

DRAWINGS ATTACHED

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(54) IMPROVEMENTS IN OR RELATING TO METHODS
 OF BONDING WORKPIECES TO SUBSTRATES

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the bonding of workpieces to substrates.

The connection of semiconductor and other very small components to printed circuit boards and thin films on substrates presents many difficulties, particularly that of avoiding damage to the component, which, in the case of semiconductor crystal may be very brittle, or in the case of a fine wire lead may be deformed or work hardened to breakage point. Damage to the substrate may also occur, since integrated circuit and printed circuit substrates may be brittle.

Two well-known methods at present in use for bonding a lead to a substrate are ultrasonic bonding and thermocompression bonding. In the first, the substrate is clamped on an anvil, the lead is positioned thereon, and the bonding tip of an ultrasonic horn is used to clamp the lead in place. A brief application of mechanical energy in the form of ultrasonic vibrations in a direction parallel to the substrate surface makes the bond. The wiping motion of the lead surface over the thin film on the substrate surface breaks up films thereon to provide nascent bonding surfaces. The heat generated by friction at the interface combined with the nascent surface, produces a true metallurgical bond. In the second, a combination of thermal and mechanical energy, in the form of heat and pressure supplied, for example, by a heated ram, are used to

make the bond. The technique used is similar to ultrasonic bonding except that the heated ram is used instead of an ultrasonic bonding tip, to transmit the energy to the workpieces.

These methods of bonding may result in either of two major defects in the bonds. The first of these is that the bond may be relatively easily pulled apart, so that subsequent strain on the bond results in its rupture. The second is that one or both of the bonded members are so deformed that they are seriously weakened, so that strain results in breakage of one or other of the bonded members.

These faults are particularly likely to occur in the simultaneous making of several bonds, so that such simultaneous bonding has not been commercially successful. Thus, while the design of a heated ram or ultrasonic bonding tip big enough to make several bonds is possible, variations in the size of the lead wire or the balled tip thereof will prevent such devices from reliably bonding each lead to the substrate. Thus, if 10 leads are positioned on a substrate and 8 of them are exactly the same size but 2 are 10-20 per cent smaller, a flat ram or bonding tip will make only 8 bonds. Or, if enough pressure is applied to contact all ten leads, 8 of them will be deformed too much, resulting in a weak bond. Also, the leads may be of exactly equal size, but the thickness of the metallic land areas on the substrates may vary, the thickness of the substrate may vary, or the bonding tip may be worn or misaligned, sufficiently to prevent the energy source (ram or ultrasonic bonding tip) from making an energy-transmitting couple with each lead. Thus, the problem is not bonding leads simultaneously *per se*, but rather reliably bonding every lead in a group, simultaneously, every time.

Attempts have been made to apply the same techniques, ultrasonic and thermocom-

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pression but mainly the latter, to the bonding of beam lead devices to substrates. This presents the same kind of problems, but to a much greater degree. Because the leads are so small, it is very easy to produce too much deformation in a bond. Also the simultaneous application of pressure to all of the leads of such a device at their outer ends tends to cause the inner ends of the leads and the device itself to move upwardly, away from the substrate, so that the device is highly stressed, which can lead to cracking, altered electrical characteristics, or bond failure. The latter may occur immediately, or may be delayed.

As an example, a simple beam lead device may have 12 or 16 leads, each 5 mils by 1/2 mil. What is believed to be the closest tolerance obtainable on the thickness of a plated slice of silicon is ± 0.2 mil. While this is a very close tolerance indeed, in absolute terms, it amounts to ± 40 per cent of the desired lead thickness. Thus, even if the bonding tip is perfectly flat and perfectly aligned, a fact which is not always true, it is quite possible that it will not simultaneously couple with all of the leads, and bonding will be incomplete.

Lastly, while there exist methods of checking the existence of a bond, i.e., electrical testing, the only reliable method of determining the strength of a bond is by mechanically testing it to failure, i.e., the well-known shear peel test. There is no qualitative non-destructive method of estimating bond strength.

It is the object of the invention to provide a bonding method which will increase the proportion of good bonds obtained and which may also be used to make simultaneous bonds.

According to the invention, there is provided a method of bonding together a lead and a metal film on a rigid substrate comprising the steps of placing the lead upon the metal film, advancing a pressure means to apply a pressure to an elastically or a plastically compliant means arranged on the side of the lead so as to compress the compliant means and thereby transmit a pressure to the lead, the pressures being applied in the same direction, and applying heat and/or ultrasonic vibration to produce with the pressure applied to the lead thermocompression bonding or ultrasonic bonding of the lead to the film, the compliant means being subsequently removed.

The invention also provides a method of bonding a lead from an integrated circuit device to a substrate comprising applying pressure to the lead positioned on the substrate through an immediately adjacent elastically or plastically compliant means and bonding the lead and the substrate by thermocompression bonding or ultrasonic

bonding with or without heat, the compliant means being subsequently removed.

The invention further provides a method of bonding together a brittle crystal body and a metal film on a rigid substrate comprising the steps of placing the crystal upon the metal film, advancing a pressure means to apply a pressure to the crystal through an immediately adjacent elastically or plastically compliant means and bonding the crystal and the substrate by thermocompression or ultrasonic bonding with or without heat, the compliant means being subsequently removed.

