Waste reduction in lapping sapphire and other compound semiconductor materials

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Abstract

This paper will discuss recent advancements in cycle time reduction and process simplification of rapid lapping of sapphire and other materials. When cycle time is reduced, so is the amount of waste generated during the process. Reduction in process waste and higher throughput are two of the major benefits of the developed process.

The technology discussed in this presentation can be applied to many different materials, among them SiC, GaN, AlN and other compound semiconductor materials.

Diamond lapping process produces fraction of waste of conventional abrasive process.

New diamond slurry has been developed. Performance, as compared to existing commercially available product, is over 25% higher removal rate and equal or better surface finish. Development procedure, test results, and selection of active components will be discussed.

INTRODUCTION

The challenge in the thinning process is quick removal of large amounts of stock material, usually 400 to 450 microns, while controlling surface roughness and minimizing subsurface damage. Lapping using diamond slurry on composite copper plate is best suited for this step. The lapping is performed on flat plate that is rotating at set speed; parts are positioned on mounting plate in groups of three to five and bonded with heat activated wax; mounting plate is driven by the power arm that also pneumatically applies set load.

Porosity of the composite copper lap plate, see Figure 1, allows the diamond particles to partially embed into the plate surface, thus creating semi-fixed abrasive platform. Plate preparation techniques will also be discussed.

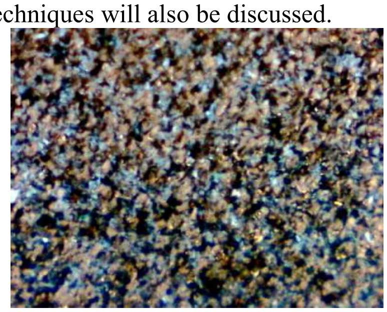

Figure 1 Porous surface of composite metal lapping plate at 200x

The liquid used in the diamond slurry is referred to as a "carrier" because it does, literally, carry the diamond powders contained within on to the tool (lap plate surface), thus allowing an abrading action to take place. Choice of carrier used in diamond slurry is strategically important - as much so as the choice of diamond powder type and size, it impacts material removal rates & surface finish. Diamond slurry carrier aids in abrasive orientation.

Defining characteristics of lapping slurry are:

- diamond type (shape and properties)
- diamond size, the median of particle distribution that is created during the grading process, see Figure 2
- vehicle type as related to:
  - solubility and cleaning
  - suspension characteristics as related to non-agglomerating qualities and the need to keep diamond particles uniformly distributed during the process
  - viscosity and ability to deliver slurry to work piece
  - cut rate as compared to other vehicles using same diamond size and type

This presentation discusses in detail the considerations for choosing and controlling each of the above qualities with comparison data to substantiate the selections.

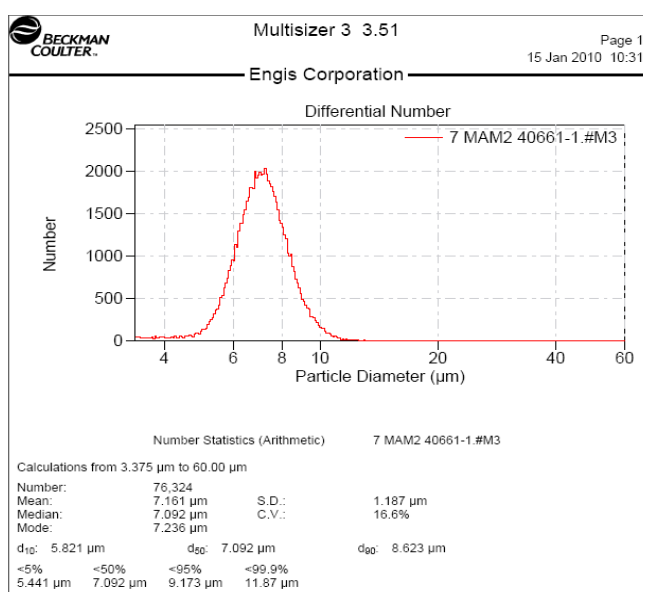

FIGURE 2 DIAMOND PARTICLE SIZE DISTRIBUTION

Plate Selection

Diamond slurries work exceptionally well with composite metal plates. The plate is made by mixing metal powder in resin matrix. Most commonly used metals for composite plates are tin (TX-10A plate), copper (HY Cu plate) and iron (X-08 plate).

