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CONDUCTOR FOR FORMING CONDUCTIVE
PATH ON AN INTEGRATED
CIRCUIT AND METHOD

TECHNICAL FIELD

This invention generally relates to conductors for forming a conductive path on a substrate surface and method of forming the conductive path. More particularly, the invention relates to a conductor having a conductive element with at least one of a diffusion barrier or a bonding medium adjacent to a conductive element surface.

BACKGROUND OF THE INVENTION

Repairing of open circuit defects in the fine lines of high density circuitry, such as thin film conductor lines, is usually accomplished by closing or bridging the open defect with conductive material. Two conventional repair techniques are laser chemical vapor deposition (LCVD) and wire bonding. LCVD involves bridging the open defect in the line by depositing conductive material across the open defect. Major shortcomings of LCVD include difficulty in controlling the dimensions (especially the height) of the conductive material deposited, poor adhesion of the conductive material and inadequate deposition control which results in depositing conductive material in unwanted areas.

In the wire bonding technique, as described in commonly assigned U.S. Patent No. 5,079,070 to Chalco et al and shown in the accompanying prior art FIGURES 1, 2A, 2B, 3A and 3B, a bonding tip 10 of an energy source and a support sheet 20 into which one or more repair lines 15 has been etched are

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used. The bonding tip 10 terminates in a substantially flat frontal surface 14. A cavity 12 is defined in the tip 10 and passes through the end of the tip 10 and the frontal surface 14 as a cylindrical opening 17.

The support sheet 20 is fabricated by blanket metallizing or laminating of a metal layer onto a support material. The metal layer and support material are circuitized by photoprocesses and etching procedures for forming the repair lines 15. The metal layer is then selectively etched for forming a window opening 25 therethrough to define the repair line 15 for performing the repair.

The repair process includes positioning one of the repair lines 15 over an open defect 35 of a circuit line 40. In accordance with commonly assigned U.S. Patent No. 4,970,365, to Chalco, incorporated herein by reference, ultrasonic vibratory motion and laser energy are used to energize the bonding tip 10 to bond the repair line 15 to the circuit line 40. After bonding, the support sheet 20 is lifted using a "peeling action" to detach the bonded repair line 15. Unfortunately, the force required for detaching the repair line 15 from the support sheet 20 may cause damage to the repair line 15, further damage to the circuit line 40 being repaired or weakening or fracturing of the bond between the repair line 15 and the circuit line 40. This is particularly true in the case of the extremely fragile and delicate fine lines used in present day state-of-the-art high density circuitry.

Further, it has been found to be exceedingly difficult to fabricate a support sheet with repair lines having very small dimensions. For instance, it has been problematic to fabricate repair lines having a height on the order of 1-10 microns, as is oftentimes required in present day technology. Repair lines which are excessive in height may result in undesirable protrusion of the repair line above the plane of the circuit line being repaired.

In U.S. Patent No. 5,310,967 to Chalco et al., which is also assigned to the present Assignee, the shortcomings of U.S. Patent No. 4,970,365 were resolved. It discloses applying conductive lines to integrated circuits. Conductive lines are suspended in a carrier. A bonding tip is used to transmit energy to bond the conductive lines to the circuit to be repaired.

There is room for improvement of the conductive lines and processes disclosed in U.S. Patent No. 5,310,967. The bonding tip life is shortened by the diffusion of the conductive material into the bonding tip. Also, depending on the composition of the circuit line and conductive material, the bond may be weak. For example, gold conductive material will form a relatively weak bond with a nickel circuit line as compared to a copper circuit line.

A conductor that inhibits diffusion of a conductive material into a bonding tip or improves the bond of the conductive material to a substrate and which does not exhibit the above shortcomings is highly desirable.



SUMMARY OF THE INVENTION

The invention provides a repair line having a conductive element and at least one of a diffusion barrier or bonding medium adjacent a conductive element surface. When the diffusion barrier is present, diffusion of the material from which the conductive element is made into a bonding tip is inhibited. When the bonding medium is present, the adhesion between the conductive element and a substrate surface is enhanced.

A method of forming a conductive path on a substrate surface includes the steps of providing the conductor having at least one of the diffusion barrier or the bonding medium and forming a conductive path with the conductive element.

