(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 June 2005 (16.06.2005)

PCT

(10) International Publication Number
WO 2005/055282 A2

(51) International Patent Classification[7]: H01L

(21) International Application Number: PCT/US2004/039676

(22) International Filing Date: 24 November 2004 (24.11.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/525,305 26 November 2003 (26.11.2003) US
10/988,053 12 November 2004 (12.11.2004) US

(71) Applicant *(for all designated States except US)*: **KULICKE & SOFFA INVESTMENTS, INC.** [US/US]; Little Falls Center Two, 2751 Centerville Road, Suite 3165, Wilmington, DE 19808 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **QIN, Ivy, W.** [US/US]; 4 Andrews Lane, Lansdale, PA 19446 (US). **WISE, Robert** [US/US]; 890 Rising Sun Road, Telford, PA 18969 (US).

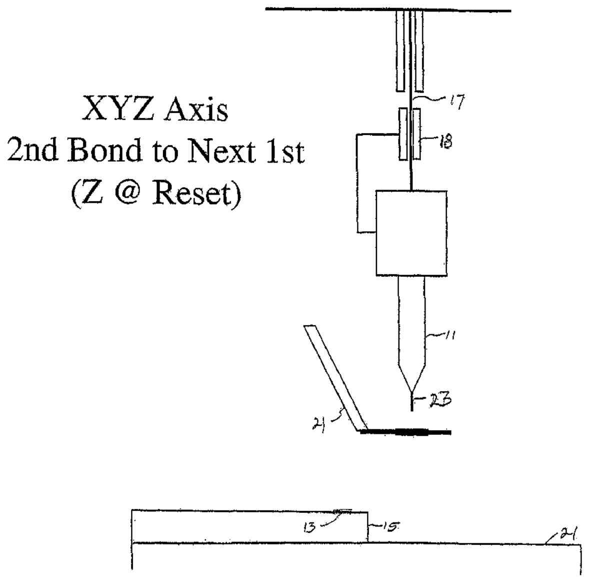
(74) Agent: **NACCARELLA, Theodore**; Synnestvedt & Lechner LLP, 2600 Aramark Tower, 1101 Market Street, Philadelphia, PA 19107 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title:** LOW LOOP HEIGHT BALL BONDING METHOD AND APPARATUS



(57) **Abstract:** In accordance with the invention, a bump is formed on top of a die bond pad by forming a ball bond there. Then, without severing the wire, the capillary undergoes a set of coordinated motions to fold the wire on top of the ball bond. The wire is then stich bonded on top of the ball bond bump without severing the wire. This is then followed by a further set of coordinated xy motions to form the loop and bring the capillary over the second bond site (e.g., on the lead frame). The wire is then stitch bonded to the second bond site and the tail severed to complete the wire loop interconnect.

WO 2005/055282 A2

Declaration under Rule 4.17:

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LOW LOOP HEIGHT BALL BONDING METHOD AND APPARATUS

FIELD OF THE INVENTION

[001] The invention pertains to wire bonding on semiconductor devices.

BACKGROUND OF THE INVENTION

[002] Ball bonding is a common technique for interconnecting the bond pads on a semiconductor die with the contact points on a lead frame or other substrate on which the die is mounted. Electrical interconnect wires typically are run from the bond pads on the top of the die to lead fingers on a lead frame in order to electrically connect the circuitry on the die to the pins of the lead frame that will extend from the package after the die has been encapsulated. The wire bonds between the bond pads of the die and the lead fingers commonly are formed using a ball bonding machine. Figures 1A-1I demonstrate the steps in a conventional technique of ball bonding. The conventional looping technique (herein termed forward looping) involves ball bonding one end of a gold wire to a bond pad on a die and stitch bonding the other end of the wire to the lead frame. More particularly, using a ball bonding machine, the wire 17 is passed through a set of clamps 18 and through a center bore of a capillary 11. At the beginning of the process, a wire "tail" 23 is protruding from the tip of the capillary 11, as shown in Figure 1A. The tail 23 at the end of the wire 17 is heated by means of an electric spark 16 termed an electric flame off (EFO) from an EFO wand 24. The spark melts the end of the wire, which, in turn, forms into a ball 19 when melted, as shown in Figure 1B. The clamps 18 are closed during EFO in order to provide a current return path through the clamps and then are opened to allow the ball to seat itself in the capillary tip. The capillary 11 is then moved to a position above the bond pad 13 of the die 15, as shown in Figure 1C.

[003] The capillary 11 is then moved downwardly with the clamps 18 still open during the initial acceleration of the capillary and then are closed during deceleration of the capillary so that the ball remains seated during the downward motion of the capillary. The clamps then open just before the ball contacts the bond pad 13. The ball 19 comes into contact with the bond pad 13 on the die 15 with the clamps 18 still open, as shown in Figure 1D. Heat and/or ultrasonic energy are applied to the die to cause the ball to become bonded to the bond pad 13. This bond typically is termed a ball bond or first bond. The capillary 11 is then raised with the clamps 18 opened to pay out a short length of wire that is still attached to the top of the ball bond, as shown in Figure 1E. Next, with the clamps 18 open, the capillary 11 is moved through a predetermined looping motion with the wire (which is still connected to the ball bond) and trailing out of the capillary 11 to a position generally near and above the lead finger 21. With the capillary 11 positioned above the lead finger 21, the clamps 18 are closed, as shown in Figure 1F. The capillary 11 is then lowered to pinch the wire between the capillary and the surface of the lead finger 21, as shown in Figure 1G. Again, heat and/or ultrasonic energy may be applied to bond the pinched portion of the wire to the lead finger 21. This bond is termed a stitch bond or second bond. The clamps 18 are now opened again and the capillary 11 is then raised with the wire still attached to the stitch bond such that an additional wire "tail" 23 pays out of the capillary, as illustrated in Figure 1H. The clamps 18 are then closed and the capillary 11 is raised further to snap the wire tail 23 at the weakest point, which is at the stitch bond location. The completed connection 22 is termed a wire loop and is illustrated in Figure 1I.

[004] At this point, the capillary is moved near the next bond pad on the die 15 for commencing the wire looping process for the next bond pad on the die. The wire tail 23 that remains protruding from the tip of the capillary after the conclusion of the formation of the preceding wire loop will be melted by EFO, as previously described, to form the next ball for commencing the next ball bonding operation. The above-described conventional forward ball bonding technique is fast, reliable, and inexpensive. However, it has limitations. Most notably, the minimal loop height is normally over 150 microns. Loop height is defined as the maximum height of the wire above the bonding surface, e.g., the top surface of the bond pad. Attempting to achieve lower loop height can cause neck damage to the wire loop. The neck is the portion of the wire loop directly adjacent to the ball bond. Reducing the loop height below 150 microns tends to weaken or break the neck.

[005] There is an increasing demand for smaller and smaller integrated circuit packaging. One of the significant aspects of reducing the size of the integrated chip packaging is reducing its thickness or height. The thinner packages are generally referred to in the trade as low profile packages. Commensurate with the desire to reduce the height of the package is the desire to reduce the height of the highest point of the wire loops, which, in many instances, is the limiting factor as to the height of an integrated circuit package.

[006] In order to reduce loop heights for integrated circuit packaging and other purposes, a wire looping technique known as reverse looping was developed. The premise behind reverse looping is that, because the highest point of the wire loop is adjacent the ball bond, it would be desirable reverse the looping process so as to make the first, ball bond on the lead frame (or other substrate) and make the second, stitch bond on the bond pad of the die because the surface of the lead frame is lower than the surface of the die. Hence, the highest point of the wire loop is near the lower bonding surface, thus reducing the overall height.

[007] However, simply reversing the direction of the looping process would not be possible because, the stitch bond requires the capillary to come in contact with the bonding surface. The bond pads on a die usually are very small and, thus, it is difficult to make a stitch bond on a bond pad on a die without the capillary contacting and, hence, damaging surrounding circuitry on the die. Furthermore, the wire loops tends to sag to their lowest points close to the stitch bond. Thus, if the stitch bond site is higher than the ball bond site, the wire might contact the edge or the top surface of the die. This could lead to electrical shorts or breakage of the wire.

[008] Thus, a reverse looping technique was developed, such as illustrated in Figures 2A through 2C, in which the first step is to form a ball bond 25 on top of the bond pad 27 on the die 29 essentially in accordance with standard techniques for forming ball bonds. However, instead of paying out the wire 17 as would be the case after making the ball bond in a conventional forward looping technique, the capillary 11 is raised, the clamps 18 are closed, and the capillary is raised further to snap the wire off from the ball bond leaving just the ball bond (or bump) 25 on the bond pad 27, as illustrated in Figure 2A. Then a complete wire looping process is performed in the reverse direction, i.e., from the substrate to the bond pad. That is, a second ball bond 37 is then formed on the lead frame 39, the capillary 11 is then moved through a series of motions to a position above the first ball bond 25 to create the desired wire loop shape, as illustrated in Figure 2B. Then, a stitch bond 43 is formed on top of the first ball bond (or bump) 25. The completed wire loop is illustrated in Figure 2C.

[009] This reverse looping process can provide low loop heights for low profile packaging. However, it is a much slower process than forward looping because it requires the formation of two ball bonds per loop. Furthermore, the die must suffer greater impact because the capillary must form a bond on the die twice per wire loop (i.e., once to create the first ball bond and a second time to create the stitch bond on top of the ball bond). Another limitation of reverse looping is that it often is the limiting factor on how fine the pitch of the bond pads on the die. Particularly, the bump 25 on top of the die bond pad must be large enough to provide support for a stitch bond. In addition, the diameter of the bump will increase in the lateral direction when the stitch bond is made on top of it.

[010] Accordingly, it is an object of the present invention to provide an improved wire loop formation method and apparatus.

[011] It is another object of the present invention to provide a wire loop interconnect with very low loop height.

SUMMARY OF THE INVENTION

[012] In accordance with the invention, a bump is formed on the die bond pad by forming a ball bond thereon. Then, without severing the wire and with the clamps open, the capillary undergoes a set of coordinated xyz motions to fold the wire on top of the ball bond. Then the wire is stitch bonded on top of the bump without breaking off the tail. This is followed by a further set of coordinated xyz motions to bring the capillary to the second bond site (e.g., the lead frame or other substrate) and perform a second, stitch bond on the substrate and then break off the tail to complete the process.

[013] In accordance with one particular embodiment of the invention for making the aforementioned wire fold, the ball bond is made and then the capillary is raised in the z direction a designated height (herein termed the separation height). It is then moved horizontally (in the xy plane) a specified distance in a direction generally away from the second bond location (herein termed the fold offset distance). The capillary may or may not be raised again in the z direction by another distance (herein termed the fold factor). This is followed by another motion in the xy plane to generally bring the capillary back to the top of the bump for formation of the aforementioned stitch bond on top of the bump. This is then followed by another coordinated xyz motion to bring the capillary to the location of the second bond site (e.g., on the lead frame) where the second stitch bond will be made.

