

PATENT SPECIFICATION (11)

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DRAWINGS ATTACHED



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(54) IMPROVEMENTS IN OR RELATING TO THE FABRICATION OF ELECTRICAL CIRCUIT DEVICES

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organised 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 a method of fabricating electrical circuit devices, and to devices fabricated thereby.

15 Copending Application No. 31259/68 (Serial No. 1,239,631) describes a method of bonding wherein the workpieces to be joined are placed on a support, a compliant medium such as an aluminium strip is placed thereover, and a heated ram applies heat and pressure. The aluminium deforms itself around the top workpiece. Bonding parameters are controlled so that when the aluminium has deformed around the top
25 workpiece and flattens against the bottom workpiece (usually a thin film substrate), the area of contact is such that the ram pressure is less than the yield strength of the aluminium over the area in contact, and all deformation stops. The method of said application is very useful in bonding beam lead integrated circuits onto thin film substrates.

35 One of the most difficult aspects of bonding any microminiature device to a substrate is the need for rigorous control of accuracy in positioning the substrate, the device and the bonding tool. A 16 lead beam integrated circuit, for example, may have
40 leads only 0.5 mil wide and spaced 0.5 mil apart; for bonding, each lead must be on the corresponding land area of the substrate, and the bonding tool must precisely cover that portion of the leads desired to be
45 bonded. In the above-mentioned copending

application, it is pointed out that the compliant medium can be used to simplify the positioning problem. Specifically, the compliant medium can be accurately apertured to receive the device on its under-side, it being retained by an adhesive or the like lightly attaching the upper surface of the leads to the lower surface of the compliant member. The latter can then be accurately indexed with notches, holes, or the like, so that its position can be precisely controlled. One of the other advantages of compliant bonding is that a flat tool may be employed and precise alignment thereof is not required. Alternatively, the device may be positioned on the substrate, a compliant frame can then be dropped thereover, and a heated flat ram brought down for bonding.

While the foregoing measures simplify the positioning problem, other problems arise. The attachment of the device to the compliant member must itself be precise, the material used for attachment must not contaminate the finished circuit, and it must release the device under bonding conditions. If the device is positioned on the substrate, care must be taken to see that it does not move from the proper position.

The fabrication of complete thin film circuits also presents other problems, even when the active devices are bonded with a compliant medium. While the circuit is always laid out to minimize or if possible eliminate the use of crossovers, they do present a problem. Further, it would be desirable in many circuits to provide relatively thick high-conductivity "power planes" for the power distribution network. "Ground planes" are desirable for providing a common ground. Since ordinary thin film conductors are not suited for this purpose, it has been proposed to bury such planes in the substrate, with "pipes" leading to the substrate surface for connection to appro-

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priate circuit elements. The number of process steps required to fabricate such a structure would be excessive however and the proposal has not met with success.

5 The problems associated with fabricating crossovers on thin film circuits are in a certain sense unique, and must be considered separately. Both air and solid dielectrics have been employed to separate the crossing conductor patterns. Air is desirable from an electrical standpoint because of its low dielectric constant, but from a mechanical standpoint, the air dielectric crossover is quite fragile and requires careful handling in its manufacture. The solid dielectric crossover may utilize either an organic or inorganic material to separate the conductors. Although more mechanically rugged, the relatively unknown electrical and mechanical ageing effects of the proposed solid dielectric materials are causes for some concern.

Of the two alternatives, the air dielectric is preferred at least by some workers from a fabrication standpoint. There are, however, two problems regarding presently proposed techniques. The first is that a number of critical processing steps are required to generate the crossovers, and these steps must be carried out on a substrate which is rather expensive. The second is that after the relatively fragile crossovers are generated, the substrate must go through the additional step of having the integrated circuits bonded to it. This can cause a variety of problems. Large area mass bonding of integrated circuits to the substrate is possible with compliant bonding, and while this may not be incompatible with a substrate already containing the air dielectric crossovers, it requires that numbers of additional holes be punched in the compliant medium. If the bonding sequence was reversed, i.e., the integrated circuits were first attached, followed by crossover bonding, the problem would be to avoid damaging the integrated circuits.