Numerous other advantages and features of the present invention will become readily apparent from the following drawings, detailed description of the preferred embodiments and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 shows a prior art support sheet;

FIGURES 2A-B show prior art bonding;

FIGURES 3A-B show a prior art bonding tip;

FIGURE 4 illustrates conductors of the present invention including conductive elements;

FIGURE 5 is a fragmentary cross-sectional view of a conductive element taken through line 5-5 of FIGURE 4;

FIGURE 6 is an end cross-sectional view of the conductive element taken through line 6-6 of FIGURE 5;

FIGURES 7-9 are end cross-sectional views of alternative embodiments of the conductive element;

FIGURES 10A-F show process steps for applying a conductor to a substrate in accordance with the present invention;

FIGURE 11 shows alternative conductors of the present invention embedded in a carrier;

FIGURE 12 shows a bonding tip for use with the present invention;

FIGURE 13 shows a front view of the bonding tip of FIGURE 12; and

FIGURES 14A-J show process step for fabricating conductors embedded in a carrier in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

One specific use of the present invention is the repair of open circuit defects. One skilled in the art will appreciate that the present invention is useful whenever and wherever a conductive element is required to be applied to a circuit. In addition to repairing circuits, a conductor

in accordance with the invention can be used for adding a connection to a circuit that was inadvertently omitted, previously unnecessary or undesired.

FIGURE 4 illustrates conductors 80 supported in a carrier 85. The conductors 80 extend into opening 44 defined by the carrier 85. FIGURES 5 and 6 illustrate that the conductor 80 includes a conductive element 46 that has first and second conductive element surfaces 48 and 50, respectively. At least one of a diffusion barrier 52 and a bonding medium 54 are adjacent to one of the conductive element surfaces 48 and 50. In the embodiment of FIGURES 5 and 6, the diffusion barrier 52 is on the first conductive element surface 48 and the bonding medium 54 is on the second conductive element surface 50. FIGURE 7 illustrates an embodiment wherein the conductor 80A has the diffusion barrier 52 but no bonding medium. FIGURE 8 illustrates an embodiment wherein the conductor 80B has the bonding medium 54 but no diffusion barrier. FIGURE 9 illustrates an embodiment wherein the conductor 80C has the diffusion barrier 52, the bonding medium 54 and a diffusion barrier 52A between the conductive element 46 and the bonding medium 54. The embodiment of FIGURE 9 is particularly well suited for applications where the bonding medium 54 is thin and it is desirable to minimize diffusion of the bonding medium 54 into the conductive element 46.

FIGURES 10A-F show a selected break area 50 of an integrated circuit over which a conductor is to be applied to connect two ends of a metallization or circuit line 55. As shown, the break area 50 may be an open circuit defect and the circuit line 55 may be a thin film line.

The break area 50 and circuit line 55 may be sandwiched between an insulating layer 60 and a circuit base 65. The insulating layer 60 is typically an insulating material such as polyimide; and the circuit base 65 may comprise a substrate, such as a multilayered ceramic substrate or a printed circuit board. In order to apply a conductor to the break area 50, the insulating layer 60 must be opened, preferably locally, so as to expose a portion of the circuit line 55, which includes the break area 50. The opening created in the insulating layer 60 should have dimensions adequate to accommodate at least a portion of the conductor carrier, as described hereinbelow. The opening in the insulating layer 60 can be created by any appropriate technique. For example, an opening can be created in a polyimide insulating layer by ablation with a pulsed excimer laser, such laser being equipped with helium jets to remove debris generated during the ablation. The insulating layer 60, or a portion thereof, is thus removed.

Further, it may be necessary to reduce contact resistance between the conductor to be applied and the circuit line 55 by "dressing" a site 70 of the circuit line 55 which is adjacent to the break area 50. Contact resistance may be caused by contaminants, such as oxidation, formed on a top surface 53 of the circuit line 55. As shown in FIGURE 10B, dressing the site 70 involves reducing the thickness of the circuit line 55 by removing a portion of the top surface 53. The portion of top surface 53 can be removed using a pulsed excimer laser. As an example, the dressed site 70 is the same length as the conductor to be applied, and extends at least about 40 microns back from each edge of the break area 50. The dimensions of the site

70 depend on the dimensions of the conductor being applied. Dressing the site 70 may also be required for effectively lowering the amount of protrusion relative to the plane of the circuit line 55 that the conductor exhibits when applied to the circuit line 55. Thus, the site 70 can be appropriately dressed for effectively meeting strict requirements of surface planarity. However, it should be appreciated that site dressing is optional, and may be unnecessary if contact resistance and/or surface planarity are not problematic.

