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**CHARACTERIZATION AND SCHEDULE DEVELOPMENT
FOR GOLD-RIBBON HYBRID-MICROCIRCUIT CROSSOVERS**

June 1973

Bendix Corporation
Kansas City, Missouri

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CHARACTERIZATION AND
SCHEDULE DEVELOPMENT
FOR GOLD-RIBBON
HYBRID-MICROCIRCUIT CROSSOVERS

Project Leader
D. L. Willyard
Department 842

Project Team:
T. J. Riehle

PDO 6984749
Topical Report

June 1973

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CHARACTERIZATION AND SCHEDULE DEVELOPMENT OF GOLD-RIBBON HYBRID-MICROCIRCUIT CROSSOVERS

Prepared by D. L. Willyard, D/842, under PDO 6984749

This work was conducted to establish a microcircuit intraconnection bonding process with rectangular gold ribbon and a Model 1360-2 Radiant Energy Systems bonder. These crossover intraconnections consist of conductive elements added to metallized substrates to connect one circuit path to another without contacting other circuits over which they pass. This work was performed on tantalum/chromium/gold-metallized alumina substrates with only the one bonding system, the purpose being to determine the optimum combination of bonding parameters. Both ultrasonic and thermocompression bonding were evaluated, including the inherent deficiencies of gold for ultrasonic bonding, and a schedule was established for one size of gold ribbon. Pull-strength tests verified adequate bond strength. The process is adaptable to other microcircuit bonding applications by making minor parameter adjustments.

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SUMMARY

Crossover intraconnections are often required in hybrid microcircuits to connect metallized conductor paths together without shorting to other circuit elements over which they pass. This evaluation was limited to flat gold-ribbon crossovers, tantalum/chromium/gold-metallized alumina substrates, and a Radiant Energy Systems Model 1360-2 Bonder.

Thermocompression bonding, both with and without ultrasonic vibration, indicated that vibration does not contribute significantly to bond strength and is detrimental to the soft gold ribbon.

The characteristics of the bonding system were determined, and pull-strength tests were conducted to optimize the bonding-process parameters. A bond schedule for one of the two sizes of gold ribbon evaluated was then certified by additional tests.

Several other tests were performed to verify bond reliability and to establish a suitable monitoring method to control the bonding process. With minor bonding-parameter adjustments, this process can be adapted to other micro-circuit bonding applications such as beam-lead and lead-frame bonding.

Evaluation of other crossover materials such as gold-plated copper ribbon and investigation of other bonding systems is recommended to increase Bendix hybrid microcircuit fabrication capability. This work should include other materials and bonding tools, and microcircuit physical-design features should be considered.

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DISCUSSION

SCOPE AND PURPOSE

The work performed in this endeavor was a portion of that developmental support authorized by PDO 6984749, Evaluation of Microcircuit Techniques.

The specific goal discussed here was to characterize the Model 1360-2 RES bonder and develop a suitable schedule to reliably bond crossovers on a tantalum/chromium/gold-metallized alumina substrate.

PRIOR WORK

The feasibility and the inherent mechanical strength of a ribbon-crossover technique using a K&S Model 576 wobble-tool beam-lead bonder has been demonstrated by Sandia Laboratories.

ACTIVITY

The metallization deposited on hybrid microcircuit (HMC) substrates is used to connect the various circuit elements. Many situations arise where two or more conducting paths must cross. The planar layout restriction of the metallization technology results in a dilemma that can only be solved by adding a conductive element that crosses over one or more planar circuit paths. Previous Bendix processing technology has dictated that these crossover intraconnections be formed by using the fine-wire gold-bonding process. In this process a gold wire of 0.001-inch (25.4 μm) diameter is connected by conventional thermocompression ball-bonding techniques. This technology has several undesirable restrictions. The first is length limitation: a fine wire crossover of greater than 0.050 inch (1.27 mm) is unreliable because the fragile wire tends to collapse against the substrate. Another restriction is the low conductivity of the very small wire often demands multiple bonds to meet current-handling needs. The hydrogen-flame torch used to make the gold balls requires special safety precautions. Ribbon intraconnection bonding is a potential means of eliminating these undesirables from the HMC processing technology.

Process Variables and Limitations

The initial approach was to examine the known process limitations or restrictions and the known process variables, excluding materials variation. The characteristics of the gold ribbon and the substrate metallization were initially assumed constant. Every practical caution was taken to use only substrate metallization typical of that produced by the Bendix microcircuit production facility.

