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(54) JOINING OF WORKPIECES BY EXPLOSIVE BONDING

(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 joining of workpieces by explosive bonding.

The problem with which the invention is concerned can be illustrated in relation to the electronics industry. Many electronic circuits are now made in integrated circuit form, the circuits and related active devices such as diodes and transistors being supported on substrate bodies which are of very small size, for example, 0.035 inch square. Furthermore, capacitors, resistors and wiring patterns are often produced on substrates of this order of size. Such circuits must be connected to external circuits, for example, power supplies and signal input and output devices which are very much larger. This may be effected by connecting the integrated circuit by means of fine wires or leads to pins or other relatively large connecting means carried by a header upon which the integrated circuit may be supported.

The bonding process necessary to effect this connection is often hand operated, which is expensive and slow, whilst automatic bonding methods often do not produce uniform bonding results. Since an integrated circuit may require a large number of external connections a fault in any one of these renders the whole circuit useless. The same difficulties are present when the integrated circuit is to be connected to a printed or deposited circuit carried by a substrate. In addition, processes for producing the circuit pattern on the sub-

strate are involved and require a number of separate steps.

Explosive welding and cladding of metals is well known for large scale operations and is used, for example, in the aircraft industry. In these cases, however, the size of the pieces to be welded is of the order of feet, so that large amounts of explosives are required. In these known methods, the explosive is a secondary explosive usually in the form of a sheet which is placed above the workpieces and is fired by means of a detonator. Any contamination resulting from the explosion can be readily cleaned off the workpieces by machining or sanding. However, this method of welding cannot be "scaled down" to meet present requirements and in any case, cleaning of the welded product cannot be done in the above ways. In some of the prior large scale methods, a buffer material is interposed between the explosive sheet and the workpieces in order to reduce or modify the effects of the secondary explosive but does not protect the workpieces from contamination.

In the above method, the detonator is a primary explosive and the bonding force is derived from the secondary explosive. A primary explosive may be easily detonated by pressure, heat, light, sound, electrical means or chemical means, whilst a secondary explosive is relatively stable and fairly difficult to set off directly by the above means. Secondary explosives generate more energy than primary explosives. Primary explosives are used to detonate secondary explosives.

Strictly speaking, the difference between a low explosive, such as gun powder, and a high explosive, such as TNT, is in the manner in which the chemical reaction occurs. The fundamental difference is between burning (or deflagration) and detonation, not between the explosive substances themselves. It is quite common to find that an explosive can either deflagrate or detonate according to the method of initiation or the quantity of ex-

plosive involved. If the mass of explosive matter is small, thermal ignition thereof, as by an open flame, usually, if not always leads to deflagration; but if the mass exceeds a certain critical value, it is possible for the burning to become so rapid that it sets up a shock-wave front in the explosive material and detonation ensues. The critical mass varies from explosive to explosive, thus, for the primary explosive lead azide, the critical mass is too small to measure, whereas for TNT it is in the order of 2000 pounds. Thus, the application of an open flame to a mass of TNT of, say, 1800 pounds would not produce detonation but only deflagration. The application of the same open flame to 2200 pounds of TNT, however, would produce an immediate detonation. Quantities of secondary explosive, therefore, which are smaller than the critical mass must be detonated by an intense shock, e.g., from the detonation of a primary explosive such as lead azide and are thus of no value for the bonding of miniature workpieces.

Primary explosives are normally used exclusively for initiating detonation in secondary explosives such as TNT, dynamite and the like. Because the critical mass of such primary explosives is so small as to be unmeasurable, the empirical equations developed for the use of subcritical masses of secondary explosives are inapplicable.

A more detailed discussion of the thermochemistry of explosives may be found in the publications entitled, "Detonation in Condensed Explosives", by J. Taylor, published by Oxford University Press, London, 1952 and "Explosive Working of Metals", by J. S. Rinehart and J. Pearson, published by MacMillan, New York, 1963.

According to the invention a method of making an electrical device or circuit includes the steps of bonding a first workpiece consisting of one element of the device or circuit to a second workpiece consisting of a second element of the device or circuit comprising placing the regions of the workpieces to be bonded in juxtaposition and detonating an explosive adjacent the juxtaposed regions so as to accelerate one workpiece into bonding contact with the other, the said explosive consisting solely of a primary explosive.

In cases where the products of the explosion of the primary explosive might produce undesirable contamination of the workpieces, a buffer medium may be used, the primary explosive being applied to one surface of the buffer medium and the other surface being placed upon the first workpiece. The primary explosive may be applied to a portion only of the first workpiece or the buffer medium by using a suitably apertured mask, the explosive being pressed through the mask aperture so that the location of the discrete portion of explosive charge is such as to

produce a controlled pattern of bonding force. Alternatively, a silk screen printing process may be employed.

Detonation of the primary explosive may be effected by physical, chemical or light means. 70

Particularly useful applications of the process are in the bonding of beam lead electrical devices, such as integrated circuits, to contacts on connecting circuits and to the production of electrical elements such as capacitors, resistors and inductors. In the latter case, a suitable conducting pattern is explosively bonded by a primary explosive to a suitable substrate. A convenient method of doing this is to apply the pattern to one surface of a buffer medium to the opposite surface of which the primary explosive is applied. 75 80

In the drawings:

FIG. 1 is an isometric view of an apparatus which may be utilised to deposit explosive material on the micro-leads of a beam lead-like device; 85

FIG. 2 is a partial top view of a plurality of beam-lead devices, prior to separation, and shows in greater detail the manner in which the explosive material is deposited thereon; 90

FIG. 3 is an isometric view of a single beam-lead device and shows the location of the explosive material on the microleads thereof in greater detail; 95

FIG. 4 is a partial, cross-sectional view of a beam-lead device prior to the explosive bonding thereof to the land areas of a substrate; 100

FIG. 5 is a partial, cross-sectional view of the beam-lead device shown in FIG. 4 after it has been explosively bonded to the substrate; 105

FIG. 6 is a partial, cross-sectional view of the beam-lead device shown in FIG. 4 illustrating the use of a buffer member positioned intermediate the explosive material and the beam-lead device; 110

FIG. 7 is a plan view of the buffer member shown in FIG. 6 depicting the location of the explosive charges thereon in greater detail;

FIG. 8 is a partial, cross-sectional view of the beam-lead device shown in FIG. 6 after explosive bonding to the substrate has occurred; 115

FIG. 9 is an isometric view of an apparatus for explosively bonding a plurality of beam-lead devices to a substrate by the application of light thereto; 120

FIG. 10 depicts the use of light from a laser to detonate the explosive material;

FIG. 11 is an isometric view of an apparatus for explosively bonding a plurality of beam-lead devices to a substrate by the use of focused light from an incandescent lamp; 125

FIG. 12 is an isometric view of an apparatus which may be used to explosively bond 130

a plurality of beam-lead devices to the land areas of a substrate by the application of heat thereto;

5 FIG. 13 is a side view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by the use of radio frequency induction heating;

10 FIG. 14 is a side view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by the use of radio frequency dielectric heating;

15 FIG. 15 is an isometric view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by the use of acoustical energy;

20 FIG. 16 is a side view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by the use of simple mechanical pressure applied through a compliant medium;

25 FIG. 17 is a side view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by means of an electrical discharge passing through the explosive material on the beam leads;

30 FIG. 18 is an isometric view of an apparatus which may be used to bond a plurality of beam-lead devices to the land areas of a substrate by means of a beam of electrons;

35 FIG. 19A is a cross-sectional view of a beam-lead device illustrating the manner in which the upper surface of the beam leads may be rendered undulating to improve the quality of the bonds; and

40 FIG. 19B is a similar cross-sectional view illustrating the manner in which the upper surface of the beam leads may be castellated to improve the quality of the bond;

45 FIG. 20 is a partial, cross-sectional view illustrating the manner in which the contact pads of a "flip chip" IC (integrated circuit) device may be explosively bonded to the land areas of a substrate;

50 FIG. 21 illustrates an alternative embodiment of the invention which may advantageously be used to deposit conductive metal paths on an insulating substrate;

