LASER CONTOURED AND DRILLED SUBSTRATES
FOR THICK FILM APPLICATIONS

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LASER CONTOURED AND DRILLED SUBSTRATES FOR THICK FILM APPLICATIONS

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The feasibility of using laser contoured and drilled substrates for thick film circuits was demonstrated. Laser contouring and drilling was found to provide the dimensional accuracy required by product and the finished product was proven capable of withstanding the thermal stresses imposed by the required thermal shock tests conducted on the product.

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SUMMARY

The technique of CO₂ laser drilling and contouring substrates and its immediate effects on thick film processing were evaluated after substrate cracking was detected on substrates which had been contoured and drilled in the green state. Substrate cracking was identified at incoming inspection and at various thick film processing intervals. The substrates support the thick film conductive networks which are part of the EA001 electronic assembly. Work on this project was done between March and August 1975.

Blank substrates were purchased from two vendors. The substrates were examined for cracks with a fluorescent dye and were thermal shock tested before being shipped to Lasermation Incorporated where they were laser drilled. The drilled ceramics were again examined for cracks using the same fluorescent dye. Some samples were thermal shock tested and the results were compared to data from the blank substrates. Hole size and location were carefully checked.

Finally, the thick film conductor networks were printed, dried, and fired onto the substrates. Since the firing profile for the particular conductor cermet used required a temperature in excess of 900°C, the ceramics were again checked for possible cracking.

CO₂ laser drilling and contouring blank substrates proved satisfactory. Product thermal stress requirements as well as hole size and location tolerances were met.

DISCUSSION

SCOPE AND PURPOSE

The goal of this program was to determine if CO₂ laser contoured and drilled substrates could be used as an alternative to the ceramics presently used in the EA001 Electronic Assembly. The project included purchasing ceramic substrates, getting them laser drilled and contoured, subjecting them to thermal shock tests, and evaluating their compatibility with thick film processes.

PRIOR WORK

Work on this project was begun in March 1975. Until then, two groups of substrates had been associated with the EA001 and both were plagued with cracking problems.

Group I substrates came from Sandia Laboratories Albuquerque (SLA) and American Lava. (American Lava is now known as the Technical Ceramics Division of the 3-M Company and is located at Lawrence, SC.) The SLA substrates were cast in blocks; hole drilling and contour machining were done in the green state. After the block was fired, substrates approximately 1.27 mm thick were sliced off with a diamond saw. Both surfaces were then machined to get a fired thickness of 0.635 mm. The American Lava substrates were made using the doctor blade process.

Two different types of ceramic configurations, referred to as A and B, were required (Figure 1). A total of 49 SLA substrates were manufactured: 24 were in the A configuration, while the remaining 25 were of the B type. The Sandia ceramics were not monitored for cracks until processing had been completed. American Lava provided 89 substrates: 50 A and 39 B. Evidence of cracking in the American Lava ceramics was present throughout the various processing steps. Table 1 details the cracking history from the Group I ceramics.

Group II substrates were purchased from Western Gold and Platinum Company (Wesgo) of Belmont, CA, by both SLA and Bendix. Wesgo isostatically pressed the substrates into blanks, they were machined, and holes were drilled in them by an automatic tape mill. After machining, the substrates were fired and then ground to the desired thickness. Since the Bendix order arrived in about one-fourth the time of the SLA order, it was assumed that the Bendix substrates were done on soft tooling while SLA's were done on hard tooling. Bendix received 51 A ceramics and 56 B ceramics; Sandia obtained 56 A ceramics and 50 B ceramics. Group II ceramic cracking data are shown in Table 2.

Figure 1. Contour and Hole Patterns for EA001 Substrates

Table 1. Group I Cracking Data

	Type A		Type B	
	SLA	American Lava	SLA	American Lava
Cracked				
As Received	--	6	--	6
After Printing	--	3	--	7
After Final Check	6	4	24	7

ACTIVITY

The two types of substrates selected for this program were American Lava 96 percent Al_2O_3 and Materials Research Corporation of Orangeburg, NY, (MRC) 99.5 percent Al_2O_3 . The MRC blank substrates were 95.25 mm by 114.3 mm, with a nominal thickness of 0.635 ± 0.025 mm. The American Lava substrates were the same size except that they had a nominal thickness of 0.635 ± 0.0635 mm. Both types of substrates were first checked for cracks with a

fluorescent penetrant test. Only cracks having lengths in excess of 3.175 mm and visible on both sides of the ceramics were identified. Of the 75 American Lava substrates examined, 55 were quite porous with no cracks, 15 were non-porous with no cracks, and 5 had cracks which exceeded 3.175 mm in length. All 75 MRC substrates checked were non-porous and free of cracks.

