Characterization and Qualification
of a Precision Diamond Saw

Federal Manufacturing & Technologies
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H. A. Morgenstern

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Abstract

A precision diamond saw was characterized and qualified for production using the MCCC Encryption Translator (MET) network. This characterization was performed in three steps. First the equipment was evaluated and characterized, and then a process was developed and characterized to saw cofire networks. Finally, the characterized process was qualified for production using the MET network.

Summary

During the development of the low-temperature cofired ceramic (LTCC) processes needed to build the MCCS Encryption Translator (MET) network, a problem was uncovered. The laser process planned for scribing and separating was found to weaken the LTCC material by about 30%. A replacement process was needed, and precision diamond sawing was chosen. Initial process development was done on a Micro Automation 1006 wafer saw, but it became quickly apparent that a new saw was needed. A K&S 986-4 saw was ordered and upon its delivery, characterization and qualification began.

The characterization was performed in three steps. First the equipment was evaluated and characterized, and then a process was developed and characterized to saw cofired networks. Finally, the characterized process was qualified for production using the MET network.

During the equipment evaluation and characterization, several parameters were investigated. These were cut depth, feed rate, spindle speed, and saw blade thickness. Once these were understood the process was then developed. Initially 24 variables were identified for the process, and eventually 12 of these variables were found to be critical. These variables were then adjusted until a process envelope was found that produced acceptable product. Finally parameters were chosen from the middle of the process envelope for production. With the production process set, the next step was to qualify it for production. Two criteria had to be met: visual acceptability and bending strength. The parts were examined under a microscope and found to be visually acceptable. Parts were then put through a four-point bend test, and the strengths recorded were equivalent to those measured in the past. With the completion of this work and the acceptable results, this process was qualified for production use.

Discussion

Scope and Purpose

Microelectronic applications needing high strength low-temperature cofired ceramic (LTCC) networks require that the substrates be sawed to size. This was shown when it was found that the strength of an LTCC substrate can be reduced by about 30% when scribed and separated using a yttrium aluminum garnet (YAG) laser. This data is shown in Table 1.¹ Since sawing is a process that had not been used at AlliedSignal Federal Manufacturing & Technologies (FM&T) for some time, equipment had to be located and a process developed to saw cofired networks. The initial product requiring this process was the MET. Its thick film version and the final LTCC version are shown in Figure 1. An example of what a populated MET network looks like is shown in Figure 2.

Table 1. Results of Modified Four-Point Test

		Surface in	Average	Standard Deviation in MPa (ksi)
Material	Separation Process	Tension	Strength in MPa (ksi)	
LTCC	Saw	All	223 (32.3)	34 (5.0)
LTCC	Laser	Entry	129 (18.7)	15 (2.2)
LTCC	Laser	Exit	232 (33.7)	33 (4.8)
Alumina	Saw	All	418 (60.6)	34 (5.0)
Alumina	Laser	Entry	367 (53.3)	40 (5.8)
Alumina	Laser	Exit	402 (58.3)	30 (4.4)

Prior Work

Previous work on this multichip module (MCM) technology has been performed as part of process development projects looking at high speed digital and high density digital applications, known good die, and MCM substrate testing. Other work in this technology has also been done as part of a Total Quality (TQ) Team, a Total Quality Leadership (TQL) II Team, and an Operational Excellence Team. The overall goal of this work is shown in Figure 3 which illustrates an MCM based on an LTCC network.

Figure 1. MET Thick Film (Top Row) and LTCC (Bottom Row) Networks

Figure 2. Populated MET LTCC Network

Figure 3. LTCC Multichip Module Illustration

It was decided during the initial LTCC technology development that all thin cofired networks would be scribed and separated to size with a YAG laser. Unfortunately, it was discovered that this process reduces the strength of a cofired network by 30%, as shown in Table 1. An alternative process needed to be developed. Precision sawing using a diamond impregnated blade was investigated and found to be able to produce acceptable product with adequate strength. This strength data is also shown in Table 1.

Initial process development was done on a Micro Automation Model 1006 precision diamond wafer saw. This work showed the potential of the process, provided samples for mechanical testing, and helped identify the major process parameters and problems. Unfortunately, several machine and process issues were encountered that made it quickly apparent that a new and more modern precision diamond saw would have to be purchased.