FIG. 22 illustrates the finished appearance of the substrate shown in FIG. 21;

55 FIG. 23 is a side view of another embodiment of the invention in which spacing elements are provided intermediate the workpieces to be bonded to ensure the creation of a strong bond;

60 FIG. 24 is a side view of the elements depicted in FIG. 23 after a bond has been formed;

65 FIG. 25 is a view view of a buffer medium having a patterned workpiece fabricated on one side thereof and a correspondingly patterned explosive charge on the other surface thereof;

FIG. 26 is an isometric view of the buffer medium shown in FIG. 25 positioned over a substrate to which the metallic pattern is to be bonded;

70 FIG. 27 is an isometric view of the substrate shown in FIG. 26 after the bond has been formed;

75 FIG. 28 illustrates yet another embodiment of the invention which may be used to manufacture thin or thick film capacitors by explosive bonding techniques;

FIG. 29 illustrates the embodiment shown in FIG. 28 after the electrode of a capacitor has been explosively bonded to a substrate;

80 FIG. 30 is another view of the capacitor shown in FIG. 29 illustrating the manner in which a counter-electrode may be explosively bonded thereto; and

85 FIG. 31 is an isometric view of the capacitor shown in FIG. 30 after the counter-electrode has been explosively bonded thereto.

FIG. 1 depicts an apparatus which may be used to deposit a small quantity of explosive material on the microleads of a beam-leaded IC (integrated circuit) device, comprising a semi-conductor body, or the like. As shown, a conventional wax-coated semiconductor carrier plate 30, having a plurality of beam-leaded IC devices 31, temporarily secured thereto, is placed on the bottom surface 32 of a hollow, rectangular container 33. Carrier plate 30 is restrained from movement, and aligned, by means of a plurality of first registration pins 34 which mate with a corresponding plurality of notches 35 in carrier plate 30. A second plurality of registration pins 38 are provided at the four corners of container 33. A rectangular stencil plate 40, having a plurality of orthogonally oriented slot apertures 41 therein, is adapted to fit down inside container 33 so that registration pins 34 and 38 mate with a corresponding plurality of apertures 39 in the stencil plate. When so mated, the slot apertures 41 align with the beam leads of the IC devices 31.

110 Referring now to FIG. 2, as is well known, each of the beam-leaded IC devices 31 is provided with a plurality of gold beam leads 42 cantilevered outward therefrom. In accordance with standard manufacturing techniques for these devices, prior to separation, the beam leads of each device are interdigitated with the beam leads of its immediate neighbours. Registration pins 34 and 38, FIG. 1, align stencil plate 40 so that the slot apertures 41 therein are positioned intermediate each pair of beam-lead devices and cross the interdigitated beam leads 42, FIG. 2 in the region of overlap.

125 Returning to FIG. 1, a squeegee 43 having a rubber roller 47 is slideably mounted in a frame (not shown) which in turn is attached to the walls of container 33. The rubber roller 47 is adapted to fit within container 33 and to engage the upper surface of stencil plate 130

40 when the plate is mated with registration pins 34 and 38 and positioned over IC carrier plate 30.

5 In operation, the carrier plate, bearing the IC devices whose beam leads are to be coated with explosive material, is placed on the bottom surface 32 of container 33 and aligned therewith by means of registration pins 34. Next, stencil plate 40 is fitted over the aligned carrier plate 30 and a metered quantity of primary explosive material deposited from a suitable container on to the stencil plate. Squeegee 43 is then lowered into engagement with the stencil plate and rolled back and forth to force the explosive material down into slotted apertures 41 and, hence, on to the beam leads of each IC device. When the measured quantity of explosive material has been consumed, the stencil plate and the carrier are removed from container 33 and the explosive material permitted to dry. The individual IC devices are then separated from the carrier by any of several conventional techniques.

25 It is, of course, necessary to select an explosive which is not so sensitive that the squeegee operation will cause premature detonation thereof. Typically, the explosive material is dissolved in some suitable chemical solution which facilitates the stenciling of the explosive on to the IC device. In addition, the solvent may inhibit premature detonation, at least until the solution has evaporated and the explosive material is dry.

35 It will be appreciated that a suitably patterned silk-screen (or other equivalent screening device) could be substituted for stencil plate 40 and the explosive printed through the screen. Other analogous printing techniques may, of course, also be used to apply the explosive to the workpiece.

45 FIG. 3 illustrates the appearance of a beam-lead device after it has been coated with explosive material and separated from its neighbouring devices. As can be seen, a small quantity of explosive material 48 has been deposited on each beam lead 42. It will be apparent that the quantity of explosive deposited, and hence the bonding force produced when the explosive is detonated, may be controlled by varying the width of the apertures in the stencil plate and/or by altering the thickness of the stencil plate, thereby affecting the amount (i.e., width and height)

of explosive material deposited on the beam leads. 55

For some special applications, it may be desirable to deposit unequal amounts of explosive material on each beam lead. The above-described apparatus can easily accommodate this requirement by a combination of the above-described changes to the apertures of the stencil plate. Further, the apparatus may easily be adapted to handle different IC circuit configurations, or different substrate arrangements, by merely substituting an appropriately configured stencil plate. The apparatus can also handle an individual IC device, if so desired, by the use of a suitably dimensioned holder for the individual device. Advantageously, slotted apertures 41 in stencil 40 are arranged to deposit explosive material on to each beam lead no closer to the main part of the device than $1/3$ of the length of the beam lead and no further from the device than $2/3$ of the length of the beam lead. Advantageously, the average distance used in practice is approximately $1/2$ of the length of a beam lead. 60 65 70 75

As previously discussed, in the bonding of miniature electrical workpieces, a primary explosive must be used. Of the many known primary explosives, the azides and the fulminates are probably the most widely understood, although many other chemical compounds exhibit similar characteristics and may also be used for the explosive bonding of miniature workpieces. The choice of the particular primary explosive to be used in any given bonding application is a function of the amount of explosive force required and/or the manner in which it is desired to initiate detonation. Detonation may be accomplished by the application of heat, light, sound, pressure, shock waves and the introduction (or removal) of a suitable chemical atmosphere. For example, if light is employed as the detonating mechanism, then silver nitride (Ag_3N) or cuprous azide ($\text{Cu}(\text{N}_3)_2$) may be used as the primary explosive. Alternatively, if detonation is accomplished by means of mechanical force and pressure, mercury fulminate ($\text{C}_2\text{N}_2\text{O}_2\text{Hg}$) or lead azide ($\text{Pb}(\text{N}_3)_2$) may be used as the primary explosive. 80 85 90 95 100

TABLE A, below, lists some of the more common azide compounds, together with their critical detonation temperatures. 105

TABLE A
The More Common Azide Explosives

	Compound	Formula	Critical Detonation Temp. °C
5	Lead Azide	$\text{Pb}(\text{N}_3)_2$	350
	Silver Azide	$\text{Ag}(\text{N}_3)_2$	300
	Titanium Azide	Ti N_3	350
	Boron Azide	$\text{B}(\text{N}_3)_2$	—
	Silicon Azide	$\text{Si}(\text{N}_3)_4$	—
10	Mercuric Azide	$\text{Hg}(\text{N}_3)_2$	460
	Copper Azide	$\text{Cu}(\text{N}_3)_2$	215
	Cadmium Azide	$\text{Cd}(\text{N}_3)_2$	144
	Ammonium Azide	$\text{NH}_4(\text{N}_3)$	170
	Mercurous Azide	$\text{Hg}_2(\text{N}_3)_2$	210

- 15 Table B, below, lists some of the more common fulminate compounds, together with their critical detonation temperatures.

TABLE B
The More Common Fulminate Explosives

	Compound	Formula	Critical Detonation Temp. °C
20	Mercury Fulminate	$\text{Hg}(\text{ONC})_2$	190
	Silver Fulminate	$\text{Ag}(\text{ONC})_2$	170
	Copper Fulminate	$\text{Cu}(\text{ONC})_2$	—

- 25 Table C, below, lists some additional primary explosive compounds, together with their critical detonation temperatures.