BRIEF DESCRIPTION OF THE DRAWINGS

[014] Figures 1A through 1I are elevation views illustrating the steps of a conventional forward looping operation.

[015] Figures 2A through 2C are elevation views illustrating steps of a reverse looping operation.

[016] Figure 3 is a pictorial elevation view of a folded wire loop interconnect in accordance with the present invention.

[017] Figure 4 is a pictorial elevation view showing the various components of the set of xyz motions involved in forming a folded bump in accordance with the present invention.

[018] Figures 5A through 5O are elevation views illustrating the steps of a folded forward looping operation in accordance with the present invention.

[019] Figure 6 is a pictorial elevation view showing the various components of the set of xyz motions involved in forming a folded bump in accordance with particularly preferred exemplary embodiment of the invention.

[020] Figure 7 is a side view of a bump and fold formed using the exemplary parameters set forth in Figure 6.

[021] Figures 8A and 8B are scanning electron micrographs of a completed loop produced after forming the bump shown in Figure 7A.

DETAILED DESCRIPTION OF THE INVENTION

[022] Figure 3 is a side elevation pictorial of a folded forward wire loop 45 formed in accordance with the present invention. Figure 3 shows an integrated circuit die 51 including a bond pad 53 on its top surface and a lead frame substrate 55 with a wire loop interconnect between the bond pad 53 and the lead frame 55. The wire loop 45 is formed in accordance with the technique of the present invention may be considered to comprise five general components. With reference to Figure 3, they are (1) a bump 56, (2) a wire fold 57 on top of the bump, (3) a stitch bond on top of the bump 58, (4) a wire loop 59 that interconnects the first and second bond sites, and (5) a second stitch bond 60.

[023] The five general components described above may be formed using a ball bonding machine.

[024] Figures 5A through 5O illustrate the position of the capillary of the ball bonding machine and the condition of the wire at various stages of an exemplary process for forming a folded forward wire loop in accordance with one particular embodiment of the present invention. In the terminology used in this specification, the vertical direction is termed the z direction and the horizontal direction is termed the xy direction. The Figures in this application are, of course, two dimensional so that all xy motions are illustrated as being in the plane of the page and thus could be considered simply as one dimensional movements, i.e., x or y, rather than xy. However, because, in the real world, the wire loops on a given die are not all parallel to each other, all lateral motion must be defined as xy motions in the machine code that controls the motion of the capillary of a ball bonding machine. Thus, we use the same terminology in this specification. In addition, the terms vertical and horizontal are merely exemplary based on the assumption that the top surface of the die is oriented horizontally, which is typical, but not necessarily always an accurate assumption.

[025] As shown in Figure 5A, the folded forward loop formation process begins with the capillary 11 at the end of the preceding looping process with a wire tail 23 extending from the capillary and the clamps 18 closed. The capillary is positioned in the vicinity of the bond pad 61 of the die 63 and the associated lead finger 65 between which the next wire loop interconnect is to be made.

[026] The wire is melted with the electric-flame-off 67 to cause the end of it to melt. Upon melting, it inherently forms into a ball 72, as shown in Figure 5B. The capillary is lowered and moved toward the bond pad 61, as shown in Figure 5C. The capillary is then lowered to contact the ball 72 against the bond pad 61. Heat and/or ultrasonic energy is applied to bond the ball to the bond pad. Figure 5D shows the process at this point, which essentially is the end of the formation of the first portion of the folded forward wire loop, i.e., the bump 56.

[027] Next, the capillary 11 rises with the clamps 18 open in order to pay out a length of wire extending from the top of the bump 56. The distance of this rise is herein termed the separation height, and is illustrated at 75 in Figure 4. Figure 5E shows the capillary position after this step. The capillary 11 then moves in the xy plane in a first direction generally opposite the direction to the second bond site 65 (to the left in Figures 5A through 5O). Preferably, the direction of the fold offset is exactly opposite the xy direction toward the second bond site 65. The distance of this xy motion is herein termed the fold offset and is shown in Figure 4 at 76. The position of the capillary after the fold offset motion is shown in Figure 5F.

[028] In some embodiments of the invention, at the end of the fold offset motion, the capillary 11 is raised again (in the positive z direction) a short distance (herein termed the fold factor) to pay out additional wire. The fold factor is shown at 77 in Figure 4. However, in some applications of the invention, a fold factor of zero will be adequate. Figure 5G shows the position of the capillary and wire at this point in the process. The fold offset and the fold factor control the amount of wire in the wire fold.

[029] The capillary 11 is then moved back toward the bump 56 to fold the wire back over on top of itself to begin forming the wire fold on top of the bump. Figure 5H shows the position of the capillary 11 and the condition of the wire as the capillary is moving to form the fold. This last-mentioned motion is herein termed the fold return motion as is illustrated at 78 in Figure 4. Preferably, the fold return motion is in the xy direction exactly opposite the xy direction of the fold offset motion. In those embodiments in which the fold factor 77 is zero, the fold return motion preferably is a purely horizontal (i.e., xy) motion. If the fold factor 77 was not zero, the fold return motion 78 may include a negative z component to return the capillary to the same height that it was at during the ball bonding. Either case returns the capillary to the separation height at the end of the fold return motion. However, this is not a requirement. In fact, in at least some preferred embodiments of the invention, as discussed further below, the capillary returns to a height below the separation height In fact, the fold return motion 78 may include a positive (upward) or negative (downward) z component, even if the fold factor 77 was zero. The important aspect is that a wire fold is formed on top of the bump 56 preferably extending in a direction directly away from the second bond site 65. The difference between the separation height and the position of the capillary at the end of the fold return motion 78 is herein termed the bump height. It may be a positive or a negative number. However, as noted previously, in some implementations of the invention, there will be no z motion of the capillary between reaching the separation height and completion of the wire fold and/or the fold factor and the z component of the fold return motion will be exactly equal and opposite so that the bump height will be zero.

[030] Furthermore, the horizontal component of the fold return motion 78 need not be the same distance as the fold offset motion. Depending on the particular application, it may be desirable to return to a position for purposes of performing the stitch bond at a position that is short of (as illustrated by path 78a in Figure 4), exactly the same as (as illustrated by path 78b in Figure 4), or long of (as illustrated by path 78c in Figure 4) the original xy coordinates of the capillary prior to the fold offset motion.

[031] The horizontal difference between the xy coordinates of the capillary at this point relative to the xy position of the capillary when the bump was formed is termed the fold return offset. In other words, the fold return offset is the difference in the xy dimension between the fold offset motion and the horizontal component of the fold return motion. If the xy component of the fold return motion 78 is less than the fold offset motion 76, the fold return offset is represented as a positive number. If the horizontal component of the fold return motion 78 is longer than the fold offset motion 76, the fold return offset is represented as a negative number. If the fold offset motion 76 and the fold return motion 78 have the same xy (i.e., horizontal) magnitudes, then the fold return offset is zero.

[032] At the end of the fold return motion, the capillary is contacting the top of the bump 56 and pinching the wire between the tip of the capillary 11 and the bump, as shown in Figure 5I. At this point, the wire has been pinched, but has not been severed. Also, at this point, the second of the five aforementioned portions of the overall folded forward wire loop (i.e., the fold 57) is completed. The wire has not been severed since the beginning of the process and the fold 57 is thus continuous with the bump 56.

[033] The wire is then stitch bonded to the top of the bump 56. Heat and/or ultrasonic energy may be applied to facilitate bonding of the compressed portion of the wire to the top of the bump 56. At this point, the third of the five aforementioned portions of the overall loop (i.e., the first stitch bond 58) is completed. Figure 5J shows the process at this point, which is essentially the same position as shown in Figure 5I since the capillary typically does not move during stitch bonding.

[034] The capillary is now moved toward the second bond site through a set of coordinated xyz motions to form the desired wire loop shape (the fourth portion of the overall loop) and to position the capillary above the second bond site 65. Figures 5K and 5L show the position of the capillary 11 at two points along an exemplary trajectory to the second bond site 65.

[035] The coordinated xyz motion can be relatively simple, comprising a straight xy motion toward the second bond site. However, typically there is motion in the z direction to help form the wire loop into the most preferable shape. As the wire has still not been severed since the beginning of the process, the wire loop 59 is continuous with the bump 56, fold 57, and stitch bond 58 at the first bond site.

[036] Next, the capillary is lowered to pinch the wire between the second bond surface 65 and the tip of the capillary 11 and the wire is stitch bonded to the second bond site. Heat and/or ultrasonic energy may be applied to facilitate bonding. At this point, the wire has been pinched, but has not been fully severed, as shown in Figure 5M. The capillary 11 is then raised with the clamps 18 still open and with the wire still attached to the second stitch bond 60 such that a wire tail 69 pays out of the capillary 11. Figure 5N illustrates the position of the capillary at this point in the process. The clamps 18 are then closed and the capillary 11 is raised further to snap the wire at the second stitch bond 60 as shown in Figure 5O. The fifth portion of the overall folded forward wire loop, i.e., the second stitch bond 60, is now completed and the entire folded forward looping process is concluded.

[037] The main purposes of the bump 56 are to prevent direct contact of the capillary with the bond pad and to raise the height (z direction) from which the wire exits the first bond site. Specifically, the wire exits the first bond site so low that, if not for the extra height above the die surface provided by starting the wire loop on top of a bump, the wire loop 59 might otherwise contact the die surface intermediate the first and second bond sites.

[038] The primary purpose of forming the fold 57 on top of the bump is so that the wire exits the first bond site generally horizontally and pointing toward the second bond site, thus creating a low loop height. The fold is generally elliptical in shape with its major axis in the xy plane and the wire exits the end of the fold generally horizontally and generally pointing directly toward the second bond site. This orientation is to be contrasted with the generally straight upward orientation of the wire as it exits the first bond site in a conventional forward wire loop. Accordingly, the looping technique of the present invention provides ultra-low loop heights because the wire exits the ball bond site pointing horizontally rather than vertically upward.

[039] In addition, the impact to the die is reduced relative to conventional reverse ball bonding because it does not perform a normal second bond on top of the bump, as is the case with reverse looping. The wire is only slightly compressed to form the loop and stitch bond on top of the ball as in Figure 7A in comparison to a normal stitch bond similar to Figure 7B as in reverse bonding.

[040] Further, finer pitches can be achieved with the present invention relative to reverse ball bonding because the bump is not compressed and squished out laterally as much as in the reverse wire looping technique.

[041] The wire bonding machine is controlled by motion control system comprising control circuitry that can cause the machine to perform the processes described herein. Commonly, the circuitry comprises a digital processing device such as a programmed general purpose computer, a digital signal processor, a state machine, a combinational logic circuit, a microprocessor, an application specific integrated circuit, or any other known digital processing means. If the circuitry comprises a computer, the invention may reside largely, if not exclusively, in the software for programming the computer to control the wire bonding machine to perform the processes described herein.