Thermal stability information had to be compiled on the blank substrates to provide a basis of comparison with the contoured substrates. The data was obtained by placing blank substrates in a fire-brick-lined oven preset to 150°C for 10 minutes and then quickly removing them and plunging them into a room-temperature water bath. This process was repeated for various temperature settings until evidence of substrate cracking appeared. No substrate was temperature shocked more than once. The data indicated that both the American Lava and MRC substrates showed evidence of cracking when the temperature was set at 300°C.

Following the thermal shock evaluation, 56 substrates (28 MRC and 28 American Lava) were sent to Lasermation Incorporated to be contoured and hole drilled in accordance with drawings AY298088 (A ceramic) and AY298087 (B ceramic). Holes were drilled in both types of substrates using a 500 watt CO₂ laser. Each laser pulse penetrated the entire thickness of the substrate. The holes were fabricated by stepping the substrate around the appropriate circular travel on an NC controlled X-Y table while pulsing the laser.

When the contoured ceramics were received from Lasermation they were again examined for cracks. No cracks were found on any of the 56 ceramics.

The same technique used to thermal shock the blank substrates was used on the contoured ceramics. In addition to the American Lava and MRC ceramics, some Group II (Wesgo) ceramics were included in the thermal shock evaluation. Table 3 shows the results of these thermal shock tests.

SEM photographs of typical holes drilled in the American Lava and the MRC substrates are shown in Figures 2 through 5.

In Figures 2 and 3 it can be seen that the surface finish of the MRC substrate is much smoother than that of the American Lava substrate. The MRC substrate also shows no evidence of splattering or other residue on the surface as a result of the laser drilling. Even though the holes display some irregularities, they are well within the required tolerances. The diameter of the hole is greater both at the top and bottom than at the middle of the hole. It is assumed that the laser beam was focused at a point near the

Table 2. Group II Cracking Data

Cracked	Type A		Type B	
	Bendix	SLA	Bendix	SLA
As Received	7	1	12	0
During Cleaning	3	0	4	0
After Printing	2	0	0	0
At Final Check	--	11	--	3

Table 3. Thermal Shock Test Results

Substrate Type	Temperature (°C)	Cracking
MRC-A	170	No
MRC-B	↓	↓
American Lava-A	↓	↓
American Lava-B	170	↓
MRC-A	210	↓
MRC-B	↓	↓
American Lava-A	↓	↓
American Lava-B	↓	↓
Wesgo-A	↓	↓
Wesgo-B	210	No
MRC-A	250	Yes
MRC-B	↓	↓
American Lava-A	↓	↓
American Lava-B	↓	↓
Wesgo-A	↓	↓
Wesgo-B	250	Yes

A
50X

B
50X

C
150X

Figure 2. General Views of Laser Drilled Holes in American Lava 96-Percent Alumina

A
50X

B
50X

C
150X

Figure 3. General Views of Laser Drilled Holes in MRC 99.5 Percent Alumina

A
150X

B
500X

C
500X

Figure 4. Detail Views of Laser Drilled Holes in American Lava 96-Percent Alumina

A
150X

B
500X

C
500X

Figure 5. Detail Views of Laser Drilled Holes in MRC 99.5 Percent Alumina

center of the thickness of the substrate to allow the material to be easily removed from the exit and entrance rather than the mid-point of the hole.

Two areas of chip-out are evident in Figure 2(B). These were probably caused by the thermal shock of having molten alumina immediately adjacent to portions of the substrate that were not substantially heated by the laser drilling. Some chipping can also be seen in Figure 3(B).

Figures 4(C) and 5(C) show the interiors of the holes at greater magnification and reveal a pattern of cracking across both the American Lava and the MRC substrates.