Activity

Overview

The initial process development was done on the Micro Automation 1006 wafer saw. Based on the product produced and the challenges presented by this equipment, it was decided to purchase a new saw and bring it into production. The saw acquired was a Kulicke and Soffa Model 984-6 precision diamond saw. Upon receiving this equipment it was placed, installed, and approved for use by the Environment, Safety & Health (ES&H) department. After this approval,

characterization began and was performed in three steps. First the equipment was evaluated and characterized, and then a process was developed and characterized to saw cofired networks. Finally, the characterized process was qualified for use on the MET.

As the work on the characterization progressed, it became quickly apparent that an end point needed to be agreed upon to properly define an acceptable process and product. It was decided that the parts produced must meet the visual criteria as described in the LTCC network acceptance specification and have an appropriate bend strength. This was acceptable to Sandia National Laboratories/New Mexico. It should be noted that during this whole process, Sandia National Laboratories/New Mexico was involved and kept informed of progress and problems.

While this characterization activity was in progress a literature search was performed. The more interesting articles are listed in the Reference section.²⁻⁷ Additionally, product literature from several companies contained very useful information.^{8,9}

Equipment Evaluation and Characterization

The first part of the characterization was to understand the equipment. This was done by evaluating and verifying the operation of the equipment and the process tooling. Several parameters were isolated as having particular interest. These were spindle speed, feed rate, cut depth, and saw blade thickness. These parameters were examined and will be discussed individually.

Cut Depth

Cut depth is the distance the saw blade cuts into the LTCC network being sawed. It is important to know how accurate and repeatable this depth is for process consistency. To examine this function, two sets of tests were performed. First, ten cuts 5 mils deep were made and measured on a laser profilometer. Then, five cuts that were 5, 25, and 40 mils deep were made and measured on a video measurement system.³ The two different measurement techniques were used because the laser profilometer was good for the shallow cuts but not very good for the deeper cuts.

The data from this work are shown in Table 2. The top part of the table shows that the ten cuts that were 5 mils deep and, measured on the laser profilometer, had a total range of 0.5 mil from the target depth. The bottom part of the table shows that the five cuts that were made at 5, 25, and 40 mils deep and measured on the video measurement system had a total range of ± 0.5 mil from the target depth. An uncertainty of 1 mil for the cut depth is acceptable for this process.

Feed Rate

The feed rate is the speed at which the substrate moves under the saw when being cut. It is important to know that this is accurate and repeatable for process consistency. To measure this function, a cut length of 6 inches and a feed rate of 0.100 inch per second were programmed into the saw, and then the time it took to traverse those 6 inches was measured. This feed rate was

chosen as it was expected to be close to the feed rate needed for cofire. The elapsed time was measured using two different timers. One is a timer that is part of the equipment software; however, it starts as the blade is moved down to the proper height for cutting and stops when the cut is completed, and the blade height returns to the home position. This results in an additional 2 to 4 seconds added to the cut time. To offset this, another timer was used that is also part of the saw, but it could be started and stopped by the operator from the control panel of the saw.

In addition to measuring the feed rate, secondary variables to this function were examined to determine if there were any concerns. The feed rate of 0.100 inch per second was programmed in for block 1 and block 2. For a rectangular part, block 1 represents the cuts made in the X-axis and block 2 represents the cuts made in the Y-axis. Two different mounting media were used. These were tape and wax. To examine all these variables, 20 runs were made, including 10 runs on tape and 10 on wax. For each of these 10 runs, five of the runs were made using block 1 and five were made using block 2.

The data from this work are listed in Table 3. It shows that the feed rate is consistent and repeatable.

Table 2. Depth of Cut Verification

Laser Profilometer

Cut Number	Material	Material Thickness	Mounting Media	Mounting Media Thickness	Total Thickness	Set Depth of Cut	Measured Depth of Cut
1	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.22 mils
2	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.07 mils
3	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.08 mils
4	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.21 mils
5	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.30 mils
6	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.41 mils
7	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.47 mils
8	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.35 mils
9	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.48 mils
10	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	5.43 mils