[042] By optimizing the various motion components described in connection with Figure 4, we can achieve desired shape with low loop height and no neck damage. As an example, Figure 6 shows exemplary parameters that were used to form the fold shown in Figure 7 and subsequently the loop profile shown in Figures 8A and 8B. The first three motions (separation height 75, fold offset 76 and fold factor 77) collectively determine the amount of the wire in the fold and the shape of the fold. If these motions are too large, a larger fold than desired may be formed. If these motions are too small, a fold may not be formed at all and the neck region of the wire could be damaged.

[043] We have found through experimentation that a separation height and a fold offset slightly larger than the wire diameter (e.g., about 1.01 to 1.55 times the wire diameter) achieves excellent results. Furthermore, the fold factor should be a positive value. In the example of Figure 7, the separation height 75 is 1.5 mil, the fold offset 76 is 1.3 mil and the fold factor 77 is 1 mil for a wire of a diameter of 1 mil). These settings pay out the proper amount of wire and angle the wire around 30 degrees from the vertical before the fold return motion 78 starts.

[044] The fold return motion 78 determines the final shape of the bump. In the particular machine we used, the fold return motion 78 is specified by two parameters. Specifically, (1) the aforementioned fold return offset parameter (which, along with the fold offset, dictates the horizontal component of the fold return motion) and (2) the bump height (which, along with the fold factor, dictates the vertical component of the return motion).

[045] To form a good fold with enough deformation to sustain the fold without overly flattening the bump, bump height normally should be a negative value (bump height being a vertical distance from the separation height). In this example, the bump height is -1.25 mil and the separation height is 1.5 mil. Thus, the final position of the capillary is about 0.25 mil above the bump 56. This provides just enough flattening of the wire to form the fold without flattening the bump significantly. The fold return offset in this example is 0.5 mil, which means that the final position of the capillary after the fold return motion 78 is offset 0.5 mil horizontally from the center of the bump (away from the second bond 60). These settings ensure that the site of the stitch bond 58 is centered on top of the bump 56.

[046] The wire loop resulting from bonding using these parameters is shown in Figure 8. Over multiple experimental samples, the average loop height using these parameters was 2.3 mil. The maximum loop height was 2.5 mil.

[047] Having thus described a few particular embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications and improvements as are made obvious by this disclosure are intended to be part of this description though not expressly stated herein, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only, and not limiting. The invention is limited only as defined in the following claims and equivalents thereto.

CLAIMS

What is claimed is:

1. A method of forming a wire loop interconnect between a first bond site and a second bond site, said method comprising the steps of:

(1) ball bonding a wire to said first bond location to form a bump on said first bond location;

(2) forming a fold of wire on top of said ball bond, said fold of wire being continuous with said ball bond;

(3) stitch bonding said fold of wire on top of said ball bond;

(4) continuously forming a wire loop between said wire fold and said second bond site; and

(5) stitch bonding said wire at said second bond site to terminate said wire loop.

2. The method of claim 1 wherein said fold of wire is generally elliptical having a major axis extending horizontally.

3. The method of claim 2 wherein said fold of wire extends in a direction substantially opposite of the direction from the first bond site to the second bond site.

4. The method of claim 3 wherein the wire loop exits the top of the ball bond substantially horizontally.

5. The method of claim 1 wherein said wire loop is formed with a ball bonding machine comprising at least a capillary and wherein step (2) comprises the steps of:

(2.1) raising the capillary vertically above the ball bond;

(2.2) moving the capillary horizontally away from said second bond site; and

(2.3) moving the capillary horizontally in a direction back toward said first bond site.

6. The method of claim 5 wherein step (2) further comprises the steps of:

(2.4) raising the capillary between steps (2.2) and (2.3).

7. The method of claim 6 wherein step (2.3) includes moving said capillary downwardly.

8. The method of claim 5 wherein step (2.3) comprises moving the capillary horizontally a distance less than the horizontal distance traversed in step (2.2).

9. The method of claim 1 wherein said first bond site is higher than said second bond site.

10. The method of claim 9 wherein said first bond site is on a semiconductor die and said second bond site is on a substrate carrying said semiconductor die.

11. The method of claim 6 wherein step (2.1) comprises raising the capillary a distance slightly greater than a diameter of said wire.

12. The method of claim 11 wherein said distance in step (2.1) is about 1.5 times said diameter of said wire.

13. The method of claim 6 wherein step (2.2) comprises moving the capillary a distance slightly greater than a diameter of said wire.

14. The method of claim 13 wherein said distance in step (2.2) is about 1.3 times said diameter of said wire.

15. The method of claim 14 wherein step (2.4) comprises raising the capillary a vertical distance about equal to a diameter of said wire.

16. The method of claim 6 wherein the distances in steps (2.1), (2.4) and (2.2) are selected relative to each other and a diameter of said wire so that, at the completion of step (2.2), said wire extends from said bump at about a 30 degree angle from vertical.

17. The method of claim 7 wherein step (2.3) comprises lowering said capillary a vertical distance greater than a distance of said moving in step (2.4).

18. A wire loop interconnect between a first bond site and a second bond site comprising:

(1) a ball bond at said first bond location;

(2) a fold of wire on top of said ball bond comprising wire continuous with said ball bond, said fold of wire being stitch bonded on top of said ball bond;

(3) a wire loop between said fold of wire and said second bond site, said wire loop comprising wire continuous with said fold of wire; and

(4) a stitch bond at said second bond site terminating said wire loop.

19. The wire loop of claim 18 wherein said fold of wire is generally elliptical having a major axis extending horizontally.

20. The wire loop of claim 19 wherein said fold of wire extends in the horizontal direction in a direction substantially opposite of the direction from the first bond site to the second bond site.

21. The wire loop of claim 20 wherein the wire loop exits the top of the ball bond substantially horizontally.

22. The wire loop of claim 18 wherein said first bond site is higher than said second bond site.

23. The method of claim 22 wherein said first bond site is on a semiconductor die and said second bond site is on a substrate carrying said semiconductor die.

24. A method of forming a wire loop for a semiconductor electrical interconnection comprising the steps of:

(1) forming a ball bond at a first bond location using a wire bonding machine with wire, said wire bonding machine having a capillary;

(2) raising said capillary a first height such that wire attached to said ball bond pays out of said capillary;

(3) moving said capillary horizontally a first distance in a first direction;

(4) moving said capillary in a second horizontal direction substantially opposite said first horizontal direction;

(5) forming a first stitch bond on top of said ball bond;

(6) moving said capillary to a second bond site spaced from said first bond site;

(7) forming a second stitch bond at said second bond site; and

(8) severing said wire adjacent said second bond site.

25. The method of claim 26 wherein said wire loop is formed with a ball bonding machine comprising at least a capillary and wherein said first

direction is substantially away from said second bond site and said second direction is substantially toward said second bond site.

26. A wire bonding machine comprising:

a capillary;

a wire delivery system for supplying wire through a bore in said capillary;

a motion control system for controlling motion of said capillary, said motion control system including circuitry for;

(1) forming a ball bond at a first bond location;

(2) forming a fold of wire on top of said ball bond, said fold of wire being continuous with said ball bond;

(3) stitch bonding said fold of wire on top of said ball bond;

(4) continuously forming a wire loop between said wire fold and a second bond site; and

(5) forming a stitch bond at said second bond site to terminate said wire loop.

27. The wire bonding machine of claim 26 wherein said circuitry for performing task (2) comprises circuitry for forming said fold of wire so that it extends in the horizontal direction substantially opposite from the direction from the first bond site to the second bond site.

28. The wire bonding machine of claim 27 wherein said circuitry for performing task (3) causes the wire loop to exit the top of the ball bond substantially horizontally.

29. The wire bonding machine of claim 27 wherein said circuitry for performing task (2) comprises circuitry for:

(2.1) raising the capillary vertically above the ball bond;

(2.2) moving the capillary horizontally away from said second bond site; and

(2.3) moving the capillary horizontally in a direction back toward said first bond site.

30. The wire bonding machine of claim 29 wherein said circuitry for performing task (2.3) comprises circuitry for moving the capillary horizontally a distance less than the horizontal distance traversed in step (2.2).

31. The wire bonding machine of claim 30 wherein said circuitry comprises a digital processing device.

32. The wire bonding machine of claim 30 wherein said digital processing device comprises a computer running computer software.

33. A computer readable product for controlling a wire bonding machine comprising a capillary, said computer readable product comprising computer executable instructions for:

(1) forming a ball bond at said first bond location;

(2) forming a fold of wire on top of said ball bond, said fold of wire being continuous with said ball bond;

(3) stitch and tail bonding said fold of wire on top of said ball bond;

(4) continuously forming a wire loop between said wire fold and said second bond site; and

(5) forming a stitch bond at said second bond site to terminate said wire loop.

34. The computer readable product of claim 33 wherein said computer executable instructions for forming said fold of wire causes said fold of wire to be generally elliptical with a major axis extending horizontally.

35. The computer readable product of claim 34 wherein said computer executable instructions for forming said fold of wire causes said fold of wire to extend horizontally in a direction substantially opposite of the direction from the first bond site to the second bond site.

36. The computer readable product of claim 35 wherein said computer executable instructions for forming said stitch bond forms said

stitch bond so that said wire loop exits from the top of the ball bond substantially horizontally.

37. The computer readable product of claim 36 wherein said computer executable instructions for forming said fold of wire comprises computer executable instructions for:

(2.1) raising the capillary vertically above the ball bond;

(2.2) moving the capillary horizontally away from said second bond site; and

(2.3) moving the capillary horizontally in a direction back toward said first bond site.

