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SEMICONDUCTOR DIE ATTACHMENT

Final Report

L. R. Zawicki, Project Leader

Published April 1978

Prepared for the United States Department of Energy
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Project Leader:
L. R. Zawicki
Department 842

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Prepared by L. R. Zawicki, D/842

A technique was established for attaching non-beam lead semiconductor devices to metallized ceramic substrates for hybrid microcircuits (HMCs). Conductive and non-conductive epoxies were shown to be capable of high shear strengths after exposure to high temperatures (125°C to 200°C) for significant periods of time (48 hours to 168 hours). Chip-on-tab devices attached to the substrate with Ablefilm 517 non-conductive epoxy was the technology chosen.

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The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

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CONTENTS

Section	Page
SUMMARY.	5
DISCUSSION	6
SCOPE AND PURPOSE.	6
PRIOR WORK	6
ACTIVITY	6
<u>Eutectic Attachment.</u>	6
<u>Conductive Epoxy Attachment.</u>	7
<u>Nonconductive Epoxy Attachment</u>	9
<u>Outgassing Analysis.</u>	10
ACCOMPLISHMENTS.	13
FUTURE WORK.	13
REFERENCE.	14
DISTRIBUTION	15

ILLUSTRATIONS

Figure		Page
1	Effect of Cure Time on Shear Strength of Epo-Tek H44 Conductive Epoxy	10

TABLES

Number		Page
1	Shear Strength Results For 18 Diodes Attached With Gold-Tin Eutectic Solder.	8
2	H44 Shear Strength Versus Cure Time at 120°C .	11
3	H44 Shear Strength Versus Aging Time and Temperature.	13

SUMMARY

A non-beam lead semiconductor die attachment technique was developed for hybrid microcircuits (HMCs). Environmental and processing requirements for the bond include high temperatures (150°C for 168 hours and 200°C for 98 hours), temperature cycles (-40°C to 125°C), centrifuge testing (5000g), and mechanical shock and random vibration testing. Previous HMC applications required beam lead semiconductor devices attached by thermocompression bonding. The only components that were attached by epoxy were capacitors and ceramic lids, and the temperatures were limited to 150°C. Ablefilm* 517 and 517B non-conductive epoxies are used for the bonding methods.

Eutectic die attachment was evaluated but was rejected because of the required high substrate temperature ($\leq 300^{\circ}\text{C}$) which is incompatible with other HMC processes at Bendix. The conductive epoxies Epo-Tek* H31 and H44 were satisfactory for strength but would not carry the high currents required. A non-conductive epoxy, Ablefilm 517 was evaluated and was found to meet the strength requirements after processing and product tests.

Further work on conductive epoxies for high current applications needs to be done for other potential applications. Epoxy Technology Incorporated has a high current silver-filled epoxy (H20E) and is developing a high current gold-filled epoxy.

*Ablefilm is manufactured by Ablestik Laboratories, Gardena, California; Epo-Tek is manufactured by Epoxy Technology Incorporated, Watertown, Massachusetts.

DISCUSSION

SCOPE AND PURPOSE

This work was conducted to develop a technique for attaching non-beam lead semiconductor devices to metallized ceramic substrates. The semiconductor die bond must be able to withstand high temperatures for significant periods of time, temperature cycles with short transfer times, centrifuge testing, and mechanical shock and vibration testing. The die bond material must not outgas corrosive elements which might compromise the reliability of the HMC package.

This work was conducted between March 1976 and February 1977.

PRIOR WORK

Earlier programs at Bendix used beam lead semiconductor devices which were attached by thermocompression bonding. Beam lead devices are not available for some current applications; therefore, a chip and wire approach is being used. Aluminum wire bonding to the chip is being developed on another project.

Previous work on epoxy attachment of capacitors was temperature limited to 150°C except for some short periods of time at 200°C for beam lead rework. Present requirements include a high temperature bake at 200°C for 48 hours prior to hermetic sealing and a 168 hour, 150°C power burn-in. In addition, the temperature cycle from -40°C to 125°C has very short transfer times (2 to 5 seconds). Previous programs had an approximately 9°C per minute rate change between the temperature extremes during temperature cycle.