Next, as shown in FIGURE 10C, a conductor 80 is aligned in juxtaposition with the break area 50 and the dressed site 70. Referring briefly to FIGURES 4 and 11, the conductor 80 may be only one of a plurality of conductors 80 suspended or embedded in the carrier 85 or 85A, respectively. Advantageously, for purposes of versatility and flexibility, the conductors 80 can be fabricated in the carrier 85, 85A in the form of a plurality of desirable shapes and sizes to allow a user to readily choose the conductor 80 which best suits his/her needs. For convenience in handling and processing, the carrier 85A is held in a rigid frame 90 of, for example, metal. Further, as is better shown in FIGURE 14J, the carrier 85A has carrier openings 183 therethrough defined by sidewalls 100; and each carrier opening 183 contains a conductor 80. The conductors 80 are each suspended by the sidewalls 100 of its corresponding carrier opening 183. In the illustrated embodiment, each conductor 80 has the diffusion barrier 52 and the bonding medium 54. It is understood that the conductor 80 can have any of the configurations illustrated in FIGURES 6-9. As explained in greater detail hereinbelow, the carrier 85A is preferably

substantially transparent for alignment purposes. Fabrication of the conductors 80 in the carrier 85A will also be explained in greater detail hereinbelow.

Referring again to FIGURE 10C, alignment of the conductor 80 in juxtaposition with the break area 50 and site 70 can be accomplished by any suitable alignment means. As an example, although not specifically shown herein, alignment can be accomplished by loading the circuit into a bonding station and superimposing the conductor 80 over the break area 50 by attaching the carrier to an X-Y-Z positioning arm-stage. A microscope is then used to align the conductor 80 over the break area 50 and site 70. Proper alignment is facilitated by the transparency of the carrier 85A which provides the operator with a substantially unobstructed view of the circuit line 55 to which the conductor 80 is to be bonded.

As shown in FIGURE 10D, a bonding tip 115 is then aligned over the conductor 80. The bonding tip 115 is applied to the diffusion barrier 52 and energized, preferably using ultrasonic vibration and laser heating as described in previously mentioned U.S. Patent No. 4,970,365 to Chalco, to bond the conductor 80 to the dressed site 70 of the circuit line 55. A first intermetallic 56 is formed between the bonding medium 54 and the material of the circuit line 55 and a second intermetallic 58 is preferably formed between the bonding medium 54 and the material of the conductive element 46.

FIGURE 12 shows that the bonding tip 115 may be pencil-like in shape, and may be comprised of a cylindrical top shank portion 120 and a frustoconical bottom portion 125 which tapers to a bonding or bottom end 130 having a nominal outside diameter of about 0.003 to about 0.005 inches. The bottom portion 125 of the bonding tip 115 has a frustoconical shaped cavity 135 therein which tapers, for example, at a nominal angle of 20° , to a nominal diameter of about 0.001 to about 0.002 inches, and merges with a vertical, cylindrical hole 140. An optical fiber 127 is centrally located in the cylindrical top shank portion 120 and bottom portion 125.

In a preferred embodiment, the vertical hole 140 is about 0.001 to about 0.002 inches nominal in diameter and about 0.003 to about 0.005 inches nominal in length. The nominal thickness of the wall 145 defining the cylindrical hole 140 is an important dimension since adjacent thereto will be the primary area that will be heated during bonding. Accordingly, the wall 145 defining the cylindrical hole 140 should have minimal thickness so as to further the heating thereof. In a preferred embodiment, the thickness of the wall 145 varies from about 0.001 inches at the bottom portion of the cylindrical hole 140 to about 0.004 inches at the top portion of the cylindrical hole 140.

In order to prevent energy loss from the bottom end 130 and to create a highly-efficient laser-beam trap, a capping layer 150 is included to provide a seal thereat. The capping layer 150 preferably covers the entire footprint of the bottom end 130, and can be integrally attached to or deposited on the bottom end 130 by any suitable means. For

instance, the capping layer 150 can be attached using plating techniques, or deposited using chemical vapor deposition.

