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THICK FILM BONDING

By G. A. Swartz

Published February 1979

Topical Report

Prepared for the United States Department of Energy
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By G. A. Swartz

Published February 1979

Topical Report
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BDX-613-2090 (Rev.), Topical Report, Published February 1979

Prepared by G. A. Swartz

This project was undertaken to determine the characteristics of thick film conductors that affect thermocompression bonding. Thick film inks were analyzed to determine compositional characteristics that could be used as acceptance criteria. Analytical methods evaluated included thermogravimetric analysis, pyrolysis gas chromatography, infrared spectrophotometry, mass spectrometry, atomic absorption spectrophotometry, scanning electron microscopy with energy dispersive X-ray spectroscopy, and an electronics counter. The effects of bonding force and substrate temperature versus bond strength were evaluated for three thick film conductor materials which had been fired at various times and temperatures. Conductor resistance was also evaluated. The scanning electron microscope with energy dispersive X-ray spectroscopy was used for the analysis of fired films.

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CONTENTS

Section	Page
SUMMARY.	6
DISCUSSION	8
SCOPE AND PURPOSE.	8
PRIOR WORK	8
ACTIVITY	9
<u>Materials Analysis</u>	9
<u>Bondability and Resistivity Versus Firing</u> <u>Conditions</u>	10
<u>Fired Films Analysis</u>	20
CONCLUSIONS.	31
REFERENCES	34
DISTRIBUTION	35

ILLUSTRATIONS

Figure		Page
1	Test Pattern and Substrate	11
2	Firing Envelope for Ink A.	13
3	Firing Envelope for Ink B.	14
4	Thick Film Bonding Envelopes for Ink A	15
5	Thick Film Bonding Envelopes for Ink B	16
6	Bond Strength Versus Bond Force and Substrate Temperature, for Ink A, Fired at 1000°C for 10 Minutes	20
7	SEM Photographs of Material B Fired at 850°C for 10 Minutes (Polaroids)	21
8	SEM Photographs of Material B Fired at 850°C for 20 Minutes (Polaroids)	22
9	SEM Photographs of Material B Fired at 1000°C for 10 Minutes (Polaroids)	23
10	SEM Photographs of Material B Fired at 1000°C for 20 Minutes (Polaroids)	24
11	SEM Photographs of Material A Fired at 850°C for 5 Minutes (Polaroids).	25
12	SEM Photographs of Material A Fired at 850°C for 10 Minutes (Polaroids)	26
13	SEM Photographs of Material A Fired at 1000°C for 5 Minutes (Polaroids)	27
14	SEM Photographs of Material A Fired at 1000°C for 10 Minutes (Polaroids).	28
15	SEM Photograph of Material B Fired at 850°C for 10 Minutes Identifying Surface Voids (Polaroid)	30
16	SEM Photograph of Material A Fired at 850°C Identifying a Surface Void and an Agglo- meration (Polaroid).	31
17	SEM Photograph of Typical Resistor-Conductor Interface Region (Polaroid).	32

TABLES

Number		Page
1	Measured Resistivity Data.	12
2	Bond Failure Strength (N) and Variance Versus Bonding Parameters for Various Conductor Firing Schedules Ink B (480 Bonds)	17
3	Bond Failure Strength (N) and Variance Versus Bonding Parameters for Various Conductor Firing Schedules, Ink A (1392 Bonds)	18

SUMMARY

The purpose of this endeavor was to develop the necessary information for the specification of thick films used for terminations on components and circuitry to improve the reliability of thermocompression bonds on thick films.

The investigation included extensive analysis to determine compositional characteristics of materials as received from the vendor. Thermocompression (TC) bonding characteristics of conductor films fired at various times and temperatures were investigated. Bonding investigations also included examination of film densification and electrical resistivity versus firing parameters. This work was initiated as a result of problems encountered during early production of an electromechanical switch when TC bonding fine wires to capacitors with thick film terminations.