Composite copper plate has been selected for process of rapid stock removal of sapphire and silicon carbide.

Plate Preparation

Plate texture aids in slurry distribution during lapping cycle. Two main techniques to apply texture to lap plate surface are conditioning and facing. Conditioning is performed by running diamond plated conditioning ring with lubricant to create "random groove pattern". Diamond-plated conditioning rings have the cutting diamond particles randomly bonded and oriented and at varying depths throughout the ring. The resulting texture is similar to cross-hatch pattern, as can be seen in Figure 3. As the ring wears, the texture will change over time. As the ring position changes, the plate curvature will change, too. This results in a variable plate texture and a process with large amount of operator attention and less consistency.

Figure 3 "Random groove" plate texture by 60/80 grit diamond plated conditioning ring at 50x magnification

Over the course of the last two decades, "facing devices" have become available for maintaining plate flatness and conditioning lap plates as an improvement over the use of diamond plated conditioning rings. Facing device uses a PCD tool bit to shave off top layer of plate's surface in well controlled manner and to calibrated flatness. This process is much easier to control and reproduce, as there is no guesswork involved in how far inboard or outboard to position the conditioning ring to correct the worn plate.

Figure 4 Plate texture by microgrooving (facing) at 50x

The facing system produces a spiral microgroove texture that serves as basis for structured embedding of diamond particles. The texture depends on tool bit radius, feed speed and rotation speed of the plate and can be adjusted to achieve best performance with sizes of diamond. Frequently, a second pass is performed, to create a 30µm to 200µm deep groove to aid in overall slurry distribution and removal of abraded material off the plate. Example of faced plate texture is shown in Figure 4.

Lapping plates with faced microgroove texture produce better cut rate on single crystal materials. Results for sapphire and silicon carbide wafers are shown in Figure 5, clearly demonstrating the superiority of faced texture.

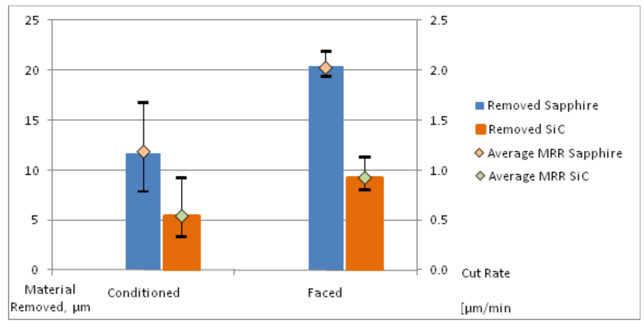

Figure 5 Effect of plate texture on removal rate of sapphire and silicon carbide

Diamond Types

Submicron and Nanometer size diamonds are characterized by the following properties: crystalline structure (using X-Ray Diffraction), crystallite size (based on line broadening effect in X-Ray Diffraction and TEM), surface roughness or porosity (using BET Surface Area) and particle shape (using TEM, SEM or AFM).

Mono-crystalline (MA) natural or High Pressure High Temperature (HPHT) synthetic diamonds, as shown in Figure , are single crystal particles with sharp corners and edges. These particles will maintain their size and shape much longer than other types of diamond during lapping operation. When mono-crystalline diamond is cleaved, smaller particles with few sharp corners are produced. MA diamonds tend to lose their sharpness very quickly during lapping of single crystal materials, e.g. silicon carbide, sapphire, aluminum nitride, and gallium nitride, and tend to remove material less enthusiastically, while creating more damage to the crystalline grid.

