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## BONDING WITH A COMPLIANT MEDIUM

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## ABSTRACT OF THE DISCLOSURE

The bonding of two workpieces by ultrasonic or thermocompression techniques requires the use of a rigid bonding tip or ram to transmit the bonding energy, whether it be vibratory, mechanical and/or thermal. In time, such a rigid medium is subject to wear, to misalignment and to pickup of material from the workpieces, the latter causing the upper workpiece to stick to the tip. Further, such a rigid medium cannot be used reliably, to make a number of bonds simultaneously, because minor size differences in the workpieces can prevent a good couple for energy transmission from being established to every workpiece. It has been discovered that a compliant or deformable medium can be employed to hold the workpieces during bonding. By deforming around the workpieces, the compliant medium eliminates the problem of size differences, as well as wear, misalignment and the like, and a good bond is achieved in each instance. In one aspect, the bonding energy is transmitted through the compliant medium to make the bond. In a second aspect, the bonding energy is transmitted through the support for the workpieces. The quality of individual bonds is improved because, for a given set of bonding conditions, there is less deformation of the workpieces than with conventional techniques. The invention is particularly applicable to the bonding of beam-lead transistors and integrated circuits to substrates, to bonding a plurality of leads to integrated circuit and thin film devices, and to bonding brittle single crystal chips to substrates.

## BACKGROUND OF THE INVENTION

### 1. Field of the invention

This invention relates generally to bonding and, more particularly, it relates to the bonding of a first workpiece to one or more second workpieces. The first workpiece may comprise a thin film component of integrated circuit mounted on an insulating substrate, a printed circuit board, or the like. The second workpiece may comprise one or more small wires, the leads from a transistor or integrated circuit device, a small, brittle crystal, or the leads of a beam-lead transistor or integrated circuit device. The invention has application to the bonding of workpieces other than the above-described types, but since it is particularly adapted for such workpieces it will be described with reference thereto.

As electronic devices and circuits have become smaller, the problems associated with making electrical and, where necessary, ohmic contact thereto have increased. The bonding of discrete devices to substrates and the making of ohmic contact to emitter and collector regions required development of special plating techniques, brazing alloys and so forth, but once the device was packaged it could be connected into a circuit by conventional techniques. The bonding of chips cut from single crystals of silicon, germanium and the like to substrates presents many problems, due mainly to the brittleness of these materials. Brazing or soldering techniques are generally employed, though ultrasonic methods are also known.

The bonding of leads to thin film devices also created special problems. The substrates were brittle and tended to crack. The leads tended to work harden and fail in service. Damage to the thin film could occur. Two methods of bonding found favor in this service. One was ultrasonic bonding, where 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 ultrasonic vibratory energy in a direction parallel to the substrate surface makes the bond. The wiping motion of the lead surface over 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.

The second method of attaching leads to thin film contact areas is thermocompression bonding. In this method, 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. Good metallurgical bonds can be made in this manner. As used herein, the term, "mechanical energy" will be understood to include both ultrasonic vibratory energy and ram pressure.

In bonding by either the ultrasonic or thermocompression method, making each bond is essentially a separate operation, and efforts to make a number of bonds simultaneously have not been commercially successful (as used herein, "simultaneous" refers to bonding a number of leads to a single substrate at the same time; ganged bonding devices can of course be assembled to bond individual leads to separate substrates at discrete bonding stations, but this saves little time or labor). While the design of a heated ram big enough to make several bonds presents no problem, and an ultrasonic bonding tip with the same capability presents no insurmountable difficulties, variations in the size of the lead wire or the balled tip thereof, will prevent such devices from reliably bonding each lead to each substrate. Thus, if 10 leads are positioned on a substrate and 8 of them are exactly the same size but 2 are 10–20% smaller, a flat ram or bonding tip will make only 8 bonds. Or, if enough pressure is applied to contact all 10 leads, 8 of them will be deformed too much, resulting in a weak or "killed" bond. In another case, 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. Even with the most sophisticated quality control techniques and the closest tolerances obtainable, simultaneous bonding of a number of leads has not proven to be reliable or economic.

Workers in the field have heretofore attempted to apply the same techniques, ultrasonic and thermocompression 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 "kill" a bond by too much deformation. An especially difficult problem in the bonding of beam lead devices is referred to as "bugging." 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, giving it the appearance of a small bug. When this happens, 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. Other problems associated with bonding these devices result from their small size; it is necessary to use a microscope to even see the device adequately. Special tools must be used to position the device on the substrate and position the leads directly under the bonding ram or tip. As an example, a highly skilled worker will be able to bond a 16-lead integrated circuit device to a substrate in anywhere from three quarters to one and a half hours, depending on how "fresh" he is. Such work demands both skill and concentration, and is fatiguing. Needless to say, the reject rate is high.