The RES Model 1360-2 thermosonic bonder was designed specifically for heavy round-wire and ribbon bonding. The bonder provides a combination of heat and force (thermocompression) and ultrasonic vibration. The machine-controllable process variables are substrate temperature, ultrasonic bonding time, bonding-wedge temperature, bonding force, and ultrasonic power. Data for characterization curves to relate the bonding system control to the physical properties of the materials are shown in Figures 1 through 6. Conventional temperature-measurement techniques were used. A calibrated chart recorder driven by the zero-referenced output from a chromel/alumel thermocouple was used for Figure 1, and care was taken to record the temperature at the exact center of the substrates. A similar technique was used for Figure 2, but a special bonding wedge with an iron/constantan thermocouple mounted on the tip was used instead of the normal bonding wedge. The substrate temperature was 200°C. Figures 3 and 4 include the heat-up time of both the bonding tip and the substrate. The 200°C temperature setting used in Figures 2, 3, and 4 was chosen because of the temperature limit in processing substrates with tantalum thin-film resistors and chromium/gold metallized conductors. Above that temperature there is a possibility that resistor values may change because of accelerated growth of the oxide layer, and chromium oxide detrimental to subsequent bonding processes may form on the gold conductor pattern.

The bonding-force data plotted in Figure 5 was obtained by two techniques. Curve 1, the most accurate, was obtained by using a pressure gage and a chart recorder during the actual bond cycle. Although the most accurate, this technique is not believed suitable as a production test setup or a monitor. As an alternate technique, data were taken with a hand-held dynamometer; the gage being held under both the bonding tool tip and under the end of the transducer horn in the Ready position. These data are shown in Curves 2 and 3 of Figure 5. The test was repeated with the gage under the tool tip while the system was in the Search position (Curve 4). Examination shows insignificant differences between Curves 2, 3, and 4, with all three displaced below the more accurate Curve 1. The technique of holding the gage under the bonding tool tip with the system in the Search position is recommended because of the need for a convenient bonding-force monitor for production use.

Text continues on page 20.

Figure 1. Substrate Temperature Versus Bonder Temperature--Control Setting

Figure 2. Bonding-Wedge Temperature Versus Bonder Temperature-Control Setting

Figure 3. Substrate Temperature Versus Bonding Time at Bonder Temperature-Control Setting of 1.75

Figure 4. Bonding-Tip Temperature Versus Bonding Time With Substrate-Temperature Control Set at 200°C

Figure 5. Bonding Force Versus Bonder Micrometer Force Setting

Bond time was measured by using an oscilloscope with the sweep triggered by the ultrasonic pulse. Figure 6 shows a plot of the actual bond time versus the timer control setting.

Figure 6. Bonding Time Versus Bonder Time-Control Setting

The measurement of ultrasonic power, the remaining system-control variable, is not straight forward. Ultrasonic power logicons are specified by measuring the electrical power delivered to a 22-ohm resistive load. This is only of secondary importance when considering the actual power delivered to the bond area. The transducer design, materials used, friction and rigidity of transducer pivot and mount, and mechanical tolerances all combine to make the logicon power output meaningless. One approach that has been used in ultrasonic power measurements is to use a dynamic pressure transducer during a simulated bonding cycle. This is basically a force measurement, and requires considerable approximation to convert to ultrasonic power.² Another technique more applicable to actual bonding is to use an ultrasonic deflectometer to measure the total vibratory displacement under actual weld conditions. Knowing the properties of the materials and the frequency of vibration, one can make an estimate of the energy per unit of contact surface. There appears to be no known technique that can measure actual ultrasonic power delivered to the weldment which meets the criteria of being adaptable to production control or monitor applications. The logical, and seemingly accepted, procedure is to experimentally determine an ultrasonic power setting that will give a good bond strength and to use the other more-easily-adjustable parameters of force, time, and temperature to optimize the bonding process.