TABLE C
Miscellaneous Primary Explosives

	Compound	Formula	Critical Detonation Temp. °C
30	Mercuric Acetylide	HgC_2	260
	Mercurous Acetylide	Hg_2C_2	280
	Copper Acetylide	CuC_2	280
	Silver Acetylide	Ag_2C_2	200
	Lead Styphnate	$\text{C}_6\text{H}_3\text{N}_3\text{O}_6\text{Pb}$	295
35	Barium Styphnate	$\text{C}_6\text{H}_3\text{N}_3\text{O}_6\text{Ba}$	285
	Silver Nitride	Ag_3N	155
	Tetrazene	—	200
	Diazodinitrophenol (DDNP)	$\text{HOC}_6\text{H}_3(\text{NO}_2)_2\text{N}(:\text{N})$	180

- 40 The above three tables are by no means all inclusive. There are many other unstable chemical compounds, for example, nitrogen iodide, which are classified as primary explosives and which, under appropriate conditions of temperature and pressure, might conceivably be utilised for the explosive bonding of miniature workpieces. However, the explosives listed in the above tables are of primary interest in this regard.
- 50 Turning now to FIG. 4, there is shown a cross-sectional view of integrated circuit device 31 prior to its being bonded to the terminal metallic land areas 50 of a ceramic or glass substrate 52. A thin film 51 of grease, dirt, metal oxide, or other contaminants is shown

on the upper surface of land areas 50. A similar film will generally also be present on the surface of beam leads 42 but, for the sake of clarity, this film has been omitted from the drawing.

It will be noted that each beam lead is bent upward away from the substrate to form a small angle α with the plane of the substrate. In order for a bond to form between a beam lead and the corresponding land areas of the substrate, the explosive charge 48, when detonated, must accelerate the beam lead downward towards the land area with a sufficiently high impact velocity that the resultant impact pressure is of sufficient magnitude to cause substantial plastic flow of the

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workpieces to be joined. Thus, the yield points of the materials from which the workpieces are fabricated must be considerably exceeded by the impact pressure.

5 An important aspect of explosive bonding of materials liable to surface contamination is the phenomenon known as "jetting", that is, the process of material flow which occurs when two metal workpieces strike each other at sufficiently high impact velocity to cause plastic flow of the workpiece metals and the formation of a re-entrant "jet" of material between the workpieces, as shown by the arrows 49 in FIG. 4. The formation of this "jet" of molten material is important to the establishment of a strong bond, as it removes any impurities and oxides which may be present on the surfaces of the workpieces to be bonded and brings freshly exposed, virgin metal surfaces into intimate contact in the high-pressure collision. Some workpiece materials, for example, gold, may be satisfactorily bonded without the presence of "jetting". This is due to the inherently oxide-free surfaces of these materials. In that event, the angle which is formed between the beam lead and the substrate becomes less critical and in some instances even unimportant.

30 The impact pressure required to bond a beam lead to the corresponding substrate land area may be calculated from the shock Hugoniot data for the workpiece materials. Once the impact pressure required for bonding is known, the impact velocity may be calculated. This in turn yields the necessary ratio of accelerating explosive charge to metal mass (C/M), hence, the quantity of explosive material required for a given bonding operation.

40 The desirable jetting phenomenon, however, only occurs if the angle of impact, β , at the collision point exceeds a certain critical value. Further, there can exist either a stable jetting condition or an unstable jetting condition, the latter being undesirable as it results in a bond of poor quality.

50 Stable jetting will occur if the collision point at which the two surfaces first meet, travels along the interface with a velocity equal to or greater than the highest sonic velocity in either of the two workpiece materials. Table D, below, lists the velocity of sound in several typical metals and, for comparison, Table E, lists the detonation velocity of several typical primary explosives.

TABLE D
Velocity of Sound in Several
Typical Metals

Metal	Velocity (m/sec)
Gold	2030
Silver	2680
Aluminium	5000
Platinum	2800

TABLE E
Detonation Velocity of Typical
Primary Explosives

Explosive	Detonation Velocity (m/sec)
Lead Azide	4000
Lead Styphnate	5000
Mercury Fulminate	5050
DDNP	6800

If the two workpieces to be bonded are positioned parallel to one another, the collision point velocity equals the detonation velocity of the accelerating explosive charge. It will thus be seen that for the types of metals commonly used for microleads and land areas in the electronics industry, by the choice of an appropriate explosive material, the collision point velocity will always exceed the bulk sonic velocity in the workpiece metals.

Actually, if the collision point velocity substantially exceeds the bulk sonic velocity in the workpiece materials, another undesirable effect is noted. That is, the generation of expansion waves in the workpieces which tend to separate the inner surfaces thereof and destroy or weaken the bond immediately after its formation. The ideal situation is when the collision point velocity slightly exceeds the bulk sonic velocity so that stable jetting occurs, yet undesirable expansion waves do not occur. For parallel geometry, this condition can be achieved by slowing down the detonation velocity of the explosive material, for example, by the addition of inert materials such as liquid paraffin or French Chalk thereto, or by reducing the density of the explosive. For example, the addition of 30% paraffin to lead azide will reduce the velocity of detonation from 4000 m/sec to 500 m/sec, but the mixing process is difficult to control and the results are often unpredictable. For these reasons, other means are preferably employed to reduce the collision point velocity.

If the workpieces to be bonded are not held parallel, but rather are aligned so that they make a small angle α to one another, the collision point velocity is no longer the same as the detonation velocity of the explosive material, but falls to some fraction thereof. Thus, by varying the geometry of the bonding configuration, the collision point velocity may be adjusted so that it is only slightly more than the bulk sonic velocity in the workpiece materials, which is the optimum condition.

As previously discussed, there is a critical angle of contact β for the collision below which jetting and satisfactory bonding usually will not occur. For parallel geometry, β can be increased by increasing the ratio of explosive charge to mass (C/M). However, if this is attempted in nonparallel geometry, such as shown in FIG. 4, it is found that the collision point velocity also increases. There is thus an

interaction between changing the impact angle so that it exceeds the critical angle below which jetting does not occur, and lowering the collision point velocity to approximately the bulk sonic velocity in the workpiece materials. Nevertheless, despite this interaction, for workpieces of the type shown in FIG. 4, and primary explosives of the types listed in Tables, A, B and C, there exists a broad range of orientations, charge densities, and explosive compounds which will simultaneously satisfy all these criteria and produce strong, sound bonds. As an example of a specific bond, which has been produced, a gold wire measuring 0.002" by 0.0005" was bonded to a gold-plated ceramic substrate by means of from 25 to 40 μ grams of lead azide. Detonation was accomplished by an electrical discharge from a 3 volt D.C. source connected between the wire and the plating. The wire made an angle of less than 5° to the plane of the substrate. Bonding was facilitated if the temperature of the substrate was raised to 175°C prior to passing the electrical discharge through the substrate.

FIG. 5 depicts the beam-leaded device shown in FIG. 4 after it has been explosively bonded to the substrate. The beam leads 43 are now, of course flattened and substantially parallel to the substrate. A small area of discoloration or pitting 53 will be noted on each beam lead in the region occupied by explosive material 48. This discoloration and pitting, however, does not affect the mechanical strength or electrical characteristics of the beam leads to any detectable degree.

The region 54 in which bonding actually occurs does not extend over the entire area of the beam lead. This is of no great import, however, as it approximates the geometry which occurs in other satisfactory bonding techniques, such as thermocompression or ultrasonic bonding.

In the case of substrates including active semiconductor devices the by-products of the explosion, both gaseous and particulate, pose a very real threat of contamination to the silicon or germanium material from which the active devices are fabricated. This contamination may, under certain circumstances, alter the operating characteristics of the devices or, worse, render them totally inoperative. The same is true, to a lesser extent, of thin-film capacitors and resistors which may also be fabricated upon the same substrate. This contamination can be reduced or prevented by conducting the explosive bonding in a partial vacuum, for example, by the use of a conventional bell-shaped vacuum jar. In addition, by removing the air which is normally present between the workpieces, the partial vacuum tends to increase the work-

piece acceleration, thereby, improving the quality of the bond. The explosive bonding may also be effected through an intermediate buffer, such as a layer of plastics material for example the polyimide sold under the registered trademark "KAPTON", of the E. I. DuPont de Nemours Co. Metallic material, for example, stainless steel, or the like, may also be used for the buffer medium.