During bonding, the bonding tip 115 or, more specifically, the capping layer 150, may completely cover and press the conductor 80 to form a bond. While bonding, the bonding tip 115 should avoid excessive contact and heating of the carrier 85, 85A on which the conductor 80 is located. Such excessive contact and heating may result in inefficient and ineffective bonding, and may also result in damage to the carrier 85, 85A. The carrier 85, 85A is typically comprised of relatively fragile material, such as polymer, and thus excessive heating with the bonding tip 115 during bonding may cause unwanted softening thereof.

Further, for convenience, manufacturability and cost effectiveness considerations, the capping layer 150 should also be adequately dimensioned for proper bonding of conductors of various shapes and sizes. By way of example, the bonding tip 115 includes a rectangular shaped capping layer 150, as shown in FIGURE 13, having a nominal width of about 80 microns and a nominal length of about 120 microns has been found adequate for properly bonding conductors having a nominal width of between 20 microns and 40 microns and a nominal length of up to about 120 microns.

If the length of the desired area requires a conductor that is substantially longer than the length of the capping layer 150 of the bonding tip 115, the conductor can still be applied by first bonding one end of the conductor to one end of the circuit line, and then subsequently bonding the other

end of the conductor to the other end of the circuit line. In other words, it is not necessary for the capping layer 150 to completely cover the entire conductor so as to complete the bond in one bonding step.

The capping layer 150 should have a thickness which allows for simplified heating thereof. A capping layer having a nominal thickness of about 5 microns to about 10 microns has been found to be adequate. However, it should be fully understood by those skilled in the art that other dimensions for the capping layer 150 may be suitable for achieving adequate bonds. Suitable material for constructing the capping layer 150 include stainless steels, nickel-based alloys, tungsten, tungsten alloys and the like.

Referring to FIGURE 10D, excessive heating of the circuit base 65 on which the circuit line 55 is located should also be avoided during bonding. The circuit base 65 is also typically comprised of relatively fragile material, such as polymer, which will undesirably soften under excessive heat conditions. Advantageously, the present invention provides for controllable and reproducible bonding conditions for forming bonds to avoid or minimize excessive heating.

Preferably, the capping layer 150 should comprise material which is resistant to wear and oxidation under the heating temperatures required for bonding, for example, typically in the range of about 300 to about 500° C. For ease of fabrication, the capping layer 150 can comprise the same or similar material as that used for construction of

the bonding tip 115, and fabrication can be achieved using chemical vapor deposition or sintering.

Referring now to FIGURE 10E, subsequent to bonding of the conductor 80 to the circuit line 55, the carrier 85, 85A in which the conductor 80 is suspended is lifted so as to detach the conductor 80 therefrom. In order to prevent or minimize damage to the conductor 80, damage to the circuit line 55, and weakening or fracturing of the bond between the conductor 80 and the circuit line 55, the amount of force required for detaching the conductor 80 from the carrier 85, 85A should be minimal and can be provided by the bonding tip to effect forming of the conductive path and separating at about the same time. In this regard, the manner in which the conductor 80 is attached, suspended in the carrier 85, 85A is important. Fabrication of the conductor 80 so as to minimize the amount of force required for detachment from the carrier 85A is explained in detail hereinbelow. After detachment, the exposed circuit line 55 and conductor 80 may be covered with a suitable insulating material 155, such as polyimide, as shown in FIGURE 10F. For instance, the purpose of the insulating material 155 may be required for passivating thin-film circuitry or for initiating the next thin-film layer.

FIGURES 14A-J show process steps for fabrication of the conductors 80 suspended in the carrier 85A as illustrated in FIGURE 11. The present invention can be used with other carriers that are known to those skilled in the art such as the carrier 85 illustrated in FIGURE 4. A support layer 160 has a carrier 85A disposed thereon. The support layer 160 can comprise any suitable material which has adequate

rigidity for providing the necessary support and proper etch selectivity to the conductors and the carrier 85A for allowing subsequent removal thereof. For example, the support layer 160 can include copper. The carrier 85A should include a material which allows the conductors 80 to be suspended or embedded therein and, for the reasons stated hereinabove, which also permits the conductors to be detached therefrom with a minimal amount of force. Further, the carrier 85A is preferably made to be sufficiently transparent, such as, by thinning, so that the integrated circuit on which a conductor 80 is to be applied can be viewed through the carrier 85A to permit proper alignment of the conductor 80. For example, the carrier 85A can comprise a polymer, such as, polyimide. The carrier 85A can be formed on the support layer 160 using a conventional spin-coating technique. As shown, the support layer 160 and carrier 85A can be positioned on a frame 90 to facilitate processing.

