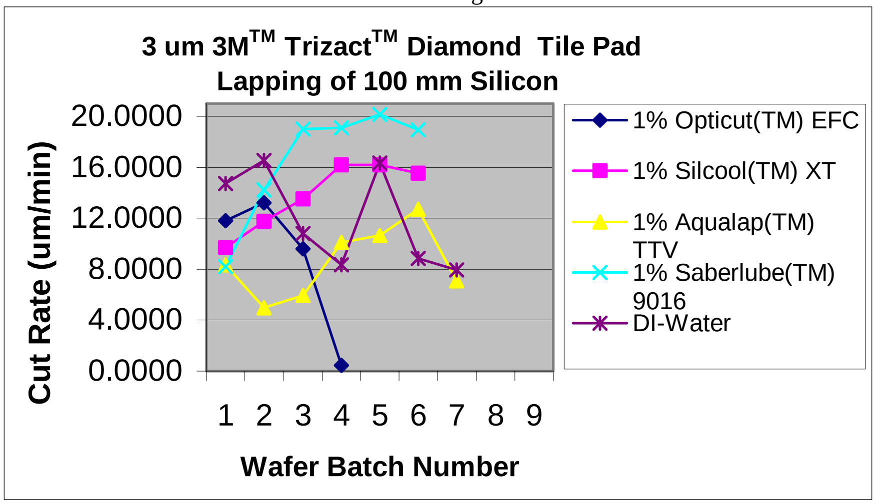
Table 3 also summarizes the results obtained when using 1.5, 3, 6 and 9 μm 3M Trizact™ Diamond Tile pads to lap silicon. From the table it is clear that the cut-rate and finish for the most part correlate with the diamond grade used. The 9 μm 3M Trizact™ Diamond Tile pad is most suited for wafer thinning applications. The flatness data reported in Table 3 are not remarkable due to the fact that the AC500 is a small machine to process 100 mm parts. It is important to note, however, that TIR values of 0.4 – 1.0 μm were observed using much larger lapping machines.

Table 3. Finish and Cut-rate Data Using a Range of Diamond Grades and 100 mm Silicon Wafer, at 1.38 PSI and 10% Sabrelube™ 9016 and DI water (available values for DI water are *Italicized)*. Incoming Ra = 6000.3 Å and TIR = 27.4 μm.

Diamond Grade (μm)	Cut-rate (μm/min)	Finish (Ra in Å)	TIR (μm)[a]
1.5	15 *7.7*	155.1 *116.3*	15.45
3	20 *12*	300.3 *230.4*	15.32
6	28 *15*	618.6 *450.2*	16.50
9	90[b]	2243.5	39.49

[a]In double-sided lapping, flatness is highly machine dependent and improved flatness values are possible using different machines.
[b]Pressure was set at 2.3 psi

Figure 1. Cut-rates Observed for 100 mm Silicon Wafer using Various Lubricants



4. CONCLUSIONS

A structured-abrasive technology, 3M™ Trizact™ Diamond Tile, has been reported. The structured abrasive technology is versatile and can be used on a wide variety of substrates that vary in hardness. The approach eliminates the need for the redressing or reconditioning step that is required for currently available fixed-abrasives. Because 3M Trizact™ Diamond Tile eliminates the use of loose abrasives in slurries, the process is cleaner. This elimination reduces the amount of consumable costs and can potentially decrease the environmental costs associated with using slurries. Further, 3M Trizact™ Diamond Tile can easily maintain flatness of substrates and produces better or competitive finish and flatness than lapping methods available to date.

5. References

1. H. H. Karow, “Fabrication Methods for Precision Optics”, pp 144 – 175, pp 412 – 413, pp 442 -463