Many discrete electrical devices (chip capacitors, chip resistors, and chip thermistors) use thick film materials for electrical terminations. Electrical connections are made from the device to conductor pads on the carrier board by TC bonding fine wire or ribbon interconnections. Beam lead devices are bonded directly to the carrier board. Bonding pads on the carrier board may be either thick film or thin film.

Thick film bondability may be affected by the particle size of paste constituents, material composition, film thickness, firing conditions, and interactions between adjacent materials. Consequently, many thick film terminations on chip components are not readily thermocompression bondable. It is sometimes necessary to try several bond sites to achieve a satisfactory bond. This difficulty in making fine wire bonds to thick film terminations necessitates double wire bonding for redundancy and 100 percent nondestructive testing of fine wire bonds.

The current project was undertaken to determine what ink characteristics influence fired films and what analytical methods should be used to characterize inks and films. Inks selected for evaluation included two platinum-gold glass bonding conductors and one gold-reactive bonding conductor. The analytical methods used were thermogravimetric analysis, pyrolysis-gas chromatography, infrared spectrophotometry, mass spectrometry, atomic absorption spectrophotometry, scanning electron microscopy with energy dispersive X-ray spectroscopy, and particle size analysis using a Coulter counter. Resistivity was evaluated for the conductor materials fired at various times and temperatures. The effect of TC bond time and temperature on bond strength was then evaluated for the conductors fired at various times and temperatures.

The following conclusions were made from these evaluations.

- Thermogravimetric analysis, particle size distribution, and atomic absorption analysis are preferred methods for verification of materials.
- Increased firing time and temperature reduce electrical resistivity of conductors.
- Conductor films fired at higher temperatures are more readily thermocompression bondable than those films fired at lower temperatures, although those films fired at the lower temperatures provide stronger bonds.
- Reactive bonding fritless conductors may require additional surface treatment prior to TC bonding.
- Comparable bonds can be made on a given film using a range of bonding parameters. Substrate temperatures are limited by the softening point of the conductor glass.
- Bonding parameters must be evaluated for each film type and for similar films produced with different conditions of time and temperature.
- Increased firing conditions increase the films cross-sectional density, but also increase surface porosity.
- The conductor films interact with the grain boundaries of the substrate to form a conductor-substrate bond.
- Thermocompression bonds should not be made within 0.2 mm of a conductor-resistor overlap because of the glazed region encountered near the interface.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this endeavor was to develop the necessary information for the specification of thick films used for terminations on components and circuitry to improve the reliability of thermocompression bonds on thick films.

The investigation included extensive analysis to determine compositional characteristics of materials as received from the vendor. Thermocompression (TC) bonding characteristics of conductor films fired at various times and temperatures were investigated. Investigations also included examination of film densification and electrical resistivity versus firing parameters.

PRIOR WORK

A number of ceramic "monolithic" or "chip" capacitors were used in the electronic switch. These small components utilized thick film terminations and were attached to thin film networks with an epoxy adhesive. Electrical connections to the circuit were made by TC bonding gold wires between the capacitor terminals and the thin film conductors on the network. Because of difficulty in bonding to the thick film capacitor terminals, it was necessary to bond two wires for each connection. Nondestructive testing of each wire was required to ensure reliability.

"Thick film technology" refers to the process of depositing conductors, resistors, or dielectrics on ceramic by screen printing. The conductor, resistor, and dielectric forming materials are fine powders which must be mixed with organic resins and solvents to provide screen printing characteristics. Frit is added to provide cohesion of the film and adhesion to the substrate through high temperature fusion. After screen printing, the volatile solvents are removed from the patterns in a drying oven. The remaining organic materials are removed during the early part of the firing cycle and the frit is melted to complete the film during the final portion of the firing cycle (600 to 1000°C).

Many discrete electrical devices (chip capacitors, chip resistors, and chip thermistors) use thick film materials for electrical terminations. Thick film materials may also be used to form bonding pads, conductors, resistors, and insulating films on the ceramic carrier board.

Discrete devices may be bonded to the ceramic carrier. Electrical connections are made from the device to conductor pads on the carrier board by TC bonding fine wire or ribbon interconnections. Beam lead devices are bonded directly to the carrier board. Bonding pads on the carrier board may be either thick film or thin film.