According to this invention there is provided a method of fabricating an electrical circuit device having a plurality of conductive members disposed on a substrate, and a further conductive member which is electrically connected to at least one of said plurality of members, overlies at least a portion of another of said plurality of members, and is electrically insulated from said other member, the method comprising forming said further member on a bonding carrier, positioning said bonding carrier with respect to said substrate, and bonding said further member to at least said one member with the aid of pressure applied to said bonding carrier, said further member being deformed, prior to or during said bonding, in the region where it overlies said portion.

65 The bonding carrier may be, for example,

a compliant medium, a polyimide film on a rigid support, or a polyimide film on a compliant support.

In the fabricated device said further member may comprise a crossover which crosses over said other member and is connected to said one and another of said plurality of members. The crossover may, except for its end portions, be deformed into an indentation or aperture in said bonding carrier prior to said bonding.

Prior to said bonding, an active device may be attached to said carrier and, except for its connection leads, be accommodated in an indentation or aperture in said carrier.

Each of said further and said other members may comprise a respective electrode of a capacitor.

The present invention can be advantageously performed with the aid of a relatively new film material of the polyimide type, specifically the product marketed by E. I. du Pont de Nemours & Co., under the trademark "Kapton". This material is not unrelated to nylon, chemically speaking, the latter being a polyamide. Polyimide materials of this type are prepared by a condensation reaction of pyromellitic dianhydride with an appropriate amine, such as oxydianiline. Films prepared of this material have several surprising properties. Because of the high aromaticity of the polymer construction, they possess remarkable thermal stability. A one mil film will withstand temperatures as high as 1,000°F., if only briefly. They are very effective thermal and electrical insulators. When heated, it has been found that absorbed water molecules are driven out of the polymer structure. Lastly, while not a malleable material, they can be deformed, and exhibit some elastic recovery as well as plastic behaviour.

As used herein, the expression "active device" is intended to mean any transistor, integrated circuit, beam leaded or not, and the like. The term "conductive member" is defined herein as a crossover, film-thickening conductor, power or ground plane, a conductor on a substrate, or a component electrode or lead. The expression "passive device" refers to a resistor, capacitor, or the like on the substrate, generally an integral part of the thin film circuit. With reference to bonding, the expression "compliant medium" will be generally employed to refer to any such material; the trademark "Kapton" will be used for convenience to refer to the polyimide films of the type described which are particularly useful in carrying out the invention.

The peculiar properties of polyimide films such as Kapton make it an excellent bonding medium or carrier in many applications. In particular, it is possible to fabricate conductive members on Kapton in the precise

position they will occupy on the circuit. This can be done, for example, by laminating or electrolessly plating a metallic layer on the film, followed by masking, exposing, developing, etching, etc. to form the desired pattern; such steps are conventional in the art of miniature circuit pattern generation. In certain instances, it may be possible to use the process described in copending Application No. 17810/69 (Serial No. 1,266,193) in which a chemical film is placed on the surface which is activated in the desired circuit pattern only by a specific type of radiation. Thereafter, metal is electrolessly plated on the circuit pattern only. Pattern thickness is then built up by successive electroless and electrolytic plating. This procedure eliminates the masking, developing and etching steps of conventional processes. All methods of generating these circuit elements will be collectively referred to herein as "chemical fabrication" of circuit elements. At some point during or after pattern generation, the back side of the film is affixed to a supporting plate, which may be rigid or compliant. If the plate is rigid, it is provided with indentations or apertures at desired cross-over locations. Then, deformation of the circuit pattern elements desired as cross-overs may be effected. The plate is then positioned with respect to the substrate, and heat and pressure or other forms of bonding energy, are applied.

While it can be shown that polyimide films such as Kapton exhibit a certain amount of flow under pressure and will, for example, deform around small leads during bonding, it would not be correct to say that, in all instances where such a film is used as a bonding carrier, the dominant mode of bonding is thermocompression with a compliant medium. For instance, a conductive member several mils thick may be fabricated on a half-mil Kapton film, which is mounted on a rigid plate. When a heated tool presses this assembly against a substrate, there may be some slight flow of the Kapton, but the mode of bonding is thermocompression *per se*. There are two significant advantages of using Kapton in thermocompression bonding: conductive members can be fabricated thereon in the relative positions they will occupy on the substrate, eliminating intermediate handling altogether, and the exudation of water and/or extrusion of the film causes the members to release from the film under bonding conditions. It is these two advantages that make this film so desirable as a bonding medium or carrier.

