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HAND PUNCHING HOLES
IN UNFIRED 99.5 PERCENT
ALUMINA SUBSTRATES

PDO 6984864, Milestone Report

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MASTER

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HAND PUNCHING HOLES IN UNFIRED 99.5 PERCENT ALUMINA SUBSTRATES

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Prepared by P. L. Blessner, D/842, under PDO 6984864

The tooling and process techniques for hand-punching holes in green (unfired) 99.5 percent alumina ceramic substrates were investigated to determine the requirements for obtaining holes with good surface finish and a minimum number of defects. Such holes are needed to provide low electrical resistance ground paths from frontside to backside of vacuum-metallized ceramic substrates used to manufacture hybrid microcircuits. It was determined that holes having excellent surface finish and maximum via resistance of 9 milliohms (with a 6 micrometer surface thickness of chromium/gold metallization) could be obtained with the following processing and tooling: use heat-treated drill bushings to line the template holes; use a conical-tipped punch; use oil as a lubricant; spin the punch approximately five revolutions during the punching operation; and blow compressed air through the hole after punching. The as-fired hole diameter should be approximately 78 percent of the nominal punch diameter.

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SUMMARY

The purpose of this project was to determine the tooling and process techniques required to hand-punch holes having good surface finish in green (unfired) 99.5 percent alumina ceramic substrates. The factors investigated included the type of template, the type of punching tool, the effect of a lubricant, the punching technique, the method of cleaning the holes after punching, and the punch diameter. A scanning electron microscope (SEM) was used to evaluate the quality of the holes, with the best hole being one that has smooth, defect-free, cylindrical walls, and unbroken square edges at the top and bottom surfaces. The resistance of the metallized hole was measured between the top and bottom substrate surfaces by means of a four-point probe system.

Certain hybrid microcircuit (HMC) applications at the Kansas City Division of The Bendix Corporation require conductive paths between the metallization layers on the top and bottom surfaces of a ceramic substrate. One method of providing this intraconnection is to vacuum metallize the walls of the hole in the substrate during normal HMC deposition. These metallized holes are called *vias*. To provide a low-resistance intraconnection from front to back, the hole must have smooth defect-free walls and edges; this will allow the thin-film metallization to be deposited in such a manner that a smooth transition exists from the substrate surfaces to the hole wall. Preliminary samples of vendor-supplied hard-tooled (several holes punched simultaneously) green-punched holes for vias resulted in less than a 55-percent yield against a via resistance requirement of 25 milliohms maximum. These holes were found to have a very irregular surface on the inside walls.

The best hand-punching process developed includes the following techniques:

- Use heat-treated drill bushings to line the holes of the template;
- Use a punch with a conical tip;
- Use oil as a lubricant;
- Spin the punch throughout the punching operation; and
- Clean the hole after punching by blowing compressed air through it.

SEM photographs indicate that holes made using this process have excellent quality after the substrates are fired. The hole walls

have a smooth polished appearance, with a surface finish comparable to that on the top side of the substrate (3 to 4 microinches [76 to 102 nm]). The diameter of the as-fired hole was approximately 21 percent smaller than the diameter of the punching tool, compared to 15 percent shrinkage for the substrate as a whole.

Fired substrates with hand-punched holes were vacuum metallized with 25 nanometers of chromium followed by 6 micrometers of gold. The resulting vias had a maximum DC resistance of 9 milliohms, with the average resistance being 7 milliohms.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this work was to determine the factors affecting the quality of holes hand-punched in green 99.5 percent alumina ceramic substrates in order to find an acceptable method of hand-punching holes for conductive via applications. The factors investigated included the type of template, the type of punching tool, the effect of a lubricant, the punching technique, the method of cleaning, and the diameter of the punch. Each factor was judged on the effect it had on the quality of the hole wall after punching. SEM photographs were used for examining the surface finish of the holes. Visually, the best hole is one that has smooth, defect-free walls and unbroken squared-off edges at the top and bottom surfaces. The ultimate criterion for evaluating a hole is the amount of resistance through the hole after it has been vacuum metallized. This work was done between October 1974 and February 1975.