Thick film bondability may be affected by the particle size of paste constituents, material composition, film thickness, firing conditions, and interactions between adjacent materials. Consequently, many thick film terminations on chip components are not readily thermocompression bondable. It is sometimes necessary to try several bond sites to achieve a satisfactory bond. This difficulty in making fine wire bonds to thick film terminations necessitates double wire bonding for redundancy and 100 percent nondestructive testing of fine wire bonds.

A thick film capability was established and tested by fabrication and evaluation of developmental samples.¹ This work has provided the expertise required to fabricate thick film elements and to evaluate the materials, processes, and workmanship required.

ACTIVITY

Materials Analysis

An extensive literature search was performed to determine what ink characteristics influence the fired film and to see what analytical methods should be used in characterizing the inks.

Laboratory tests were performed on two classifications of materials, organics and inorganics. The methods applied to the analysis of the organics were: thermogravimetric analysis (TGA), pyrolysis-gas chromatography (P-GC), infrared spectrophotometry (IR), and mass spectroscopy (MS). The methods applied to inorganics were: scanning electron microscopy/energy dispersive X-ray spectrometry (SEM/EDAX), atomic absorption spectrophotometry (AA), and analysis using an electronics counter. The organic component in most inks is a complex mixture of pine oils and resins which vary from lot-to-lot with each manufacturer. This variation does not affect the properties of the fired film but may affect printing characteristics. The temperatures at which the organics volatilize are important in drying and firing. Thermogravimetric analysis is capable of measuring the temperature at which various components volatilize and the weight percent volatilization. Pyrolysis-gas chromatography and infrared spectrophotometry are methods that identify groups of compounds without giving an explicit composition. TGA, P-GC, and IR are fingerprinting techniques which detect some facet of lot-to-lot variation. Qualitative analyses were made

using the mass spectrograph, but this does not appear to be necessary to assure sufficient lot-to-lot uniformity. Thermogravimetric analysis is recommended as the receiving inspection method for the organic components.

The inorganic portion of the ink consists of particles of metal and glass. The scanning electron microscope/energy dispersive X-ray analyzer was used to view individual particles and to analyze their composition. Atomic absorption (AA) spectrophotometry was used to obtain a quantitative chemical analysis of metal and glass combined. An electronics counter was used to measure the particle-size distribution of the metal and glass in combination. Coulter and AA analysis are recommended as the receiving inspection methods for the inorganic component.²

Bondability and Resistivity Versus Firing Conditions

Two fritted platinum-gold conductor inks and one fritless-gold conductor ink were used for this evaluation.

Films of these materials were fired at various time and temperature combinations determined from vendor product data sheets. The fired films were evaluated for electrical resistivity and TC bonding characteristics.

Sample Preparation

Test samples for this investigation were prepared in the configuration shown in Figure 1. The pattern consists of fifteen 1.016-mm-square pads along one edge, a meandering pattern 0.508-mm-wide by 101.6-mm-long near the opposite edge, and twelve 2.032-mm-square pads in the center. The test patterns were screen printed using standard printing techniques on 25.4-mm-square by 0.63-mm-thick, 96 percent aluminum-oxide substrates. Printed patterns were dried in accordance with the manufacturer's recommendations and fired as specified in the individual test sections. Firing conditions consisted of the minimum and maximum times and temperatures of the manufacturer's recommended range. The meander pattern was used to determine sheet resistivity of the fired films. The 2.032-mm-square pads were used for all TC bonding tests. The 1.016-mm-square edge pads were included for solder attachment of lead frames, even though soldering had not been investigated at the termination of work. No sample cleaning was included prior to any testing.

Resistivity

Resistance measurements were made on the conductor materials that had been fired at the various time and temperature conditions. The conductor pattern consisted of a meandering pattern 0.508-mm-wide by 101.6-mm-long providing an aspect ratio of 200 unit

Figure 1. Test Pattern and Substrate

squares. The data summary shown in Table 1 indicates that increasing the peak firing temperature from 850 to 1000°C at constant time decreases resistivity by a factor of 13 to 15 percent. Doubling the firing time at a constant peak temperature decreased the resistivity by a factor of from 1 to 5 percent.