While a compliant medium may be easy or difficult to deform, it will transmit pressure while absorbing energy. Thus, if a 100 pound weight is placed on a 1 inch cube of steel resting on a rigid support, the steel will deform very little and the pressure on the support will be 100 psi. If the cube is made of hard rubber rather than steel, the deformation will be much greater but the pressure on the support will still be 100 psi. The energy of deformation in each instance is represented by the distance moved by the weight. If the weight squeezed the rubber to a height of 3/4 inch, for example, the energy of deformation would be $(1-3/4) \times 1/12 \times 100 = 2.09$ foot pounds. The potential energy represented by the 100 psi pressure on the support still available to perform work. An alternative method of effecting pressure transmission with absorption of energy is to use a relatively rigid body which is resiliently mounted, so that the combination forms a more compliant member, although the body is not readily deformable.

If a second piece of deformable material is placed between the rigid support and the hard rubber cube, there will be a relative deformation of both the second deformable material and the cube. Naturally, if the second material is also a cube of hard rubber, the deformation of both pieces will be equal. The distribution of deformation between two dissimilar materials can be determined from the stress-strain curve of each material. That is, under a given stress, the strain of each material can be read directly from the curve. This is not limited by the points on the curves where the mode of deformation changes from elastic to plastic (i.e. the elastic limit). Thus, if a cube of material A is resting on a cube of material B which is, in turn, resting on a rigid support, and a weight is placed on cube A, the deformation of both may be elastic or plastic, or one may deform elastically while the other deforms plastically. In any case, the behaviour of the respective materials can be predicted from the stress-strain curve.

From the foregoing it is believed to be clear that under the influence of pressure

(i.e., mechanical energy) alone, one compliant (or deformable) material can deform another deformable material.

The above discussion was concerned only with two cubes of the same size. If, in place of the cube of material B, there is substituted two spaced bars, the pressure on the bars will still be that applied to cube A. However, the deformation of material A will be considerably different. With two equal cubes, both materials will tend to flatten, i.e., bulge outwardly on the sides, where they are not confined, but with cube A resting on the two bars, it will tend to deform downwardly, between or around the bars. If, now, in place of cube A there is substituted a round rod laid across the two bars, the stress-strain situation changes radically. The area of contact between the rod and the two bars is very small, so the stress (for the same applied weight) must be very large. This will cause an appropriate increase in the strain (deformation) of both materials. In other words, it is the stress at the interface, rather than the total force applied, which determines the deformation of both materials. Thus, by controlling the geometry of the two materials, a relatively small force can be made to cause a relatively large deformation.

The mode and amount of deformation will also be radically influenced by the application of thermal energy. This is also predictable from the stress-strain curve of the chosen materials at the specified temperature.

In summary, the following factors can be used to control relative deformation between the two bodies: (1) Selection of materials; (2) Total mechanical energy applied; (3) Geometry of the pieces; and (4) Application of heat.

To illustrate the above discussion relating to a deformable medium, suppose it is desired to bond a 16-lead beam device (gold leads) to the gold land areas on a substrate, using a ram pressure of 30 pounds at 400°C. The leads are material B, the land areas are the rigid support, and material A is what is referred to herein as the compliant member or medium which is also deformable. To select a suitable compliant medium, the stress-strain curve of gold at 400° is plotted, preferably on a log-log plot where the yield point is on the ordinate, and the slope of the curve is the strain hardening index. From this plot, the stress necessary to achieve any degree of deformation of the gold can be determined. If 50 per cent deformation of the lead is desired, the particular stress to achieve it is selected. If the compliant medium is twice as thick as the lead, it will only deform 25 per cent in deforming the lead 50 per cent, so any material having a stress-strain curve which

deforms 25 per cent at the selected stress is a suitable medium. In this instance, aluminium is a satisfactory medium. Having selected a medium, the geometry is considered. The substrate rests on an anvil, the device is placed thereon, and the compliant aluminium in the form of a frame, covering only the leads, is laid thereover. The heated ram is brought down under a 30 pound (absolute) load. The pressure at the ram-aluminium interface is found to be about 2000 psi. This is below the yield point of this frame at 400°C. However, the pressure at the aluminium-lead interface which is a much smaller area, is in excess of 100,000 psi, above the yield point of both metals, and deformation proceeds here. When the aluminium has deformed around the leads and touches the substrate (as described in detail hereinbelow), the area of contact increases (and the pressure decreases) until it is the same as the area of the ram-aluminium interface, i.e., the pressure drops to about 2000 psi and deformation stops.

In the bonding of leads to thin films on substrates by conventional thermocompression or ultrasonic techniques, it was necessary that the lead be substantially deformed against the substrate to achieve good bonding, although deformation *per se* did not necessarily mean a good bond was made. By using a deformable, compliant medium, however, plastic deformation after the bond is made, may be so slight as to be essentially invisible. This may be illustrated by the ultrasonic bonding of chips cut from single crystal slices of silicon or other brittle crystals. Any deformation of such materials such as would be produced by prior art bonding methods will result in fracture; they just do not deform, at least in the ordinary sense of the word. Yet, they are successfully bonded to substrates by the use of a deformable compliant medium with heat and ultrasonic energy. All of the deformation is apparently confined to the plated surface adjacent the substrate. Similarly, beam lead devices may be bonded to substrates without significant visible deformation.

