COMPLIANT BONDING

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Summary

A solid-state joining process referred to as compliant bonding employs a deformable or compliant media between an energy source and bond regions. As a result of the inherent flow properties of compliant media, the process offers unique advantages in the art of bonding workpieces such as beam lead devices, conventional leads and chips to metallized contact areas. Heat and pressure, as well as ultrasonic energy sources, have been employed with compliant media.

In compliant bonding gold wires and gold beam leads with relatively thick 2024 aluminum compliant media, the bond pressure is a function of the flow stress properties of the media ($P = \gamma\sigma$). And in the case where the media does not work harden, the pressure is proportional to its yield strength ($P = \gamma\sigma_o$). As a result of the pressure controlling properties of the media, reliable beam lead peel strengths were recorded over a wide range of bonding parameters. This points to a unique self-controlling property which is desirable in a production environment.

Applications in the area of beam lead bonding are also demonstrated such as bonding a multiple number of beam lead devices; bonding closely spaced leads wnere controlled deformation is paramount; bonding a multiple number of beam leads to contact pads of nonuniform thickness.

Introduction

Solid-state joining of metal couples using mechanical and thermal energy has been employed in processes such as forge welding, cladding, and pressure welding. With the emergence of solid-state electronic devices, the need to join metal leads to metallized semiconductor surfaces well below their respective melting points led to the development of thermocompression bonding (Figure 1).[1] The bond is formed by inducing a suitable amount of material flow in the lead by a heated bonding ram so that adhesion takes place in the absence of a liquid phase. To extend the material range of solid-state bonding and eliminate the need of applying heat from an external source, a process referred to as ultrasonic bonding was developed. The bond is formed by applying high frequency vibrations from a ram to mating metal surfaces in contact under relatively low pressures. This paper will describe a development in solid-state joining referred to as compliant bonding, where the formation of reliable multiple bonds are facilitated by transmitting bond energy through a deformable media (Figure 1).

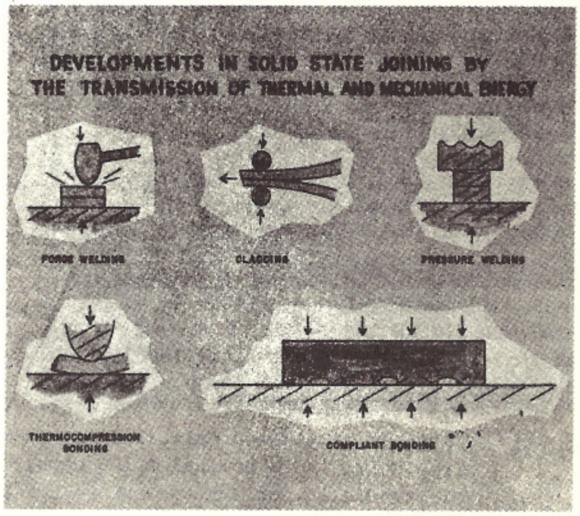

Figure 1. Illustration of various solid-state joining processes.

A significant number of lead failures bonded by thermocompression or ultrasonic techniques are associated with the rigidity of the bonding ram where the cross-sectional area of the lead is excessively reduced. This condition is generally relieved by controlling the bond parameters and contouring the face of the ram (Figure 2).[2] Economic advantages of attaching a multiple number of metal leads simultaneously with a single-energized ram presented additional problems related to the rigidity of the ram. For example, a uniform transmission of energy from the tool to each lead throughout the joining cycle is difficult to attain. This is generally due to the need to critically control the bond parameters, fine misalignments, imperfections (wear or flaws) on the ram surface, variations in lead thickness, and the natural topography of the substrate. With smaller leads such as those incorporated in beam lead devices,[3] tolerance considerations become more important. And as beam lead spacings decrease, control of bond energy transmission becomes paramount in order to avoid bridging of adjacent leads.

Compliant bonding substantially reduces problems related to conventional bonding rams, since it incorporates a deformable or compliant medium between an energy source and bond region(s). Due to the inherent flow properties of compliant media, the process markedly reduces tolerance problems, automatically controls the extent of lead deformation, and facilitates transmission of a uniform quantity of bond energy to a multiple number of leads in one cycle.

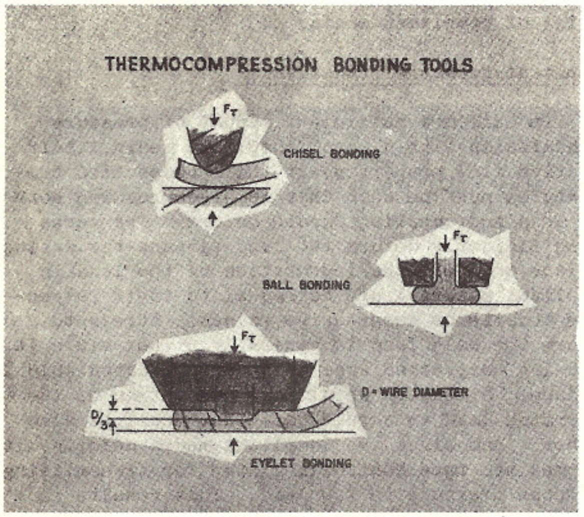

Figure 2. Illustration showing various means of controlling the bond structure such as contouring the ram (chisel and eyelet[2]) and "balling" the lead.