Within the manufacturer's recommended limits, temperature apparently has a greater effect on dc resistance than time does, although an increase in either variable will reduce resistance.

Table 1. Measured Resistivity Data

Material	Peak Firing Temperature (°C)	Resistivity ($\Omega/\square$)			
		5 Minutes At Peak	10 Minutes At Peak	15 Minutes At Peak	20 Minutes At Peak
A	1000	0.068	0.065		
	850	0.079	0.075		
B	1000		0.094		0.092
	850		0.109		0.108
C	1000	0.004		0.003	

Thermocompression Bondability Versus Firing Schedule

Gold ribbons 0.051 by 0.127 mm were used for all bonds. The bonding wedge presented a 0.178- by 0.635-mm-bonding face with front and back radii of 0.020 mm. Bonding wedge temperature was maintained at 300°C and bonding time was held constant at 1.75 seconds for all bonds.

Manufacturer A's recommended firing schedule is 850 to 1000°C for 5 to 10 minutes. Substrates printed with this ink were fired for 5 minutes at 850°C, 10 minutes at 850°C, 5 minutes at 1000°C, and 10 minutes at 1000°C. These conditions are represented by the four corners in Figure 2.

Manufacturer B's recommended firing schedule is 10 to 20 minutes at 850 to 1000°C. Substrates printed with this ink were fired for 10 minutes at 850°C, 20 minutes at 850°C, 10 minutes at 1000°C, and 20 minutes at 1000°C. These conditions are represented by the four corners shown in Figure 3.

Manufacturer C's recommended firing schedule for the reactive-bonding fritless-gold conductor was 5 to 15 minutes at 1000°C. Substrates printed with this ink were fired for 5 minutes at 1000°C, and 15 minutes at 1000°C.

Examination of Figure 4 indicates that bonds are achievable at considerably lower bond force and substrate temperature on those films fired at 1000°C than for those fired at 850°C. The effects of firing time at peak temperature are negligible. In all four

Figure 2. Firing Envelope for Ink A

cases, the upper boundary of the envelope was limited by excessive bond deformation. This limit indicates the region where the predominant failure mode changed from the bond to the ribbon. The upper limits of bond force and substrate temperature are determined by excessive ribbon deformation for all four firing conditions.

Examination of Figure 5 indicates a much greater tolerance of bonding parameters with respect to firing conditions than in the previous group. The minimum and maximum firing conditions (10 minutes at 850, and 20 minutes at 1000°C) may require slightly higher bond force and substrate temperature to achieve minimum bonds than the mid-point firing conditions (20 minutes at 850, and 10 minutes at 1000°C). For this material, the upper boundary of the envelope was limited by the maximum force capability of the bonder. Excessive ribbon deformation did not occur for any of these firing conditions.

The reactive bonding, fritless-gold conductor paste was not readily thermocompression bondable. The vendor indicated that an oxide layer was probably forming on the surface of the film during the cooling portion of the firing cycle. A base metal or

Figure 3. Firing Envelope for Ink B

its oxide is added to the paste to provide a molecular bonding mechanism for the film to the substrate. A faster cooling rate was recommended to eliminate the undesirable oxide by retaining it in solution with the gold. The desired results were not achieved; therefore, an alternate approach consisting of cleaning the films in a 10 percent solution of ammonium persulfate $[(\text{NH}_4)_2\text{S}_2\text{O}_8]$ was evaluated. Although TC bonds could then be made to the conductor film, the adhesion of the conductor to substrate had deteriorated beyond the point of usefulness. Further work on this material was discontinued pending this investigation.

Effects of Bonding Parameters on Bond Strength

In order to evaluate the effects of bonding parameters, bond force, and substrate temperature on bond strength, a number of samples were prepared using bonding conditions within the envelopes shown in Figures 4 and 5. A 90° peel test was used to determine bond failure strength. Data from 1872 bond test samples, evaluated in the bonding parameter study, are summarized in Tables 2 and 3.