The precise mechanisms of release of a device is not known. The exudation (or volatilization) of water from the film surface under bonding conditions obviously plays a part, but it is believed that actual extrusion of the film, which is being squeezed between

the element being bonded and the ram (or rigid or compliant member), also plays a part.

In compliant bonding, as in ordinary thermocompression bonding, both thermal and mechanical bonding energy are applied through a heated ram or tool, the substrate being supported below on a suitable anvil. When using Kapton as the bonding medium, however, it is difficult to transmit sufficient heat through the film to the bond area during a reasonable bonding cycle and obtain consistently good bonds, at least with bonding materials that require a relatively high temperature. (The extraordinary insulating properties of Kapton are fully appreciated when it is realized that the film may be only 1 mil thick.) In instances where high temperatures are required it is desirable to either supply thermal bonding energy from below, as by preheating the thin film substrate, by providing a hot anvil, etc. or else to invert the assembly and move the heated ram against the bottom of the substrate, which is functionally the same thing. If, on the other hand, the Kapton is only 0.5 mil thick, it is usually possible to transmit enough heat to bond without charring the film or creating other problems.

It is of course desirable to effect the simultaneous bonding of both active devices and conductive members. If this can be done, several distinct advantages are brought about. The first is obviously the elimination of an extra processing step, and the problems which arise if one attempts to bond active devices after bonding crossovers or *vice-versa*. A second advantage is that of non-destructive testing. With all of the active devices and conductive members in place on the substrate, and under normal clamping pressure but prior to actual bonding, it is possible to test the circuit for operability, often with as few as two or three probes. This contrasts with the large number of individual tests which must be made when the circuit is still incomplete.

With a conventional compliant medium such as aluminium, bonding of active devices and conductive members can be carried out as follows.

The compliant member is first apertured at points where active devices are to be located. Then, an etch resistant adhesive layer is applied over the entire surface, followed by a laminated or plated layer of a metal such as gold. The desired pattern of crossovers and other conductive members is then generated by conventional steps of masking, exposing, developing, etching, etc. A tool then depresses that portion of those members which are to be crossovers. Active devices are then attached at appropriate points. The compliant member is then inverted, positioned over the substrate, and bonding

effected. If a solid rather than an air dielectric is desired under the crossovers, the solid material is either prepositioned on the substrate or attached to the crossover prior to bonding.

5 An advantageous alternative to the foregoing is to substitute a very thin film of Kapton for the adhesive layer (more precisely, the Kapton is bonded to the compliant member with an adhesive).

10 When the compliant member is Kapton affixed to a rigid plate the procedures are similar, except that the plate must be initially provided with depressions for the crossovers as well as openings for the active devices. Also, a separate adhesive must be used to attach the active devices to the film.

20 The generation and bonding of low-resistance power distribution networks and/or ground planes may be accomplished by a combination of the foregoing techniques. Thus, a relatively thick conductor pattern may be initially generated on an aluminium compliant member and a layer of Kapton then adhesively bonded thereto. A crossover pattern may then be generated on the Kapton on top of the conductors, bonding then proceeding as before.

30 The invention will now be further described with reference to the accompanying drawings in which:

Figs. 1A—E illustrate the fabrication and bonding of two cross-overs to a substrate;

35 Figs. 2A—E illustrate the fabrication of a crossover and the positioning of an active device prior to bonding;

Fig. 3 shows in cross-section power and ground planes prior to bonding;

40 Figs. 4A—C illustrate the fabrication of a solid dielectric crossover; and

Figs. 5A—C illustrate the fabrication of a thin-film capacitor.

Referring now to Figs. 1A—E a compliant member 10, such as aluminium, is coated with an etch-resistant adhesive 12 which may be a styrene or acrylic adhesive, and a one mil gold foil 14 is laminated thereon. Next, a layer of a suitable photoresist (not shown) is applied, the surface is appropriately exposed, the pattern is developed by removing the soluble (unexposed) portions of the resist, and the now-unprotected area of the gold is etched away, leaving the pattern shown in Fig. 1B. As can be seen, gold strips 16, 18 are all that remain of foil layer 14. Crossovers 16, 18 are then dimpled with a suitable tool (not shown) to form the desired crossover shape, as shown in Fig. 1C. The compliant member 10 is then inverted and positioned over a thin film substrate 20 having a conductor pattern 22 thereon, (Fig. 1D). Lastly, Fig. 1E shows substrate 20 with crossovers 16, 18 bonded thereto.