Video Measuring System

Cut Number at Depth	Material	Material Thickness	Mounting Media	Mounting Media Thickness	Total Thickness	Set Depth of Cut	Measured Depth of Cut
1	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	4.4 mils
2	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	4.6 mils
3	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	4.4 mils
4	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	4.4 mils
5	LTCC	47 mils	Tape	4 mils	51 mils	5 mils	4.5 mils
1	LTCC	47 mils	Tape	4 mils	51 mils	25 mils	24.3 mils
2	LTCC	47 mils	Tape	4 mils	51 mils	25 mils	24.6 mils
3	LTCC	47 mils	Tape	4 mils	51 mils	25 mils	24.5 mils
4	LTCC	47 mils	Tape	4 mils	51 mils	25 mils	24.5 mils
5	LTCC	47 mils	Tape	4 mils	51 mils	25 mils	24.6 mils
1	LTCC	47 mils	Tape	4 mils	51 mils	40 mils	39.9 mils
2	LTCC	47 mils	Tape	4 mils	51 mils	40 mils	39.9 mils
3	LTCC	47 mils	Tape	4 mils	51 mils	40 mils	40.5 mils
4	LTCC	47 mils	Tape	4 mils	51 mils	40 mils	40.2 mils
5	LTCC	47 mils	Tape	4 mils	51 mils	40 mils	40.1 mils

Table 3. Feed Rate Verification

Block Number	Entry Speed	Programmed Cutting Speed (ips)	Substrate Material	Mounting Media	Length of Cut (inches)	Target Time (min./sec..)	Saw Timer (min./sec..)	APC Program Timer (min./sec)
1	0.1000	0.1000	LTCC	Tape	6.0000	1:00	0:59	1:03
1	0.1000	0.1000	LTCC	Tape	6.0000	1:00	0:59	1:02
1	0.1000	0.1000	LTCC	Tape	6.0000	1:00	1:00	1:03
1	0.1000	0.1000	LTCC	Tape	6.0000	1:00	1:00	1:03
1	0.1000	0.1000	LTCC	Tape	6.0000	1:00	0:58	1:02
2	0.1000	0.1000	LTCC	Tape	6.0000	1:00	1:00	1:03
2	0.1000	0.1000	LTCC	Tape	6.0000	1:00	1:00	1:02
2	0.1000	0.1000	LTCC	Tape	6.0000	1:00	1:00	1:03
2	0.1000	0.1000	LTCC	Tape	6.0000	1:00	0:59	1:02
2	0.1000	0.1000	LTCC	Tape	6.0000	1:00	0:59	1:03
1	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:04
1	0.1000	0.1000	LTCC	Wax	6.0000	1:00	0:59	1:02
1	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:02
1	0.1000	0.1000	LTCC	Wax	6.0000	1:00	0:59	1:03
1	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:01
2	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:01
2	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:04
2	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:01	1:04
2	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:03
2	0.1000	0.1000	LTCC	Wax	6.0000	1:00	1:00	1:02

Spindle Speed

The spindle speed is the rate at which the spindle that holds the saw blade spins. It was initially thought that it was important to know the offset between the set point and true spindle speed for process accuracy. To determine this, a spin tach was used. It is an rpm meter that is physically connected to the spindle with a rubber coupling.

The results of this work are shown in Figure 4. As can be seen in the graph, there is an offset between the set point and the true speed. The field representative for the vendor noted that he had never seen this technique used before and that the factory sets the spindle speed based on the resistance of an electronic circuit. The results were reproducible which meant that the spindle speed was consistent. It was decided that a consistent speed was the most critical feature of this parameter.

Figure 4. Spindle Speed Set Point vs. Measured RPM

Saw Blade Thickness

The blades used for this process are made of a resin that is impregnated with friable diamonds. The blades are placed in a metal hub that clamps the blade and exposes a specific length of blade. This metal hub is then attached to the spindle of the saw. Blades are specified for purchase by primarily defining the size of the diamonds in the blade, the size of the blade, and the thickness of the blade. It was initially thought that there might some variation in the thickness of the blades; therefore, three different types were measured.

The results of this work are shown in Table 4. No unacceptable variation in thickness was found.

Table 4. Confirmation of Blade Thickness

Resinold Blade Thickness	Actual Measured Thickness
4.600 x 0.020	
325 (45 MIC) 20 mils (777-6045-020)	19.9 - 20 mils
4.600 x 0.010	
325 (45 MIC) 10 mils (777-6045-010)	10 - 10.1 mils
4.600 x 0.010	
270 (53 MIC) 10 mils (777-6053-010)	9.9 - 10 mils

*Measurements were made with a 1-inch hand-held micrometer.