In contrast to other solid-state bonding processes which are highly equipment dependent, compliant bonding offers a unique concept in joining where the mechanism of energy transmission is controlled by the properties of compliant media. And as a result, the process offers both reliability and a standardization of process variables for both laboratory and manufacturing scale environments.

Modes of Compliant Bonding

Compliant bonds are formed by compressing deformable or compliant media against the topography of bond regions* with suitable energy sources. The process offers a wide range of flexibility since various energy sources and compliant media may be developed for a particular application. For example, bond energy may be supplied to compliant media by thermally (Figure 3) or ultrasonically activated rams. In this case, compliant media are generally thicker than the lead or chip. Development of thin compliant membranes, less than the thickness of the bond regions and compressed by heated fluids, is expected to produce similar bonds. Combinations of flexible membranes (as energy sources) compressing thick compliant media would facilitate bonding over larger and irregular contoured areas.

*Bond regions - generally refers to electrical leads or conventional chips positioned on metallized substrates.

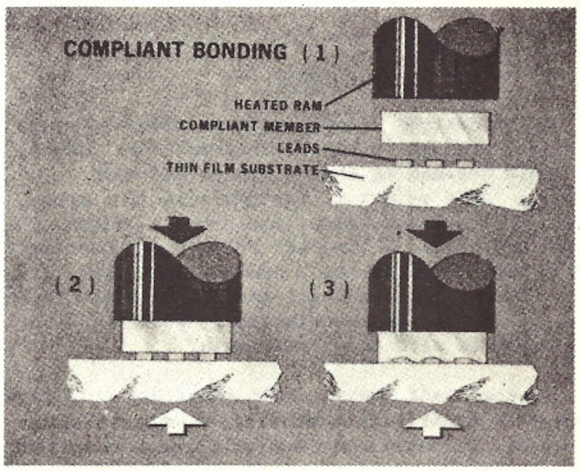

Figure 3. Illustration showing the stages of compliant bonding gold leads.

Though heated rams (energy source) and relatively thick compliant media have been extensively developed, cursory experiments with ultrasonic activated rams have been performed. For example, metallized silicon devices and gold wires have been compliant-sonic bonded to gold thin films by techniques illustrated in Figure 4. Feasibility in attaching gold wires and conventional silicon chips was demonstrated using compliant media such as five-mil Kapton and one-mil Kapton cladded to five-mil aluminum tape. The gold wires were controlled from excessive deformation by the flowing media. In attaching conventional silicon devices, the compliant media partially conforms to the device by a slight vertical force of the ram, producing a coupling effect for transmitting the lateral oscillatory motion of the ram to the bond interface. Similar mechanical coupling would require a precision-shaped ram for each device. In some cases, the increased rate of mechanical stress introduced parallel to the medium-coupled chip by high frequency oscillatory motion could result in a stiffer or more efficient transmitting media. This is expected to occur for materials whose flow stress properties increase with strain rates comparable to the high frequency motion. Thus compliant media may be developed which easily conform to the device while transforming to a stiffer material during the transmission of lateral motion. Obviously, the media may also serve as a chip carrier to the bonding station.

The remaining sections of this paper will pertain to compliant bonding conventional gold leads and beam lead devices with heated flat-faced rams (energy source) and relatively thick compliant media - a form of compliant bonding that has been most extensively studied up to the present time.

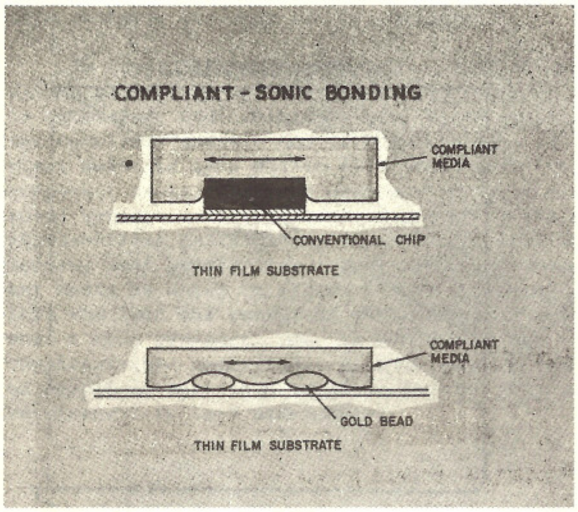

Figure 4. Illustration showing the transmission of ultrasonic energy through compliant media to a conventional chip and gold leads. The energy is applied by compressing the media with an ultrasonically-activated ram.

Compliant Bonding Gold Leads

Solid-state bonds between gold leads and gold metallized surfaces may be formed by inducing a suitable amount of material flow at the interface by the application of heat and pressure so that adhesion takes place in the absence of a liquid phase. Processes utilizing this bonding mechanism are cladding, pressure welding, forge welding, and thermocompression bonding - the latter being widely applied to attaching electrical leads.