During the period of experimentation to determine a practical method of power measurement, observation of bond area deformation showed a considerable variation for a given power setting. An attempt was made to empirically set a combination of system controls that would result in a strong bond. It was discovered that a very light force was required for even a very low setting of ultrasonic power, and that wire deformation under the bonding tool was excessive and not repeatable. In attempting to discover the cause of the varying deformation a considerable variation in the vertical displacement of the bonding tool was observed in the Search position at the low force setting. This was considered the cause of the lack of bond repeatability. Experimental results obtained with the ultrasonic power disconnected and with the required higher force setting were much more repeatable, giving a consistently better bond. With this empirical background, a review of available literature on ultrasonic bonding was appropriate. This review indicated very little reporting of results with gold wire or ribbon. A summary of the ultrasonic welding process is appropriate before explaining this lack of success with gold.

Ultrasonic Vibratory Welding Process

An excellent description of the vibratory welding process has been stated by J. N. Antonevich³ of the Battelle Memorial Institute:

The mechanics of ultrasonic welding are relatively simple. When material surfaces are to be welded they are made to slide in contact with each other under a compressive force. The compressive force provides intimate contact, and the work done in sliding heats the interface to a temperature at which the materials will interact metallurgically to eliminate the interface. This metallurgical interaction may be fusion between materials or cohesion from intimate contact that causes the interface to become a grain boundary between the materials.

The actual mechanism appears to be as follows. During the first few cycles of sliding, the contacting surfaces are abraded, fracturing any oxide layer and creating frictional heating aided by the fractured oxide serving as a built-in grinding compound. This generated heat first drives off the adhered moisture layer present on any ordinary metallic surface. Secondly, the heating lowers yielding forces, causing deformation of surface asperities and increasing the contact area. When yielding ceases, the surfaces are said to be in intimate contact and a metallurgical bond is produced. P. M. Uthe of Uthe Technology, summarizes the process as follows.⁴

The vibratory welding process involves two separate and distinct steps. First, the metal interfaces are cleaned and heated through the mechanism of vibratory friction. Second, the applied pressure forces the softened interfaces into convergence, thereby producing a hot pressure bond.

Shortcomings of Gold for Ultrasonic Bonding

Considering the above analysis of the ultrasonic bonding process, a logical conclusion is that an ideal material for ultrasonic welding should have a strength-temperature relationship such that the bond interface can be made soft and plastic in the area of heating, while the bulk material remains hard and supportive (insignificant heating). A brief consideration of some of the physical properties of gold readily indicates the difficulty in obtaining consistent ultrasonic gold bonds. First, gold oxidizes only to a minimal extent, if at all, depriving the process of the presence of an interface griding compound. Examination of The Tensile Strength Versus Temperature⁵ curve of Figure 7 shows that gold has negligible change in strength over a wide

temperature range. This implies that it is most difficult to obtain the required plasticized interface while retaining the bulk material in a nondeformed or slightly deformed hardened state. A practical observed shortcoming of gold-to-gold bonding is that because of the soft nature of gold, the bonding tool has a tendency to vibrate on top of the gold ribbon, resulting in a scrubbed deformation on top of the ribbon, but little or no bonding at the interface. P. M. Uthe⁶ reports on another undesirable feature of gold in this type of bonding in a discussion of vibrational standing waves (resonance) encountered in gold at ultrasonic frequencies.

Figure 7. Tensile Strength Versus Temperature, Gold/99-AL/1-Si

These limitations lead to considerable doubt that gold vibrational bonding offers any significant advantage over gold thermocompression bonding, and in fact, may have more disadvantages in terms of process control. At this point the decision was made to disconnect the ultrasonic power source and develop a process for crossovers of gold ribbon by the use of thermocompression bonding, the goal being to shorten the development time and provide a more immediate manufacturing process.

Bonder Modification

The first bonding-system modification consisted of disconnecting the ultrasonic power source, as described previously; however, continued use of the power logicon is necessary because the bond-time sequence is programmed through that unit. Removing the logicon output signal from the transducer horn allows all other functional sequences to operate normally, but with no vibratory action.

The next bonder modification was to remove the cutting knife. During the early bonder characterization the knife adjustment required to ensure cutting was very critical. In addition, the requirement that the 0.100-inch-wide (2.54 mm) cutting edge lower to the surface of the substrate dictated either extensive modification or complete removal in order to bond close to applique circuit components. During early experimentation with the bonder wire-clamp and knife assembly, it was discovered that the wire clamp could be adjusted to pull and break the wire at the completion of the second bond. Throughout the remainder of this report, Bond 1 is the first bond made during the cross-over bonding, Bond 2 is the second bond, as shown in Figure 8. The wire break occurs at the trailing edge of Bond 2, resulting in a tailless bond that is automatically pull tested during the bonding sequence. Lifting this bond, instead of breaking at the heel, can be a warning of weak bonding. The data (discussed and shown later) indicate that Bond 2 is typically stronger than Bond 1; therefore, all subsequent data were taken only on Bond 1 with the exception of the hook-pull data.