Process Development and Characterization

With the equipment evaluated, characterized, and understood it was now time to work on the process. Initially 24 variables were identified for the sawing process. These are listed as the first column on the four tables in Appendix A, Diamond Saw Parameters and Variables. The variables were divided into six groups which are programmable variables, cooling water variables, chuck variables, alignment variables, blade variables, and mounting variables.

The first table in Appendix A, Diamond Saw Parameters and Variables, shows what factors were chosen to be varied, held constant, investigated, and become part of the error for this evaluation. Those factors that are listed as "Investigate" mean their effect was not clear at the outset of this work, and they required investigation. At the end of the evaluation both of these investigated factors, cut depth and cooling water flow rate, were found to be important and became part of the study. Those factors listed as "Part of Error" were not easily controlled and therefore were considered to be part of the error function of this work. If after controlling all the other variables the product produced was not optimal, these factors would have been re-evaluated. The three factors that are in this category are cooling water temperature and pressure and chuck vibration.

With the 24 variables listed and categorized, the next step was to choose the range over which they would be varied. The second table in Appendix A, Diamond Saw Variables and Limits, shows this with the columns marked "Bold Limits" and "Expected Process Limits." The bold limits column shows the kinds of end points that should be possible without danger to the equipment or the operator. The expected process limits column shows the region within the bold limits that was expected to produce an acceptable process. In doing this evaluation several factors were thrown out of this evaluation because they would not affect the quality of the edge

of the part. These factors were all those that were listed as alignment variables and would just affect the final size of the part. These were dealt with at the end of the evaluation when the part size was critical.

The next step was to review the list of factors and the range at which they were going to be examined, and make sure that their accuracy or repeatability had been addressed. This information is listed in the third table of Appendix A, Diamond Saw Variables, Accuracy and Repeatability.

With all this information established it was time to begin running evaluations on parts. This work is shown in Appendix B, Saw Characterization Data. The 98 runs listed here represent the majority of the runs that were performed to develop this process. Across the top of this table are listed the 12 variables that were eventually determined to be critical to this process. In this list are the five factors that were initially thought to be important: feed rate, spindle speed, blade thickness, blade exposure, and diamond grit size. It includes the three factors that were listed as needing to be investigated or tracked: cut depth, cooling water flow rate, and blade wear. That leaves four factors that were not originally anticipated but during the evaluation found to be important. These are material being cut, spacer thickness, backing material, and dressing procedure. Since these were not anticipated, they will be discussed.

The backing material used for most of this work were glass plates that were approximately 0.200 inch thick and approximately 6 inches in diameter. The two faces were flat and parallel. At one point alumina plates were tried and found not to work. This was a surprise, and that is why it was added as a critical variable.

Spacer thickness refers to a small piece of Kapton that was placed between the cofired network to be sawed and the glass backing plate during the mounting process. Its intent was to set the thickness of the wax used to glue the cofired network to the glass plate. It was a surprise to find that using the spacer was better than no spacer and that is why it is a critical variable.

Dressing procedure refers to a series of cuts made in different materials that preconditions the saw blade and makes a significant impact on the cut quality and consistency. It was hoped that this would not be needed, but it really helps the process. A lot of time was spent developing this procedure and process. If one were to rank the importance of the different variables, the dressing procedure comes immediately after the top five factors initially known to be important. Another aspect of the dressing procedure noted in Appendix A is the mention of blade loading. The first parts to be cut on the saw had metal lines on them to help align the networks. It was found when the metal was being sawed through that the cut quality degraded and that a clearing cut made in the cofired material without metallization was required to bring back the cut quality. It is thought that the metal is loading or gumming up the blade, and the clearing cut removes that metal from the blade.

The last surprise was the material being cut. It is not completely understood yet, but there is a significant difference in cut quality depending on the cofired material being sawed. This was discovered when the process developed on just cofired material did not work on a fully processed MET network. This occurred several times with several different cofired materials. The materials used were cofired and processed through 10 thick film furnace runs; cofired and processed through 20 thick film furnace runs; excess material from a production MET network

that had already been sawed; and finally the best match to the production process was excess material from a production MET network that had metallization on its edge. Again, it is not clear why all these materials sawed differently, but they did.