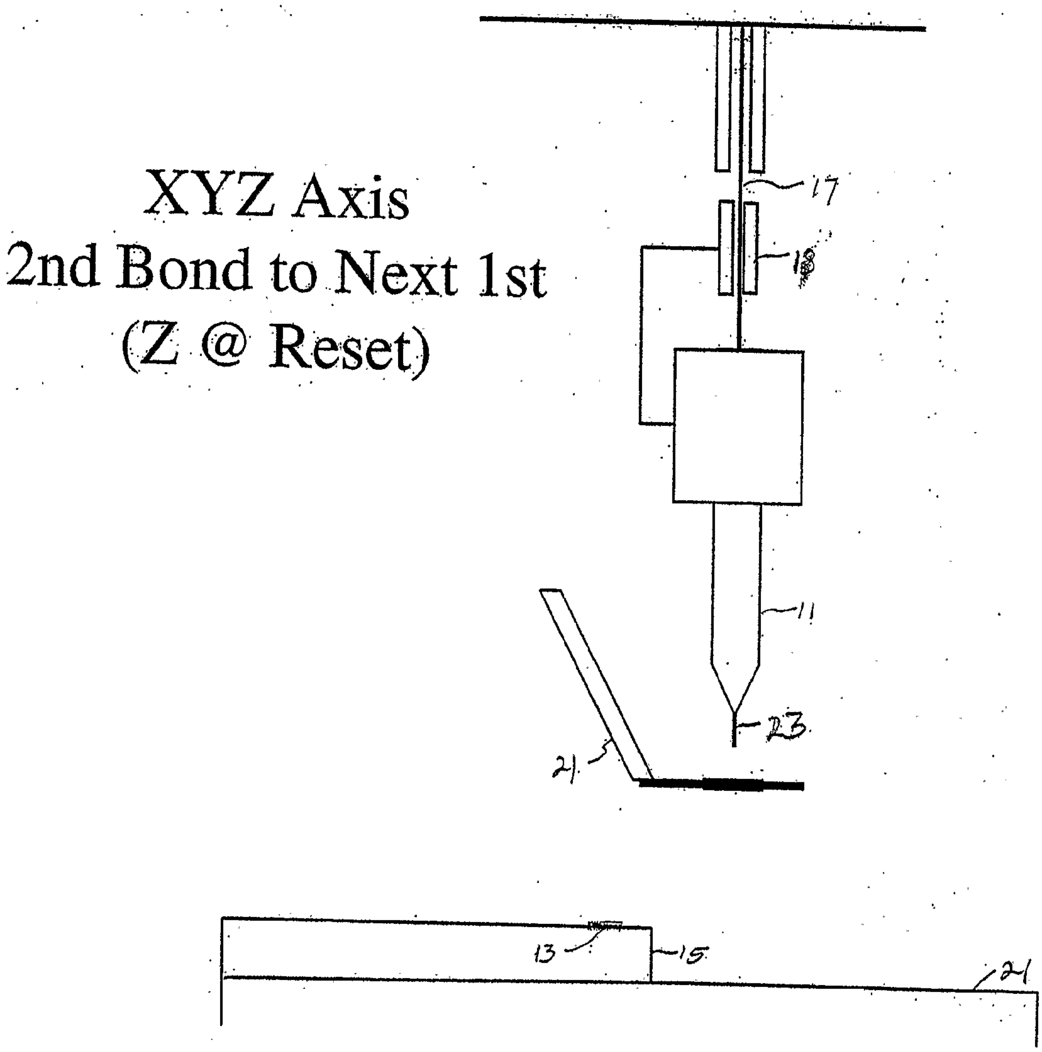


Fig. 1A

XYZ Axis
2nd Bond to Next 1st
(ball formation)