In one embodiment of the present invention, the workpieces and the substrate are positioned on a supporting anvil or table and the compliant medium is placed over the desired bond area. In this embodiment, deformable metals having tough, adherent oxide surface films are preferred as the compliant medium, and thermocompression is the preferred mode of bonding. Any non-wetting surface should be satisfactory, though. A heated ram is used to plastically deform the compliant medium and simultaneously make the bond between the workpieces. The oxide film prevents the compliant medium from bonding to either of

the workpieces (it is assumed herein that all bond surfaces are free of surface films or contaminants). While a heated ram is the normal mode of applying heat and pressure in thermocompression bonding, it will be understood that the heat can be supplied in a variety of ways: a hot gas may be passed around the bond area, the anvil may be heated, or resistance heating can be employed.

A surprising aspect of this embodiment of the invention is that the plastically deformed compliant medium has, after bonding, a perfect replica of the bond area im- pressed therein which can be used to determine the fact that a bond has been made. It has been discovered that, when a good bond has been made, this replica bears every detail thereof, including even surface imperfections, but where the bond is a poor one, the replica is also poor and has a much different appearance. Further, the compliant medium may be formed into a lead frame which holds one or a large number of beam lead devices in a manner which facilitates positioning of the leads on the substrate. The use of a compliant plastically deformable medium is also most desirable for making reliable bonds on a mass production basis. The devices, for example beam lead integrated circuits, are mounted a few centimeters apart on a ribbon or tape of aluminium as the compliant medium. For small (i.e. 3-lead) devices, attachment to the ribbon may be by adhesive. With larger devices now available, it is preferred to have apertures or windows in the ribbon large enough to retain the body of the device. The aluminium is provided with indexing means such as edge markings or holes, and the devices are positioned on the ribbon in an exact relation thereto. The substrate is positioned under the ram, the ribbon or tape is indexed in position, and the bond is made. A new substrate is placed under the ram (which can be done automatically), the tape is advanced one space, and the next bond is made. Alignment of the ram, wear of the ram surface, and material pick-up on the ram tip are eliminated as problems, because a "fresh" compliant medium is used to make each bond. The "used" tape bears a replica of each bond for checking purposes.

Bonds may also be made by applying ultrasonic energy through a plastically deformable compliant medium, and this technique is preferred in bonding brittle chips of silicon or the like to thin films on substrates (as used herein the terms "ultrasonic energy" or "ultrasonic vibratory energy" are intended to include vibratory energy of substantially any frequency, roughly, from 60 hertz into the kilohertz range). The chip ordinarily has both major surfaces metal-

lized and plated before it is cut from the slice. The substrate is mounted on an anvil, the chip is positioned thereon, and a compliant medium, typically a piece of aluminium several times thicker than the chip, is placed thereon. Heat is applied for a fraction of a second and both heat and ultrasonic energy are applied to the piece of aluminium for an additional fraction of a second. The heat softens the aluminium slightly and, with the application of ultrasonic energy, the aluminium plastically deforms around the chip, again only slightly, but enough to establish an energy-transmitting couple with the chip. Within much less than one second, the chip is bonded to the substrate. Bonds have also been made with ultrasonic energy using plastically deformable polytetrafluorethylene known as Teflon (trade-mark) as the compliant medium between the workpiece and the bonding tip.

In another embodiment of the invention, the workpieces and the substrate are again positioned on an anvil or table, but in this instance the table itself is capable of ultrasonic vibration in a direction parallel to the surface. A compliant medium is lowered over the bond area to clamp the workpieces together and ultrasonic energy is used to make the bond. Heat may be advantageously applied to the bond region through the compliant medium, thus reducing the amount of ultrasonic energy required to make the bond.

In this embodiment the compliant medium preferably deforms elastically, and is attached to the bottom of a plunger. It may be an organic material such as silicone rubber or, alternatively, it may take the form of a plurality of spring-loaded pins mounted in a jig, the position of each pin corresponding to a single bond area. The use of such a jig is mainly useful in the bonding of relatively large devices.

Understanding of the invention will be facilitated by referring to the following detailed description of several embodiments, in conjunction with the accompanying drawings, wherein:

FIGS. 1A and 1B are side and end elevations, respectively, showing all parts in place for bonding a lead to a thin film on a substrate by thermocompression bonding in accordance with the invention;

FIGS. 2A and 2B are similar to FIGS. 1A and 1B, showing all parts during thermocompression bonding in accordance with the invention.