With the process developed, the next step was to characterize it. Process characterization involves the selection of the best process point and the determination of how much process parameter variation this point can withstand. This work is summarized in the fourth table in Appendix A, Diamond Saw Variable Ranges. This table shows in the first column all the factors that affect the process. The next column shows the range explored for each of these factors. The third column shows the process envelope for the MET, and the last column shows the processing point chosen for the MET networks. The table shows that the process envelope is acceptable, and the processing point is about centered in that envelope.

Process Qualification for the MET

With the process envelope found and a process point chosen, the next step was to qualify this process for the MET. This was done by meeting the two requirements agreed to by the AlliedSignal FM&T and Sandia National Laboratories/New Mexico and by meeting the requirements specified by the MET network drawings. The requirements were to meet visual criteria defined in the LTCC network acceptance specification and to demonstrate an adequate bend strength. The MET network drawing requirements that were of concern were the size and outline of the network.

To meet the MET network drawing requirements, a set of variables that had been set aside needed to be addressed. These were the alignment variables which are fiducial placement and clarity, reticle line to kerf alignment, and camera focus. Camera focus with the Kulicke & Soffa saw is easily adjusted and was quickly taken care of. In working with the fiducials it became clear that using the alignment lines that were already on the network was not going to work. The magnification of the optics was high enough that the seemingly crisp thick film lines were not crisp enough. This led to the use of the three alignment boxes on the corner of the board that are present on all cofire and alumina thick film hybrids at FM&T. Using these boxes required that the saw be programmed with an offset so that the edge of the blade would be in the center of these boxes and cut along the true edge of the board. This took some time, but was eventually completed and the networks were cut to the size and outline requirements.

To demonstrate that MET networks produced by this process would meet the visual requirements of the LTCC network acceptance specification, three scrap MET networks were sawed and submitted to inspection. Using the LTCC network acceptance specification and the standard procedures, the networks passed inspection.

To demonstrate that MET networks produced by this process would have an acceptable bend strength, several plates of cofired material were sawed into bars appropriate for a four-point bend test. The results of this bend test are listed in Table 5 along with historical data strength data. Acceptable results were achieved.

Table 5. Bend Strength Data

	Average (ksi)	Std. Dev.
Old Saw, Initial Process	32.3	5.0
Du Pont Saw Process	27.3	5.2
Old Saw, Optimized Process	33.8	4.7
New Saw, As Cofired Material	36.4	4.4
New Saw, As Cofired		
+ 10 TKN firings	30.6	4.6
New Saw, As Cofired		
+ 10 TKN + Resistor Firing	34.6	4.2

Accomplishments

The project objective was achieved. A new precision diamond saw was evaluated, characterized, and qualified for production.

During the equipment evaluation and characterization,

- Cut depth was found to have an uncertainty of 1 mil, which is acceptable for this process;
- Feed rate was found to be consistent and repeatable;
- Spindle speed was found to be slightly offset from the set point but consistent and reproducible; and
- Saw blade thickness had no unacceptable variations.

During the process development and characterization,

- Twenty-four variables were identified;
- Twelve of these variables were found to be critical to the process; and
- A process was developed, an envelope was defined, and a process point was chosen.

Finally, the process developed was qualified for production. Product acceptable to the inspection criteria was produced, and acceptable bend strength was achieved.

Future Work

The sawing process needs further work. There are still some inconsistencies that indicate that the process is not yet fully understood. The following are areas that should be investigated further:

- Refine and improve the blade dressing process; perhaps the use of aluminum nitride (AlN) instead of alumina will reduce the amount of edge scoring.
- Replace the water-soluble wax with either an alcohol-soluble wax or tape; the expected benefit would be less erosion during processing and more consistent glue thickness.
- Replace the grooved chuck with a porous chuck for a better and more even vacuum.
- Remove the metal alignment lines from the cofired network.