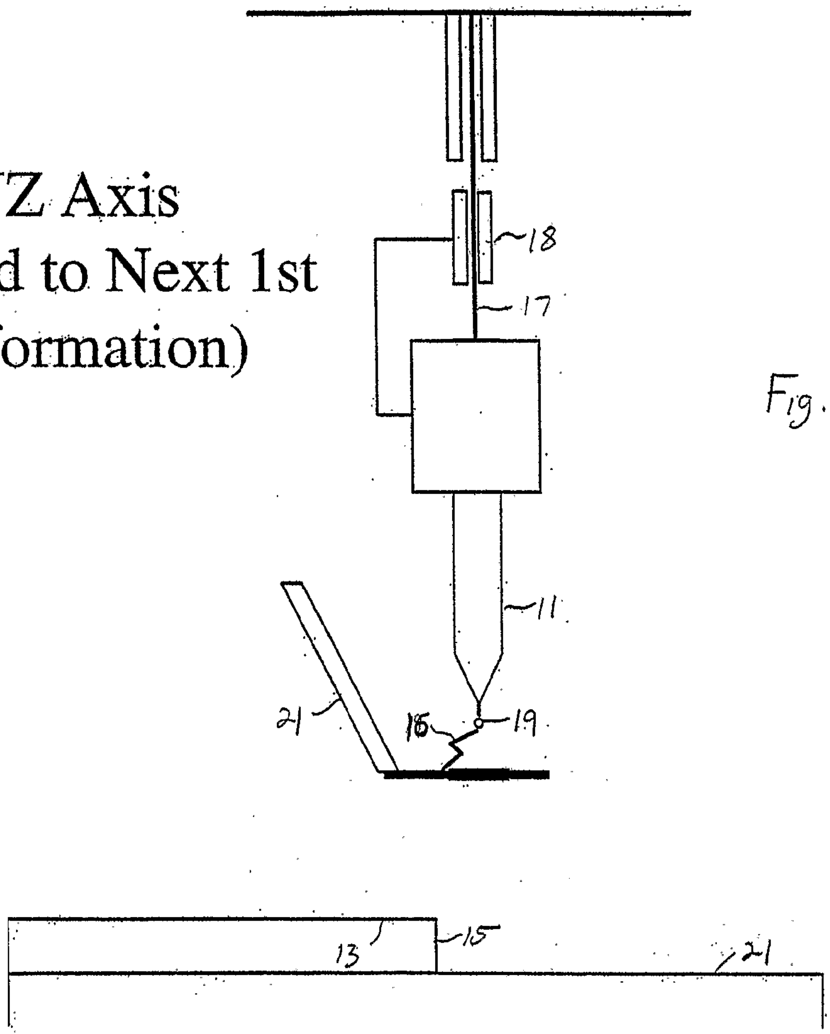


Fig. 1B

XYZ Axis
Bond to Next 1st

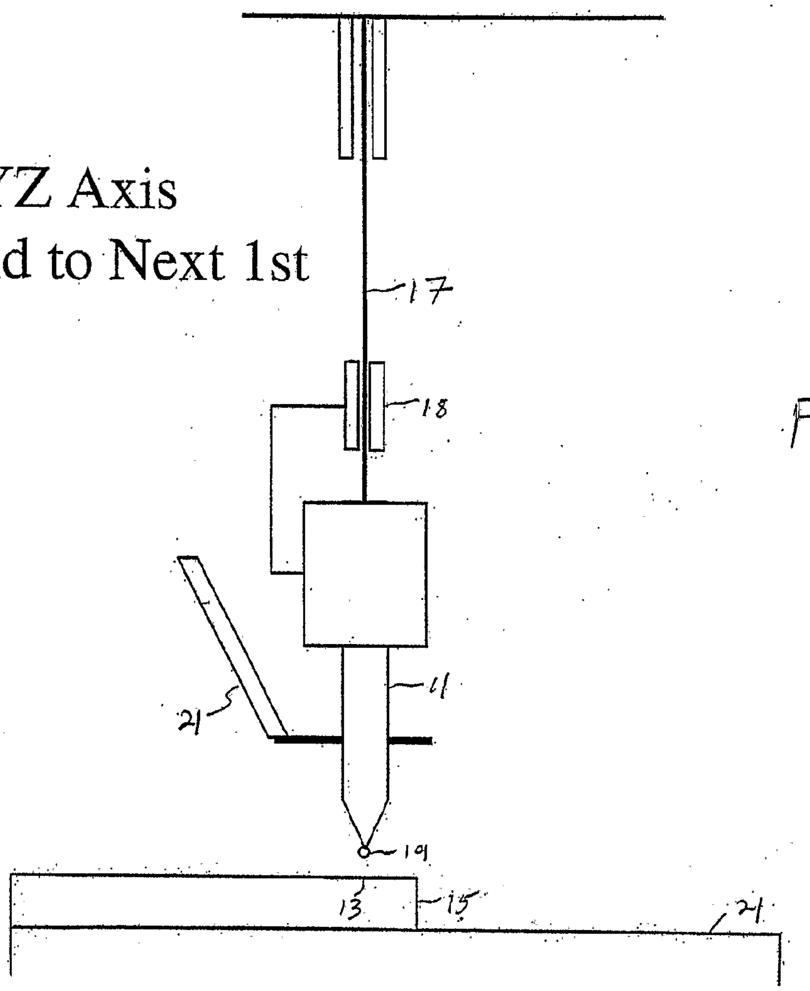


Fig. 1C

1st Bond

- Z Axis Force
- USG Power
- USG Time

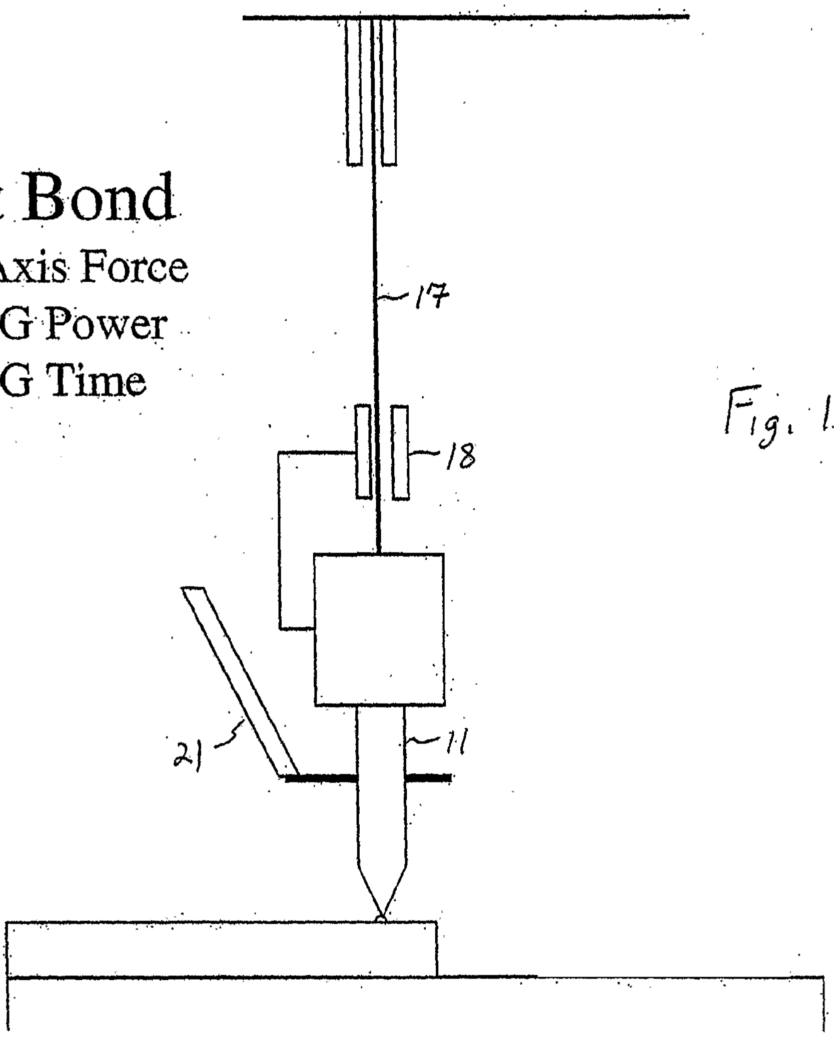


Fig. 1D

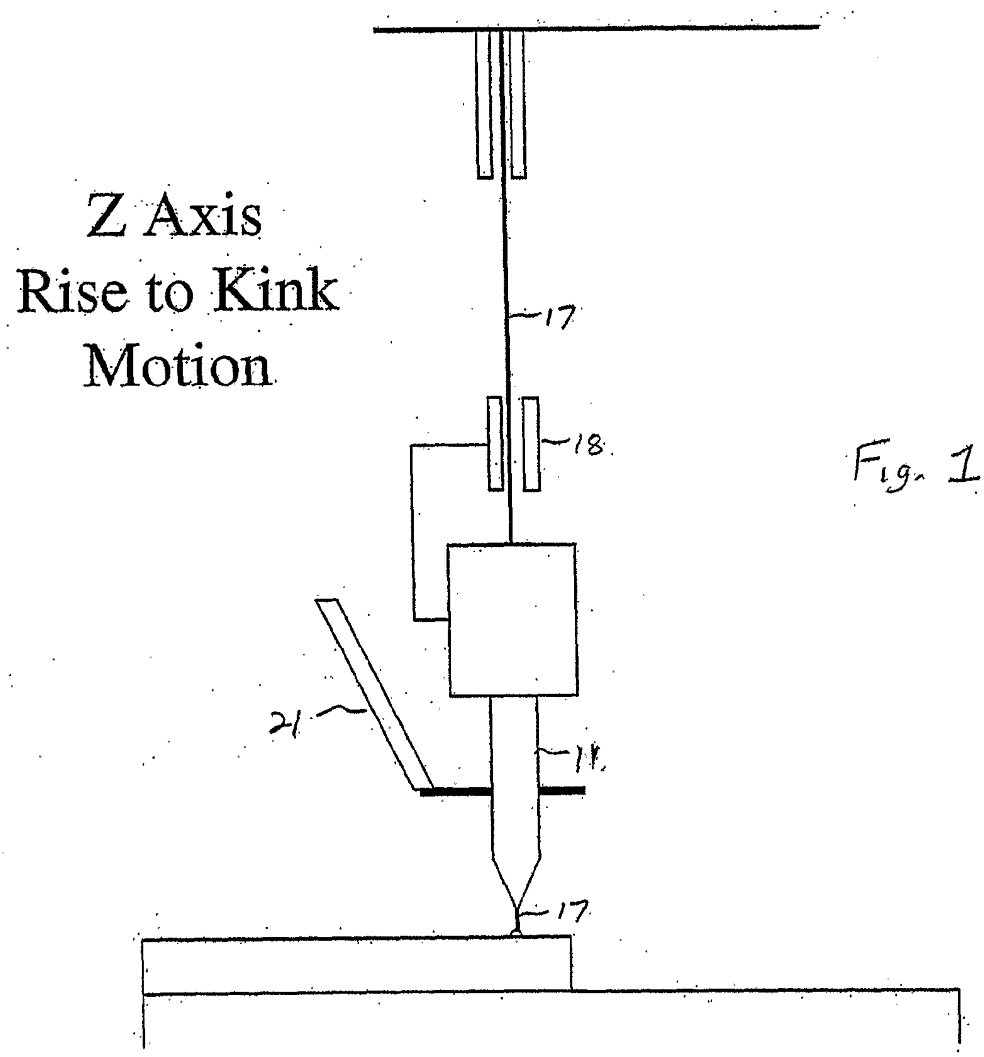


Fig. 1E

XYZ Axis
Looping Trajectory
to Second Bond

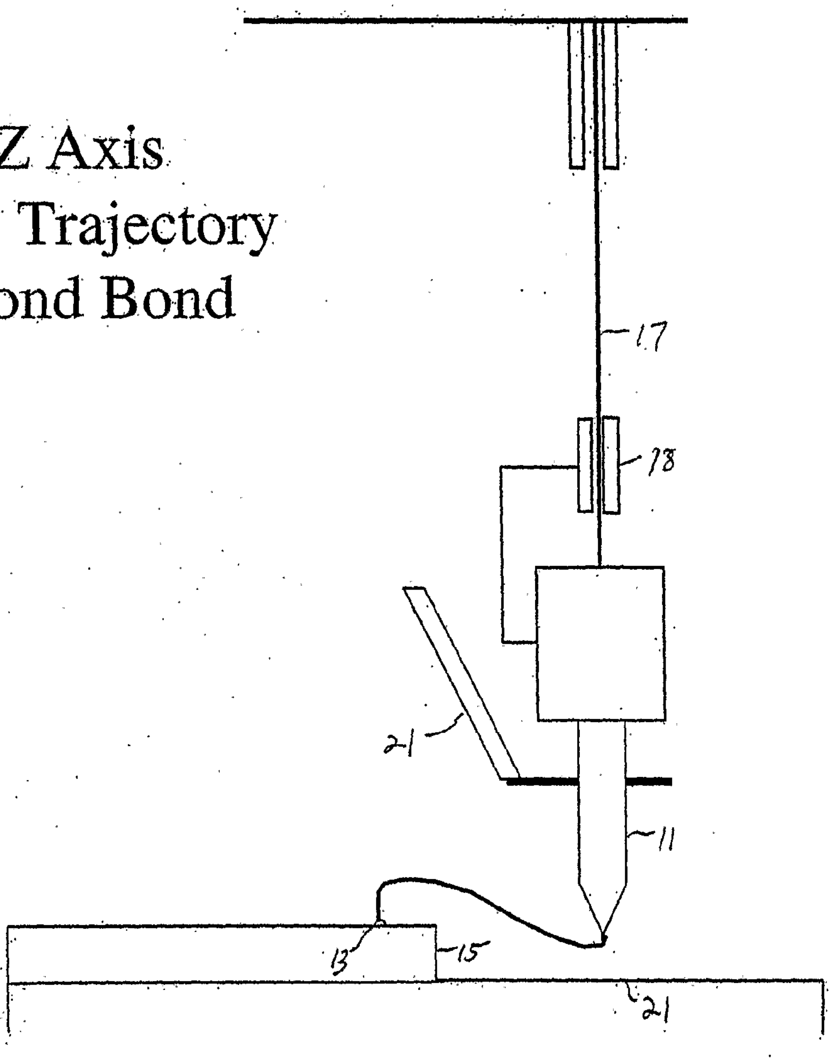


Fig. 1F

Z Axis
Seek(tip)
(clamp open)

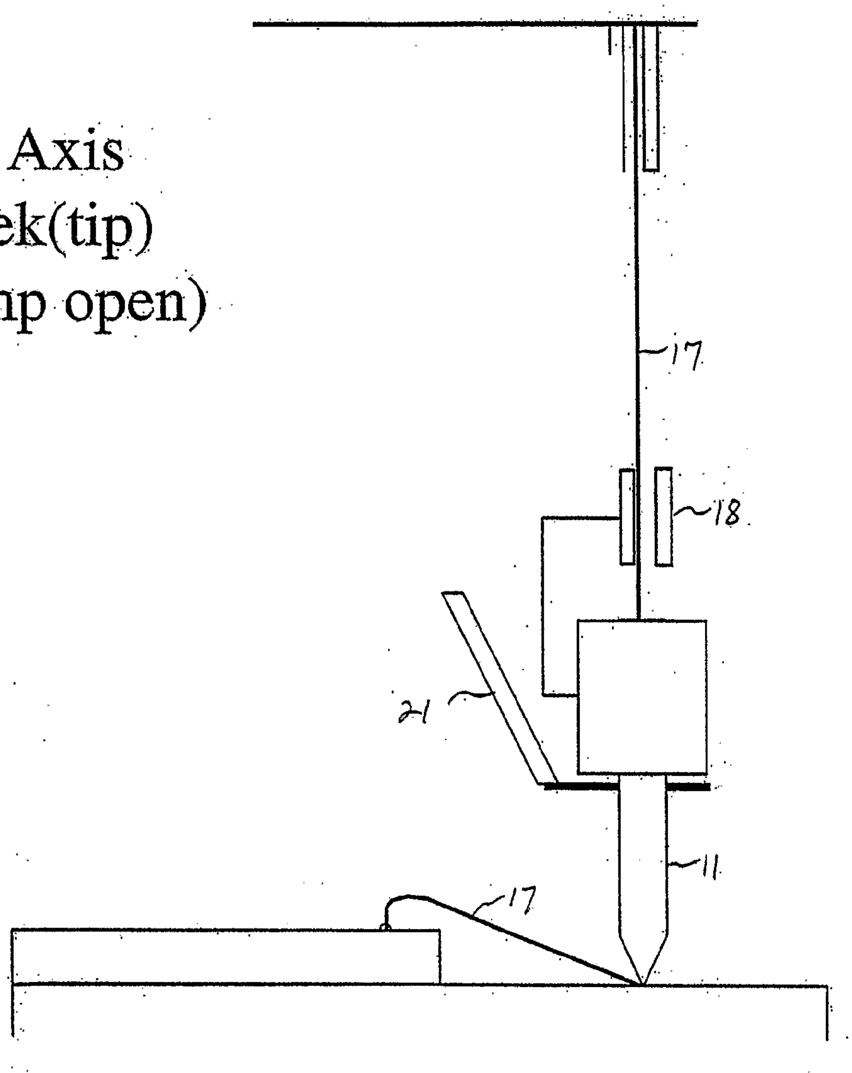


Fig. 1G

Z Axis
Rise to Clamp

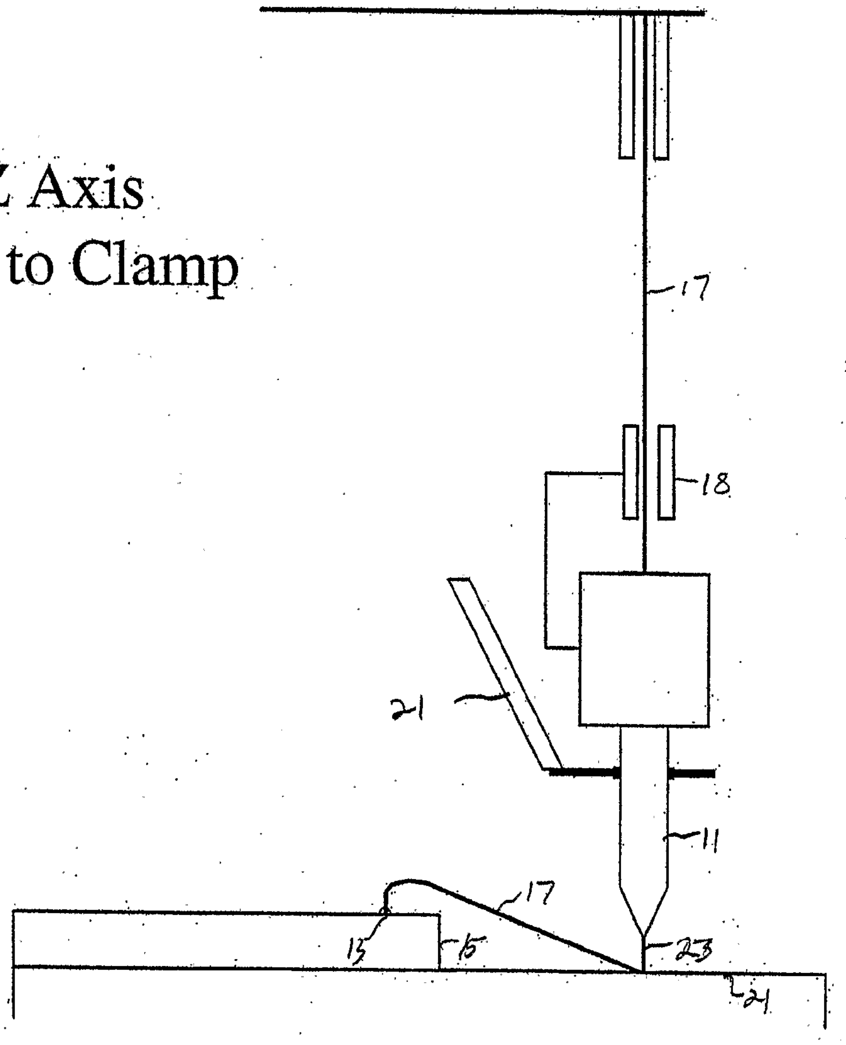


Fig. 1H

XYZ Axis
Bond to Next 1st
Z rise to reset)