Compliant-Bond Structure

Solid-state bonds may be accomplished by compressing a 2024 aluminum alloy (compliant media) against a gold lead with a heated ram (energy source). As the lead is deformed against the metallized gold surface during the bond cycle, it also plastically penetrates the compliant media. This produces controlled deformation of a compliantly bonded gold wire which is largely attributed to two separate mechanisms associated with the mutual flow of the lead and compliant media. By compressing a 10 mil thick 2024 aluminum compliant tape against a 5 mil gold wire with a flat-faced, heated ram, the gold wire deforms more in the central portion of the bond structure, while the deformation gradually decreases near the free-length portion of the wire. The deformation gradient is associated with greater forces transmitted to the wire by the compliant media in the central portion as compared to the ends where the media is free to extrude over the wire. Secondly, controlled sidewise flow of the lead is due to the conforming compliant media as it contacts the substrate on either side. Similar to thermocompression bonds formed with contoured rams (Figure 2) and critically controlled bond forces, the resultant compliant bond structure effectively eliminates problems associated with excessive lead deformation. The structure is simply formed with a flat-faced ram and the inherent flow properties of compliant media.

Compliant Pressure Transmission

To obtain a sufficient amount of pressure transmission with a metal compliant media, their relative flow properties at their respective temperatures must be such that upon compression both the lead and compliant media deform. Pressures to sufficiently deform the lead against the mating surface and form the indentation of the lead in compliant material are not equal to their respective tensile or compressive values. Stress to deform the bulk lead is generally higher since it is being compressed against a nonlubricated gold surface. Stress to obtain an indentation of the deforming lead in a bulk compliant metal is also higher. And since the compliant media deforms, it becomes the rate controlling step for transmitting the bond pressure to the lead. This results in a self-controlling property unique to compliant bonding. For example, with other solid-state bonding processes, the ram force and bond area define the bond pressure, whereas in compliant bonding with relatively thick compliant media, the applied bond pressure is dependent upon the flow stress properties of the compliant media.

As a deforming lead penetrates a metal compliant media, stresses are set up in various directions in the media as opposed to simple tensile or compressive stresses. Thus the mean bond pressure, P_c, developed at the compliant-lead interface is greater than the inherent flow stress properties of the compliant medium.

$$P_c = \gamma\sigma \qquad (1)$$

where

P_c = compliant bond pressure

σ = flow stress of the compliant medium

γ = compliant constant (>1)

In the case of compliant bonding gold leads, the yielding or bond pressure would, of course, be a maximum at the central portion of the lead where the compliant medium is largely constrained. Thus the rate controlling step for compliant flow would be controlled by the flow stress properties of the media in the central portion where the pressure for compliant flow is highest.

Mean pressures developed at the compliant-lead interface are analogous to pressures required to plastically penetrate a bulk metal with a hard, spherical indenter, except for the unique condition that the penetrator (gold lead) changes shape during the process. According to the Tresca or Huber-Mises criterion,[4] the onset of plastic deformation on a metallic surface by a hard, spherical indenter commences when:

$$P_m = 1.1\,\sigma_o \quad (2)$$

where

P_m = mean pressure for the onset of plastic deformation

σ_o = yield strength

As the pressure increases, plastic deformation in the vicinity of the indenter increases until the whole of the metal immediately around the indentation is in a state of plasticity while the rest remains largely elastic. This prevents the spread of plastic flow in the bulk metal. The mean pressure increases to a value of about 3 σ_o as the deformation passes from the onset of plastic deformation to the fully plastic state. The compliant constant, γ (Equation 1), is expected to equal a similar value.

Nonwork Hardening Compliant Media

The simple tensile or compressive stress-strain relationship for a metal in the plastic region is:

$$\sigma = \sigma_o \epsilon^n \quad (3)$$

where

n = strain hardening index

ϵ = strain

For a nonwork hardening (or ideally plastic) metal where n = 0, the flow stress, σ, remains constant at σ_o as the extent of strain increases in the plastic region. And in the case of penetrating a nonwork hardening bulk metal media with a spherical indenter, the mean pressure would remain proportional to the yield strength, regardless of strain variations ($P = 3\,\sigma_o$). Similarly, in the case of a deforming wire penetrating a nonwork hardening metal compliant media, the mean pressure (or compliant bond pressure, P_c) remains proportional to the yield strength of the compliant media ($P_c = \gamma\sigma_o$). A mutual (plastic) stress-strain relationship (Equation 3) of a deforming lead penetrating a nonwork hardening compliant media is shown in Figure 5. In this case, the lead first plastically deforms until a pressure ($\gamma\sigma_o$) is reached at the compliant lead interface. At this point, the media begins to deform about the lead until it contacts the substrate. In the actual case of compliant bonding gold leads, a 2024-0 aluminum compliant media is at a temperature during the bond cycle which closely approaches a nonwork hardening state.