65 Figs. 2A—E illustrate the steps for fabricat-

ing crossovers and bonding both active and passive devices in a single operation, using Kapton as a compliant medium. In Fig. 2A, a steel plate 24 is provided with apertures or indentations 26, 28. As long as these depressions are deeper than the device or element they will accommodate, their depth is unimportant. As seen in Fig. 2B, plate 24 is covered with a layer of Kapton 30 and a layer of gold foil 32. As an example, each of these layers may be one mil thick. Pattern generation procedures are then followed, as before, producing (in this instance) a single crossover bar 34 (Fig. 2C). A different procedure may utilize a copper-plate Kapton film as starting material. The pattern is generated using gold as an etch resist, i.e., a photoresist is patterned covering the foil except where crossovers are desired, gold is plated on these areas, the resist is removed and all exposed copper is etched away. The result is a pattern of gold-plated copper. Regardless of the method of sequence employed, the configuration of Fig. 2C results. Referring now to Fig. 2D, the next step is to dimple crossovers 34 into indentation 26 to form the desired crossover profile. If film 30 is ruptured during this operation it is of no concern; the interface between the dimpled portion and the film will not take part in the bonding operation, and the heat supplied during bonding will cause the two surfaces to part. If plate 24 is rigid, it will be appreciated that it must be indented or apertured prior to other operations, as it is much harder than cross-over 34, and a blow sufficient to indent plate 24 would damage crossover 34.

Plate 24 may be rigid, compliant or a combination of the two. As an example of the latter, a molybdenum plate may be initially apertured at all places where active devices, crossovers, etc. are desired. A sheet of copper foil is then apertured to produce corresponding apertures in the foil. The Kapton layer is then applied over the copper. In this instance the copper adds some compliance to the resulting bonding carrier. Alternatively, the Kapton and apertured foil may be used with a different support, and the apertured plate used essentially as a die for preparing the foil.

Along with the dimpling operation, film 30 may be punched to open aperture 28. This allows a beam leaded device 36 to be adhesively bonded to film 30, in the inverted position, therein. This is shown in Fig. 2E. In some applications, it may be desirable to position active devices on the substrate and bring the assembly containing the cross-overs etc. down thereover. The entire assembly is now ready to be inverted, positioned over a thin film substrate, and bonded in a single operation. In this instance, bonding of the leads of device 36 may be substantially com-

pliant (due to their small size) while bonding of crossover 34 is essentially thermocompression. As pointed out hereinabove, the insulating properties of Kapton are such that difficulties may be encountered supplying the heat required for bonding through the film. If the heat is supplied through the substrate, on the other hand, care must be taken not to thermally shock the substrate, which may be made of glass or an alumina ceramic.

Whether the polyimide film material should be laminated onto a support (rigid or compliant) before or after pattern generation depends on a number of factors. If the film is mounted on a support prior to pattern generation, the dimensional stability of the pattern will be improved, but the support will need to be protected from the various reagents used during pattern generation.

As noted above, Kapton exhibits some compliance and serves to release circuit elements during bonding. A very desirable bonding carrier is thus a compliant medium such as aluminium or copper with a very thin film of Kapton adhered thereon. To obtain such thin films, two methods are possible. A thicker film, such as one mill, may be etched down. This is satisfactory up to the point where unevenness of the etched product becomes a problem. For very thin films, it is preferred to start with the imide material in liquid form (i.e., un-polymerized) and generate the polymer *in situ*. The technique is generally the same as that used in forming photoresist films: the liquid is spun onto the support to form a uniform film of controlled thickness, the latter being a function of the liquid viscosity and spin rate. The coated support is then heated to drive off solvents and baked to polymerize the material. In this manner very thin films can be produced, the lower limit being the point where pinhole porosity becomes a problem.

Application of the invention to the generation and bonding of power planes and ground planes follows similar procedures to those described in connection with Figs. 2A—D, and is illustrated in Fig. 3 in which an aluminium compliant member 38 has a ground plane 40 bonded to its lower surface by adhesive (not shown). A layer of insulation 42, conveniently Kapton, separates ground plane 40 from a power plane 44. Another layer of insulation 46 separates the latter from a crossover 48. This assembly is constructed by repeating the various steps described previously, as required. The economic advantages of such a structure, over the previously proposed buried planes, is manifest. In relatively simple circuits, it will usually be preferred to merely thicken the conductors of an existing power distribution network by bonding flat, thick conductors (as shown

in Fig. 2C) rather than using the more complex assembly of Fig. 3.