FIGS. 6 and 7 illustrate the use of such a buffer layer in an explosive bonding operation. As shown therein, a film of plastics material (e.g. a KAPTON film 3 mils thick) or metallic material (e.g. stainless steel 2 mils thick) 60 having a plurality of apertures 61 therein is positioned over the top surface of beam-lead device 31 by locating use of the apertures 61 over the device 31. The explosive material 48, is deposited on the upper surface of the film 60.

The explosive charges which are deposited on to the buffer film may be placed there by means of the apparatus illustrated in FIG. 1, or by the use of printing using a patterned silk-screen or printed on to the film, intaglio fashion, by means of a suitable rubber or metallic roller having a raised surface thereon which corresponds to the desired locations of the explosive charges.

FIG. 8 depicts the beam-lead device shown in FIG. 6 after the explosive material 48 has been detonated. As was the case illustrated in FIG. 5, the metallic beam leads 42 are now substantially parallel to the ceramic or glass substrate 52 and bonded to the metallic land areas 50 of the substrate at locations 54. The buffer film 60 is forced down about device 31 by the explosion, but is not ruptured. As a result, unwanted by-products of the explosion are prevented from reaching the sensitive portions of the substrate, and damage thereto is avoided. Although in FIG. 6 buffer sheet 60 is depicted as being apertured so that it may be fitted over the beam-lead devices, it will be appreciated that sheet 60 could be contoured, rather than apertured, and in that event would also serve to protect the IC device from contamination as well as the substrate. After the bonding operation has been satisfactorily performed, buffer film 60 may be peeled off the substrate. If the sheet is fabricated from plastics material, however, no deleterious effects will occur if it is permitted to remain in place.

As previously mentioned, the detonation of the primary explosive, may also be accomplished by exposure to light.

Table F, below, lists some of the primary explosive compounds exhibiting this property, together with the minimum light intensity required to initiate detonation thereof.

TABLE F
Photosensitive Explosive Compounds

	Compound	Formula	Light Intensity in Joules/Centimetre ²
5	Silver Azide	AgN ₃	2.6
	Silver Nitride	Ag ₃ N	0.2
	Silver Acetylide	Ag ₂ C ₂	0.8
	Silver Fulminate	AgONC	2.1
	Lead Azide	Pb(N ₃) ₂	2.0

10 The mechanism which renders these and other similar primary compounds sensitive to detonation by light is not fully understood.

15 FIG. 9 illustrates an apparatus which may be used to explosively bond the beam leads of an IC device using light as the detonating mechanism. It will be appreciated that this apparatus may also be used to bond other types of workpieces, for example, to explosively bond metal paths on to a ceramic or glass substrate or to explosively bond the elements of capacitors or resistors, to a substrate. The same is also true for the other apparatus discussed below with reference to FIGS. 10—18. The beam leads of the devices 20 62 to be bonded are coated with a quantity of light-sensitive primary explosive, for example, silver azide, and the devices then aligned with respect to the land areas of the substrate 63 in a conventional manner. If 25 desired, the devices may be temporarily tacked to the substrate by means of a drop of alcohol, or the like. Substrate 63 is then placed within a glass vacuum jar 64, which may be wholly transparent or contain one or more transparent windows and which is exhausted by means of an exhaust pipe 65 and a pump 66. One or more photo flash lamps 67, for example, krypton-filled quartz flash lamps are positioned outside the vacuum jar so that the light 30 which is generated by the tubes will fall upon the photosensitive material on the beam leads. Photo flash lamps 67 are connected via a pair of conductors 68 to a switch 69, thence to a suitable source of energising potential 40 70. Operation of switch initiates an intense burst of light which detonates the silver azide on each beam lead, and explosively bonds each of the IC devices 62 to substrate 63.

50 Silver azide is primarily responsive to light in the ultraviolet range ($\lambda=3500$ Å units) and krypton-filled photo flash lamps of the type shown in FIG. 9 produce more than enough energy in this ultraviolet range to detonate photosensitive silver azide. The typical duration of the flash from photo flash lamps 55 67 is approximately 67 μ s and explosion of the silver azide usually occurs within 20 μ s thereafter. From Table F the critical light intensity required to detonate silver azide is 60 2.6 joules/cm² which corresponds to 8×10^{-4} calories/mm². This critical light intensity is independent of the mass of explosive material used, at least in the range of from 200 to 1500 micrograms. Unwanted by-products of the explosion are, as previously discussed, 65 vented from vacuum jar 64 by pump 66. However, in applications where these by-products are not troublesome, the bonding process can, of course, be conducted in a normal atmosphere. The use of a transparent plastics film 70 positioned over line IC devices for alignment purposes is, of course, possible, provided that the intensity of the photo flash is sufficient to compensate for any light energy lost in passing through the transparent film. Further, this 75 method of detonation may also be used with a transparent buffer member coated with explosive positioned over the IC device and the substrate.

80 If the intensity of light from photo flash lamps 67 is not sufficient, a simple lens system (not shown) may be placed in front of each lamp to focus the light energy therefrom on to the explosive.

85 A laser beam may be used to detonate the light-sensitive explosive, rather than the photo flash lamp illustrated in FIG. 9. As shown in FIG. 10, light from a pulsed or Q-switched laser 71 is expanded by a pinhole beam expander 72 and collimated by a lense 73. The 90 collimated beam of laser energy is then directed upon the IC devices 62 on substrate 63 detonating the silver azide, or other photosensitive primary explosive, deposited on the beam leads thereof. Again, the substrate and IC devices may be positioned within a transparent vacuum jar, if desired, and the laser energy applied through the walls of the jar to 95 detonate the photosensitive explosive material.

100 The amount of light energy required to initiate detonation of a photosensitive explosive varies inversely with the duration of the flash. Thus, a longer flash, as might be obtained, for example, from a magnesium-filled flash bulb, would have to be several times as 105 intense to produce detonation of the same explosive material. Further, due to thermal lag, if the duration of the flash is too great, the explosive material will deflagrate rather than detonate, regardless of the intensity. 110 Thus, the use of pulsed light sources is, generally speaking, preferable to the use of a continuous light source.

115 FIG. 11 illustrates the use of a conventional light source to explosively bond a plurality of beam devices to a substrate. As shown, a quartz incandescant lamp 74 is positioned at

the focus of an ellipsoidal reflector 75. The filament of lamp 74 is connected by a circuit 76 and a switch 77 to a suitable source of energising potential 78. When switch 77 is closed and lamp 74 energised, the focused light therefrom impinges upon the surface of substrate 63 and detonates the photosensitive explosive deposited on the beam leads of the integrated circuits to be bonded.

Actually, because of the intense heat which is generated by quartz incandescent lamps of this type, which, may be rated at as much as 5 kilowatts, it is difficult to say whether it is the light energy or the thermal energy from the lamp which initiates the explosion. As with the previous examples, the substrate and the IC devices may be placed within a glass or quartz vacuum jar and the light from the incandescent lamp focused through the transparent walls of the vacuum jar.

The threshold sensitivity of certain photosensitive explosives may be lowered by the addition of other non-explosive elements thereto. For example, by mixing approximately 28% by weight gold powder with the silver azide powder, the minimum light energy required to induce detonation of the mixture is significantly reduced.

In any application employing photosensitive explosives, it is necessary to apply the explosive to the beam leads of the devices to be bonded in total darkness, or at least at levels of illumination which are sufficiently low that there is no danger of premature detonation of the explosive.