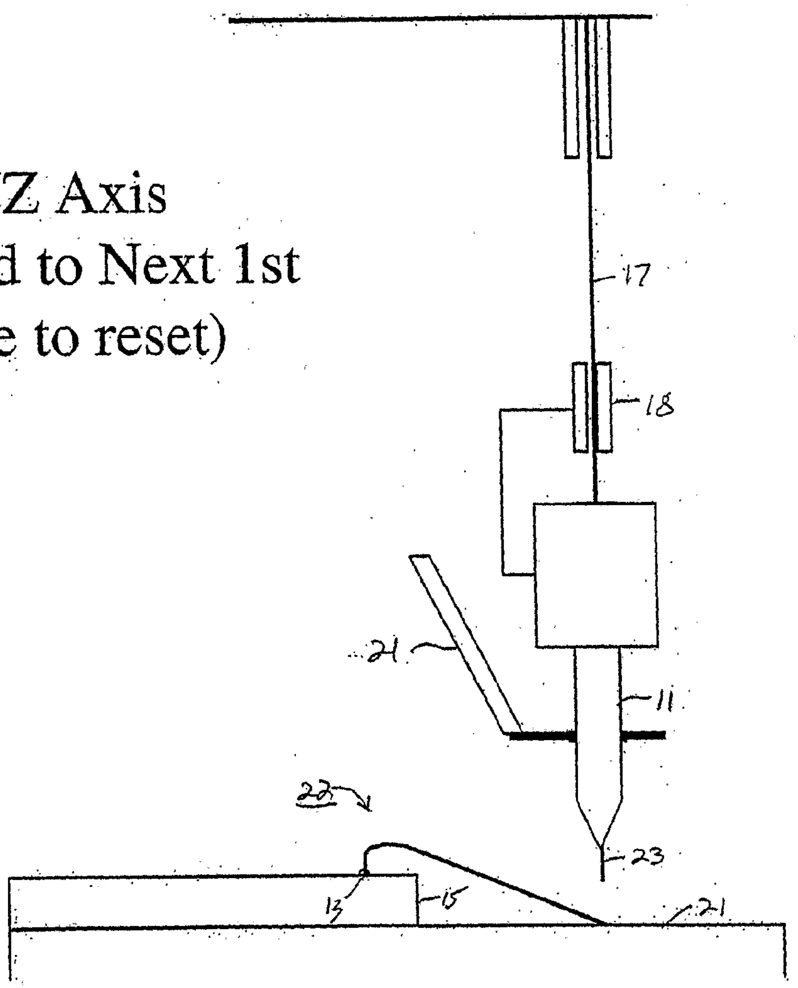


Fig. 1I

Fig. 2A

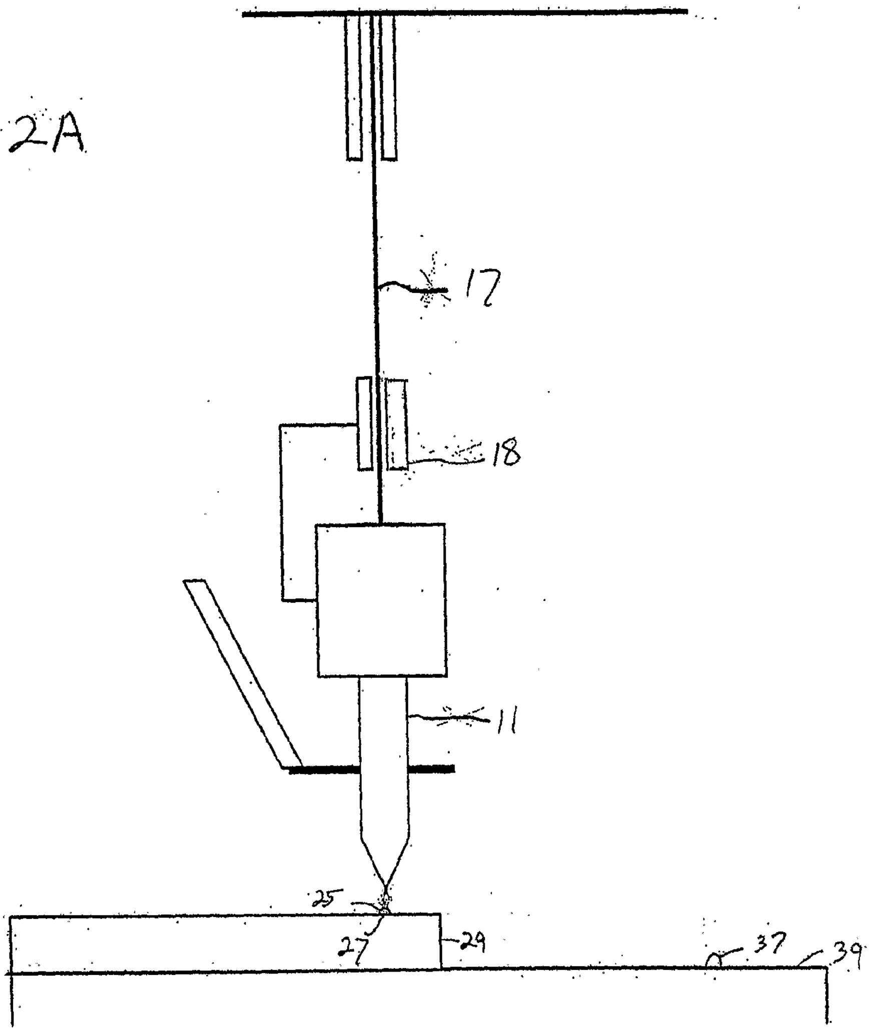


Figure 2B

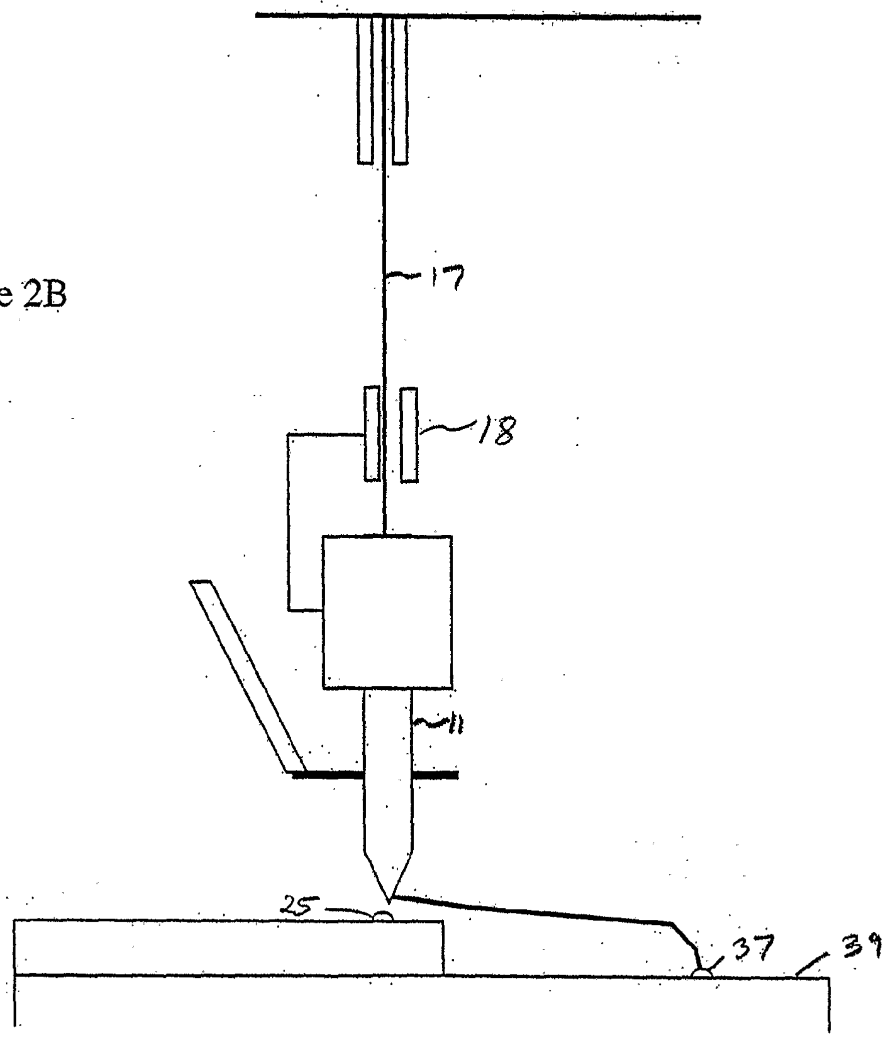
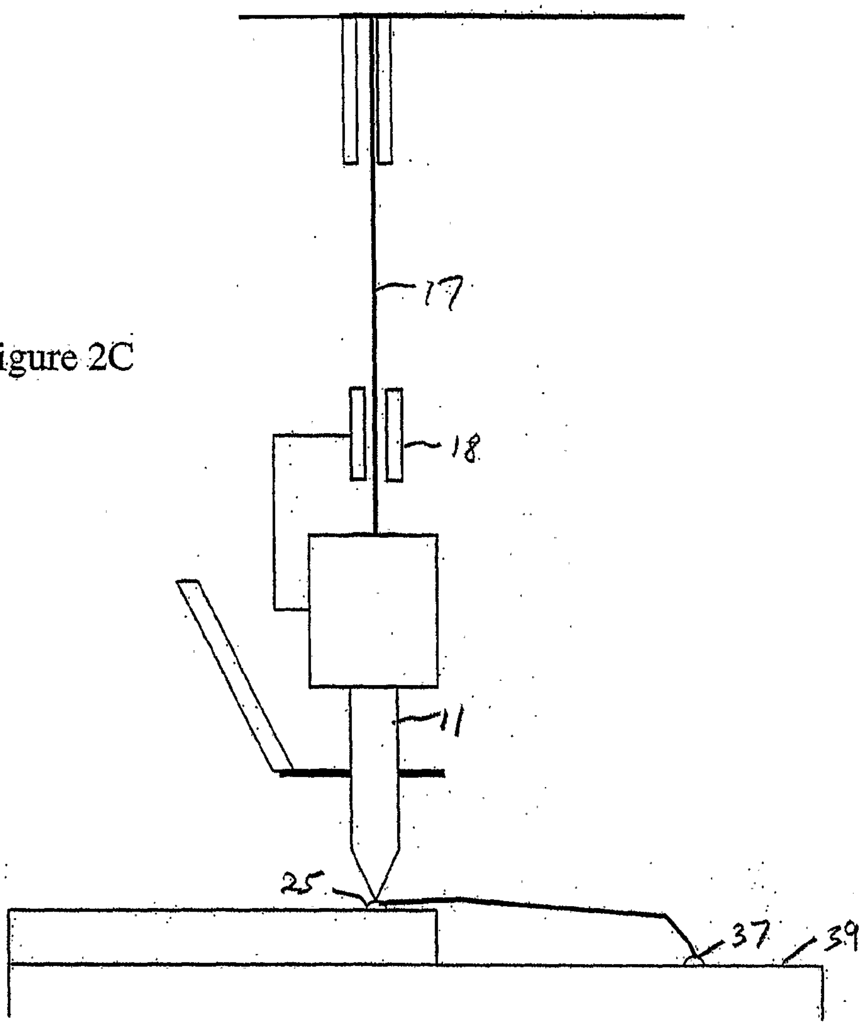