Work-Hardening Compliant Media

For a work-hardening material, the tensile or compressive flow stress (σ) increases with an increasing strain (ϵ), since the strain hardening index (n) is greater than zero (Equation 3). In

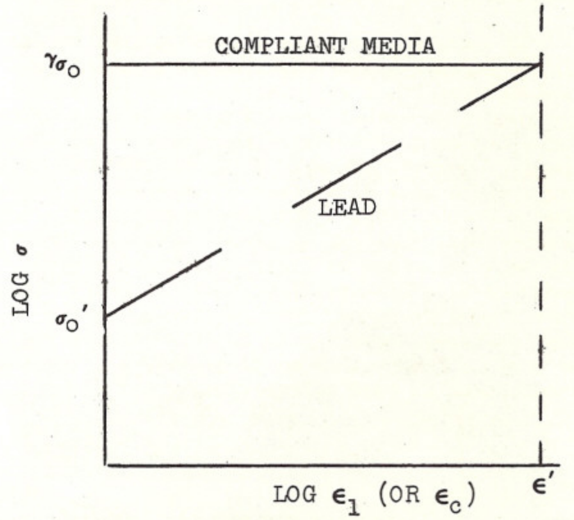

Figure 5. Mutual stress-strain relationship in the plastic region for a deforming lead ϵ_1 (against a metallized substrate) and its corresponding strain indentation, ϵ_c, in a bulk nonwork hardening compliant media. Note that ϵ' is defined as the strain conditions when the compliant media contacts the substrate, and the mean pressure at the compliant-lead interface is defined by the flow curve of the lead.

the case of indenting a bulk metal, strain is dependent on the geometric shape of the indentation. For example, the strain of a hard, spherical indenter penetrating a bulk metal is:

$$\epsilon = f(C/D) \quad (4)$$

where

C = chordal diameter of the indentation

D = diameter of the indentation

In the more general case, this simply means that geometrically similar indentations produce similar strains.

$$\epsilon = f(\psi) \quad (5)$$

where

ψ = geometric shape factor

Thus if two indentations are made of the same geometric shape, whatever their size, the strain and stress distribution around the indentations will be geometrically similar. In its simplest terms, the principle implies that a large indentation is essentially a magnified picture of a small indentation, the strains and hence the stresses being the same at any geometrically similar region.

Consequently, the indentation yield pressure or mean pressure acting on the indenter will be the same whatever the size of the indentation.

In compliant bonding a lead, a similar condition exists, except that the penetrating lead is deforming, thus changing shape as it penetrates the compliant media. And if geometrically equivalent deformed lead shapes have penetrated the compliant media, the mean pressure (or bond pressure) would also be similar. A mutual (plastic) stress-strain relationship (Equation 3) of a deforming lead penetrating a work hardening compliant media is shown in Figure 6. As indicated, both the lead and compliant media mutually deform when a mean pressure, $\gamma\sigma_o$, is reached at the compliant-lead interface. In this case, a family of compliant materials would satisfy a given end requirement in lead deformation.

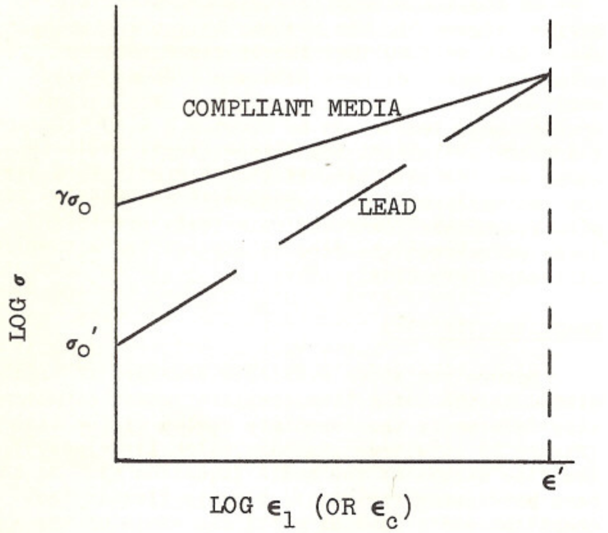

Figure 6. Mutual stress-strain relationship in the plastic region for a deforming lead ϵ_1 (against a metallized substrate) and its corresponding strain indentation, ϵ_c, in a bulk work hardening compliant media. Note that ϵ' is defined as the strain conditions when the compliant media contacts the substrate. The mean pressure at the compliant-lead interface is defined by the flow curve of the lead.

Figure 7 shows the geometric similarity and near equivalent per cent deformation of five-mil and two-mil gold wires that were compliantly deformed by a ten-mil thick 2024 aluminum compliant media. This suggests (Equation 5) that the final mean compliant bond pressures were similar. The final condition is related to the material equivalence of the leads and the pressure controlling property of the compliant media. Of course, if different size wires had not deformed to similar geometric shapes, this would imply a greater variation in the final compliant bond pressures with the use of strain hardening compliant media. This would be expected to occur if the leads were of different material composition. The ability of a compliant media to overcome lead thickness variations during a multiple lead bonding operation is also demonstrated (Figure 7).