PRIOR WORK

Good quality holes in 99.5 percent alumina ceramic substrates are required to provide conductive paths between the metallization pattern on the top side of a hybrid microcircuit (HMC) substrate and the ground plane on the bottom side. A thin-film metallization layer is deposited on the hole wall by vacuum deposition using a planetary evaporation fixture. This provides a continuous path of metallization between the top and bottom substrate surfaces. The amount of resistance the via (metallized hole) presents between the two surface metallization layers depends upon the quality of the hole.

The walls of the hole must be smooth and free of defects. Irregularities in the hole wall cause abrupt variations in the via metallization layer. Roughness or discontinuities will cause discontinuities in the film because of the line-of-sight deposition characteristics and will increase resistance by shadowing, thinning the film, and lengthening the current path. Severe discontinuities in the hole wall, particularly in the plane of the substrate, may result in an open-circuited via. The top and bottom edges of the hole must be smooth and free of breakage to allow the metallization to form a smooth transition from the substrate surfaces to the hole walls.

Holes can be fabricated in ceramic substrates in either the green (unfired) state or the as-fired state. Fired substrates are hard and brittle and difficult to machine. However, hole location can be controlled more closely since it is not necessary to compensate

for the shrinkage which occurs during firing. Green ceramic is soft and pliable, and crumbly when broken. Punching holes in green ceramic is not difficult; however, the hole-making process must be controlled to produce holes whose walls are not crumbly or marred.

Preliminary samples of vendor-supplied hard-tooled green-punched holes were found to have very irregular inside surfaces (Figure 1). When metallized, these holes resulted in less than a 55 percent yield against a via resistance requirement of 25 milliohms maximum.

ACTIVITY

All substrates used in this study were MRC brand. To evaluate each of the factors described, at least 50 holes were punched and then visually examined under a microscope. SEM photographs were then taken of holes which typified the hole finish produced by a given technique.

Type of Template

Two 0.0125-inch-thick (0.318 mm) steel plates, each with an array of 25 holes drilled in it, were initially used for the template. Two pins projecting from the bottom plate were used to align and interlock the two halves of the template by mating with two holes in the top plate. The substrate was sandwiched between the two plates. Repeatable location of the substrate with respect to the hole pattern was assured by the use of metal plates approximately the same thickness as the substrate. These were cemented to the inner surface of the bottom half of the template, and it was on them that the two adjacent edges of the substrate rested.

After this template was used to punch several holes, the quality of the holes appeared to be declining. In particular, the bottom edges of the holes were breaking away, resulting in slightly tapered edges (Figure 2). Examination of the bottom half of the template showed that its holes were deformed on the edge in contact with the substrate (Figure 3). This damage was apparently caused by the tip of the punch scraping the edge of the template hole during each punching operation.

To provide additional support for the ceramic around the periphery of the holes and thus reduce the amount of breakaway, one sheet of 0.0013-inch-thick (0.033 mm) paper was placed between the substrate and the bottom plate of the template prior to punching. The paper did diminish the amount of breakaway on the bottom edge of the hole but it did not eliminate it. A negligible amount of breakaway occurred when two thicknesses of the same paper were

Figure 1. SEM Views of 0.050-Inch-Diameter (1.27 mm) Holes Green-Punched by Vendor Using Hard Tooling

used under the substrate. However, the increased resistance to the punch, a result of the paper, caused the separation of a thin layer of ceramic from the top edge of the hole and the formation of ridges inside the hole when the punch was spun as it penetrated the substrate.

To obtain good square edges on the template holes, heat-treated 0.03125 inch (0.794 mm) inner diameter tool steel drill bushings were press fit into the template. These are annular rings of hardened steel, with the inner diameter being the desired size of the hole to be punched or drilled. The drill bushings were found to provide good shearing action on the ceramic and appeared to eliminate breakaway of the bottom edge of the hole (Figure 4). After several punching operations, the bushing holes were examined and were found to be undamaged (Figure 5).