FIGS. 3A and 3B are similar to FIGS. 1A,B and 2A,B, showing all parts after thermocompression bonding is complete;

FIG. 4 is a side elevation of a beam lead device positioned on a substrate;

FIG. 5 is similar to FIG. 4 and shows the compliant medium in place;

FIG. 6 is a side elevation of the assembly of FIG. 5 during thermocompression bonding in accordance with the invention;

FIG. 7 is a side elevation of the device of FIG. 4 after bonding;

FIG. 8 is a side elevation showing a beam lead device on a substrate ready for ultrasonic bonding in accordance with another embodiment of the invention;

FIG. 9 is a side elevation of the assembly of FIG. 10 during ultrasonic bonding;

FIG. 10 is a side elevation showing all parts in place for ultrasonic bonding of a plurality of balled wire leads to a thin film on a substrate in accordance with another embodiment of the invention;

FIG. 11 is a side elevation showing the assembly of FIG. 10 during ultrasonic bonding;

FIG. 12 is a perspective view of a lead frame for a beam lead device or devices for use in thermocompression bonding;

FIG. 13 is a side elevation of a jig for use in ultrasonic bonding in accordance with the invention;

FIG. 14 is a plan view of the jig shown in FIG. 13;

FIG. 15 is a cross-sectional elevation of an alternative embodiment of the jig of FIGS. 13 and 14;

FIG. 16 is an elevational view, partly in section, showing all parts in place for the bonding of a silicon single crystal chip to a substrate in accordance with the invention;

FIG. 17 is similar to FIG. 16, showing the same parts during bonding; and

FIG. 18 is a partial perspective view of a machine capable of making either thermocompression or ultrasonic bonds in accordance with the invention.

FIGS. 1-3 illustrate bonding of a single lead to a thin film on a rigid substrate. An insulating substrate 10 having a metallic land area 12 on the surface thereof is placed on a rigid support (not shown). A lead 14 is placed over land area 12 at the desired point. For purposes of illustration, substrate 10 is a high alumina ceramic, and land area 12 and lead 14 are both gold. The compliant medium is in the form of a wire 16 of an oxide film-forming metal such as aluminium. A heated ram 18 initially clamps the workpieces to the support and, as pressure is applied, wire 16 and lead 14 commence to deform, as shown in FIGS. 2 (A and B). In particular, the line of contact 20 between the two pieces becomes a zone of contact 22, and bulges 24 appear on the unconfined edges of lead 14. At the same time, wire 16 deforms around lead 14. When bonding is complete, as shown in FIGS. 3 A and B, the initial bulges have been deformed into area 26, and wire 16 has deformed plastically so as to completely cover

the entire bond area on both workpieces. The flow of the lead metal in the area 26 against the land metal 12 contributes to the quality of the bond.

When bonding is complete, ram 18 is raised and wire 16 is removed. The existence of the bond can be checked by examination of the impression left in wire 16, which is an exact replica of the bond area. This is of course greatly preferable to the destructive shear-peel test.

The wire 16 will not itself bond to the workpieces because of the tough oxide film on its surface. Since film-forming metals (for example, aluminium, nickel, titanium and tantalum) always have such oxide films and the thickness thereof can be readily controlled by anodizing, they are preferred as the compliant medium in this embodiment. Other materials can be employed and parting materials used to prevent bonding of the medium to the workpiece, but parting materials will of course be avoided where they might present a contamination problem.

Since gold is a relatively soft metal, compared to aluminium, it might be expected that the wire 16 would seriously deform or cut right through lead 14, but this is not the case. Successful bonds of gold leads have even been made using nickel as the compliant medium, which is even harder than aluminium.

The foregoing bonding method results in fewer unsatisfactory bonds than result from conventional ultrasonic and thermocompression techniques and the individual bonds are of superior quality and indicated by shear-peel tests.

The following is a possible explanation of this superiority. It would appear that in any particular case, and assuming a constant bonding time, that there is a range of total bonding energy which will produce a good bond and this energy can be divided between mechanical and thermal energy in any desired way. If insufficient total bonding energy is applied, the lead will not adhere satisfactorily to the substrate and may be pulled off. If too much bonding energy is applied, the lead is damaged and will break when pulled.

In bonding with a compliant medium in accordance with the above embodiment, the upper limit of total bonding energy that produces a good bond is raised substantially, since the compliant medium is deforming rather than the workpiece and this reduces the risk of over-deforming the lead. The actual mechanism of bonding at the interface is believed to be diffusion, regardless of the type of bonding employed. Diffusion is a time and temperature dependent process. With the compliant medium bonding, a slightly longer bonding time can be em-

played, thus allowing for greater diffusion at the interface, so that a strong and better bond results. The same considerations apply to ultrasonic bonding as to thermocompression techniques, but the mechanisms at work are quite different. For example, in ultrasonic bonding, heat is generated by both internal and external friction and hysteresis, in addition to any external sources that might be used.

FIGS. 4-7 also illustrate the bonding of a beam-lead integrated circuit device to a thin film on a substrate in a similar manner to that shown in connection with FIGS. 1-3. As shown in FIG. 4, the device comprises a silicon chip 28 having gold leads 30 issuing therefrom. It rests on a substrate 32 having metallic land areas (not shown) under each lead.

As shown in FIG. 5, a hollow compliant preform or lead frame 34 is placed over leads 30 and around device 28. Preform 34 extends substantially above the top of device 28 so that, during bonding, the hot ram will not press upon device 28.