Figures 6 and 7 show the contrast in surface finish between the laser drilled holes and the ultrasonically-milled and green-drilled holes.

A thick film conductor circuit was printed and fired on four Type A and four Type B ceramics. Each type was a combination of two American Lava and two MRC substrates. A Cermalloy 4100 series platinum-gold conductive paste, fired at a peak temperature of 950°C for 10 minutes, was used. After completion of the thick film circuit fabrication, the ceramics were again checked for cracks and all eight were found to be free of cracks.

Twelve sample substrates were examined to determine the accuracy of contour and hole location. Six each of Type A and Type B were involved in the test; three of each type were from MRC while the other three were from American Lava.

A total of 85 holes was drilled in the Type A substrates. Blueprints called for three different hole diameters: 3.048 mm, 1.574 mm, and 1.016 mm, with 0.05 mm tolerance on all holes.

The Type B substrates had 113 holes drilled in them. The tolerance requirement on all holes was 0.05 mm and the hole diameters were 1.574 mm, 1.016 mm, and 0.812 mm.

Hole size was determined by a wire probe; a coordinate measuring machine (Cordax) was used to determine the hole location. Both hole size and hole location were well within the required tolerances. Tables 4 and 5 show the data compiled during the examination.

ACCOMPLISHMENTS

It was demonstrated that the method of contouring and drilling substrates used by Lasermation Incorporated provides the dimensional accuracy required for the EA001 and that the finished product is capable of withstanding the thermal stress demands placed on the unit.

Figure 6. SEM Views of 99.5 Percent Alumina Substrates Ultrasonically Milled by SLA, After Cleaning, Secondary Mode, 45 Degrees from Top, 80X

SECONDARY

BACKSCATTER

Figure 7. SEM Views of MRC 99.5 Percent Alumina Substrates Green Drilled at 25,000 rpm With a Feed Rate of 635 mm/min, 45 Degrees from Top, 70X

Table 4. Hole Dimensional Tolerances for Type A Substrates

Substrate Number	Number of Holes Measured	True Position Diameter (mm)	True Position Deviation (mm)		
			Average	Maximum	Minimum
MRC Substrates					
1	1	0.127	0.035	--	--
1	81	0.203	0.046	0.129	0.005
1	2	0.356	0.051	0.056	0.048
2	1	0.127	0.030	--	--
2	81	0.203	0.043	0.104	0.002
2	2	0.355	0.041	0.046	0.038
3	1	0.127	0.056	--	--
3	81	0.203	0.046	0.156	0.008
3	2	0.356	0.066	0.089	0.046
American Lava Substrates					
1	1	0.127	0.020	--	--
1	81	0.203	0.051	0.094	0.010
1	2	0.356	0.066	0.071	0.061
2	1	0.127	0.048	--	--
2	81	0.203	0.036	0.107	0.005
2	2	0.356	0.051	0.068	0.033
3	1	0.127	0.015	--	--
3	81	0.203	0.038	0.137	0.005
3	2	0.356	0.038	0.041	0.036

Table 5. Hole Dimensional Tolerances for Type B Substrates

Substrate Number	Number of Holes Measured	True Position Diameter (mm)	True Position Deviation (mm)		
			Average	Maximum	Minimum
MRC Substrates					
1	1	0.127	0.010	--	--
1	74	0.203	0.056	0.183	0
1	37	0.406	0.043	0.107	0.010
2	1	0.127	0.010	--	--
2	74	0.203	0.071	0.190	0.005
2	37	0.406	0.038	0.079	0.005
3	1	0.127	0.041	--	--
3	74	0.203	0.071	0.147	0.010
3	37	0.406	0.043	0.089	0.001
American Lava Substrates					
1	1	0.127	0.041	--	--
1	74	0.203	0.066	0.180	0.008
1	37	0.406	0.046	0.137	0.008
2	1	0.127	0.000	--	--
2	74	0.203	0.081	0.180	0
2	37	0.406	0.046	0.089	0.013
3	1	0.127	0.007	--	--
3	74	0.203	0.053	0.140	0.008
3	37	0.406	0.036	0.059	0.008

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