Figure 4. Thick Film Bonding Envelopes for Ink A

It is shown in Figures 4 and 5 that bonds are more readily made on those films fired at higher temperatures, although Tables 2 and 3 indicate that stronger bonds are attained on the films fired at lower temperatures. It is also seen that comparable bonds can be made using a range of bonding parameters with the higher substrate temperature requiring lower bond force. This is shown graphically in Figure 6 for the 1000°C films of Table 3. Comparable maximum bond strengths are seen at substrate temperatures from 250 to 450°C. The loss in bond strength for bonds

Figure 5. Thick Film Bonding Envelopes for Ink B

made at the 550°C substrate temperature is probably caused by a weakening or a softening of the glassy phase of the film during the bonding operation.

The range of nominal bond strengths attained, not only between the two different films, but also between the different processing conditions on the same film, indicates the necessity to evaluate bonding parameters for films of a given type which have been fired at the limiting conditions which may occur during normal processing.

Table 2. Bond Failure Strength (N) and Variance Versus Bonding Parameters for Various Conductor Firing Schedules Ink B (480 Bonds)

Bond Force (N)	Substrate Temperature (°C)			
	250	350	450	550
20 Minutes at 1000°C				
3.20		0.31* (0.503)		
4.93				0.32 (0.532)
7.89		0.31 (0.555)	0.36 (0.279)	0.28 (0.564)
10 Minutes at 1000°C				
1.97			0.38 (0.250)	
4.93		0.28 (0.489)	0.42 (0.160)	
7.89	0.33 (0.500)	0.26 (0.469)	0.25 (0.462)	0.23 (0.442)
20 Minutes at 850°C				
4.93	0.50 (0.232)	0.54 (0.169)	0.51 (0.072)	0.43 (0.251)
7.89	0.48 (0.291)	0.50 (0.246)	0.47 (0.156)	0.46 (0.106)

*Parenthetical entry is variance.

Table 3. Bond Failure Strength (N) and Variance Versus Bonding Parameters for Various Conductor Firing Schedules, Ink A (1392 Bonds)

Bond Force (N)	Substrate Temperature (°C)								
	200	250	300	350	400	450	500	550	600
10 Minutes at 1000°C									
4.44						0.39 (0.211)*		0.38 (0.188)	
5.42				0.30 (0.174)		0.53 (0.116)		0.45 (0.210)	
6.41			0.37 (0.169)	0.42 (0.253)		0.54 (0.127)		0.49 (0.115)	
6.90								0.45 (0.158)	
7.40			0.37 (0.214)	0.43 (0.211)		0.53 (0.094)		0.50 (0.145)	
7.89		0.31 (0.303)				0.52 (0.131)			
8.38		0.44 (0.218)		0.53 (0.152)		0.48 (0.176)		0.41 (0.153)	
9.37	0.40 (0.222)	0.45 (0.154)							
10.35	0.43 (0.244)	0.42 (0.266)							

Table 3 Continued. Bond Failure Strength (N) and Variance Versus Bonding Parameters for Various Conductor Firing Schedules, Ink A (1392 Bonds)

Bond Force (N)	Substrate Temperature (°C)								
	200	250	300	350	400	450	500	550	600
10 Minutes at 850°C									
3.30									0.65 (0.105)
3.75									0.60 (0.066)
4.24								0.63 (0.143)	0.63 (0.169)
4.68							0.67 (0.102)	0.66 (0.088)	
5.13						0.65 (0.119)	0.67 (0.184)	0.62 (0.109)	0.59 (0.125)
5.62						0.65 (0.123)			
6.06				0.66 (0.066)	0.65 (0.136)	0.65 (0.127)	0.63 (0.140)	0.61 (0.124)	0.59 (0.130)
6.56				0.65 (0.066)	0.68 (0.134)				
7.00				0.65 (0.094)	0.64 (0.101)	0.63 (0.102)	0.58 (0.142)	0.58 (0.139)	0.57 (0.128)
7.30			0.51 (0.088)	0.59 (0.141)		0.66 (0.071)			
7.64			0.58 (0.098)	0.59 (0.111)	0.62 (0.134)	0.59 (0.132)			

*Parenthetical entry is variance.