Next, a mask layer 170 is formed over the carrier 85A, such as by blanket deposition (FIGURE 14B). The mask layer 170 can comprise any suitable masking material, such as, aluminum. A photoresist layer 175 is then applied over the mask layer 170 (FIGURE 14C). The photoresist layer 175 is conventionally exposed and etched to form one or more openings 180 in the photoresist layer 175. The openings 180 are configured in accordance with the requirements of the patterns of the conductors being formed so that each of the openings 180 has a pattern, linear or non-linear, which matches the pattern of a conductor to be formed. The mask layer 170 is then etched by conventional techniques, e.g., chemical etching, through the openings 180 in the

photoresist layer 175 so as to form corresponding openings 182 through the mask layer 170 (FIGURE 14D). The photoresist layer 175 is subsequently removed (FIGURE 14E). The carrier 85A is then etched also using conventional techniques, such as reactive-ion-etching, through the openings 182 in the mask layer 170 so as to form corresponding openings 183 in the carrier 85A (FIGURE 14F). The mask layer 170 is then removed using, for example, a conventional chemical etching technique (FIGURE 14G).

Optionally, after removal of the mask layer 170, the carrier 85A can be thinned to a desired thickness which corresponds to the thickness of the conductors being formed, for example, between 1 and 10 microns; or the carrier 85A can be made thinner than the thickness of the conductors being formed. Such thinning increases the transparency of the carrier 85A. Thus, the amount of thinning, if any, depends on the degree of transparency desired for the carrier 85A. Thinning can be accomplished using, for example, conventional reactive-ion-etching techniques. In another embodiment, the step of thinning the carrier 85A is performed prior to deposition of the mask layer 170.

The openings 183 in the carrier 85A are then filled with suitable conductive material, such that the conductive material appropriately, snugly fits, such as by friction fit, against the sidewalls 100 of the openings 183 so as to be suspended by the sidewalls 100, for forming the conductive elements 46 of the conductors (FIGURE 14H). Filling can be accomplished by any appropriate technique, and the conductive material can comprise any appropriate material which will not readily react with and/or adhere to

the carrier 85A. The conductive elements 46 should each be suspended within its respective opening 183, but should also be readily and easily detachable therefrom so that the amount of force required to detach the conductive material from the opening 183 of the carrier 85A should be minimal. For instance, gold can be electroplated to the support layer 160 through the openings 183; advantageously, gold will react and adhere minimally with a polymer carrier. More specifically, the thickness or height of the conductive elements 46, hence the conductors, will increase as more gold is electroplated to the support layer 160. The conductors can be made to be higher than the carrier 85A by electroplating an appropriate amount of gold to the support layer 160; and thus the thickness or height of the conductors is not limited by the thickness or height of the carrier 85A.

The support layer 160 is removed, such as by chemical etching, so that the conductive elements 46 are left suspended or embedded in the carrier 85A (FIGURE 14I). The conductive elements 46, and hence the conductors, will not detach from the carrier 85A without adequate external forces inducing such detachment.

FIGURE 14J illustrates the conduit 80 with the diffusion barrier 52 and the bonding medium 54 thereon. The diffusion barrier 52 and the bonding medium 54 are applied by conventional plating before removal of the support layer or by evaporation techniques after removal of the support layer.

The diffusion barrier preferably has a thickness in the range of about 1 to about 3 microns prior to bonding.

The diffusion barrier is made of a material that inhibits the diffusion of the material from which the conductive element is made, e.g., refractory materials such as chrome, tungsten, tantalum and the like.

The bonding medium is present in an amount effective to enhance bonding. Preferably, the thickness of the bonding medium is in the range of about 2,000Å to about 2 microns prior to bonding. When the thickness of the bonding material is less than about 0.5 microns, a diffusion barrier is preferably positioned between the conductive element and the bonding material to inhibit diffusion of the bonding material into the conductive element.