Figure 2C



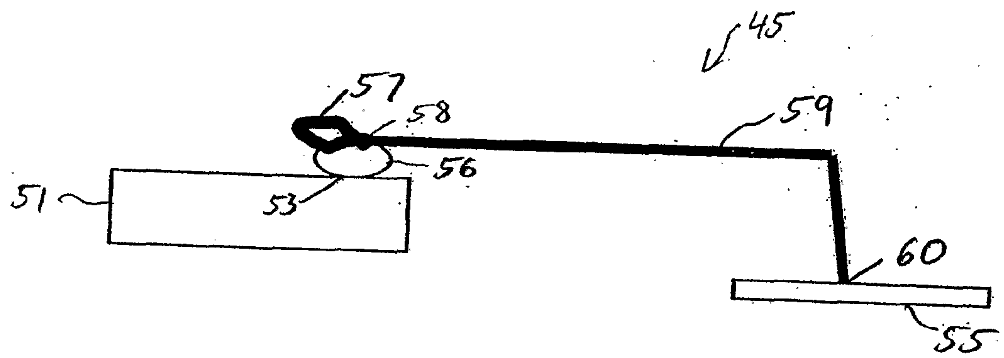


Fig. 3

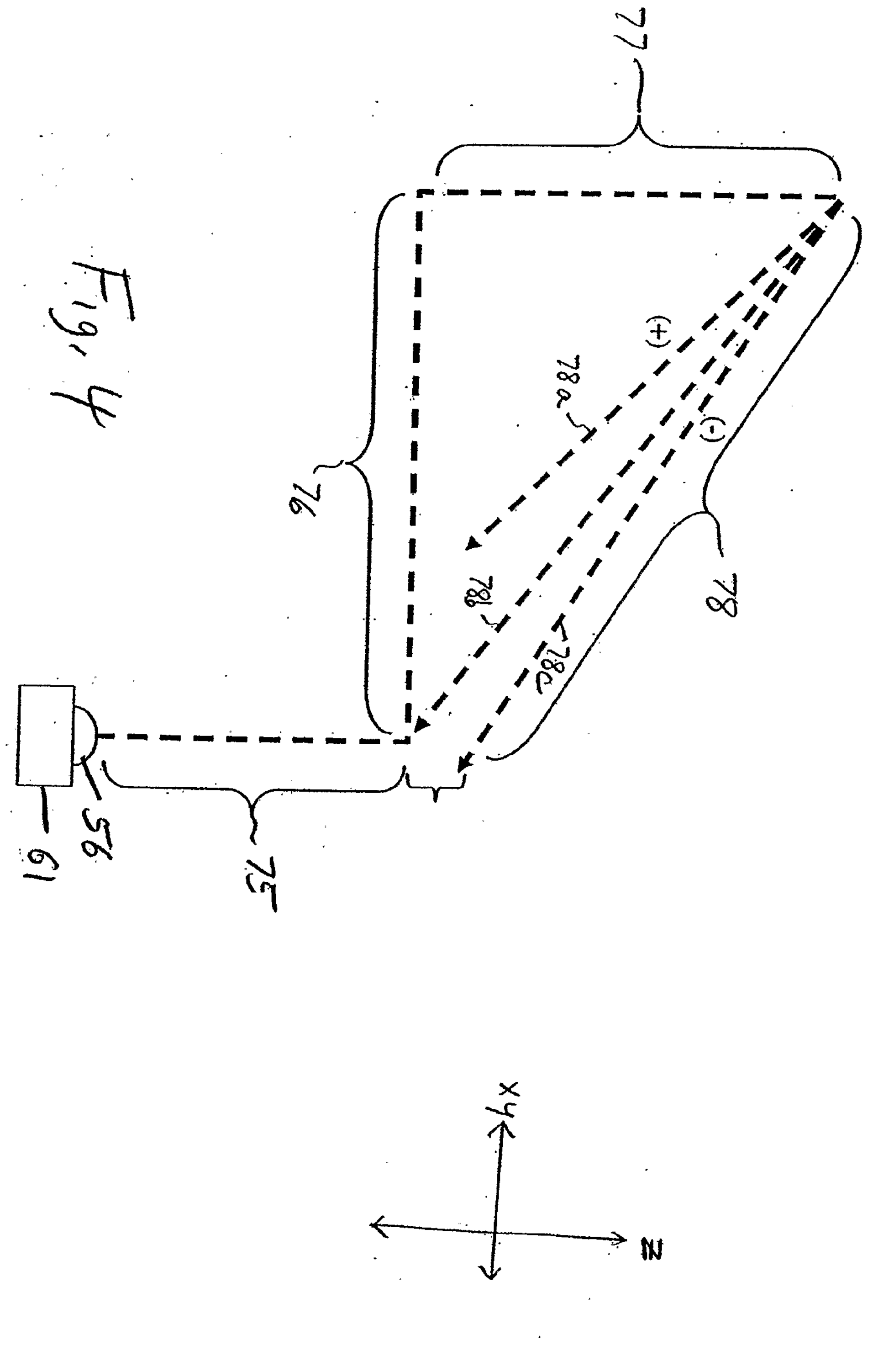


Fig. 4

XYZ Axis
2nd Bond to Next 1st
(Z @ Reset)

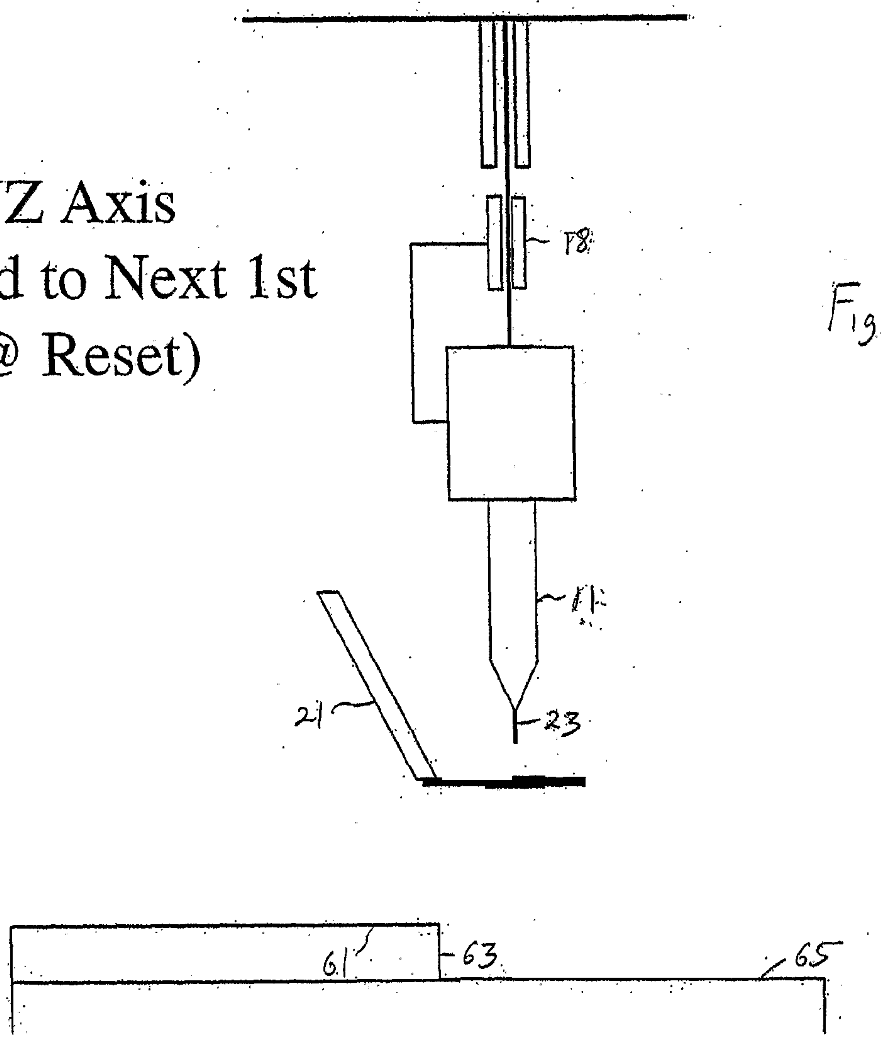


Fig. 5A

XYZ Axis
2nd Bond to Next 1st
(ball formation)