The simultaneous bonding of all of the beam leads in a given device has heretofore been commercially impractical. A simple beam lead device may have 12 or 16 leads, each 5 mils by ½ mil. What is believed to be the closest tolerance obtainable on the thickness of a plate slice of silicon is ±0.2 mils (0.0002 in.). While this is a very close tolerance indeed, in absolute terms, its amounts to ±40% 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. The above-mentioned problem of "bugging," and the ease with which leads may be "killed" by too much deformation, add to these difficulties.

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.

## 2. Description of the prior art

The techniques of ultrasonic and thermocompression bonding, particularly as applied to bonding leads to substrates, are well known in the art. In the field of electric welding, the use of flexible electrodes and electrodes mounted on resilient supports was proposed many years ago (see, for example, U.S. Pat. No. 475,191 and No. 2,226,424).

Gang welding at several, spaced welding stations was proposed in U.S. Pat. No. 3,053,125. The patentees place the workpieces on movable supports located under each bonding head, then move the support up to clamp the workpieces in place. The welding heads are located on a long rod at points of antinodal vibration. The rod is connected to an ultrasonic transducer, and a single application of ultrasonic energy will make a single bond at each welding station. There is no known prior art utilizing a compliant medium in connection with ultrasonic or thermocompression bonding.

There has been proposd, however, a method of soldering connections to a plurality of flexible cables at one time. In this method, the portions of the conductors desired to be bonded are coated with solder, and the cable assembly is laid over the contact elements, which rest on a rigid support. A Teflon (trademark) sheet is laid over the cable insulation and a quartz plate is laid on top of the sheet. A tungsten halogen lamp provides infrared heat energy which passes through the quartz, Teflon and insulation (all of these members being more or less transparent to infrared radiation) which melts the solder and makes the bond. The quartz acts as a heat sink and a clamp (see Broyer and Mammel: "Flex Cable Interconnections Mass Bonded With Infrared," Proceedings, NEP/CON, 67, July 1967).

## OBJECTS OF THE INVENTION

It is a general object of the present invention to provide an improved method of bonding metallic surfaces of workpieces.

Another object of the present invention is to provide an improved method of bonding leads to substrates.

A further object of the present invention is to provide

an improved method of bonding a plurality of leads to a substrate simultaneously.

Still another object of the invention is to provide a method of bonding brittle single crystal chips to substrates with heat and mechanical energy.

Yet another object of the invention is to provide a method of ultrasonic or thermocompression bonding which produces bonds of improved quality when compared to conventional methods of this type.

A still further object of the invention is to provide a novel method of nondestructively checking a bond between workpieces.

Yet another object of the invention is to provide an improved method for simultaneously bonding all of the leads of a beam-leaded semiconductive device to the metallic land areas of a substrate.

Still another object of the invention is to provide a method of bonding beam-lead devices to substrates which avoids "bugging" and killing of leads.

Still another object of the invention is to provide an improved method of bonding leads to substrates which is relatively fast, highly reliable and economic, even with substantial variations in lead size.

Still a further object of the present invention is to provide a novel lead frame structure useful in achieving the foregoing objects.

Another object of the invention is to provide a novel jig assembly useful in carrying out the method of the invention.

Still another object of the present invention is to provide a novel apparatus for achieving the foregoing objects.

Various other objects and advantages of the invention will become clear from the following summary and detailed description thereof, and the novel features will be particularly pointed out in connection with the appended claims.

## SUMMARY OF THE INVENTION

In essence, the present invention is based, at least in part, on the discovery that the use of a compliant or deformable medium to hold the workpieces has many significant advantages in bonding, and that sufficient thermal and/or mechanical energy can be transmitted through or absorbed by such a medium to effect a good bond between the workpieces.

Understanding of the invention will be facilitated if, prior to considering embodiments of the invention, some attention is given to the transmission of energy through a compliant or deformable medium, which is considered to be one of the more surprising aspects of the invention.

While a compliant medium may be easily 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 p.s.i. 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 p.s.i. The energy of deformation in each instance is represented by the distance moved by the weight lower than one inch. If the weight squeezed the rubber to a height of ¾ inch, for example, the energy of deformation would be $(1\frac{3}{4})\times 1\frac{1}{12}\times 100=2.09$ foot pounds. The potential energy represented by the 100 p.s.i. pressure on the support is still available to perform work.

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 substrates. 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 de-