ACTIVITY

Three methods were evaluated to accomplish the semiconductor die attachment objective: eutectic die attachment, conductive epoxy attachment, and non-conductive epoxy attachment.

Eutectic Attachment

Eutectic die attachment was the primary method evaluated, but early in the project it was dropped from consideration because of the high

substrate temperature (300°C or greater) required. This high substrate temperature is incompatible with the HMC technology in use at Bendix. Tantalum nitride resistors are stabilized at 300°C, and there is concern about chromium diffusion at temperatures above 200°C. The following paragraphs summarize the work that was done on eutectic attachment.

Gold Silicon Eutectic

Because the chips are gold-plated silicon the bonding tool must be kept below the eutectic temperature of 370°C or a eutectic will be formed on the chip prior to attachment to the substrate. With the tool temperature below 370°C the substrate temperature must be 350°C. If a hot gas (500°C helium) is used for localized heating, the substrate temperature can be lowered to 300°C. Ten devices were eutectically bonded at a substrate temperature of 350°C. The average shear strength for the ten devices was 3.3 N (0.75 lb). This attachment method is unsatisfactory for two reasons: the high substrate temperature and the low shear strengths.

Gold-Tin Eutectic Solder

With the substrate temperature at 250°C and the helium torch temperature at 500°C, 18 diodes were attached with a force of 25 grams. The diodes were gold metallized on the backside. Difficulty in wetting was encountered during this process. The diodes were shear tested at an average of 8.9 N (2.0 lb) and individual results are shown in Table 1. This method of attachment is unsatisfactory because of inconsistent shear strengths and high substrate temperature.

Lead Indium Solder

Solder composed of 75 percent lead and 25 percent indium was considered as an attachment method but was dropped from consideration because the flux removal procedure oxidizes the aluminum metallization on the semiconductor devices. This oxide interferes with subsequent aluminum wire bonding for electrical interconnection.

Conductive Epoxy Attachment

Because of the incompatibility of substrate temperatures in eutectic attachment, another method, conductive epoxy, was evaluated. The two conductive epoxies evaluated were H44 and H31, both manufactured by Epoxy Technology, Incorporated. Epo-Tek H44 is a 100 percent solids, single-component, electrically-conductive gold epoxy in a paste form containing very fine gold particles. It is screen printable and solventless. The cure schedule is 1 hour at 120°C or 30 minutes at 150°C. Epo-Tek H31 is a 100 percent solids, single-component electrically-conductive silver epoxy in a paste form that is screen printable and solventless. The cure schedule is 1 hour at 120°C or 30 minutes at 150°C.

Table 1. Shear Strength
Results For 18
Diodes Attached
With Gold-Tin
Eutectic Solder

Sample	Individual Measurements
	Newtons (lb)
1	9.8 (2.2)
2	5.3 (1.2)
3	2.7 (0.6)
4	2.7 (0.6)
5	8.9 (2.0)
6	12.0 (2.7)
7	26.2 (5.9)
8	1.8 (0.4)
9	21.4 (4.8)
10	12.0 (2.7)
11	6.2 (1.4)
12	8.5 (1.9)
13	2.7 (0.6)
14	15.6 (3.5)
15	4.4 (1.0)
16	12.0 (2.7)
17	7.1 (1.6)
18	3.6 (0.8)

Epo-Tek H44

Evaluations of this epoxy are discussed below.

Four diodes and four capacitors were bonded to each of two substrates with H44. The parts were cured for 1 hour at 120°C. All devices were centrifuge tested to 20,000 g's without failure.

Ten diodes were bonded to a chromium-gold mirror with H44 and cured for 1 hour at 120°C. The parts were high temperature soaked for 16 hours at 200°C. Five parts were shear tested at an average of 24.9 N (5.6 lb), a range of 18.2 to 33.4 N (4.1 to 7.5 lb). The remaining five parts were soaked for an additional 8 hours at 200°C. After a total of 24 hours at 200°C five parts were shear tested at an average of 21.4 N (4.8 lb), a range of 10.2 to 34.3 N (2.3 to 7.7 lb).