Figs. 4A—C illustrate the production of a solid dielectric crossover. Fig. 4A shows a substrate 50 having conductive members 52, 54, 56 thereon, it being desired to join members 52, 54 with a crossover. In Fig. 4B a layer of insulating material 58 is applied over member 56 between members 52 and 54. A crossover 60 is then bonded to conductive members 52, 54, as shown in Fig. 4C. The dielectric 58 may be initially applied to the substrate or it may be fabricated on the crossover prior to bonding. In either case, it is not necessary that the crossover be shaped prior to bonding, as it will naturally deform over insulating material 58 during the course of the bonding operation.

In some cases, it may be desired to have solid dielectric crossovers, with their high mechanical strength, initially during manufacturing, but air dielectric crossovers, with their superior insulation, in the final assembly. To this end, solid crossovers are fabricated as described above with reference to Figs. 4A—C. After completion of the assembly (bonding integrated circuits, testing etc.), the solid dielectric is removed. The nature of the removal step depends on the insulating material used. If the insulating material is Kapton, it can be removed by dissolving it in sodium hydroxide solution. It will be appreciated that if material 58 is going to be removed before testing it need not even be an insulator. It need only have the physical properties necessary to withstand bonding, and some property which allows its removal without damage to the assembly.

A similar procedure may be employed to fabricate a thin film capacitor, as shown in Figs. 5A—C. In Fig. 5A, a substrate 62 is provided with a conductive member 64, and a bottom electrode 66, the latter being integral with a conductive member 68. The capacitor dielectric 70 (Fig. 5B) is then either generated in place or on the top electrode, in a manner similar to the solid dielectric under the crossover (Fig. 4). Lastly, the top electrode 72 is bonded in place, as shown in Fig. 5C. Top electrode 72 is fabricated in the form of a "partial crossover", having a lead extending to one side for bonding to conductive member 64. It is of course essential that the top and bottom electrodes 66, 72 be bonded to the dielectric 70 therebetween, as well as the respective conductive members.

Although the invention has been described with reference to thermocompression bonding in general and compliant bonding in particular, it will be understood that it is not limited thereto and that other forms of bonding with the aid of pressure, such as ultrasonic bonding, may be employed.



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WHAT WE CLAIM IS:—

1. A method of fabricating an electrical circuit device having a plurality of conductive members disposed on a substrate, and a further conductive member which is electrically connected to at least one of said plurality of members, overlies at least a portion of another of said plurality of members, and is electrically insulated from said other member, the method comprising forming said further member on a bonding carrier, positioning said bonding carrier with respect to said substrate, and bonding said further member to at least said one member with the aid of pressure applied to said bonding carrier, said further member being deformed, prior to or during said bonding, in the region where it overlies said portion.
2. A method as claimed in claim 1 wherein said bonding carrier is a compliant medium.
3. A method as claimed in claim 1 wherein said bonding carrier is a polyimide film on a rigid support.
4. A method as claimed in claim 1 wherein said bonding carrier is a polyimide film on a compliant support.
5. A method as claimed in any one preceding claim wherein in the fabricated device said further member comprises a crossover which crosses over said other member and is connected to said one and another of said plurality of members.
6. A method as claimed in claim 5 where-

in said crossover is, except for its end portions, deformed into an indentation or aperture in said bonding carrier prior to said bonding.

7. A method as claimed in any one preceding claim wherein, prior to said bonding, an active device is attached to said carrier and, except for its connection leads, is accommodated in an indentation or aperture in said carrier.

8. A method as claimed in claim 1 wherein each of said further and said other members comprises a respective electrode of a capacitor.

9. A method as claimed in any one preceding claim wherein said bonding is effected by a combination of heat and pressure.

10. A method of fabricating an electrical circuit device substantially as herein described with reference to Figs. 1A to 1E, or to Figs. 2A to 2E, or to Fig. 3, or to Figs. 4A to 4C, or to Figs. 5A to 5C of the accompanying drawings.

11. An electrical circuit device fabricated by a method as claimed in any one preceding claim.

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