Figure 6. Bond Strength Versus Bond Force and Substrate Temperature, for Ink A, Fired at 1000°C for 10 Minutes

Fired Films Analysis

Visual analysis of fired films were conducted using the scanning electron microscope (SEM). Film samples from the four firing conditions of each platinum-gold conductor paste were examined. Of particular concern was the outer surface of the film and the ceramic-film interface.

Figures 7 through 10 show the surface figuration of the ink B samples at 300X magnification while Figures 11 through 14 show the same thing for ink A. For both materials porosity appears to increase with increasing time and temperature during the firing cycle. Cross sections of these films taken at 1000 and 3000X are shown in the same figures. Here film thickness is seen to decrease from approximately 17 to 10 μm for material B and from approximately 22 to 15 μm for the material A as firing time and temperature were increased. Probably more glass is diffused from the film into the substrate and additional sintering of conductor particles

300X

1000X

3000X

Figure 7. SEM Photographs of Material B Fired at 850°C for 10 Minutes

300X

1000X

3000X

Figure 8. SEM Photographs of Material B Fired at 850°C for 20 Minutes

300X

1000X

3000X

Figure 9. SEM Photographs of Material B Fired at 1000°C for 10 Minutes

300X

1000X

3000X

Figure 10. SEM Photographs of Material B Fired at 1000°C for 20 Minutes

300X

1000X

3000X

Figure 11. SEM Photographs of Material A Fired at 850°C for 5 Minutes

300X

1000X

3000X

Figure 12. SEM Photographs of Material A Fired at 850°C for 10 Minutes

300X

1000X

3000X

Figure 13. SEM Photographs of Material A Fired at 1000°C for 5 Minutes

300X

1000X

3000X

Figure 14. SEM Photographs of Material A Fired at 1000°C for 10 Minutes

is noted at the more severe firing conditions. The lower film resistance attained at the higher firing temperatures in (Table 1) verifies this conclusion.

Further examination of these surface photographs, reveals white or apparently void areas in the films. The frequency and size of these voids increase with increased firing conditions. SEM with energy dispersive X-ray analysis of these areas identifies aluminum which in most cases is related to the aluminum-oxide substrate, and verifies the noncontinuity of the conductor metallizations and the presence of voids due to shrinkage of these films. These results are shown in Figures 15 and 16. In another instance, a "white spot" was identified as silicon and is probably an agglomeration from the glassy phase of the paste itself.

The area of these voids and inclusions approach the area of a bond zone which might be expected when TC bonding a 0.025-mm-diameter wire. A form of redundancy should be considered when bonding fine wires to films of this type. The bond zone attained with a ribbon 0.127 mm wide may provide adequate bond strength even when a void is included. Each application must be considered with respect to individual application requirements.

Fired structures of thick film conductors, materials A and B, were analyzed with the electron microprobe to identify the elements and their distribution at the outer surface and at the thick film-alumina interface. In order to estimate the amounts and distribution of the gold, platinum, lead, palladium, and bismuth, regions of the outer surfaces were examined. Resulting electron microprobe data, when compared to atomic absorption analysis previously reported,² indicated a lead and bismuth (oxide) rich layer at the outside surfaces of both conductors with a fairly uniform distribution of platinum, palladium, and gold. The thickness of this bismuth and lead oxide layer at the outer surface may affect bonding parameters and bond strength.

To further analyze the fired films outer surface, Auger analyses were conducted on the A and B samples. In-depth elemental profiles of their as-fired surfaces revealed the outer layer of bismuth and lead oxide was less than 100 nm thick. The palladium, platinum, and gold amounts increased and remained constant after the bismuth and lead oxide layer was dislodged following 45 minutes of sputtering with argon at 1 kV.