Bonding is illustrated in FIG. 6. A hot ram 36 is pressed down on the assembly, causing deformation of preform 34 and leads 30 in the same manner as described hereinabove in connection with FIG. 1-3. It will be noted that preform 34 deforms plastically in exact compliance with the leads even when they are very closely spaced. FIG. 7 illustrates the bonded device after removal of the preform.

The extent of deformation of the leads during bonding is apparently a function of the geometry of the compliant medium and the physical properties of the materials, more than anything else. FIGS. 1-3 and 4-7 illustrate two shapes of a compliant medium and two somewhat different lead deformations. Where the compliant medium is sheet which covers essentially the entire lead right up to the device, bonds are made with little or no visible deformation of the lead. In the bonding of simple beam lead devices, a solid sheet of the compliant medium e.g. of polytetrafluorethylene which covers the entire device and the leads may be used, when the device is strong enough. Ram pressure is applied overall, the medium deforms around the device and the leads, and makes good bonds. Bonding of the device is manifestly impossible, since the device and the leads are subjected to the same forces.

The foregoing can be illustrated by a specific example of the bonding of a 16-lead beam lead device to the Au/Ti alloy land areas on a glass substrate. The compliant medium was aluminium 0.005 inch thick with a square 0.0535 inch hole punched therein. The device was positioned on the substrate and the aluminium was

placed thereover, the hole just fitting over the body of the device. The ram was stainless steel with a flat, Inconel (Registered Trade Mark) tip heated by a 150 watt cartridge heater. Bonding was carried out for 1.5 seconds with a total ram pressure of about 48 pounds (3 pounds per lead) at a temperature of 400°C. Lateral deformation of the beams due to bonding was less than 10 per cent. After bonding, the device could not be blasted loose with 400 psi compressed air. When a sharp probe was used to shear the device from the substrate, all 16 leads broke off and remained bonded to the substrate.

In general, it has been found that successful thermocompression bonds can be made by this method at temperatures in the range of 350°C-500°C, bonding cycles of 1 to even 5 seconds and ram pressures of 30-50 pounds. It will be appreciated, however, that all of these parameters are related. At lower temperatures, for example, longer cycles are in order, and vice versa.

FIGS. 8-11 illustrate another method of effecting bonding. In this embodiment a support or table 38 is provided which is connected to an ultrasonic horn for vibration in a direction parallel to the upper surface. It is convenient to provide a slight depression 40 in the upper surface of support 38 which conforms to the size of the substrate to the thin film of which leads are to be bonded. A substrate 42 is placed in this depression and, as shown in FIGS. 8 and 9, a beam lead device 44 is positioned thereon. A plunger or clamp 46 has a tip 48 made of an elastically deformable material e.g. an organic material such as silicone rubber which is capable of deforming around a device and clamping all the leads, regardless of size differences, securely to substrate 42. Plunger 46 can be hydraulic, cam actuated, solenoid actuated, or other suitable means can be employed.

Ultrasonic energy is applied and causes support 38 to vibrate in the direction shown by the arrow in FIG. 9, i.e., parallel to the surface. The bond may be made in the conventional ultrasonic manner without heating or alternatively by thermocompression bonding.

It has been heretofore disclosed that heat can be advantageously applied during ultrasonic bonding with the benefit of preventing work hardening of the leads. The application of heat through a conventional ultrasonic bonding tip creates problems, however, in that the sonic properties of the tip are in part temperature dependent. This problem is eliminated in the present embodiment of the invention because the heat can be applied through plunger 46 and compliant medium 48.

The bonding of two balled wire leads to

land areas on a substrate is shown in FIGS. 10 and 11. The substrate 42 has two conductive land areas 50 and two balled leads 52 are positioned thereon. It will be noted that leads 52 differ substantially in size. In this instance discrete, compliant spring-loaded plungers 54 are employed instead of compliant member 48, each plunger 54 accommodating one lead and clamping it firmly to the substrate. Bonding is carried out in the same manner as described above in connection with FIGS. 8 and 9 and heat is advantageously supplied through plungers 54. It will be appreciated that the embodiments of FIGS. 10 and 11 (and the equipment described below in connection with FIGS. 13 and 14) is suitable only for bonding wire leads or relatively large devices, and could not be used for bonding very small beam lead devices or integrated circuit devices. Further, it does not have the advantage of producing a bond replica.

FIG. 12 illustrates the use of a compliant medium, particularly a film-forming metal, as a lead frame for one or more discrete beam lead devices to be thermo-compression bonded. A rectangular frame 56 having an aperture 58 is provided, into which the device 60 is placed through the bottom, the leads 62 of device 60 being lightly adhered to the underside of frame 56 by use of an adhesive. Alternatively, aperture 58 may be sized to that the body 60 fits snugly therein and is frictionally retained. Indexing marks 64 are provided on the outside of frame 56 and are designed to register with corresponding marks on the substrate to which the device is to be attached. Similar marks (not shown) on the underside of frame 56 will facilitate the accurate placement of the device within the frame. In this manner, proper registration of each lead with its corresponding land area on the substrate is considerably simplified. The dotted lines 65 show how frame 56 may be part of a much larger frame holding a plurality of devices 60. As noted hereinabove, the lead frame may take the form of a long ribbon or tape of the compliant medium. Also, indexing may be accomplished with optical equipment by having small holes in the tape or lead frame.