Figure 8. Crossover Bonding Sequence

The final bonder modification was to modify the work holder to hold the substrate by vacuum. Of the three bonders characterized, one originally had a mechanical spring holddown clamp, and the other two had small vacuum holds. The two latter systems were modified by milling out the work holder surface with an X pattern sufficiently large to vacuum hold 1.5-inch (38.1 mm) square substrates. The work holder of the other bonder was modified in the same manner by adding a vacuum line, hole, and X-pattern grooves.

Pull-Test Techniques

Equipment characterization and process optimization are both determined largely by bond performance. Pull strength is the most obvious test of bond performance. Two important factors that affect the pull strength value are the rate of pull and the angle of pull. To minimize these variables, all bond strengths for system characterization were taken at an angle of 45 degrees, and a controlled pull rate of 10 cm/minute was obtained by using a constant speed motor-driven pull tester. A sketch of the two pull-test techniques is shown in Figure 9. The bond failure modes are defined in Figure 10.

A. 45° RIBBON PULL TEST

B. HOOK PULL TEST

Figure 9. Ribbon Crossover Pull-Test Techniques

- B RIBBON BREAKS IN BOND AREA
- H RIBBON BREAKS AT HEEL OF BOND AREA
- W BREAK IN WIRE AWAY FROM BOND AREA
- BL BOND SEPARATION FROM SUBSTRATE METALLIZATION
- ML METALLIZATION SEPARATION FROM SUBSTRATE

Figure 10. Ribbon Crossover Bond Failure Modes

Test Substrate Configuration

Preliminary work on thin-film networks now in production indicated that physical layout dimensions are fundamentally important in developing a manufacturing process. To obtain meaningful data on dimensional tolerances, a test metallization pattern (Figure 11) was designed and used for all additional data collection. This pattern can be used also for operator training and certification.

Optimization of Thermocompression Bonding Parameters

Without the application of ultrasonic power, the controllable system parameters are bonding force, tip temperature of the bonding tool, bonding time, and substrate temperature. It is desirable to reduce the process control to as few variables as possible. Previous experience in thermocompression bonding dictates that a certain temperature threshold be present to ensure quality thermocompression bonds. This threshold level may vary for different bonding situations, but in general is above 200°C. Another input from HMC processing literature is that approximately 200°C is the practical upper limit at which tantalum-nitride thin-film resistors can be held without causing resistor value changes. Also, chrome diffusion through the gold metallization occurs above 200°C and can degrade the bondability of the surface. For these reasons, a substrate temperature of 200°C ±10°C was chosen as a desirable operating

Figure 11. Substrate Test Pattern

point. Three controllable parameters around which an optimum schedule was to be developed now remained. Before assigning an order to these three, a review was made of the thermocompression bonding mechanism. A Bendix report⁷ stated the process as follows:

Thermocompression bonding is a technique which welds material through the application of pressure and heat. It is a solid state process in that neither weldment changes phase during welding. Since the temperatures used are well below the melting point of the weldments, very little diffusion exists, and the technique is an example of 'intimate contact theory'. The theory of intimate contact states that free energy is associated with all surfaces and if two surfaces are brought into contact the energy at their interface will decrease. Furthermore, the energy (force) required to rupture the interface is equivalent to the decrease in surface energy which occurred during the joint formation. Thus, one may speculate that to create a bond he must simply place the weldments in contact. A weld would be created by this process, but the strength of the resulting joint would be poor since the free energy of practical surfaces is low and since practical surface roughness will not permit contact over an appreciable area. Thermocompression bonding relies upon the application of force, heat and time to remove contaminants and achieve conformity of weldment surfaces.