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Appendix A

Diamond Saw Parameters and Variables

Diamond Saw Parameters and Variables				
Factors	Vary	Hold Constant	Investigate	Part of Error
Programmable Variables				
Feed Rate	X			
Spindle Speed	X			
Cut Depth			X	
Single Cut/Multiple Cuts		Single Cut		
Cooling Water Variables				
Flow Rate			X	
Temperature				X
Angle to Blade		X		
Pressure				X
Chuck Variables				
Flatness		X		
Vibration				X
Chuck Zero	Perform after each experimental set			
Alignment Variables				

Fiducial Placements and Clarity		X	Effect part size not cut
Reticle Line to Kerf Alignment		X	quality
Camera Focus		X	
Blade Variables			
Quality/Fit		X	
Blade Manufacturer		X	
(would like to vary)			
Thickness	X		
Exposure	X		
Grit Size	X		
Diamond Concentration		X	
(would like to vary)			
Wear/Number of Parts per Blade	Track		
Mounting Variables			
Wax and durability		X	
(Vary wax if can)			
Thickness Uniformity of Backing Material		X	
Stability (flexibility) of Backing Material		X	

Diamond Saw Variables and Limits

Factors

Bold Limits

Expected Process Limits

Programmable Variables

Feed Rate	.010 inches/sec to .500 inches/sec	.075 inches/sec to .125 inches/sec
Spindle Speed	3,000 to 20,000	8,000 to 15,000
Cut Depth	just into wax to 10 mils into glass	3 to 5 mils into glass
Single Cut/ Multiple Cuts	Single Cut	Single Cut

Cooling Water Variables

Flow Rate	10 - 40 gph	15 - 40 gph
Temperature	Error Function	Error Function
Angle to Blade	Constant	Constant
Pressure	Error Function	Error Function

Chuck Variables

Flatness	Constant	Constant
Vibration	Error Function	Error Function
Chuck Zero	Perform after each experimental set	

Alignment Variables

Fiducial Placements and Clarity	Doesn't effect cut quality	Doesn't effect cut quality
Reticle Line to Kerf Alignment	Doesn't effect cut quality	Doesn't effect cut quality
Camera Focus	Doesn't effect cut quality	Doesn't effect cut quality

Blade Variables

Quality/Fit	Constant	Constant
Blade Manufacturer	Constant	Constant

(would like to vary)

Thickness	10 & 20 mils	20 Mils
Exposure	100 & 125 mils	125 mils
Diamond Size	45 & 53 micron	45 micron
Diamond Concentration	Constant	Constant

(would like to vary)

Wear/Number of Parts per Blade	Track	Track
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Mounting Variables

Wax and durability	Constant	Constant
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(Vary wax if can)

Thickness Uniformity of Backing Material	Constant	Constant
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Stability (flexibility) of Backing Material	Constant	Constant
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Diamond Saw Variables, Accuracy and Repeatability

Factors	Checked for Accuracy	Check for Repeatability
Programmable Variables		
Feed Rate	X	X
Spindle Speed	X	X
Cut Depth	X	X
Blade Variables		
Thickness	X	X
Exposure	X	X
Wear/Number of Parts per Blade	Track	Track

Mounting Variables

Thickness Uniformity of Backing Material	X		X
--	---	--	---

Diamond Saw Variable Ranges

Factors	Range Explored	MET Process Envelope	ME
Programmable Variables			
Feed Rate	25 mils/sec to 300 mils/sec	25 mils/sec to 125 mils/sec	
Spindle Speed	10,500 to 15,000	10,500 to 11,500	
Cut Depth	just into wax to 10 mils into glass	3 to 5 mils into glass	4
Single Cut/ Multiple Cuts	Single Cut	Single Cut	
Cooling Water Variables			
Flow Rate	15 to 40 gph	20 to 40 gph	35
Temperature	variable	variable	
Angle to Blade	Constant	Constant	
Pressure	variable	variable	
Chuck Variables			
Flatness	Constant	Constant	
Vibration	Direct contact, Tape between chuck and glass plate	Either	Tape be
Chuck Zero	None to 4 cuts	4 to 18 cuts	After
Alignment Variables			
Fiducial Placements and	Doesn't effect cut quality	Doesn't effect cut quality	Does

Clarity

Reticle Line to Kerf Alignment

Doesn't effect cut quality

Doesn't effect cut quality

Does

Camera Focus

Doesn't effect cut quality

Doesn't effect cut quality

Does

Diamond Saw Variable Ranges (con't)