FIG. 13 and 14 are elevation and plan views respectively, of a jig for clamping a device similar to the device 60 shown in FIG. 12 for bonding in accordance with the embodiment illustrated in FIGS. 10 and 11. A plate 66 is provided with apertures 68 for attachment in exact registry to pins on a bonding machine. A set of apertures 70 is provided equal in number to and spaced for registry with the leads on the device to be bonded. A pin 72 having a stop-key 74 near one end and a collar 76 near the other is placed in each aperture

70 with a spring 78 partially compressed between collar 76 and the underside of plate 66, stop-key 74 serving to retain each pin 72 in position.

Plate 66 is mounted in a vertically movable fixture in a bonding machine and, when the device similar to the device 60 is positioned on a suitable substrate on the support, the fixture is lowered. The tips of pins 72 engage the individual leads and, as the fixture is lowered still more, springs 78 are further compressed, exerting through pins 72 a clamping force sufficient to effect bonding upon the application of heat and/or ultrasonic energy. The small size of pins 72 may preclude the application of heat directly therethrough, in which case a hot gas can be passed around the bond regions or other means can be employed.

FIG. 15 illustrates a jig useful for carrying out bonding of a beam-lead device in accordance with the embodiment shown in FIGS. 8 and 9. A plate 80 is apertured 82 for retention on the bonding machine, and a compliant medium 84 is attached permanently to the underside thereof around a central aperture 86, said compliant medium 84 engaging with the beam leads of a beam lead device. Aperture 86 is provided only for visual checking of registry of the substrate, device and medium 84. Compliant medium 84 is preferably an elastically deformable material such as silicone rubber or the like. It is to be noted that jigs shown in FIGS. 13-15 may be made with any desired configuration for bonding devices, wire leads to substrates of varying sizes.

FIGS. 16 and 17 illustrate the preferred embodiment of the invention for bonding brittle chips cut from single crystal slices to a substrate. These figures illustrate bonding of a silicon chip to a copper stud for use as a power rectifier.

An anvil 88 has a hole 90 into which a copper stud 92 fits snugly. The head portion of stud 92 rests on the surface of the anvil. Stud 92 is usually made of copper so as to act as a heat sink and, since silicon and copper have very different thermal expansion properties, it is necessary to attach a suitable preform 93 to the surface thereof. Preform 93 may be molybdenum, tungsten, a silver-impregnated tungsten compact, or the like. The object thereof is to absorb the thermal stresses of the copper and prevent the active element from cracking. The preform 93 is usually brazed to copper stud 92. A wafer of silicon 94 is positioned on preform 93. Wafer 94 must be metallized and plated on its lower side, but this must also be done for soldering or brazing. The compliant medium 95, which again may be a film-forming metal such as aluminium, is laid over silicon wafer 94, and the bonding tip 96 is positioned thereover and lowered

so as to clamp the assembly in place. Needless to say, only a very slight clamping pressure is employed. Heat and ultrasonic energy are applied for a fraction of a second, the bonding tip vibrating in the direction shown by the arrow in FIG. 17. As also shown in FIG. 17, compliant medium 95 deforms around wafer 94, and the brief application of bond energy is sufficient to bond wafer 94 to preform 93 without deformation or cracking of the wafer. Of course, total bonding energy applied will vary with the size of the wafer and the materials involved.

In an embodiment of the invention, a gallium arsenide junction laser diode was metallized with gold on both sides and bonded to an Au/Ti plated substrate. The chip measured about 10 mils square, and was less than 5 mils thick. The chip was placed on the surface of a substrate, and a piece of high purity aluminium 15 mils thick was placed thereover. An ultrasonic bonding tip was placed over the assembly and about 1.5 pounds clamping pressure was used. Heat, supplied through the bonding tip, was turned on and, 1 second later, the ultrasonic energy was applied at a level of 1 watt from a 40 Kh. generator for 0.5 second. The exact temperature reached by the aluminium or the chip could not be measured, but the bonding tip reached 315°C. Existence of a true bond was confirmed by connecting the chip into a circuit through the gold on the substrate and the plate top contact; the chip functioned as a laser diode and emitted light.

FIG. 18 is a simplified perspective view of a bonding machine designed to carry out bonding by the embodiments of the invention. It will be understood that for commercial usage machines will be constructed to employ a particular embodiment rather than any embodiment.

With reference to FIG. 18, a base 100 is integral with a back portion 102 which, together, form the support for the machine. A generally U-shaped arm 104 (shown partially) extends outwardly from the back 102 and supports a suitable binocular microscope (not shown) for use by the operator in positioning the various parts. Base 100 has provided thereon a rigid table 106 on which there rests a plate 108 which is coupled to an ultrasonic horn 110 adapted to vibrate plate 108 in the horizontal plane. The ultrasonic energy source is conventional and is not shown. A second plate 112 is screwed onto plate 108 by means of four screws 114. Plate 112 is provided with a central depression 116 on the top surface thereof adapted to contain and retain a specific substrate. The reason for providing separate plate 112 is so that variously sized substrates or circuit boards can be easily accommodated.