Of the three process variables, bond time is of the least importance, and is a factor only to the extent that finite masses with finite mobilities require time to heat and flow. Considerable work has been done, as evident in the literature,⁷ to show that the time required for gold-to-gold welding is less than 0.2 second. This time depends on the physical and material properties of the bonding tool, as well as the relative temperatures of the bonding tool tip and the substrate. In any particular application, bond time must be sufficient for the bond interface to reach equilibrium temperature, thus allowing for contaminant dispersion and material flow. Measurements taken of the interface temperature versus time for the range of bonding tip temperatures used in this application indicated that 0.5 to 1.0 second is necessary for interface equilibrium. The RES bonder was temporarily set at 2.0 seconds to remove this factor as a process variable.

Temperature has an important, but secondary, influence on bond quality. A previous discussion outlined the reasons for holding the substrate temperature to 200°C. As previously mentioned, the RES bonding system provides additional temperature by heating the bonding tip. The two heat sources contribute to produce the required interface temperature. The interface temperature

obtained must be sufficient to facilitate plastic deformation, to increase the elasticity of the materials, and to increase the mobility of surface contaminants, thereby increasing the surface free energy. Interface temperature interacts with and depends on the bonding force used. A practical upper limit is imposed by the material construction of the tip heater and the ability of the bonding tip to transfer this heat. At this point in the schedule development the tip temperature was set near the maximum of 310°C.

The remaining variable, and the major factor in thermocompression bond integrity, is bonding force. The bond force must deform the surfaces sufficiently to break-up and disperse surface asperities and contaminants. The bond then results from intimate contact of the materials. The previously discussed temperature parameter helps to accomplish this, but is overshadowed by the force mechanism. There is no transport of material other than flow from the pressure applied. Thermocompression bonding, therefore, is deformation bonding in that the dominate mechanism is the application of force between two materials to create plastic flow and cause intimate contact.

In order to determine the optimum bonding force for highest pull strength,* bonds were made at various force settings with the bond time and tip temperature set as discussed above. Figure 12 is a plot of the results of this test using 0.002-by-0.010-inch (50.8 by 254. μm) gold ribbon. The recorded data are shown in Table 1. Figure 12 and Table 1 reveal that excellent bonds were obtained from approximately 575 to 900 grams bonding force, with the strongest bonding occurring at 750 grams. However, bond failures occurred both below and above these settings. A bonding force range can be tentatively determined from this data by keeping in mind that it is for a given value of bond time and bonding tip temperature. Data were recorded for various tip temperature settings and at various force settings within the above determined range. These data are shown in Figure 13. This graph indicates little difference over the force range for bonding tip temperatures above 220°C. The curve taken at 195°C begins to drop off appreciably in bond strength, indicating little or no deformation bonding. High vacuum experiments⁸ have shown that heating is not required for bonding thoroughly clean surfaces.

*Although force is often expressed in pounds or newtons, the gram is a more convenient unit for expressing the small values of pull strength measured on microcircuit substrates, and is commonly used in this technology. A Gramme gage (dynamometer) calibrated directly in grams is used for this purpose. Therefore, the force measurements expressed in this discussion and in the following figures are not converted to newtons. For those who wish a relative comparison, one gram force is approximately equal to 0.0098 newton.

Table 1. Pull Strengths and Failure Modes for Various Bond-Force Settings

Bond Force Setting and Force in Grams	Bond 1, Failure Force and Mode	Bond 2, Failure Force and Mode
1.75, 225 g force	140B, 150B, 100B*	††
1.5, 500 g force	150BI., 185H, 130BI., 165BI., 170H, 145B, 140B (Avg 155†)	††
1.25, 575 g force	175H, 140H, 180H, 175H, 145H, 170H (Avg 164†)	190W, 200W, 205H, 190W, 200W, 185H (Avg 196†)
1.0, 650 g force	170H, 180H, 180H, 175H, 180H, 155H (Avg 173†)	210W, 180H, 175W, 210W, 190H (Avg 193†)
0.75, 750 g force	175H, 160H, 170H, 175H, 170H, 190H, 180H, 190W, 180H (Avg 177†)	210H, M1., 195W, 200W, M1., 205W, 200W (Avg 202†)
0.50, 825 g force	160H, 180H, 190H, 165H, 170H, 175H, 180H, 165H, 170H (Avg 173†)	180W, 185W, 190W, 200H, 205W, 190H, 200W (Avg 193†)
0.25, 900 g force	165H, 165H, 160H, 155H, 180H, 160H, 170H, 120H, 160H (Avg 159†)	180W, 200W, 180W, 190W, 195W, 210W, 195W (Avg 193†)
0, 1100 g force	150H, 125H, 155H, 140H, 140H, 160H, 160H, 120B (Avg 144†)	160B, 175W, 175W, 180W, 190W, 195H, 185W (Avg 180†)
<p>*Bond strength beyond this was not sufficiently consistent to provide reliable data. †Averages of above strength values. ††Bond 2 did not withstand pig-tail pull tests. The failure modes are defined in Figure 10. Bonding time: 2 seconds Substrate temperature: 200°C Flip temperature: 310°C</p>