SEM analysis of the fractured cross sections of the A and the B fired films indicated that their glassy constituents interacted with the silicon and calcium oxide rich grain boundaries of the 96 percent alumina substrates to provide a solid-state bond. The photomicrographs shown in Figures 7 through 14 also revealed that the fired A films are more porous than the B films. During

300X

Figure 15. SEM Photograph of Material B
Fired at 850°C for 10 Minutes
Identifying Surface Voids

preparation, the samples shown in Figure 9 developed a fracture near the conductor-alumina interface. Energy dispersive X-ray analysis of this zone indicated that it was rich with aluminum, silicon, calcium, and lead oxides. By comparison, the fired A-alumina interfacial region contained bismuth oxides as well as aluminum, silicon, calcium, and lead oxides.

Fractured cross sections of fired conductor-resistor overlap regions revealed that the porous thick film conductors were infiltrated and coated with the thick film resistor. Figure 17 represents the observed diffusion zone between the conductor and resistor fired thick films. The glazed area approximately 0.18 mm wide is unacceptable for thermocompression bonding. While reactions between these materials do occur, they are essentially confined to the interface region. There is no evidence that bonds made to adjacent conductors will be affected. Consequently, this diffusion zone must be avoided when designing bonding pads adjacent to a conductor-resistor interface.

300X

Figure 16. SEM Photograph of Material A Fired at 850°C Identifying a Surface Void and an Agglomeration

CONCLUSIONS

Material evaluation indicates that thermogravimetric analysis, particle size distribution, and atomic absorption analysis are preferred methods for acceptance testing of materials at receiving inspection.

Thick-film conductors fired at higher temperatures and longer times provide lower electrical resistivity than their lower temperature, shorter time counterparts.

Conductor films fired at higher temperatures are more readily thermocompression bondable than those films fired at lower temperatures, although those films fired at the lower temperatures provide stronger bonds.

Reactive bonding fritless conductors may require additional surface treatment such as etching or burnishing prior to TC bonding, due to an oxide layer formed on the surface during high temperature processing.

300X

Figure 17. SEM Photograph of Typical Resistor-Conductor Interface Region

Comparable bonds can be made on a given film using a range of bonding parameters with the higher substrate temperatures requiring lower bonder force. Substrate temperatures that approach the softening point of the conductor glass produce weaker bonds.

It is necessary to evaluate bonding parameters for each film type and for similar films produced with different conditions of time and temperature in order to optimize bond strength.

Increased firing conditions increase the films cross sectional density and increases surface porosity. Pore diameter approaches the expected diameter of a bond zone when bonding a 0.025-mm wire and verifies the necessity for redundancy when bonding fine wires.

The glassy constituents of the conductor films interact with the silicon and calcium oxide grain boundaries of the substrate to form a solid state conductor-substrate bond.

Examination of fired conductor-resistor overlap regions shows a glazed zone less than 0.2 mm wide that should be avoided during TC bonding. This zone is the result of resistor material diffused into the conductor.

REFERENCES

¹G. A. Swartz, "Thick Film Networks" (Final Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-363 (Rev.), May, 1972 (Available from NTIS).

²D. H. Brewer, "Analysis of Thick Film Conductor Inks" (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1491 (Rev.), September, 1976 (Available from NTIS).

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J. E. Long, D/531, 1A46	11
H. T. Barnes, D/554, BD50	12-13
L. Stratton, D/554, 2C44	14-16
T. J. Riehle, D/265, FV43	17
C. R. Beary, D/755, 1A42	18
R. P. Frohmberg, D/800, 2A39	19
D. L. Stoltz, D/814, 2C43	20
D. H. Brewer, D/816, SA-1	21
L. L. Lantz, D/816, SA-1	22
J. P. Starkey, D/816, SA-1	23
A. O. Bendure, D/842, MD40	24
P. L. Blessner, D/842, MD40	25
J. S. Bosnak, D/842, MD40	26
J. J. Hartenbower, D/842, MD40	27
G. A. Swartz, D/842, MD40	28
T. A. Wiley, D/842, MD40	29
R. E. Kessler, D/865, 2C40	30

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ELECTRICAL: Thick Film Bonding

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