The bonding material is one that bonds with the material at the surface of the substrate to preferably form an intermetallic and is selected based on the material at the surface. Representative bonding materials include tin, copper and the like.

The substrate surface is made of a conventional material to which the conductive element or the bonding material will bond. Copper, nickel and the like are representative of the material of the substrate surface.

The substrate is a piece on which it is desired to bond a conductor. A preferred substrate is an integrated circuit chip.

It presently is theorized that the above-described advantages are achieved because of the diffusion barrier, when present, inhibits the material of the conductive element from diffusing into the bonding tip where it can cause degradation of the tip. It is also theorized that the bonding medium, when present, enhances bonding by forming an intermetallic with the material of the substrate surface and, when a diffusion barrier is not adjacent to the bonding medium, an intermetallic with the material of the conductive element. It also is theorized that the processing methods used contribute to obtaining the advantages.

This invention has been described in terms of specific embodiments set forth in detail. It should be understood, however, that these embodiments are presented by way of illustration only, and that the invention is not necessarily limited thereto. Modifications and variations within the spirit and scope of the claims that follow will be readily apparent from this disclosure, as those skilled in the art will appreciate.



CLAIMS

WE CLAIM:

1. A conductor for forming a conductive path on a surface of a substrate, the conductor comprising:

a conductive element having a conductive element surface; and

at least one of a diffusion barrier or bonding medium adjacent to the conductive element surface, the bonding medium being distinct from the conductive element.
2. The conductor of claim 1 wherein the conductor includes the diffusion barrier and not the bonding medium.
3. The conductor of claim 1 comprising both the diffusion barrier and the bonding medium.
4. The conductor of claim 3 wherein the diffusion barrier is between the conductive element surface and the bonding medium.
5. The conductor of claim 1 wherein the at least one of the diffusion barrier or bonding medium is on the conductive element surface.
6. The conductor of claim 1 wherein the bonding medium has a thickness in the range of about 2,000 Å to about 2 microns.



7. The conductor of claim 1 further comprising a carrier to support the conductor.
8. The conductor of claim 7 wherein the carrier defines an opening therein and the conductive element extends into the opening.
9. The conductor of claim 1 wherein the conductor is suitable for use in a laser bond process.
10. The conductor of claim 1 wherein the diffusion barrier has a thickness in the range of about 1 to about 3 microns.
11. A conductor for forming a conductive path on a surface of an integrated circuit, the conductor comprising:

a carrier defining an opening therein;

a conductive element having first and second conductive element surfaces, the conductive element extends into the opening; and

at least one of a diffusion barrier adjacent to at least one of the first or second conductive element surfaces or a bonding medium adjacent to one of the first or second conductive element surfaces for joining the conductive element to a surface of an integrated circuit, the bonding medium being distinct from the conductive element.



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12. The conductor of claim 11 wherein the conductor comprises both the bonding medium and the diffusion barrier.

13. A method of forming a conductive path on a substrate surface between two locations on the substrate surface, the method comprising the steps of:

providing a conductor comprising a conductive element having first and second conductive element surfaces and at least one of a bonding medium between the first conductive element surface and the substrate surface, the bonding medium being distinct from the conductive element, or a diffusion barrier adjacent at least one of the conductive element surfaces; and

forming a conductive path with the conductive element on the substrate surface.

14. The method of claim 13 further comprising the steps of:

providing a carrier for the conductive element, the carrier defining an opening therein in which the conductive element extends; and

separating the conductive element from the carrier.

15. The method of claim 14 wherein the forming and separating steps are performed at about the same time.

16. The method of claim 14 wherein the carrier comprises a polymer.



17. The method of claim 13 wherein the conductor includes both the bonding medium and the diffusion barrier and the diffusion barrier is provided between the conductive element and the bonding medium.
18. The method of claim 13 wherein the conductor includes both the bonding medium and the diffusion barrier and the bonding medium and the diffusion barrier are adjacent to different conductive element surfaces.
19. The method of claim 13 further comprising the step of bonding the conductive element to a substrate surface with the bonding medium.
20. The method of claim 13 wherein the bonding medium has a thickness in the range of about 2,000 Å to about 2 microns.