Figure 12. Bond Strength Versus Bonding Force and Bonder Force Setting

These observations are consistent with and are explained by the view that heating is effective because it is a means of cleaning by dispersing surface contaminants. The combination of low bonding force and high tip temperature in Figure 13 also produced a decrease in bond strength. BL type failures were observed with this combination. English and Hokanson⁹ attribute this result to lack of intimate contact at the lower force. Their analysis indicates that sufficient force is necessary to cause a shearing displacement at the intended bond interface.

Figure 13. Bond Strength Versus Bonding Force for Four Tip Temperatures at Various Bonder Force Settings

The parameter that required additional investigation at this point was the bond time. Figure 14 is the result of this test. As in Figure 13, each data point is the average of ten bonds. The interdependence of time and temperature is well indicated in Figure 14. At the higher tip temperatures, good bonds are obtained at bond times of less than one second. A drop off in bond strength for bond times less than 1.75 seconds occurs at the lower tip temperature of 220°C.

Figure 14. Bond Strength Versus Bonding Time for Three Tip Temperatures at 750 Grams Constant Bonding Force

Bonding Schedule

From the data of Figures 12, 13, and 14, a bonding schedule can be determined. Before interpolating these data a minimum average bond strength criterion was arbitrarily chosen at 160 grams. A temperature constraint is placed on the tip by the short lifetime of the tip heaters when operated above 300°C. With these factors in mind, the following bond schedule was chosen: bond time--greater than 1.75 seconds; bond tip temperature--220 to 300°C; and bond force--650 to 850 grams.

It is often convenient to use the limits of a schedule of this type in a graphical manner to develop an operating zone. This graphical representation is then referred to as the schedule polygon, and can be used in the setup of any similar bonding system after the bonder characterization is complete. A graphical display of the bond schedule described above is shown by the solid line in Figure 15. The enclosed area defines an operating region wherein any combination of bonding force and tip temperature so chosen will result in consistently strong bonds. (Note that this polygon is for the specific size of gold ribbon used.) It is by no means exclusive of other combinations of bonding force and tip temperature that will give consistent bonds. In this particular

Figure 15. Ribbon Crossover Bonding Schedule Polygon

process the schedule polygon is large enough that no problems should occur in process control. In the event that it is desirable to expand the polygon, a trial-and-error process of picking and verifying schedule points by pull test data is used. The dotted line of Figure 15 is shown to include the six data points verified by this technique. The bond-time variable was removed by selecting a "longer than safe" bond time of 2.0 seconds. A decrease in bond time would tend to shift the polygon to the right and upward. Appreciable change in bonding time would also alter the shape of the polygon. Again, this polygon is not only the result of the physical laws of bonding, but also is determined in part by the constraints of bonding strength criteria, processing temperature limitations, and the lifetime of the bonding tool.

In selecting a bonding schedule point from the developed polygon, one should initially begin with the center point (peaks of Figure 12 and Table 1). Recalling that thermocompression bonding is basically a deformation process, any adjustment for a specific bond strength should be made along the force axis. Temperature adjustments should be made to reduce adherence problems, prevent BL-type failures and, secondarily, to improve bond strength.

Design Layout Dimensions for Ribbon Bonding

As shown previously in Figure 11, a test substrate metallization pattern was designed to determine dimensional restrictions imposed by the ribbon bonding process. As with many processes used in HMC manufacturing, trade-offs are necessary, depending on the required end result, be it economics, production ease, or circuit performance. The tabulated dimensions in Figure 16 are determined by several factors, and are intended as a design guide only. The preferred dimensions are premised upon having good bonding yields when using normal manufacturing care and techniques. Minimum values indicate that additional precautions such as better-than-average operators and increased inspection or testing will be necessary, or lower yields must be expected.