Polycrystalline (PC) diamond particles from the explosion process are composed of many nanometer sized crystallites chemically bonded together in random orientation. The bond between crystallites is not as strong as in single crystal particles, and therefore PC diamond has higher friability compared to MA diamond. When PC diamond breaks during lapping, new sharp edges are readily formed to remove more material. Polycrystalline diamonds have many more cutting edges than MA diamonds (see Figure 7), making them more suitable for lapping hard materials like sapphire, silicon carbide, and gallium nitride. Figure 8 clearly demonstrates the benefit of PC diamond for lapping sapphire.

FIGURE 6 MICROGRAPH OF MA DIAMOND

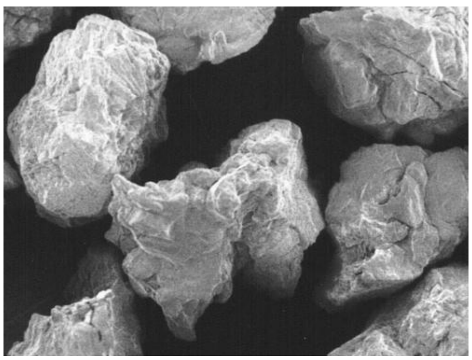

FIGURE 7 MICROGRAPH OF PC DIAMOND

Poly-like mono-crystalline diamond, or engineered diamond (EN), is created by thermally treating monocrystalline particles vacuum. As a result, more 3-D based crystalline defects are created throughout the grains. These defects make EN diamond particles more prone to stress-induced breakage during lapping thus creating many new sharp cutting edges that enhance the cut rate and produce finer surface finishes. However, the particle remains single crystal and maintains tendency to create more subsurface damage in lapping and polishing operations compared to a true PC type diamond.

Nano-clustered (ND) diamond is composed of nearly spherical nanometer size crystallites mechanically bonded together with many open pores or open structures; therefore having much lower than theoretical density of diamond. These particles have higher surface roughness when compared to polycrystalline diamond and significantly higher surface area, providing large number of cutting edges but weaker crystal strength. Grading in range 30nm to 300nm with no oversized particles is achievable.

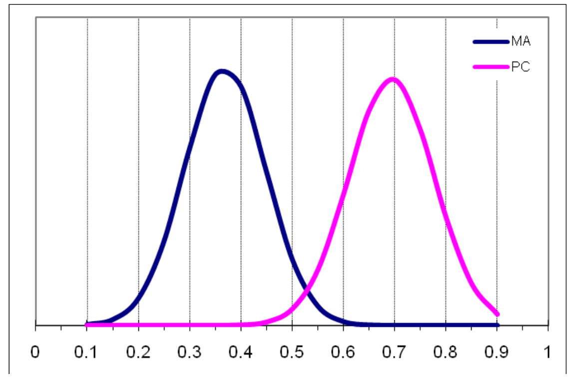

FIGURE 8 CUT RATE COMPARISON FOR LAPPING R-PLANE SAPPHIRE USING 3μm DIAMOND ON HY-CU PLATE, DIAMOND TYPE MA VS. PC.

DESCRIPTION OF EXPERIMENT

Slurry efficiency was tested using the protocol described in Table 1. Material removal rates in microns per minute were calculated based on wafer thickness measurements performed before and at certain time point during the lapping cycle. Wafer thickness was measured using drop gauge digital indicator with 1 μm accuracy. Surface finish was measured at the end of lapping cycle using white light interferometer.