The detonation of the primary explosive, may also be accomplished chemically. Thus, if the substrate and the beam-lead devices which are to be bonded thereto are placed within a container, for example, a vacuum jar, and a suitable chemical atmosphere allowed to flow over the substrate, the reaction which occurs between the primary explosive and the chemical atmosphere will initiate detonation of the explosive and bonding will occur.

Other primary explosives are inhibited from explosion by the presence of an appropriate chemical atmosphere. For example, the detonation of nitrogen iodide ($\text{NI}_3 \cdot \text{NH}_3$) is inhibited by the presence of ammonia (NH_3) or water vapour. Thus, if the primary explosive is applied to the beam leads of an IC device in the presence of such an inhibitory atmosphere, detonation and bonding may be accomplished, after the device has been properly positioned over the land areas of a substrate, by exhausting the inhibitory atmosphere. In either of the above cases, care must be taken that the chemical atmosphere does not deleteriously affect the IC devices or the substrates.

The primary explosive may be detonated by other means. FIG. 12, for example, illustrates a method of explosively bonding a

plurality of IC devices to a substrate by the application of heat to the bottom surface of the substrate. As shown, substrate 63, with a plurality of IC devices 62 temporarily tacked thereto, is placed upon the surface of a flat metal susceptor 79. A plurality of cartridge-type heaters 80 are mounted within the body of susceptor 79 and connected via a circuit 81 and a switch 82 to a suitable source of potential 83. When switch 82 is closed, the cartridge heaters rapidly increase the temperature of the susceptor, and hence the substrate, so that when the critical detonation temperature of the explosive material deposited on the beam leads is reached, the explosive detonates to explosively bond the IC devices to the substrate. Again, to prevent deflagration of the explosive material, the thermal inertia of the system must be kept as low as possible.

As can be seen from Tables, A, B, and C, above, the critical detonation temperature of primary explosives therein ranges from about 150°C to over 400°C, with most compounds detonating in the range of from 280°C to 300°C. The maximum temperature to which an integrated circuit device may be safely raised is about 350°C, although this may be exceeded for short time intervals, without damage to the device. It will be evident that since the critical detonation temperature of most primary explosives is well below the maximum safe temperature for the IC device, detonation of the explosive material by the direct application of heat to the substrate poses no real danger to the characteristics and operability of the IC devices fabricated thereon. The heat required to initiate detonation may be applied to the substrate by means other than thermal induction from a heated susceptor. Referring back to FIG. 11, if quartz lamp 74 is replaced by an infrared source, the focused radiant energy therefrom will rapidly raise the temperature of the substrate above the critical detonation temperature and explosive bonding will again occur. As previously, the radiant energy from lamp 74 may be applied through the walls of a glass vacuum jar, if it is desired to conduct the explosive bonding in a partial vacuum.

FIG. 13 illustrates another technique which may be used to raise the temperature of a device to initiate detonation of the explosive material deposited on the beam leads thereof. As shown, substrate 63 with beam-lead devices 62 temporarily tacked thereto is placed upon a suitable non-metallic support member 84. An induction coil 85 surrounds support member 84 and is connected via a pair of conductors 86 to a source of radio frequency energy 87. When source 87 is energised, a radio frequency current flows through the windings of coil 85 and eddy currents are induced in all of the metallic portions of the substrate and the IC devices. These eddy cur-

rents rapidly raise the temperature of the beam leads above the critical detonation temperature of the explosive compound deposited thereon, so that the explosive compound detonates, bonding the devices to the substrate.

FIG. 14 illustrates the analogous use of dielectric heating, rather than induction heating, to raise the temperature of the substrate. As shown, substrate 63, with the IC devices 62 to be bonded thereto, is placed between the capacitor plates 88 of a dielectric oven 89. A sheet of plastics material 90 may be placed between the substrate 63 and each plate 88 to prevent physical damage to the IC devices, and the substrate, during the bonding process. Plates 88 are connected via circuit 91 to a radio frequency source 92 which, when energised, supplies a high-frequency alternating current to capacitor plates 88. The rapidly alternating electric field which is generated between plates 88 will induce hysteresis excursions in the nonconducting ceramic substrate, which excursions will rapidly raise the temperature of the substrate, and hence the beam leads, above the critical detonation temperature of the explosive material on the beam leads. It is not entirely clear if the explosive compound is heated directly by the hysteresis losses or by thermal conduction from the heated substrate, but in any event, the net effect is to detonate the explosive and bond each of the beam leads to the substrate.

The detonation of the primary explosive may be accomplished by the application of mechanical shock or vibration to the explosive. For example, acoustic energy may be employed to detonate the explosive material. Referring to FIG. 15, the substrate, and IC devices to be bonded, are positioned beneath the outlet end of an acoustical horn 93 which is coupled to an ultrasonic oscillator 94. When energised, ultrasonic oscillator 94 generates ultrasonic waves which are propagated by horn 93 into the atmosphere. The acoustic waves from horn 93 strike the surface of the substrate, as well as the explosive material present on the beam leads of the IC devices to be bonded thereto, and, if the energy level of ultrasonic oscillator 94 is sufficiently high, shock waves are induced in the explosive material which are of sufficient magnitude to detonate the explosive material and bond the devices to the substrate. In this instance, it is not possible to conduct the bonding operation in a vacuum, as sound waves are not propagated in a vacuum. However, essentially if the explosion may be obtained by flowing an inert gas, such as helium, through the vacuum jar during the bonding process so that unwanted by-products of the explosion are vented by the flow of inert gas. Subsonic and sonic waves may also be utilised to detonate the explosive material, although the use of ultrasonic energy is preferred as it requires

less energy from the transducer and is easier to direct on to the substrate.

FIG. 16 illustrates yet another method which may be used to mechanically detonate the primary explosive on the beam leads of each device. As shown, a substrate 63, to which a plurality of IC devices 62 are to be bonded, is placed upon a support bed 95 and a sheet of compliant material 96, for example, KAPTON or aluminum overlaid thereon. A contoured bonding tool 97 (or a flat bonding tool with a fluid pressure transmitting medium attached thereto) is then forced down into engagement with the compliant sheet to deform the sheet about the IC devices. As the sheet deforms about the IC devices, it contacts the beam leads thereof, detonating the explosive material 48 which is deposited thereon, thereby bonding the IC devices to the substrate.

In addition to transmitting mechanical pressure from the bonding tool to each of the beam leads, the compliant sheet also acts to constrain the upward forces of the explosions thereby increasing the bonding pressure which is applied to the beam leads. To a certain extent, the compliant member also inhibits contamination of the IC devices and the substrates, but not, of course, to the same extent as would be the case illustrated in FIG. 6, where the explosive material is applied to the upper surface of the buffer member rather than to the beam leads themselves.

Explosive bonding of workpieces can be accomplished by the use of primary explosives, for example, copper acetylide, lead styphnate, lead azide, mercury fulminate and tetrazine, which are detonated by an electrical discharge. The minimum spark energy necessary for detonation of these explosives varies from 20 ergs for copper acetylide to more than 100,000 ergs for mercury fulminate. The minimum energy required is also a function of impurities present in the explosive material.

FIG. 17 illustrates a method in which an electrical discharge is utilised to initiate detonation of the primary explosive. As shown, an IC device 62, which is to be bonded to a substrate 63, is aligned over the land areas 50 of the substrate and temporarily tacked thereto in a conventional manner. A plurality of spring leaf contacts 98 are pressed into engagement with the terminal land areas 50, or other contact points, of the substrate. Contacts 98 are connected via a lead 99 and a switch 100 to one terminal of a high-voltage source 101. The other terminal of source 101 is connected via a lead 102 to a metallic plate 103 to which a plurality of second spring leaf contacts 104 are riveted. Contacts 104 are positioned on plate 103 so that when plate 103 is lowered, by means of an insulated handle 105, into engagement with device 62, each one of the plurality of contacts 104

engages the explosive material 48, which is deposited on the corresponding one of the plurality of beam leads 42.

Since device 62 is not yet permanently bonded to substrate 63, there will be an imperfect electric contact between each beam lead 42 and the corresponding land area 50 of the substrate. For example, dirt, grease, metal oxide and other contaminants may be present on the surfaces of the connection, so that the unbonded resistance of the connection is typically several hundred ohms, or greater.