An upright member 118 is centrally located against back 102; this is provided for the mounting of the vertically movable portions of the machine. Member 118 has a rack 120 on the forward vertical surface thereof which engages a pinion or pinions (not shown) on the vertically movable elements, much in the same manner as the barrel of a microscope is raised and lowered on its frame.

For thermocompression bonding, a hydraulic or solenoid actuated ram mechanism 122 is mounted on member 118. Ram mechanism 122 has a downwardly extending ram 124 with a replaceable tip 126. The reason for having a replaceable tip 126 is, so that variously sized devices can be accommodated. Thus, tip 126 may be of a plastically deformable film-forming metal, it may be apertured, or it may be a flat piece of molybdenum (i.e. where a lead frame is employed). Coarse and fine adjustments 128, 130 are provided for positioning ram 124 prior to bonding. A dial 132 indicates ram pressure and a dial 134 indicates ram temperature. Power necessary for actuating and heating the ram is provided via line 137. Other controls may be provided as required.

For ultrasonic bonding in accordance with the invention, ram mechanism 122 is replaced by fixture 136. This also has a pinion gear or gears (not shown) and is adapted to be mounted on rack 120 on member 118. Fixture 136 has a simple frame 138 with an aperture 140 having an annular shoulder 142 therein. Aperture 140 and shoulder 142 are adapted to contain and retain a jig such as is illustrated in FIGS. 13-15. Threaded posts (not shown) are provided on shoulder 142 to register with the apertures (68, 82) of the jig so that the latter can be screwed down. For ultrasonic bonding, an ultrasonic horn would be used in place of ram assembly 122.

In bonding by either method the substrate is placed in depression 116 and the device (or leads) is positioned thereon. The operative element, either ram 124 or fixture 136 is then lowered to engage the assembly, and bonding energy is supplied by either ram 124 or horn 110. In either case, all of the leads are bonded simultaneously, and bonding is both quick and reliable. For example, a reasonably skilled worker can bond at least 12 16-lead beam lead devices to individual substrates in an hour and can maintain this rate all day without undue fatigue. The reject rate is negligible. With suitable automatic positioning equipment and large lead frames, the production rate should be much higher. For example, small holes can be punched in the lead frame at specified positions and optical equipment used to determine exact positioning. The most significant advantage is, of course, that the production rate and reli-

ability will be just the same for a more complex device, even one having a hundred or more leads, since it is no more difficult to bond. The further advantage, when a plastically deformable metal is used as the compliant medium, of having an exact replica of each and every bond made, is a most substantial one. For a given work-piece, a series of replicas can be used as a standard against which each replica can be judged, indicating both the existence of a bond for each lead and bond quality. When the metallic compliant medium is in the form of a lead frame, there is the additional advantage of presenting the device in a readily handleable manner which is easy to position on the substrate.

WHAT WE CLAIM IS:—

1. A method of bonding together a lead and a metal film on a rigid substrate comprising the steps of placing the lead upon the metal film, advancing a pressure means to apply a pressure to an elastically or a plastically compliant means arranged on the side of the lead so as to compress the compliant means and thereby transmit a pressure to the lead, the pressures being applied in the same direction, and applying heat and/or ultrasonic vibration to produce with the pressure applied to the lead thermocompression bonding or ultrasonic bonding of the lead to the film the compliant means being subsequently removed.

2. A method of bonding a lead from an integrated circuit device to a substrate comprising, applying pressure to the lead positioned on the substrate through an immediately adjacent elastically or plastically compliant means and bonding the lead and the substrate by thermocompression bonding or ultrasonic bonding with or without heat, the compliant means being subsequently removed.

3. A method as claimed in claim 1 or claim 2 wherein the compliant means is a metal having an adherent oxide coating thereon, for example, aluminium.

4. A method as claimed in claim 1 or claim 2 wherein the compliant means is polytetrafluorethylene.

5. A method as claimed in any one of claims 1 to 4 wherein the compliant means is capable of retaining an impression of a bond when made.

6. A method as claimed in claim 2 wherein a plurality of leads are provided and in which the substrate comprises a plurality of metallic land areas, the bonding being effected between the leads and the land areas.

7. A method as claimed in claim 6 wherein the thermocompression bond is carried out at a temperature of 350°C-500°C for 1 to 5 seconds.

8. A method as claimed in claim 6

wherein bonding is effected at a temperature of 400°C for 1 to 5 seconds and at a pressure of 3 pounds per lead.

9. A method as claimed in claim 6 wherein 16 leads are provided and the land areas are an Au/Ti alloy.

10. A method as claimed in claim 1 in which bonds are effected between one or more discrete first leads and the substrate wherein the compliant means comprises one or more resiliently mounted pins, a separate one of which is adapted to engage each of the leads.

11. A method as claimed in claim 10 wherein the leads are maintained in position prior to bonding by means of a jig having a separate aperture therein for each of the resiliently mounted pins.

12. A method as claimed in any one of the preceding claims in which the ultrasonic bonding is in a direction of vibration substantially parallel to the plane of the substrate.

13. A method as claimed in claim 2 wherein the compliant means is provided with an aperture or apertures adapted to retain the electrical device in position during bonding.

14. A method as claimed in any one of claims 6 to 9 wherein the leads are maintained in position with respect to the compliant member by adhesive prior to bonding.