If the clearance between the punch and the template holes becomes too great, lateral motion of the punch within the holes will

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 2. SEM Views of Hole Green-Punched in MRC Substrate Using Conical 0.032-Inch (0.81 mm) Punch, With Spin, Oil as Lubricant, and an As-Drilled Template

Figure 3. Top Edge of
0.032-Inch-Diameter
(0.81 mm) Hole
Drilled in Bottom
Half of Template
and Then Punched
Through Several
Times

occur. This may allow the punch tip to strike the upper edge of the hole in the bottom half of the template (Figure 6), preventing the punch from passing freely through the template. This may cause some breakage around the edge of the substrate hole and may also damage the tip of the punch and the edge of the template hole. This problem may be reduced either by using a thicker plate for the top half of the template or by allowing the drill bushings to extend above the top surface of the template (Figure 6).

Type of Punching Tool

Two types of punches were used in this study, one having a flat tip and the other having a conical tip (Figure 7). With a flat-tipped punch, the top edge of the hole was damaged and the walls of the hole were usually scraped away (Figure 8). The force applied to the punch is evenly distributed over the flat tip,

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 4. SEM Views of Hole Green-Punched in MRC Ceramic Using Conical 0.032-Inch (0.81 mm) Punch, With Spin, Oil as Lubricant, and Drill Bushings Installed in Template Holes

Figure 5. Top Edge of
0.032-Inch Inner
Diameter (0.81 mm)
Drill Bushing
Which Was Fitted
Into the Bottom
Half of a Template
and Then Punched
Through Several
Times

compressing the top surface of the substrate until the punch finally breaks through. This apparently is the cause of the cracking at the top edge of the hole (Figure 9).

With a conical-tipped punch, this problem was not encountered, apparently because the center of the tip penetrates the substrate surface before the circumference does.

Effect of a Lubricant

Punching holes in green ceramic without using a lubricant resulted in holes with crumbly walls. Two lubricants, water and oil, were studied to determine their effect on hole surface finish. They were applied with a medicine dropper, prior to punching, by filling each of the holes in the top half of the template.

Figure 6. Reduction of Punch-Template Misalignment by Increasing Template Thickness

Holes punched using water had better wall surfaces than those punched without using a lubricant; however, the walls at the bottom half of the hole were still rough (Figure 10).

The use of oil (Eel Skid brand) as a lubricant resulted in walls with a smooth polished appearance (Figure 11). The oil seemed to soften the ceramic and allow the punch to penetrate the substrate smoothly rather than tear its way through. It was also determined that the bottom edge of the punched hole could be improved by applying oil to the bottom surface of the substrate before the hole was punched.

Figure 7. Outlines of Conical-End and Flat-End
Punches 0.032 Inch (0.81 mm) in
Diameter, Used for Punching MRC
Green Ceramic

Punching Technique

Spinning the punch as it penetrates the ceramic was found to produce better quality holes than punching without spinning. When spin was not used, the top edge of the hole was usually deformed, typically with a thin layer of ceramic peeled away from the hole wall (Figure 12). Spinning eliminated this, apparently by allowing the punch to shear its way into the top of the ceramic, although this occasionally caused the formation of ridges inside the hole.

To hold the punch for spinning, it was inserted into a cylindrical tool about the size of a pencil. The tool has a pin vise on each end and a knurled shaft (Figure 13). With the punch inserted into the top of the template, about 5 pounds (22 N) of force was applied to the top of the tool while the tool was simultaneously spun and the hole made (Figure 14).

Spinning should be employed not only during the actual punching but also during the withdrawal of the punch. This seems to help polish the walls of the hole. The punch was spun approximately five revolutions during the total operation.

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 8. SEM Views of Hole Green-Punched in MRC Ceramic Using Flat-End Punch, No Lubrication, No Spin, and As-Drilled Template

500X SECONDARY

Figure 9. SEM View of Top Edge of Hole Green-Punched in MRC Ceramic Using Flat-End 0.032-Inch-Diameter (0.81 mm) Punch With No Spin, No Lubrication, and As-Drilled Template

Cleaning Method

Typically, small particles of ceramic are found in the substrate hole after it is punched. If these are not removed before the substrate is fired, they will be fired onto the hole walls and will interfere with via metallization. These particles apparently adhere to the punch after it penetrates the ceramic and are deposited in the hole when the punch is withdrawn. To clean the punch before removing it, air was blown over the portion of it protruding from the bottom of the template. However, this apparently dried the oil off the punch, so that when it was withdrawn it abraded the walls of the hole. It was found that the holes could be sufficiently cleaned by blowing compressed air through the holes of the template before the substrate was removed from it.