Factors	Range Explored	MET Process Envelope	ME
Blade Variables			
Quality/Fit	Constant	Constant	
Blade Manufacturer	Constant	Constant	
(would like to vary)			
Thickness	10 & 20 mils	20 Mils	
Exposure	100 & 125 mils	125 mils	
Diamond Size	45 & 53 micron	45 micron	
Diamond Concentration	Constant	Constant	
(would like to vary)			
Wear/Number of Parts per Blade	0 to 15 mils	2 to 15 mils (with dressing)	change t
Blade Dressing			
Dressing Side of Blade	60 mils	60 mils	
(Depth & Number of cuts)	10 to 20 cuts	10 to 20 cuts	
Dressing Tip of Blade and	10 to 30 mils	10 to 30 mils	
truing blade to spindle	10 to 20 cuts	10 to 20 cuts	
(Depth & Number of cuts)			
Shaping Tip of Blade	2 to 5 mils	2 to 5 mils	

(Depth & Number of cuts)	5 to 10 cuts	5 to 10 cuts	
Dressing Material	Alumina, Glass, Silicon Carbide	Alumina, Silicon Carbide	Alum
Blade Loading	Never to clear blade after 2 cuts	Clear after every 2 cuts	Clear b

Diamond Saw Variable Ranges (con't)

Factors	Range Explored	MET Process Envelope	ME
Mounting Variables			
Wax and durability (Vary wax if can)	Crystallbond 555	Used Crystallbond 555	C
Thickness Uniformity of Backing Material	Constant	Constant	
Spacing Between substrate and Backing Material	0 to 2 mils	2 mils	
Stability (flexibility) of Backing Material	Constant	Constant	

Appendix B

Saw Characterization Data

Saw Characterization Data							
Run Number	Material	Speed (RPM)	Feed Rate (Inches per Sec)	Blade Exposure (inches)	Diamond Grit Size (Microns)	Blade Width (Mils)	Cooling Water (GPH)
1	Cofired	11,000	0.125	0.100	45	10	20
2	Cofired	11,000	0.100	0.100	45	10	20
3	Cofired	11,000	0.150	0.100	45	10	20
4	Cofired	11,000	0.075	0.100	45	10	20
5	Cofired	11,500	0.100	0.100	45	10	20
6	Cofired	11,000	0.100	0.100	45	10	20
7	Cofired	10,000	0.100	0.100	45	10	20
8	Cofired	10,500	0.100	0.100	45	10	20
9	Cofired	12,000	0.100	0.100	45	10	20
10	Cofired	11,000	0.100	0.125	45	10	20
11	Cofired	12,000	0.150	0.125	45	10	20
12	Cofired	15,000	0.150	0.125	45	10	20
13	Cofired	15,000	0.300	0.125	45	10	20
14	Cofired / 10 TKN	11,500	0.100	0.100	45	20	20
15	Cofired / 10 TKN	11,000	0.100	0.100	53	20	20
16	Cofired / 10 TKN	11,000	0.100	0.100	53	10	20
17	Cofired / 10 TKN	11,000	0.100	0.100	45	10	20
18	Cofired / 10 TKN	10,000	0.100	0.100	45	10	20
19	Cofired / 10 TKN	10,000	0.075	0.100	45	10	20
20	Cofired / 10 TKN	10,500	0.075	0.100	45	10	20
21	Cofired / 10 TKN	10,500	0.100	0.100	45	10	20
22	Cofired / 20 TKN	11,000	0.100	0.100	45	20	20

23	Cofired / 20 TKN	12,000	0.100	0.100	45	20	20
24	Cofired / 20 TKN	11,000	0.100	0.125	45	20	20
25	Cofired / 20 TKN	12,000	0.100	0.125	45	20	20
26	Cofired / 10 TKN	11,000	0.100	0.100	45	20	15
27	Cofired / 10 TKN	11,000	0.100	0.100	45	20	20
28	Cofired / 10 TKN	11,000	0.100	0.100	45	20	40
29	Cofired / 10 TKN	11,000	0.100	0.100	45	20	35
30	Cofired / 10 TKN	11,000	0.100	0.100	45	20	30
31	Cofired / 10 TKN	11,000	0.100	0.100	45	20	25
32	MET Excess	11,000	0.100	0.100	45	20	20
33	MET Excess	11,000	0.100	0.100	45	20	35
34	MET Excess	11,000	0.100	0.100	45	20	35
35	MET Excess	11,000	0.100	0.100	45	20	35
36	MET Excess	11,000	0.100	0.100	45	20	20
37	MET Excess	11,000	0.100	0.100	45	20	20
38	MET Excess	11,000	0.100	0.100	45	20	20
39	MET Excess	11,000	0.100	0.100	45	20	20
40	MET Excess	11,000	0.100	0.100	45	20	20
41	MET Excess	11,000	0.100	0.100	45	20	20
42	MET Excess	11,000	0.100	0.100	45	20	20
43	MET Excess	11,000	0.100	0.125	45	20	20
44	MET Excess	11,000	0.100	0.125	45	20	20
45	MET Excess	11,000	0.100	0.100	45	20	20
46	MET Excess	11,000	0.100	0.100	45	20	20
47	MET Excess	11,000	0.100	0.100	45	20	20
48	MET Excess	11,000	0.100	0.100	45	20	20