Ten diodes were bonded to a chromium-gold mirror with H44 and cured for 1 hour at 120°C. The parts were temperature soaked for 1008 hours at 150°C. After the temperature soak the parts were shear tested at an average of 28.5 N (6.4 lb), a range of 15.1 to 36.0 N (3.4 to 8.1 lb).

The shear strength of H44 was determined for various cure times at 120°C (Figure 1, Table 2). It appears that the shear strength begins to level off at 90 minutes at 120°C. Ten diodes were bonded to each mirror. Most failures were mixed mode: a failure in the epoxy, breaking of the diode, and epoxy delamination from the substrate. Those shear strengths indicated with an * in Table 2 had diode breakage failures.

Shear test results for various times and temperatures are shown in Table 3. Each sample is 10 diodes (1.016 by 1.016 mm) bonded to 3 μ m gold mirrors and cured for 1 hour at 120°C.

Epo-Tek H31

Eighteen chips were bonded to three circuits with H31. The parts were cured for 1 hour at 120°C. The chips were shear tested (after exposure to 200°C for 48 hours) to 57.8 N (13 lb) without failure. However, this epoxy would not meet the high current requirement for these chips and was dropped from present consideration.

Nonconductive Epoxy Attachment

As mentioned in the previous section a problem was encountered with the current density of H31. A similar intermittent problem occurred during electrical testing of some circuits using H44 to attach power devices. This led to an evaluation of nonconductive epoxy, Ablefilm 517, manufactured by Ablestik Laboratories. Ablefilm 517 is a glass-cloth-supported tack-free epoxy film adhesive. The 25.4 μ m thick glass fabric is sized with epoxy resin prior to impregnation to prevent shifting of the fibers. The total adhesive film is 76.2 μ m $\pm$ 12.7 μ m thick. The cure schedule of this epoxy is 30 minutes at 149°C, or 60 minutes at 121°C, or 2 hours at 93°C, or 3 hours at 74°C. The epoxy must be stored at -40°C and should be used within 8 hours of exposure to ambient temperature.

Evaluations of this epoxy are discussed below.

Four gold-clad molybdenum tabs were attached to gold mirrors using Ablefilm 517. Two of the tabs were 4.06 by 5.08 mm and the other two tabs were 5.58 by 5.58 mm. The preform sizes were 3.68 by 5.08 mm and 3.68 by 5.58 mm, respectively. The tabs were cured for 2 hours 45 minutes at 75°C. All four tabs were shear tested to 57.8 N (13 lb) without failure.

Figure 1. Effect of Cure Time on Shear Strength of Epo-Tek H44 Conductive Epoxy

Two nickel-clad molybdenum tabs were attached to each of eight HMCs using Ablefilm 517. The tabs were 4.06 by 5.08 mm. The adhesive preforms were the same size as the tabs. The tabs were cured for 90 minutes at 120°C. The eight HMCs were then subjected to a high temperature bake for 48 hours (four HMCs at 175°C and four HMCs at 200°C). After the high temperature bake, the tabs were shear tested to 57.8 N (13 lb) without failure. The eight HMCs were temperature cycled 10 times from -40°C to 125°C with short transfer times. After the temperature cycles, the tabs were shear tested to 57.8 N (13 lb) without failure.

Outgassing Analysis

Following tests of the strength of the different bonding attachment methods through various times, temperatures, and centrifuge levels, outgassing analyses were performed on the epoxy bonding materials. Specific attention was given to any halogens that might be outgassed since halogens can be hostile to silicon.¹ A summary of the outgassing analyses is given in following paragraphs.