However, if the potential of source 101 is made sufficiently high, the electric field developed across the interface of the connection will break down at least a portion of the nonconducting film, and cause a momentary spark. This momentary spark, however, detonates the primary explosive 48 on each beam lead thereby forming a permanent bond between each beam lead and the corresponding land area of the substrate.

The primary explosive may be detonated by other forms of energy. Lead and silver azide, for example, may be detonated by the use of an electron beam and nitrogen iodide may be detonated by means of gamma rays and neutron bombardment.

FIG. 18 illustrates an apparatus which may be utilised to explosively bond a plurality of beam-lead integrated circuits by the use of an electron beam. As shown, the integrated circuit devices 62 to be bonded are aligned with respect to a substrate 63 and temporarily secured thereto. The substrate is then placed upon the objective stage 106 of an electron beam machine 107. The vacuum chamber of the electron beam machine is then evacuated by means of a pump 108 and the electron beam gun activated. A control circuit 109, which may be connected, for example, to a suitably programmed general purpose digital computer (not shown), successively deflects the electron beam to the approximate location of each beam lead on the substrate. As the electron beam strikes each charge of explosive material it detonates it, thereby explosively bonding the device to the substrate. Since the electron beam is not used to create the bond, *per se*, but only to detonate the explosive charge on the beam leads, it need not be of a particularly high intensity, and thus the electron beam can be defocused into a relatively broad beam. This eliminates most of the registration problems inherent with the use of an apparatus of this type.

A combination of more than one of the above-described detonation techniques facilitates the bonding operation. For example, where the primary explosive is to be detonated by the passage of an electric current therethrough, raising the temperature of the substrate prior to detonation reduces the amount of current required to produce detona-

tion and results in a more reliable bond. Similarly, where the explosive mechanism is optical or acoustical, the application of heat to the substrate will also improve the quality of the bond.

The above-described light, acoustical and electrical methods of detonation assumed that the explosive material was deposited directly on to the beam leads of the device. However, one skilled in the art will appreciate that these methods are equally applicable to the situation where the explosive material is deposited on to the upper surface of a buffer member, such as a sheet of stainless steel, with the explosive bonding force being applied through the buffer sheet to the beam leads.

The above-described detonation techniques may be used with workpieces other than IC devices. They may be used, for example, to explosively bond the electrode and counter electrode of a thick- or thin-film capacitor to a ceramic substrate.

Returning momentarily to FIG. 4, it will be recalled that each of the beam leads 42 of IC device 31 were bent upwards to form a small angle α with the plane of the substrate. This bending may be accomplished by any of several simple mechanical devices, as the beam leads are extremely thin and easily bent. FIGS. 19A and 19B, however, illustrate two alternative arrangements for the beam leads of IC device 31. In FIG. 19A, the beam leads are fabricated so that they have an undulating upper surface. In FIG. 19B, the beam leads are fabricated so that they have a castellated upper surface. The undulations and castellations may be effected, during fabrication of the beam leads, by the use of an appropriately exposed photo mask. In both instances, when the IC device is inverted over the land areas of the substrate to which it is to be bonded, and an explosive charge detonated proximate what is now the upper surface of the beam leads, there will be a plurality of air gaps separating the beam leads from the land areas of the substrate. Thus, portions of the beam leads are capable of being accelerated downward towards the substrate, as is required for explosive bonding to occur. If the beam leads are so patterned, it is not necessary to bend the beam leads upwards to form an angle α with respect of the plane of the substrate. This, of course, eliminates the slight risk of damage to the integrated circuit device which exists when the beam leads are so bent.

In some instances, neither beam lead bending nor castellation of the beam leads is necessary to obtain a good metal-to-metalised substrate bond. While this phenomenon is not fully understood, it is believed that the "hills" and "valleys" in substrate surfaces provide sufficient space through which the leads can accelerate to provide a high quality bond. This effect is more noticeable on ceramic

substrates than glass substrates and is even more noticeable when an explosive bond is made directly between metal and bare ceramic, rather than between metal and metalised ceramic.

Not all integrated circuits are provided with beam leads. FIG. 20 illustrates the so-called "flip chip", another widely used configuration. Here the integrated circuit 121 is provided with a plurality of contact pads 122 and, in the prior art, connection of the "flip chip" device to the external circuit is accomplished by applying heat and pressure directly to the upper surface of the device by means of a suitably shaped bonding tool. The heat and pressure is transmitted through the device to the contact pads to bond the pads to the land areas 123 of the substrate.

It will be apparent that explosive bonding is adaptable for use with the "flip chip" as well as with many other integrated circuit configurations. In FIG. 20, for example, the explosive charges 124 are applied to the upper surface of "flip chip" device 121 so that they are located directly above the contact pads 122 on the bottom surface thereof. Thus, when detonated, the explosive charges 124 apply pressure, through the substrate, to the contact pads 122, bonding them to the land areas of the substrate.

A metallic (e.g., stainless steel) or plastics (e.g., KAPTON) buffer layer may also be used intermediate the explosive charge and the "flip chip" device. As in the example discussed with reference to FIG. 6, the buffer layer acts to cushion the force of the explosion and, in addition, inhibits contamination of the workpiece surfaces.

FIG. 21 illustrates yet another embodiment of the invention which may advantageously be used to fabricate "printed circuit" substrates, that is to say, substrates having a patterned arrangement of conductive metal paths arranged thereon in the well known fashion. As shown in FIG. 21, a plurality of spaced metallic (e.g. aluminium film) elements 131, are to be bonded to an insulating substrate 132 of alumina or glass. Elements 131 may be shaped to the desired pattern by any of several known techniques, for example, by stamping the pattern from a continuous roll of metallic tape by means of a cutting die, or the like. A plurality of apertures 133 are provided in substrate 132 and align with a corresponding plurality of apertures 134 in elements 131. These apertures are provided to receive the leads of electronic components when the finished substrate is utilised in a manufacturing process. Alternatively, apertures 133 may be drilled through the substrate after the elements 131 have been bonded thereto, in the well-known manner. A buffer medium of metallic or plastics material (e.g. KAPTON) 136, having a shaped charge 137 of explosive material 137 deposited on the

upper surface thereof, is positioned over the elements 131 and substrate 132.

In operation, the explosive charge 137 is detonated by any of the previously discussed detonation techniques and the explosive force which results forces the patterned metallic elements 131 down on to the substrate, thereby forming an explosive bond between each of the metallic elements 131 and the substrate. For the sake of clarity, the various layers depicted in FIG. 21 are separated; in actual practice, however, the metallic elements, buffer medium, and substrate are placed in close proximity to each other prior to detonation of the explosive material. As previously stated, in most instances, it has not been found necessary to provide a gap between each metallic element 131 and the substrate 132, through which gap each element is accelerated to form the explosive bond. It is believed that the "hills" and "valleys" in the surface of the substrate provide sufficient space for the required acceleration to occur and it is for this reason that, in most cases, it has not been found necessary to provide spacing elements.

Buffer medium 136, in addition to providing a support mechanism for the shaped pattern of explosive charge 137, also acts to inhibit contamination of substrate 132 by by-products of the explosion. In addition, buffer medium 136 cushions the effect of the detonation and tends to reduce the creation of concentrated mechanical and thermal stresses in the workpiece, which, of course, is an important consideration in the case of fragile substrates, such as glass or ceramic.

FIG. 22 illustrates the appearance of the substrate after metallic elements 131 have been explosively bonded thereto. It will be noted that the substrate is indistinguishable from a substrate product by one of the more conventional techniques (e.g., by metal deposition followed by a selective etch procedure), except that the insulation resistance of the substrate produced by the explosive bonding technique is somewhat superior, due to the absence of chemical residues of the etching solutions, photoresist and developers.