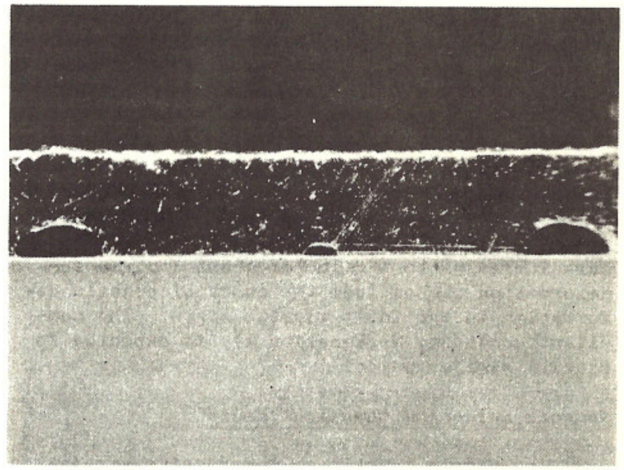

Figure 7. Cross section of three gold wires compliantly bonded to a Au-Ti thin film deposited on an alumina substrate. The original diameters of the wires were five mils, two mils, and five mils. The penetrated ten-mil thick 2024-0 aluminum compliant media is shown above. 65X.

Yield Strength-Temperature Relation

As previously indicated, 2024-0 aluminum approaches a nonwork hardening state which controls the compliant bond pressure at a value proportional to its yield strength. And since the yield strength of 2024 aluminum is a function of temperature, $\sigma_o = f(T)$, temperature variations will influence the compliant bond pressures. Table 1 shows that over a wide range of elevated temperatures (where acceptable bonding of gold to gold occurs), the corresponding change in yield strength is relatively small. This results in compliant bonding pressures remaining well within an acceptable range for bonding fine gold leads. If temperatures were increased further than shown, the yield strength would remain nearly constant as

Table 1. Yield strength of 2024-0 aluminum compliant media as a function of temperature.

Temperature (^oC)	Yield Strength, σ_o (kg/mm^2)
280	4.2
300	3.5
320	3.2
340	2.8
360	2.8

a result of the inherent properties of the metal until the solidus temperature (502°C) were approached.

Compliant Bonding Gold Beam Lead Devices

Compliant bonding a beam device may be accomplished by positioning a five-mil thick 2024-0 aluminum frame over the device as shown in Figure 8. Upon compressing a heated flat-faced ram against a compliant frame, mechanical and thermal energy are transmitted to the extending beam leads (Figure 9).

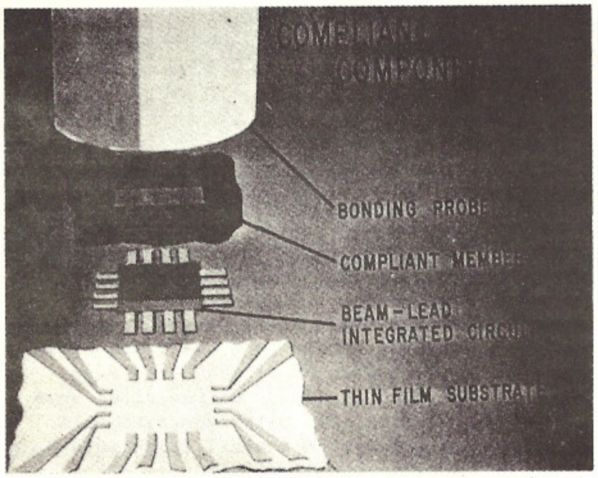

Figure 8. Schematic of compliant bonding a beam lead device with a flat-faced ram and compliant media.

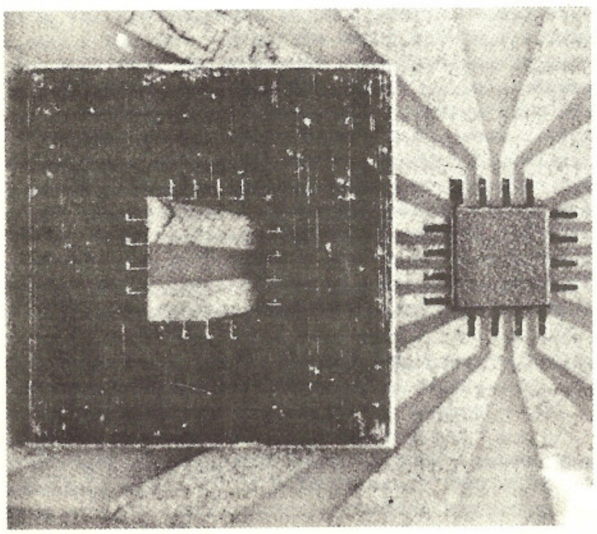

Figure 9. Top view of a compliant bonded beam lead device. Aluminum alloy 2024 compliant media is shown turned over after bonding with replicas of bonded beam leads. 20X.

Initial Stage

As a ram compresses a compliant frame, the force generally increases with time until an equilibrium value is reached. Therefore, the available noncompliant bond pressure on a beam lead for a dwell time (t) would be:

$$P_a = F_r/A_b \qquad (6)$$

where

P_a = available noncompliant pressure

F_r = ram force

A_b = nominal beam lead-compliant medium interface area (0.050 mm by 0.076 mm)

In compliant bonding a sixteen-beam lead device (Figure 9), the ram may be set to transmit about 13.6 kg (~30 lbs) force, three seconds after the onset of bond pressure. Under these conditions, the available pressure, P_a, for one nominal beam lead would be about $3.5 \times 10^{+3}$ kg/mm^2 (~5×10^6 psi) which would excessively reduce the cross section of a beam if the transmitting media was noncompliant. Of course, with thermocompression techniques lower and relatively critical force parameters are used to control the extent of lead deformation.