Bond Strength Comparison of Various Ribbon Types

The development work in the bonding system characterization was all performed using 0.002- by 0.010-inch (50.8 by 254 μm) gold ribbon of 3- to 5-percent elongation. This degree of hardness (elongation) was recommended by the bonding system vendor. A comparison of bond strength and tensile strength of various elongations is shown in Figure 17. Slightly higher bond strengths were obtained with the 3- to 5-percent elongation. Data for 0.002 by 0.005-inch (50.8 by 127. μm) ribbon of 3 to 5-percent elongation also are shown.

Ribbon Size (Inches)*	Dimensions (Inches*) †							
		A	B	C	D	E	F	K
0.010 by 0.002	Minimum	0.010	0.005	0.010	0.030	0.015	0.015	0.020
	Preferred	0.015	0.010	0.015	- - -	0.020	0.020	0.025
	Maximum	- - -	- - -	- - -	0.250	- - -	- - -	- - -
0.005 by 0.002	Minimum	0.010	0.005	0.005	0.020	0.010	0.010	0.015
	Preferred	0.015	0.010	0.010	- - -	0.015	0.015	0.020
	Maximum	- - -	- - -	- - -	0.025	- - -	- - -	- - -
*0.001 Inch = 25.4 μ m								
†Maximum Dimensions Not Shown Are Not Applicable								

Figure 16. Ribbon Crossover Layout Dimensions

Figure 17. Gold Ribbon Tensile and Bond Strengths

Bond Strength and Reliability

Several tests were performed in order to increase the knowledge of the process, verify the reliability of ribbon bonded crossovers, and determine process control monitors.

Hook-Pull Strength Versus 45-Degree Pull

As previously shown in Figure 9, there are two fairly-simple techniques for pull testing this type of bonding. As also discussed, the 45-degree pull test was used throughout the major portion of this work. After completing the bonding schedule development, data were taken to compare the results of the two methods. This data distribution is shown in Figure 18 as pull strength versus accumulative percent elongation. In the 45-degree pull one end of the bonded loop is cut with a sharp knife and the bonded ribbon is pulled until failure by clamping and pulling at an angle of 45 degrees in relation to the substrate surface. In the hook-pull the ribbon is left connected at both ends, and a hook is placed under the loop and pulled perpendicularly away from the

Figure 18. Gold-Ribbon-Bond Pull Strength Distribution

substrate. In the hook-pull test, an attempt was made to keep the bond length and loop height constant to minimize the change in pull angle. The lesser slope of the 45-degree pull curve in Figure 18 indicates a tighter distribution. The straight line for the 45-degree pull test indicates a normal distribution curve, whereas the curved line of the hook-pull test indicates a skewed or possibly even binodal distribution. The conclusion is that the hook-pull test is unpredictable, with probable reasons being lack of pull-angle control and the tendency of the hook to cut the ribbon.

Loop Strength

Data were recorded to indicate the support strength of loops formed in bonding crossovers. Pressure was applied at the top of the loop arc to push the crossover down against the conductor over which it crosses. Figure 19 indicates that over the limited crossover length range of 0.030 by 0.100 inch (76.2 by 254 μm) the support strength is a linear function of crossover length. Additional data points over a longer crossover span range or the application of the theory of mechanics to the problem of the critical force required to buckle a curved beam supported at both ends would no doubt give a nonlinear variation with span length.

Figure 19. Ribbon Crossover Support Strength

Temperature Cycle and Centrifuge Test

Ninety bonds were made using the developed bond schedule. One-third of the bonds were pull tested after bonding, one-third after temperature testing, and the remaining one-third after centrifuge. The temperature testing consisted of ten cycles from -55 to +125°C, 5 minutes dwell at each temperature limit, and a cycle rate of 10°C per minute. The centrifuge test was one cycle

to 20,000 g in a direction perpendicular to and tending to pull the bonds away from the substrate. Distribution of these data is shown in Figure 20. All failures after bonding were H type. After temperature cycle all failures were H type with the exception of three W and one BL failure. Two after-centrifuge failures were W type, the others were H type. No appreciable degradation in the bond strength was observed.