FIG. 23 illustrates a modification of the previous embodiment of the invention which may advantageously be employed if the surface of the substrate is highly polished so that the "hills" and "valleys" required for satisfactory bonding are not present. As shown a pair of spacing elements, for example, 0.004 inch diameter, gold or aluminium wire, are positioned intermediate substrate 132 and metallic element 131. Buffer sheet 136, with explosive charge 137 overlaid thereon, is then positioned adjacent metallic element 131 and the explosive charge detonated, as in the previous example. Spacing elements 141 ensure that a sufficient gas exists between substrate 132 and metallic element 131 so that

an acceleration of element 131 towards substrate 132 occurs and a sound metal-to-ceramic bond is formed between the element and the substrate.

- 5 FIG. 24 illustrates the appearance of the completed bond. Spacing elements 141, slightly flattened by the force of the explosion, may be removed from the bond area. Alternatively, the spacing elements may simply
10 be left in place as, in general, they do not affect the operation of the completed circuit.

- The techniques described with reference to FIGS. 21—24 may not be practical for all
15 types of metallic film patterns. For example, some patterns of conductive metal film may be so complicated and intricate that they are not self-supporting or pose difficult alignment or orientation problems. Accordingly, FIGS.
20 25—27 illustrate yet another embodiment of the invention which overcomes this difficulty. The specific example is directed towards a thin- or thick-film resistor, but the method may be applied whenever at least
25 one of the workpieces to be bonded is not self-supporting or needs careful alignment, e.g., the formation of an inductor or capacitor. As shown in FIG. 25, a castellated pattern of resistive metallic film 151 is to be
30 explosively bonded to an insulating substrate 152. The metallic film 151 which is to be bonded to the substrate is fabricated, in a reverse image, on the bottom surface of buffer medium 153. Advantageously, buffer
35 medium 153 comprises a polyimide film, such as KAPTON, and the patterned layer of metallic film may be deposited thereon, for example, by an electrode or an electroplating method, or by initially producing the
40 pattern by electrode plating and then built up to a desired thickness by electroplating.

- After metallic film 151 has been deposited on buffer medium 153, a correspondingly patterned charge of explosive material is stencilled, screened, or otherwise deposited on the
45 upper surface of buffer medium 153. As shown in FIG. 26, the combined structure is then positioned over substrate 152 and the explosive material detonated, by any of the
50 previously discussed techniques, to explosively bond the intricately patterned conductive metal film 151 (which is now "right side up") on to the substrate. After detonation, the buffer medium is stripped away, leaving the
55 finished product, as shown in FIG. 27. The polyimide KAPTON is particularly good in this respect and is thus preferred for this embodiment. As in the case discussed with reference to FIG. 24, spacing elements may
60 be interposed between metallic film 151 and substrate 152, if necessary. Alternatively, as film 151 is deposited on to the bottom surface of buffer medium 153, portions of the film may be deliberately made thicker than

others to provide the necessary gap required for a good metal-to-ceramic bond. 65

In the embodiments illustrated in FIGS. 21—27, the explosive charge is deposited in the approximate size and shape of the workpiece to be bonded. This is not an absolute
70 requirement and the charge may assume a pattern somewhat smaller or somewhat larger than the actual outline of the workpiece, or need not be patterned at all. All that is required is that a sufficiently large bonding
75 force be created to accelerate the workpiece down on to the substrate.

FIGS. 28 to 31 illustrate yet another embodiment of the invention which may advantageously be used to manufacture thin- or
80 thick-film capacitors on an insulating substrate, such as glass or ceramic. As is well known, in the prior art, such capacitors may be fabricated by sputtering, or vacuum depositing an electrode on to the insulating substrate,
85 either directly or through a selective masking and etching process, forming a non-conductive dielectric layer on the upper surface; and finally depositing, or sputtering, a counter-electrode on top of the dielectric layer. Any
90 one, or all of the above steps may instead be performed by an explosive bonding technique.

As shown in FIG. 28, electrode 161 is bonded to ceramic substrate 162 by positioning the electrode over the substrate and then applying a buffer medium 163 over the
95 electrode 161 and substrate 162. Buffer medium 163 may comprise a sheet of stainless steel of from two to three mils thickness or a sheet of polyimide plastics material, such
100 as KAPTON, of approximately the same thickness. A patterned charge of explosive material 164 is deposited on the upper surface of buffer medium 163 and, when detonated by any of the detonation techniques previously
105 discussed, accelerates the electrode 161 down into the "hills" and "valleys" of the ceramic substrate 162, forming an explosive bond therebetween.

As with regard to the example illustrated in FIG. 23, spacing elements (not shown) may
110 be interposed between electrode 161 and substrate 162, if the surface characteristics of the substrate are such that a good explosive bond cannot be formed without the use of such
115 spacing elements. After the detonation has occurred, the buffer medium 163 may be stripped away, leaving electrode 161 firmly bonded to the substrate. As previously discussed, electrode 161 may be formed on the
120 lower surface of buffer medium 163 by any suitable technique.

As shown in FIG. 29, the upper surface of the electrode 161 may now be oxidised
125 by any of several well-known techniques to form an insulating dielectric layer thereon. Alternatively, the previously discussed technique illustrated in FIG. 28 may be repeated to explosively bond an insulating dielectric

layer to the electrode 161. Indeed, the buffer medium itself may be left in place for this purpose; however, the buffer medium may be too thick for most practical applications and, in that event, a thinner dielectric layer may be created on the lower surface of the buffer medium, explosively bonded to the electrode and the buffer medium stripped away, as previously discussed.

As shown in FIG. 30, the technique used to bond the electrode may be repeated to explosively bond a counter electrode to dielectric layer 166. To that end, a counter electrode 167, which may be either self-supporting or formed on the lower surface of a second buffer medium 168, is positioned over, and aligned with respect to, electrode 161 and dielectric layer 166. The upper surface of buffer medium 168 is provided with a patterned explosive charge 169 and, when this charge is detonated, counter electrode 167 is accelerated towards electrode 161 and dielectric layer 166, forming an explosive bond therebetween.

FIG. 31 illustrates the appearance of the finished product. It is, of course, feasible to apply the counter electrode to the dielectric layer by conventional sputtering or deposition procedures. Further, although FIGS. 28 and 30 indicate that the explosive charges 164 and 169 are patterned to correspond to the underlying electrode 161 and counter electrode 167, respectively, it will be appreciated that the explosive charges may have a shape which does not exactly correspond to the underlying electrode and counter electrode. The creation of capacitors, or other electronic components, such as inductors and resistors, by explosive bonding techniques may, of course, be coupled with the simultaneous deposition of conductive metallic paths on the same substrate. That is to say, a single large area, explosive bonding process may be used to simultaneously lay down thin-film resistors, the electrodes of thin-film capacitors, and the necessary conductive circuitry to interconnect these devices. One or two additional explosive bonding steps will bond the additional circuit elements required so that an entire operating package, including explosively bonded semiconductor devices may be manufactured in only two or three processing steps, which contrasts to the dozens of steps which would be required to manufacture an equivalent package by conventional techniques.

WHAT WE CLAIM IS:—

1. A method of making an electrical device or circuit including the steps of bonding a first workpiece consisting of one element of the device or circuit to a second workpiece consisting of a second element of the device or circuit comprising placing the regions of the workpieces to be bonded in juxtaposition and detonating an explosive adjacent the juxtaposed regions so as to accelerate one workpiece into bonding contact with the other, the said explosive consisting solely of a primary explosive.

2. A method according to claim 1 including utilising a buffer medium over the juxtaposed regions of the workpieces, the buffer medium having the primary explosive thereon adjacent the said juxtaposed regions, and the buffer medium being such as to protect the workpieces from contamination by the products of the explosion.

3. A method according to claim 1 or 2 wherein the primary explosive is applied to a portion of the first workpiece or to the buffer medium by means of a masking device so that the location of the discrete portion of explosive charge is such as to produce a controlled pattern of bonding force.

4. A method according to claim 1, 2 or 3 wherein both the first and second workpieces are metallic.

5. A method according to claim 1, 2 or 3 wherein the first workpiece is metallic and the other is a metallic land area on an electrically non-conducting substrate.