Compliant Yielding

Before the above available pressure is transmitted to the beams, the compliant media plastically deforms in the immediate region of the beam (Figure 3) at a mean pressure which is related to the flow stress of the media (Equation 1). As the beam penetrates the media, plastic flow in the compliant media spreads until the whole of the 2024 aluminum in the vicinity of the beam indentation is in a state of plasticity while the rest of the media remains largely elastic.

Compliant yielding becomes the rate controlling step in transmitting pressure to the beam leads. It is also the maximum bond pressure transmitted during the entire cycle. Thus the bond pressure may be independent of the absolute ram force for a wide range of beam leads (or beam lead area). For example, three, sixteen and fifty beam lead devices have been compliantly bonded with an identical ram force setting. Also, a wide range of ram forces have been used to compliantly bond each of these devices. And in all cases, beam lead deformation and bond characteristics were indistinguishable.

Latter Stage

During the latter portion of the cycle, the compliant media comes in contact with the thin film substrate. Pressure on the media and beam lead automatically decreases significantly as the ram force is distributed over the entire area of the compliant frame:

$$P_{cs} = F_r/A_{cs} \quad (7)$$

where

P_{cs} = pressure at the compliant-substrate interface

A_{cs} = compliant medium-substrate interfacial area

The limiting pressure at the compliant-substrate interface (P_{cs}) must be less than the yield stress required to grossly distort or strain the original dimensions of the media.

$$P_{cs} < \sigma_o' \quad (8)$$

where

σ_o' = yield stress of a nonlubricated five-mil thick 2024 aluminum tape in compression ($> \sigma_o$)

It is this final self-limiting condition which ensures a control in the extent of beam lead deformation without changing or relieving the ram force during the latter part of the cycle. Though pressures on the lead substantially decrease during the latter stage which controls the extent of lead deformation, interfacial plastic flow of asperities and diffusion in the bond region are still acting.

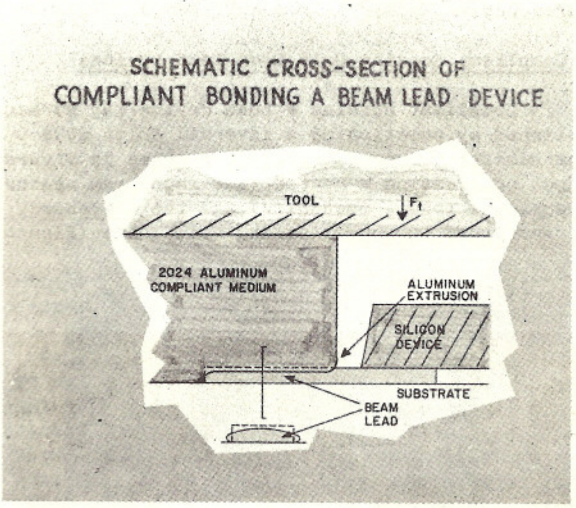

Figure 10. Illustration of initial (dotted lines) and final (solid lines) state of beam lead and compliant media. Note the slight extrusion of the media near the free length which produces a gradual tapering in the beam lead bond structure. During bonding the silicon chip is slightly raised from the substrate (not shown).

Thickness of the Compliant Frame

The five-mil thickness of 2024 aluminum compliant frames serves the following three functions during bonding of a beam lead device:

1. The silicon portion of the beam lead device does not physically contact the ram during the bonding cycle (Figures 8 and 10). This is a result of maintaining the original five-mil frame thickness during the latter part of the bonding cycle (Equation 8).

2. The thickness ratio (Equation 9) must be large enough to prevent gross lateral flow of the compliant media as it yields about the beam leads.

$$R_t = T_c/T_1 \quad (9)$$

where

T_c = thickness of the compliant media

T_1 = original thickness of the lead

Thus a portion of the compliant medium between the ram and the plastic region around the compliant indentation caused by the beam must be in a near elastic state. If the thickness ratio were low enough to cause gross distortion of the medium, the beam leads might be displaced from their original positions during bonding. As described above, the lower limit for frame thickness was determined by the height of the device. This resulted in a more than sufficient thickness ratio, R_t, to prevent gross frame distortion [nominal beam lead thickness = 0.0127 mm (0.0005 inch); compliant media = 0.127 mm (0.005 inch).]

3. Lateral flow of the compliant medium as it deforms about a gold lead would contribute to "sticking" by a shearing force at the compliant-substrate interface. For example, some adhesion between gold thin film substrates and five-mil thick 2024 compliant media was observed when bonding five-mil diameter gold wires. With the availability of ten-mil thick compliant media, no significant sticking was observed when bonding five-mil gold wires (where $R_t = 2$).

Mechanism of Nonadhesion Between the Compliant Frame and Gold Surface

As the 2024 aluminum compliant medium comes in contact with the gold metallized substrate during the latter stage of bonding, conditions to prevent any significant metal-to-metal bonding between them must be available. First, the mechanism of non-adhesion is aided by the thermodynamic stability of the natural formed aluminum oxide film on the parent 2024 aluminum frame, which serves as a barrier between nascent gold-aluminum surfaces. Standard free energy calculations show aluminum oxide (Al_2O_3) to be stable in the temperature range used to compliantly bond beam leads.