Figure 20. Pull Strength Versus Percent Elongation of Gold-Ribbon Bonds After Temperature-Cycle and Centrifuge Tests

Process Control--Visual Inspection

The process control of a manufacturing process such as thermocompression bonding requires continued attention to ensure reliable output. Temperatures, bond time, and bond force can be physically measured and the system can be certified for a given period of time based upon Engineering and Quality Control inputs as to the system capabilities. Further certification might be through the bonding of a determined number of samples and pull testing for a desired strength value. If desired, a sample may be selected during actual production runs and used as a lot certification. All of these do not ensure a reliable bond on an individual bond basis. Short of nondestructive pull testing, generally impractical in a bonding process, visual inspection criteria can be the most significant factor in process control. Figure 21 illustrates the important physical dimensions and visual characteristics of the crossover and the bond. The height of the crossover as it traverses the underlying conductor must be maintained above a minimum level to prevent shorting. This

Figure 21. Physical Dimensions of Significance in Crossover Bonding

height will depend upon the length of the crossover, the distance from the bond area and to the underlying conductor, and the type of ribbon used. Data recorded for 0.002- by 0.010-inch (50.8 by 254 μm) ribbon, conductor spacing of 0.005 inch (127 μm) and crossover length of 0.030 inch (762 μm)

averages 0.0043 inch (109 μm) for H and 0.0031 inch (79 μm) for J, as shown in Figure 21. Minimum value for H was 0.00356 inch (90 μm) and for J was 0.00270 inch (69 μm). In the same order, the corresponding values for a 0.040-inch-long (1016 μm) crossover are 0.00441, 0.0036, 0.00384, and 0.0027 inch (0112, 91, 97, and 69 μm). This upward-looping or arcing of the crossover ribbon is called bugging. The bonding system used in this work does not have a control mechanism for this variable. The technique used was to move the manipulator control arm during the second bond so that the ribbon was placed in compression and caused to flex upward.

The deformation distance, d , and the spread out in the bond area, ΔW , are more difficult to observe visually and to measure accurately. For Bond 1, consistent bonds as determined by pull strength data had typical deformations of 0.0001 to 0.00015 inch (2.54 to 3.81 μm). For Bond 2, d was typically 0.0002 to 0.00025 inch (5.08 to 6.35 μm). Values of ΔW on Bond 1 were typically 0.00025 to 0.0005 inch (6.35 to 12.7 μm) and ΔW for Bond 2 was 0.0005 to 0.001 inch (12.7 to 25.4 μm). The scrubbing action caused by the operator moving the manipulator during the bond cycle accounts for the large deformation and increased spread-out of Bond 2.

The X dimension is a direct function of the size of the bond wedge footprint and should be consistent for Bond 1. The bond also can be inspected visually for a complete footprint to help verify bond reliability. The X dimension also is elongated on Bond 2 because of the scrubbing action. For the bonding wedges used in this work, $X = 0.007$ inch (177.8 μm) for Bond 1 and varies from 0.009 to 0.010 inch (228.6 to 254 μm) for Bond 2. Tolerances for these critical dimensions may be specified and the process can be monitored as determined by the bonding wedge size, the ribbon size, and the other requirements of the particular application. Visual aids such as the photographs of Figures 22 and 23 can be used to assist in training operators and inspection personnel. Figure 22 shows the type of footprint expected on Bond 1. Figure 23 shows a complete crossover of both 0.005-inch (127 μm) and 0.010-inch (254 μm) ribbon widths.

BONDER SETTINGS:
TIP TEMPERATURE 8
BONDING TIME 6
FORCE 0.75

MAGNIFICATION 115X

Figure 22. Bonding Tip Imprint on Bond 1

30X

Figure 23. Typical Gold-Ribbon Crossover Bonds

ACCOMPLISHMENTS

A bonding schedule was developed for thermocompression bonding gold ribbon crossovers to gold metallization. Data were compiled to indicate the strength of this type of intraconnection.

FUTURE WORK

Several areas of investigation involving extension of the work performed to date are required to obtain production capability for fabricating gold-ribbon crossovers. Recommended further work includes the following:

- Evaluation of bonding tools, material, and necessary physical design work;
- Re-evaluation of thermosonic gold bonding (This should include techniques of ultrasonic bond power measurement which should overlap and interface with the bonding-tool design investigation);
- Evaluation of other models of ribbon bonding systems;
- Extension of reliability data, including but not limited to a study of the resonant frequencies of gold ribbon intraconnections; and
- Evaluation of other materials such as gold-plated copper ribbon.

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