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 10. SEM Views of Hole Green-Punched in MRC Ceramic Using Flat-End Punch, No Spin, Water as Lubricant, and As-Drilled Template

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 11. SEM views of Hole Green-Punched in MRC Ceramic Using Conical 0.032-Inch (0.81 mm) Punch, With Spin, Oil as Lubricant, and With Two Sheets of 0.0013-Inch-Thick (0.33 mm) Paper Placed Under Ceramic

70X SECONDARY (BOTTOM)

70X SECONDARY (TOP)

70X BACKSCATTER

Figure 12. SEM Views of Hole Green-Punched in MRC Ceramic Using Conical 0.032-Inch (0.81 mm) Punch, No Spin, Oil as Lubricant, and With Two Sheets of 0.0013-Inch-Thick (0.033 mm) Paper Placed Under Ceramic

Figure 13. Carbide Twist Drill Mounted in Pin Vise With Drill Bushings Used in Making Template, Bottom of Bushing (Left) and Counter-sunk Top (Right)

Selection of Punch Diameter

Two factors must be considered when determining the size of punch required to produce a given diameter hole in the fired substrate: the difference between the punch diameter and the green hole diameter, and the hole shrinkage which occurs during firing of the substrate.

To determine the size of a green hole after punching, holes were punched using a tool which had made 250 holes (Figure 15). The diameters of these holes were approximately 0.0288 inch (0.732 mm), which is the diameter of the extreme tip of the punch. Since the shaft of the punching tool is larger than this, the ceramic apparently expanded when the punch was inserted and contracted when it was withdrawn. Based on a nominal punch diameter of 0.03125 inch (0.794 mm), the punched hole was 92 percent of the desired size.

Hole diameters were measured on two of ten substrates which were green-punched and then fired by the vendor. The average diameter of 50 holes was 0.0243 inch (0.617 mm). Based on an average green hole diameter of 0.0288 inch (0.732 mm), the hole shrinkage was about 15 percent, which was the same amount of shrinkage which occurred in the hole-to-hole spacing. The as-fired hole

Figure 14. Hand Punching Operation:
Thumb Provides Punching
Pressure; Pin Vise is
Rotated With Other Hand

diameter therefore was determined to be approximately 78 percent of the nominal punch and template hole size.

ACCOMPLISHMENTS

The best process developed for hand-punching holes in 99.5 percent alumina ceramic substrates includes the following techniques:

- Use heat-treated drill bushings to line the template holes;
- Use a punch with a conical tip;
- Use oil as a lubricant;
- Spin the punch throughout the punching operation; and
- Blow compressed air through the hole after punching it.

Using this process, holes with excellent properties for making vias were consistently produced (Figure 16).

- The surface finish inside the hole was almost as smooth as the surface of the substrate.

UNUSED PUNCHING TOOL

PUNCHING TOOL AFTER PUNCHING
250 HOLES

Figure 15. Wear on Punching Tool; Nominal
Diameter is 0.03125 Inch (0.794 mm)

- The irregularities which were produced did not consist of abrupt changes in surface level (which would produce shadowing during vacuum deposition of the metallization).
- The process for producing good hand-punched holes does not add appreciable labor to the punching process. (Applying oil and spinning the punch are the main additional operations.)
- A technique was developed for predicting the punch diameter which is required to produce a given as-fired hole diameter.
- Metallized vias had less than 9 milliohms resistance when 6-micrometer-thick gold metallization was used.

The hand-punched holes used as vacuum-metallized vias should consistently meet product requirements of 25 milliohms maximum resistance.

80X, -45°

80X, +45°

80X, BACKSCATTER

Figure 16. SEM Views of Hole Green-Punched and Fired in MRC Ceramic Using 0.03125-Inch (0.794 mm) Conical Punch, With Spin, Oil as Lubricant, and With Drill Bushings Installed in Template Holes

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