Secondly, a sufficient continuity of the aluminum oxide film must be maintained during the bonding cycle. This is accomplished by minimizing plastic distortion of the underlying aluminum metal. As previously described, since the thickness ratio, R_t, is relatively large, there is no significant lateral distortion of the frame during compliant yielding. This results in a negligible shearing mode between the media and metallized substrate which eliminates undue "sticking" by nascent metal exposure. Similar conditions are acting at the compliant-lead interface.

Also when the compliant media comes in contact with the substrate, the pressures automatically decrease below the compressive yield stress of a nonlubricated aluminum alloy (Equation 8). The resultant negligible distortion or strain in the compliant medium together with the frictional forces acting at the interface results in a sufficient continuity in the aluminum oxide layer between the frame and gold metallized substrate. In bonding aluminum leads to gold thin films, lead deformation has to be sufficient enough to break the oxide to form aluminum-to-gold solid-state bonds.

Transmission of Thermal Energy

In general, a reliable steady-state temperature between a 2024 aluminum compliant media and substrate (during the latter part of the bonding cycle) is about 300°C to produce acceptable beam lead peel strengths. Interface temperatures as low as 240°C have produced equivalent peel strengths. In compliant bonding beam leads, the ram mass and properties of the compliant media result in an efficient and reliable method of heat transfer. Aluminum alloy 2024 is a relatively good thermal conductor, both from its inherent conductivity (0.45 $cal/cm^2/cm^{\circ}C/second$) and its ability to flow about and contact topographical features of the bond region.

Beam Lead Peel Strength Versus Bonding Parameters

Destructive testing of solid-state bonds generally includes a 90° peel test. To peel test individual beam leads, a bonded device was first immersed in an etchant to preferentially remove the silicon. The following bond parameters were then evaluated (Figure 11):

1. Mean peel strength versus tool force (constants were tool temperature = 550°C; bond time = four seconds).

2. Mean peel strength versus tool temperature (constants were tool force = 9.1 kgm; bond time = four seconds).

3. Mean peel strength versus bond time (constants were tool force = 9.1 kgm; tool temperature = 550°C).

Each point shown in Figure 11 represents sixty-four individual beam lead peel strength values obtained from four, sixteen-beam lead devices. Each device was compliantly bonded as shown in Figures 8 and 9. All failures in the evaluation occurred in the beam lead, leaving the bonded portion intact. The strength consistency and narrow range of individual values (as indicated by each pair of parallel lines) is indicative of the compliant process. Though the parameters were varied over a wide range, controlled beam lead deformation, as shown in Figure 12, remained consistent. Secondly, the gradual tapered lead deformation as a result of a slight extrusion of the media (Figure 10) contributed to the relatively high strength values.

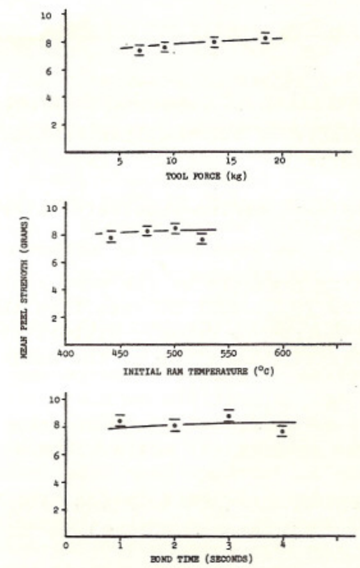

Figure 11. Compliant bond parameter evaluation.

Figure 12. Top view of three compliantly bonded beam leads of a sixteen-beam lead device showing the gradual tapered deformation near the free length portion of the lead. (See Figure 10) 200X.

Applications of Compliantly Bonded Beam Lead Devices

The adaptability of compliant bonding in the area of beam lead technology can be shown by the following examples:

1. A multiple number of beam lead devices have been compliantly bonded under a production environment with the same bonding parameters and flat-faced ram used to bond a single sixteen-beam lead device. In this case, a multiple-frame compliant media (Figure 13) is first aligned over pre-positioned beam lead devices and brought down in the Z direction to within about two mils of the bond regions. A multiple device bonding operation is then completed by compressing the compliant media (Figure 13) against the beam leads. As many as thirteen beam lead devices (composed of seventy-six beam leads) have been bonded in this manner. The center-to-center tolerances in the tape were controlled during bonding by the mechanical stability of the media (Equation 8). In this production item, there are various codes or combinations of beam lead devices (using identical size substrates). For compliant bonding all the codes use the same flat-faced ram and bond parameters with the appropriate compliant media.