49	MET Excess	11,000	0.100	0.100	45	20	20
50	MET Excess	11,000	0.100	0.100	45	20	20
51	MET Excess	11,000	0.100	0.125	45	20	20
52	MET Excess	11,000	0.100	0.125	45	20	20
53	MET Excess	11,000	0.100	0.125	45	20	20
54	MET Excess	11,000	0.100	0.125	45	20	20
55	MET Excess	11,000	0.100	0.125	45	20	20
56	MET Excess	11,000	0.100	0.125	45	20	20
57	MET Excess	11,000	0.100	0.125	45	20	20
58	MET Excess	11,000	0.100	0.125	45	20	20
59	MET Excess	11,000	0.100	0.125	45	20	20
60	MET Excess	11,000	0.100	0.125	45	20	20
61	MET Excess	11,000	0.100	0.125	45	20	30
62	MET Excess	11,000	0.050	0.125	45	20	20
63	MET Excess	11,000	0.050	0.125	45	20	20
64	MET Excess	11,000	0.050	0.125	45	20	20
65	MET Excess (metallization)	11,000	0.050	0.125	45	20	35
66	MET Excess (metallization)	11,000	0.050	0.125	45	20	35
67	MET Excess (metallization)	11,000	0.025	0.125	45	20	20
68	MET Excess (metallization)	11,000	0.025	0.125	45	20	20
69	MET Excess (metallization)	11,000	0.025	0.125	45	20	30
70	MET Excess (metallization)	11,000	0.025	0.125	45	10	20
71	MET Excess (metallization)	11,000	0.025	0.125	45	10	30

72	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
73	MET Excess (metallization)	11,000	0.025	0.125	45	20	40
74	MET Scrap Part	11,000	0.025	0.125	45	20	35
75	MET Scrap Part	11,000	0.025	0.125	45	20	35
76	Cofired/10 TKN/ Resistor	11,000	0.025	0.125	45	20	35
77	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
78	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
79	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
80	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
81	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
82	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
83	10 TKN/Resistor	11,000	0.025	0.125	45	20	35
84	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
85	MET Excess (metallization)	11,000	0.025	0.125	45	20	35
86	MET Scrap	11,000	0.025	0.125	45	20	35
87	MET Scrap	11,000	0.025	0.125	45	20	35
88	MET Scrap	11,000	0.025	0.125	45	20	35

89	MET Scrap	11,000	0.025	0.125	45	20	35
90	MET Scrap	11,000	0.025	0.125	45	20	35
91	MET Excess (metallization)	11,000	0.050	0.125	45	20	35
92	MET Excess (metallization)	11,000	0.100	0.125	45	20	35
93	MET Scrap	11,000	0.100	0.125	45	20	35
94	MET Scrap	11,000	0.100	0.125	45	20	35
95	Cofire	11,500	0.100	0.125	45	20	35
96	Cofire	10,500	0.100	0.125	45	20	35
97	Cofire	11,000	0.150	0.125	45	20	35
98	Cofire	11,000	0.125	0.125	45	20	35

1ME** - Added single dress cut to start of
MET program

2ME*** - Added a single dress cut to the start of each block
in the MET program

Dressing Procedure
(DA) 60 mil Cuts in 80 mil Alumina

(SA) 2 mil Cuts in Alumina

(DG) 60 mil Cuts in Glass

((A/G) 60 mil Cuts thru 40 mil Alumina, 20 mil in Glass

(ME) MET Excess

Glass*

Glass Plate w/Tape and Frame