6. A method according to claim 5 wherein the substrate is ceramic or glass.

7. A method according to claim 1, 2 or 3 wherein there are a plurality of first workpieces forming electrically conductive leads connected to an electronic device or circuit and there are a plurality of second workpieces forming a plurality of electrically conducting lands on a substrate, to which the leads are to be bonded.

8. A method according to claim 7 wherein the electronic device comprises a semiconductor body.

9. A method according to claim 3 wherein the masking device is in the form of a stencil and the explosive is forced through an aperture of the stencil.

10. A method according to claim 3 wherein the masking device is in the form of a silk screen device and the explosive is applied therethrough by a printing process.

11. A method according to claim 2 or any one of claims 3 to 10 when appended to claim 2 wherein the buffer medium is of a polyimide plastics material.

12. A method according to claim 2 or any one of claims 3 to 10 when appended to claim 2 wherein the buffer medium is of stainless steel.

13. A method according to any preceding claim wherein the primary explosive is detonated by heat.

14. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by electrical means.

15. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by light.

16. A method according to any one of



layer to the electrode 161. Indeed, the buffer medium itself may be left in place for this purpose; however, the buffer medium may be too thick for most practical applications and, in that event, a thinner dielectric layer may be created on the lower surface of the buffer medium, explosively bonded to the electrode and the buffer medium stripped away, as previously discussed.

As shown in FIG. 30, the technique used to bond the electrode may be repeated to explosively bond a counter electrode to dielectric layer 166. To that end, a counter electrode 167, which may be either self-supporting or formed on the lower surface of a second buffer medium 168, is positioned over, and aligned with respect to, electrode 161 and dielectric layer 166. The upper surface of buffer medium 168 is provided with a patterned explosive charge 169 and, when this charge is detonated, counter electrode 167 is accelerated towards electrode 161 and dielectric layer 166, forming an explosive bond therebetween.

FIG. 31 illustrates the appearance of the finished product. It is, of course, feasible to apply the counter electrode to the dielectric layer by conventional sputtering or deposition procedures. Further, although FIGS. 28 and 30 indicate that the explosive charges 164 and 169 are patterned to correspond to the underlying electrode 161 and counter electrode 167, respectively, it will be appreciated that the explosive charges may have a shape which does not exactly correspond to the underlying electrode and counter electrode. The creation of capacitors, or other electronic components, such as inductors and resistors, by explosive bonding techniques may, of course, be coupled with the simultaneous deposition of conductive metallic paths on the same substrate. That is to say, a single large area, explosive bonding process may be used to simultaneously lay down thin-film resistors, the electrodes of thin-film capacitors, and the necessary conductive circuitry to interconnect these devices. One or two additional explosive bonding steps will bond the additional circuit elements required so that an entire operating package, including explosively bonded semiconductor devices may be manufactured in only two or three processing steps, which contrasts to the dozens of steps which would be required to manufacture an equivalent package by conventional techniques.

WHAT WE CLAIM IS:—

1. A method of making an electrical device or circuit including the steps of bonding a first workpiece consisting of one element of the device or circuit to a second workpiece consisting of a second element of the device or circuit comprising placing the regions of the workpieces to be bonded in juxtaposition and detonating an explosive adjacent the juxtaposed regions so as to accelerate one work-

piece into bonding contact with the other, the said explosive consisting solely of a primary explosive.

2. A method according to claim 1 including utilising a buffer medium over the juxtaposed regions of the workpieces, the buffer medium having the primary explosive thereon adjacent the said juxtaposed regions, and the buffer medium being such as to protect the workpieces from contamination by the products of the explosion.

3. A method according to claim 1 or 2 wherein the primary explosive is applied to a portion of the first workpiece or to the buffer medium by means of a masking device so that the location of the discrete portion of explosive charge is such as to produce a controlled pattern of bonding force.

4. A method according to claim 1, 2 or 3 wherein both the first and second workpieces are metallic.

5. A method according to claim 1, 2 or 3 wherein the first workpiece is metallic and the other is a metallic land area on an electrically non-conducting substrate.

6. A method according to claim 5 wherein the substrate is ceramic or glass.

7. A method according to claim 1, 2 or 3 wherein there are a plurality of first workpieces forming electrically conductive leads connected to an electronic device or circuit and there are a plurality of second workpieces forming a plurality of electrically conducting lands on a substrate, to which the leads are to be bonded.

8. A method according to claim 7 wherein the electronic device comprises a semiconductor body.

9. A method according to claim 3 wherein the masking device is in the form of a stencil and the explosive is forced through an aperture of the stencil.

10. A method according to claim 3 wherein the masking device is in the form of a silk screen device and the explosive is applied therethrough by a printing process.

11. A method according to claim 2 or any one of claims 3 to 10 when appended to claim 2 wherein the buffer medium is of a polyimide plastics material.

12. A method according to claim 2 or any one of claims 3 to 10 when appended to claim 2 wherein the buffer medium is of stainless steel.

13. A method according to any preceding claim wherein the primary explosive is detonated by heat.

14. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by electrical means.

15. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by light.

16. A method according to any one of

claims 1 to 12 wherein the primary explosive is detonated by sound.

17. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by pressure.

18. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by exposure to or removal from a chemical atmosphere.

19. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by exposure to a neutron beam or gamma radiation.

20. A method according to any one of claims 1 to 12 wherein the primary explosive is detonated by exposure to an electron beam.

21. A method according to claim 14 wherein the primary explosive is detonated by an alternating electric field.

22. A method according to claim 15 wherein the light is produced by a laser.

23. A method according to claim 16 wherein the sound is produced by an ultrasonic generator.

24. A method according to claim 2 or 3 when appendant to claim 2 or 9 or 10 to any one of claims 11 to 20 when appended to claim 2 or 3 when appendant to claim 2 wherein the first workpiece consists of a pattern formed on one surface of the buffer medium, the primary explosive being applied to the opposite face of the medium and the second workpiece being a substrate body to which the pattern is to be bonded.

25. A method according to claim 24 including forming the pattern comprising the first workpiece on a surface of the buffer medium and applying a pattern of primary explosive on the opposite face thereof.

26. A method according to claim 24 or 25 wherein the pattern forms a capacitor electrode.

27. A method according to claim 24 or 25 wherein the pattern forms a resistor.

28. A method according to claim 24 or 25 wherein the pattern forms an inductor.

29. A method according to claim 25 wherein the pattern is formed by an electroless plating process.

30. A method according to claim 25 wherein the pattern is formed by an electroplating process.

31. A method according to claim 25 wherein the pattern is initially deposited by electroless plating and is then built up to a desired thickness by electroplating.

32. A method according to claim 1 wherein the first workpiece is a capacitor electrode and the second workpiece is an insulating support.

33. A method according to claim 32 including the additional step of explosively bonding a dielectric layer to the bonded electrode by a primary explosive.

34. A method according to claim 33 including the further step of explosively bonding a counter electrode to the dielectric layer by a primary explosive.

35. A method according to claim 2 wherein the said pattern comprises a plurality of spaced metallic elements.

36. A method according to claim 7 wherein the electrically conducting leads are beam leads.

37. A method according to claim 36 wherein the beam leads have undulations or castellations along their lengths to render them more flexible.

38. A method according to claim 36 or 37 wherein the primary explosive charges are located between one third and two-thirds of the length of the leads from the junction of the lead with the device or circuit.

39. A method according to claim 1 wherein the bonding is effected in an enclosure having means for exhausting the explosion products therefrom.

40. A method according to any preceding claim wherein the primary explosive is lead azide.

41. A method of making an explosive bond substantially as herein described with reference to FIGS. 1 to 5 or FIGS. 6 and 7, or any one of FIGS. 9 to 20 of the drawings.

42. A method of making an explosive bond substantially as herein described with reference to FIGS. 21 and 22 or FIGS. 23 and 24, or FIGS. 25, 26 and 27 or FIGS. 28 and 29 or FIGS. 30 and 31 of the drawings.

43. An article having an explosive bond made in accordance with the method of any one of the preceding claims.

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