15. A method of bonding together a brittle crystal body and a metal film on a rigid substrate comprising the steps of placing the crystal upon the metal film, advancing a pressure means to apply a pressure to the crystal through an immediately adjacent elastically or plastically compliant means and bonding the crystal and the substrate by thermocompression or ultrasonic bonding with or without heat, the compliant means being subsequently removed.

16. A method of bonding together workpieces substantially as herein described with reference to FIGS. 1A to 3B or FIGS. 4 to 7 or FIGS. 8 and 9 or FIGS. 10, 11, 13 and 14, or FIG. 12 or FIGS. 16 and 17 of the accompanying drawings.

17. An apparatus for carrying out the method of any one of claims 1 to 16 arranged and adapted to operate substantially as herein described with reference to and as shown in FIG. 18 of the accompanying drawings.

18. An article having a bonded joint made in accordance with the method of any one of claims 1 to 16.

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ability will be just the same for a more complex device, even one having a hundred or more leads, since it is no more difficult to bond. The further advantage, when a
 5 plastically deformable metal is used as the compliant medium, of having an exact replica of each and every bond made, is a most substantial one. For a given work-piece, a series of replicas can be used as a
 10 standard against which each replica can be judged, indicating both the existence of a bond for each lead and bond quality. When the metallic compliant medium is in the form of a lead frame, there is the additional
 15 advantage of presenting the device in a readily handleable manner which is easy to position on the substrate.

WHAT WE CLAIM IS:—

1. A method of bonding together a lead
 20 and a metal film on a rigid substrate comprising the steps of placing the lead upon the metal film, advancing a pressure means to apply a pressure to an elastically or a plastically compliant means arranged on the
 25 side of the lead so as to compress the compliant means and thereby transmit a pressure to the lead, the pressures being applied in the same direction, and applying heat and/or ultrasonic vibration to produce with
 30 the pressure applied to the lead thermocompression bonding or ultrasonic bonding of the lead to the film the compliant means being subsequently removed.

2. A method of bonding a lead from an
 35 integrated circuit device to a substrate comprising, applying pressure to the lead positioned on the substrate through an immediately adjacent elastically or plastically compliant means and bonding the lead and the
 40 substrate by thermocompression bonding or ultrasonic bonding with or without heat, the compliant means being subsequently removed.

3. A method as claimed in claim 1 or
 45 claim 2 wherein the compliant means is a metal having an adherent oxide coating thereon, for example, aluminium.

4. A method as claimed in claim 1 or
 claim 2 wherein the compliant means is
 50 polytetrafluorethylene.

5. A method as claimed in any one of
 claims 1 to 4 wherein the compliant means is capable of retaining an impression of a
 bond when made.

6. A method as claimed in claim 2
 55 wherein a plurality of leads are provided and in which the substrate comprises a plurality of metallic land areas, the bonding being effected between the leads and the
 60 land areas.

7. A method as claimed in claim 6
 wherein the thermocompression bond is carried out at a temperature of 350°C-500°C
 for 1 to 5 seconds.

8. A method as claimed in claim 6

wherein bonding is effected at a temperature of 400°C for 1 to 5 seconds and at a pressure of 3 pounds per lead.

9. A method as claimed in claim 6
 wherein 16 leads are provided and the land
 70 areas are an Au/Ti alloy.

10. A method as claimed in claim 1
 in which bonds are effected between one or more discrete first leads and the substrate
 75 wherein the compliant means comprises one or more resiliently mounted pins, a separate one of which is adapted to engage each of the leads.

11. A method as claimed in claim 10
 wherein the leads are maintained in position
 80 prior to bonding by means of a jig having a separate aperture therein for each of the resiliently mounted pins.

12. A method as claimed in any one of
 the preceding claims in which the ultrasonic
 85 bonding is in a direction of vibration substantially parallel to the plane of the substrate.

13. A method as claimed in claim 2
 wherein the compliant means is provided
 90 with an aperture or apertures adapted to retain the electrical device in position during bonding.

14. A method as claimed in any one of
 claims 6 to 9 wherein the leads are main-
 95 tained in position with respect to the compliant member by adhesive prior to bonding.

15. A method of bonding together a
 brittle crystal body and a metal film on a
 100 rigid substrate comprising the steps of placing the crystal upon the metal film, advancing a pressure means to apply a pressure to the crystal through an immediately adjacent
 105 elastically or plastically compliant means and bonding the crystal and the substrate by thermocompression or ultrasonic bonding with or without heat, the compliant means being subsequently removed.

16. A method of bonding together work-
 110 pieces substantially as herein described with reference to FIGS. 1A to 3B or FIGS. 4 to 7 or FIGS. 8 and 9 or FIGS. 10, 11, 13 and 14, or FIG. 12 or FIGS. 16 and 17 of the
 115 accompanying drawings.

17. An apparatus for carrying out the
 method of any one of claims 1 to 16 ar-
 ranged and adapted to operate substantially
 as herein described with reference to and as
 shown in FIG. 18 of the accompanying
 120 drawings.

18. An article having a bonded joint
 made in accordance with the method of any
 one of claims 1 to 16.

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