Table 2. H44 Shear Strength Versus Cure Time at 120°C

Cure Time (Minutes)	Shear Strength Newtons (lb)	Average Shear Strength Newtons (lb)
30	12.0 (2.7)	16.5 (3.7)
	18.7 (4.2)	
	17.8 (4.0)	
	14.2 (3.2)	
	18.7 (4.2)	
	11.6 (2.6)	
	19.1 (4.3)	
	18.7 (4.2)	
	14.2 (3.2)	
	18.7 (4.2)	
45	24.0 (5.4)	24.9 (5.6)
	28.5 (6.4)	
	28.0 (6.3)	
	29.4 (6.6)	
	23.1 (5.2)	
	33.4 (7.5)	
	28.0 (6.3)	
	21.8 (4.9)	
	17.8 (4.0)	
	14.2 (3.2*)	
60	47.6 (10.7)	28.9 (6.5)
	36.9 (8.3)	
	14.7 (3.3*)	
	15.6 (3.5*)	
	46.3 (10.4)	
	20.5 (4.6)	
	31.1 (7.0)	
	15.6 (3.5*)	
	32.0 (7.2*)	
	28.0 (6.3*)	
75	23.1 (5.2)	31.1 (7.0)
	23.6 (5.3)	
	28.5 (6.4)	
	26.2 (5.9*)	
	42.3 (9.5*)	
	41.4 (9.3*)	
	38.3 (8.6)	
	23.6 (5.3*)	
	28.0 (6.3)	
	35.6 (8.0)	

Table 2 Continued. H44 Shear Strength
Versus Cure Time at
120°C

Cure Time (Minutes)	Shear Strength	Average Shear Strength
	Newton's (lb)	Newton's (lb)
90	44.5 (10.0)	32.0 (7.2)
	24.0 (5.4*)	
	30.2 (6.8*)	
	48.5 (10.9)	
	19.6 (4.4)	
	37.8 (8.5)	
	27.1 (6.1)	
	32.5 (7.3)	
	34.7 (7.8)	
	22.2 (5.0*)	

*Diode Breakage Failures

Epo-Tek H44

Outgassing initiates around 80°C with some weight loss shown as low as 225°C. This gold-filled epoxy outgasses a great variety of low molecular weight materials such as hydrogen fluoride, hydrogen chloride, and ethyl chloride. This mass spectrometric analysis was performed on cured material.

Ablefilm 517

Uncured Material. Outgassing of this epoxy preform material begins immediately at ambient temperature and continues through 80°C. The most abundant component is 2-ethyl-4-methylimidazole. There is very little outgassing from 80°C through 250°C. Beginning around 250°C through 300°C the 2-ethyl-4-methylimidazole and epoxy fragments make up the mass spectra.

Cured Material. The outgassing from this material was from 250°C through 300°C and consisted of bisphenol ether epoxy fragments.

Neither of the uncured or cured samples showed any signs of halogens.

Table 3. H44 Shear Strength Versus Aging Time and Temperature

Time (Hours)	Temperature (°C)	Average Shear Strength Newtons (lb)	Shear Strength Range Newtons (lb)
168	150	37.8 (8.5)	9.3 to 56.0 (2.1 to 12.6)
336	150	32.9 (7.4)	11.6 to 52.9 (2.6 to 11.9)
504	150	24.9 (5.6)	16.5 to 39.1 (3.7 to 8.8)
672	150	18.2 (4.1)	14.7 to 24.0 (3.3 to 5.4)
840	150	29.8 (6.7)	20.9 to 36.5 (4.7 to 8.2)
50	300	0.44 (0.1)	--

ACCOMPLISHMENTS

A technique for attaching non-beam lead semiconductor devices to metallized ceramic substrates was developed.

Because of the high substrate temperature required for eutectic attachment, it was dropped from consideration. The conductive epoxies Epo-Tek H44 and H31 were able to withstand the process and product requirements in regard to strength, but did not have the capability of carrying the high current required. As a result, Ablefilm 517, a non-conductive epoxy, was evaluated and proved to be satisfactory in meeting the process and product requirements. Ablefilm 517 has a good history in capacitor attachment. It also showed the least amount of outgassing and no evidence of halogens.

FUTURE WORK

Conductive epoxies capable of carrying high currents, such as Epo-Tek H20E, need to be evaluated for strength and electrical characteristics. Further work needs to be done on Epo-Tek H31 and DuPont 6838, both silver-filled conductive epoxies, with regard to low current applications, whisker growth, and silver migration. This effort is needed to establish conductive epoxy technology for potential HMC applications.

REFERENCE

¹Silva, Joe A., *Adhesives For Hybrid Microcircuits*, Sandia Corporation, Albuquerque, SAND76-0179, August 1976.

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ELECTRICAL: Die Attachment

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