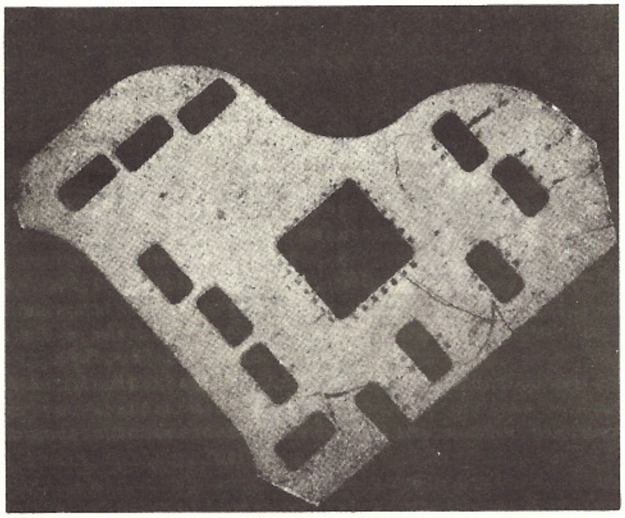

Figure 13. A multiple-framed compliant media cut from a tape which was used to bond thirteen beam lead devices (seventy-six leads) in one bonding cycle. 16X.

2. Figure 14 shows a compliantly bonded fifty-beam lead device. Their 1.5-mil beam lead spacings on two sides were easily kept from bridging without special parameter adjustments.

3. Figure 15 shows a portion of a beam lead device bonded to thin film contact area and one thicker ground plane. Due to the inherent flow characteristics of compliant media (Figure 16), all the leads were bonded in one cycle, regardless of the topographical substrate features.

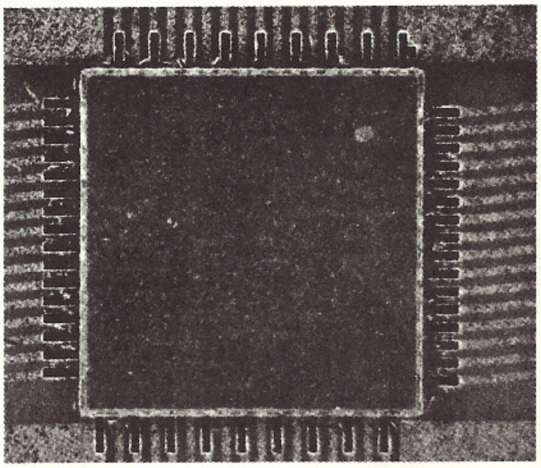

Figure 14. Compliantly bonded fifty-beam lead device. Note the controlled deformation of the closely spaced leads. 30X.

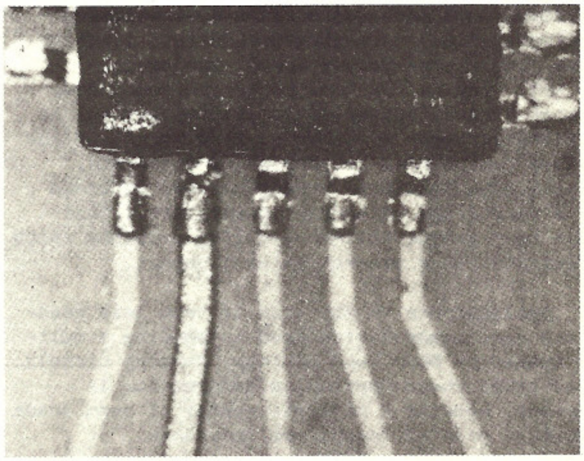

Figure 15. Portion of a beam lead device showing beam leads bonded to thin films lands and a one-mil thick plated ground plane (second from left). ~100X.

Conclusions

A solid-state joining process referred to as compliant bonding employs a deformable or compliant media between an energy source and bond regions. As a result of the inherent flow properties of compliant media, the process offers unique advantages in the art of bonding workpieces such as beam lead devices, conventional leads and chips to metallized contact areas. Heat and pressure, as well as ultrasonic energy sources, have been employed with compliant media.

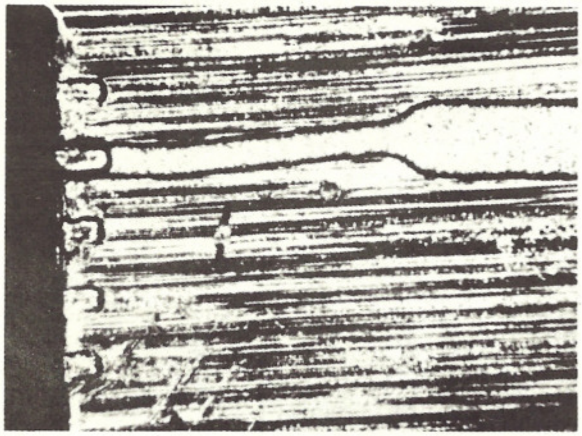

Figure 16. Portion of compliant frame used to bond beam leads to thin film lands and thicker ground plane (see Figure 15). Note replica of the thicker ground plane in media. ~100X.

In compliant bonding gold wires and gold beam leads with relatively thick 2024 aluminum compliant media, the bond pressure is a function of the flow stress properties of the media ($P = \gamma\sigma$). And in the case where the media does not work harden, the pressure is proportional to its yield strength ($P = \gamma\sigma_o$). As a result of the pressure controlling properties of the media, reliable beam lead peel strengths were recorded over a wide range of bonding parameters. This points to a unique self-controlling property which is desirable in a production environment.

Applications in the area of beam lead bonding are also demonstrated such as bonding a multiple number of beam lead devices; bonding closely spaced leads where controlled deformation is paramount; bonding a multiple number of beam leads to contact pads of nonuniform thickness.

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