TABLE 1
PLATE PREPARATION AND SLURRY TEST PROTOCOL

Test Conditions	Using **HY-Cu** composite copper plate solid configuration	
Facing	Tool bit	60deg 0.4R
	Surface Facing, RPM	180
	Facing x-speed, mm/min	30
	Pass Spacing, mm	0.167
	Groove depth, μm	100
	Groove Spacing, mm	1.1
Charging	Plate Speed, RPM	80
	Oscillation speed, RPM	0
	Head Speed, RPM	60
	Weight, kg	0 (ring)
	Charging time, min	20
Lapping	Plate Speed, RPM	80
	Oscillation	None
	Head Speed, RPM	60
	Weight, kg	19
	Unit load, gm/cm²	230

Results and Discussion

Cut rate results for rapid lapping of c-plane sapphire and silicon carbide (4H polytype, 4 degrees off axis) are shown in Figure 9. Novel slurry 1 is a lower cost alternative to novel slurry 2 and was not tested on silicon carbide. Newly developed slurry achieves cut rates that are 25 to 50 percent better than currently available commercial product. Resulting surface finish is comparable, as shown in Figure 10.

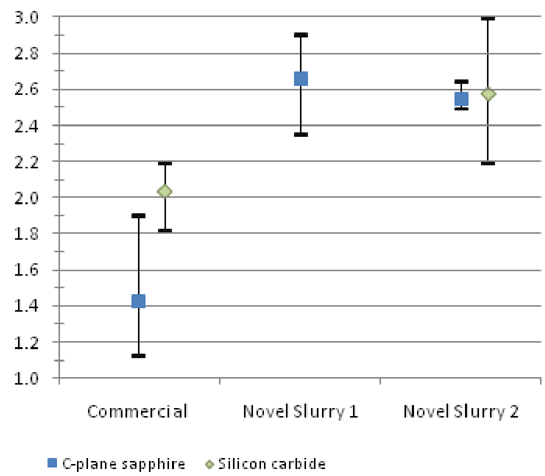

Figure 9 Cut rate results for rapid lapping of sapphire and silicon carbide.

One of the very important characteristics of the newly developed slurry is "permanent suspension". The diamond particles remain uniformly distributed in the oil-based slurry carrier, eliminating the need for stirring during use. There is also no need to shake the slurry before use as the diamond will not settle out during storage.

Commonly, higher cut rate leads to higher resulting surface roughness. A chemical additive has been identified to cut rate and at the same time reduce surface roughness.

One of the main objectives of this project has been reduction in processing waste that normally includes harsh chemicals for wafer cleaning post-lapping. Specialty cleaning agent has been added to both Novel slurry 1 and Novel slurry 2 so that post-lapping cleaning can be done with just water alone, using gentle scrubbing technique. The addition of the cleaning agent does not affect the performance of the slurry and does not cause the diamond to drop out of suspension.

The novel slurries have been compared to currently commercially available products from two different companies.

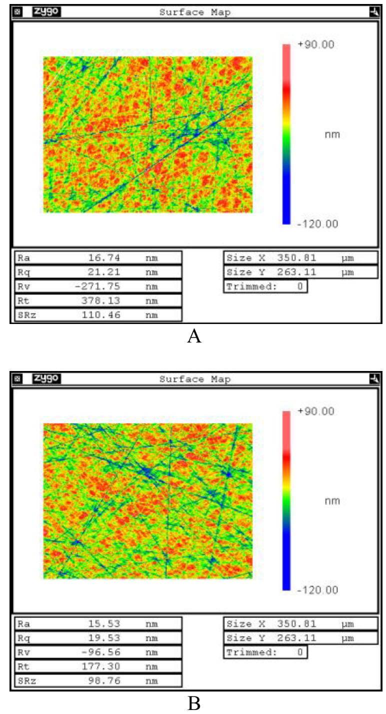

Figure 10 Surface finish after lapping C-plane sapphire: A) existing commercial product, B) novel slurry developed by Engis

Conclusions

The novel slurry presented here is superior in cut rate reducing process duration and waste, is easy to clean with water, is permanent suspension and does not need to be continuously stirred during use.

References

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Acronyms

MA: Monocrystalline diamond type
PC: Polycrystalline diamond type
EN: Engineered diamond
ND: Nano-clustered diamond
PSD: Particle Size Distribution
MRR: Material removal rate