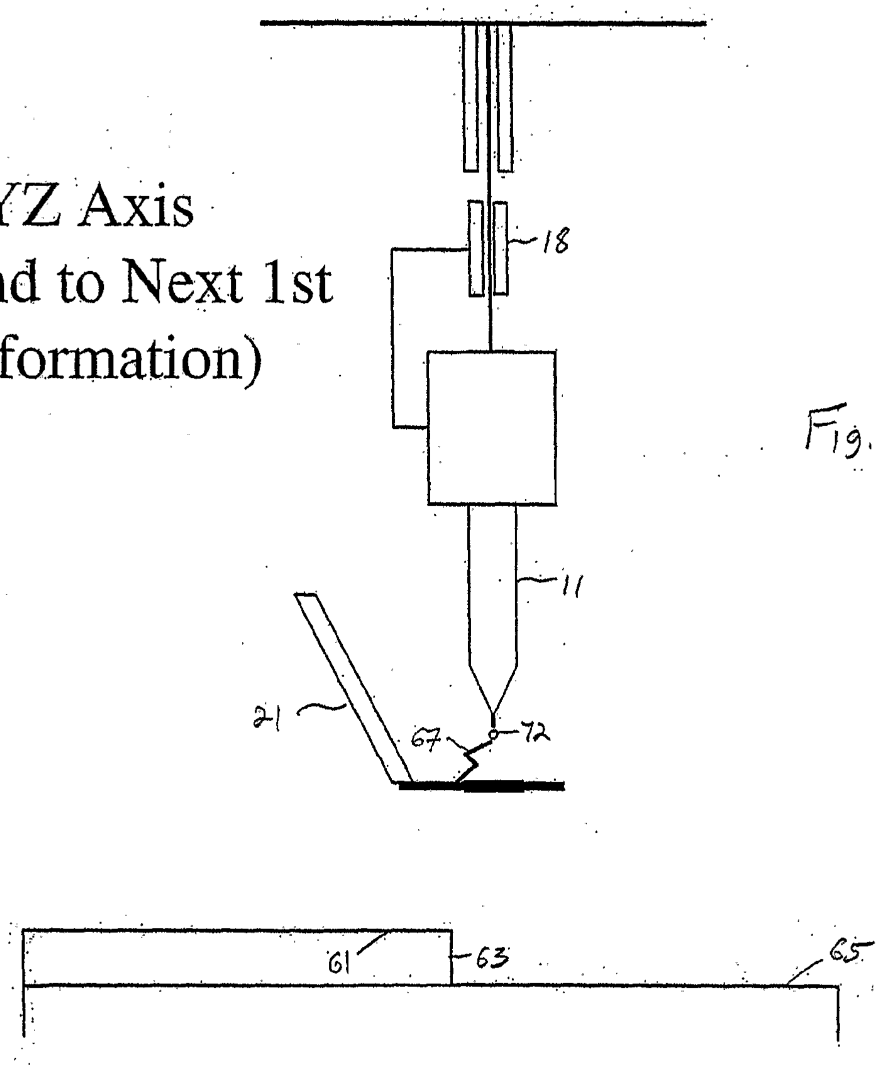


Fig. 5B

XYZ Axis
2nd Bond to Next 1st

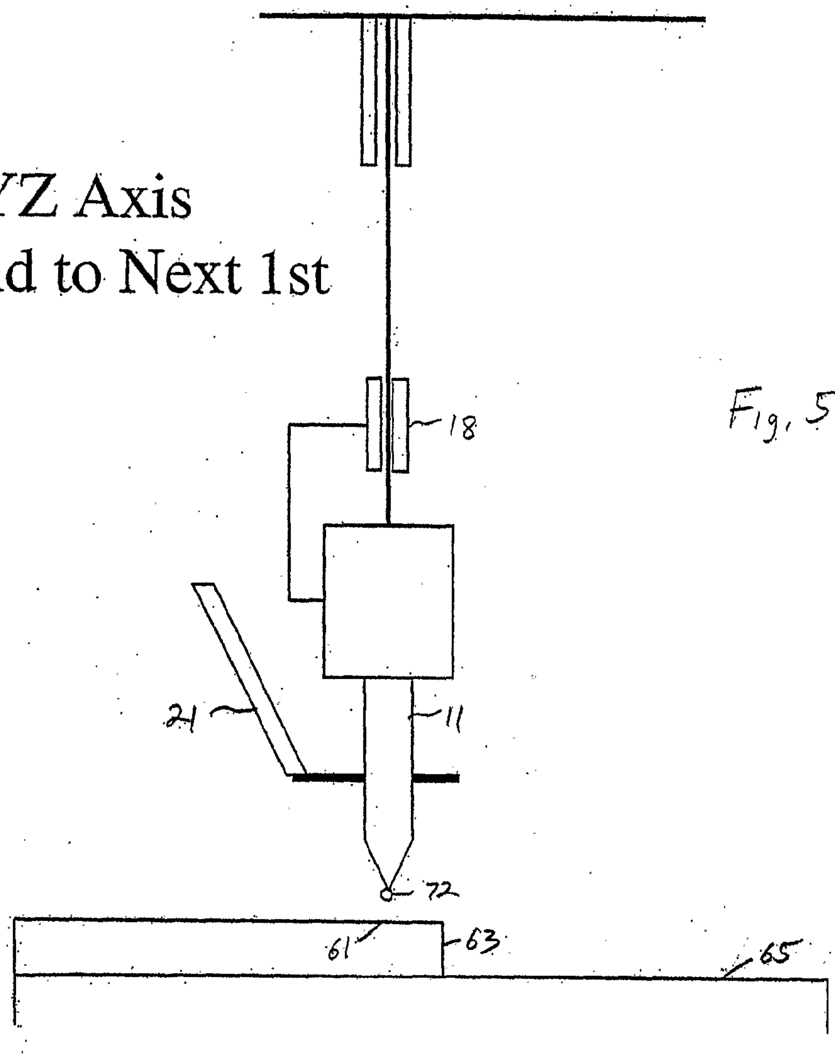


Fig. 5C

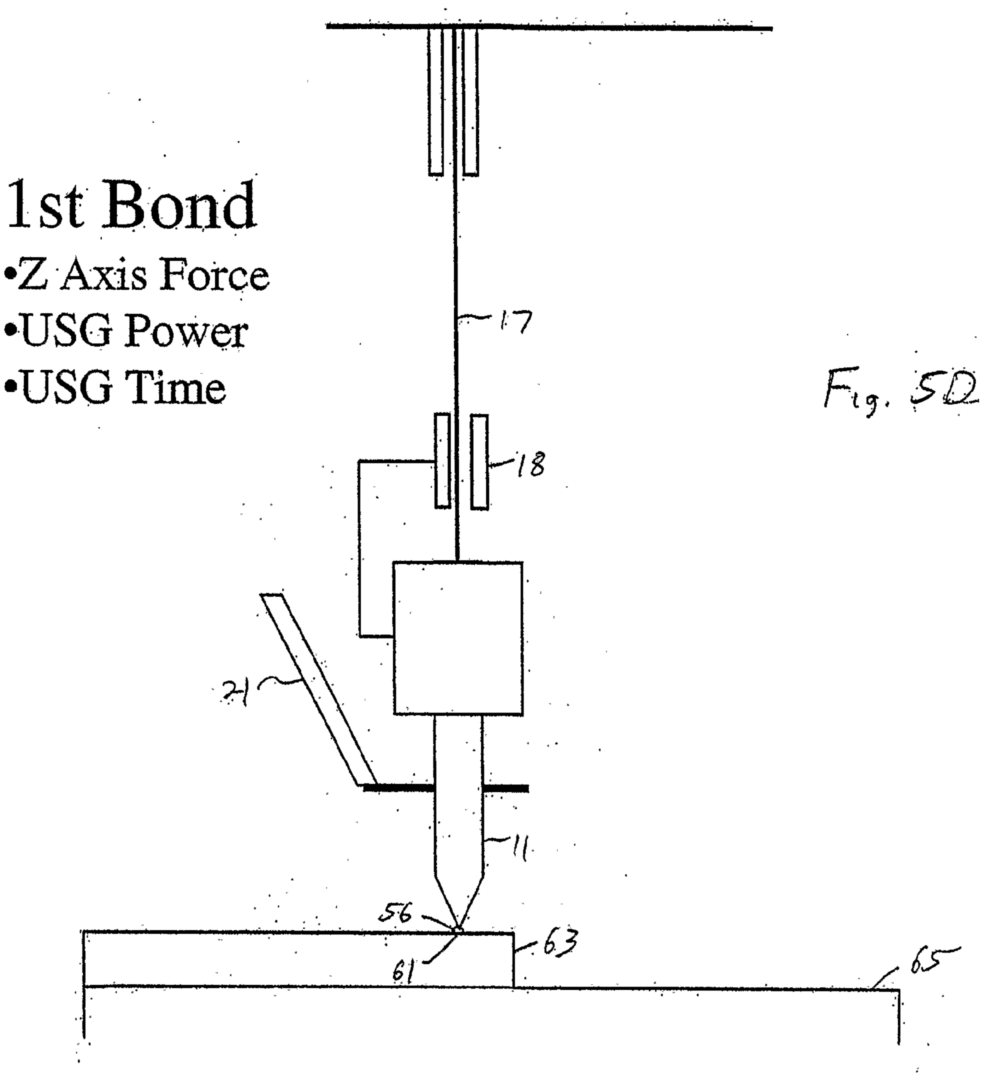


Fig. 5D

Z Axis
Rise to Kink
Motion

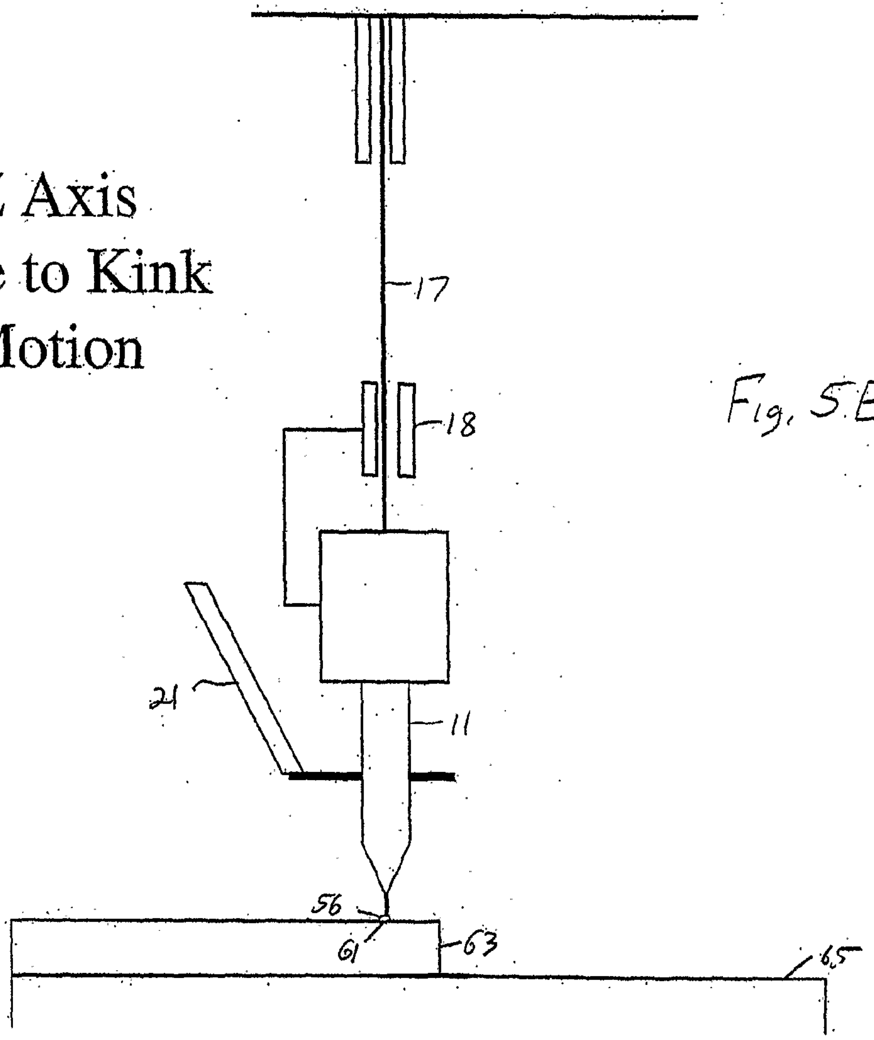


Fig. 5E

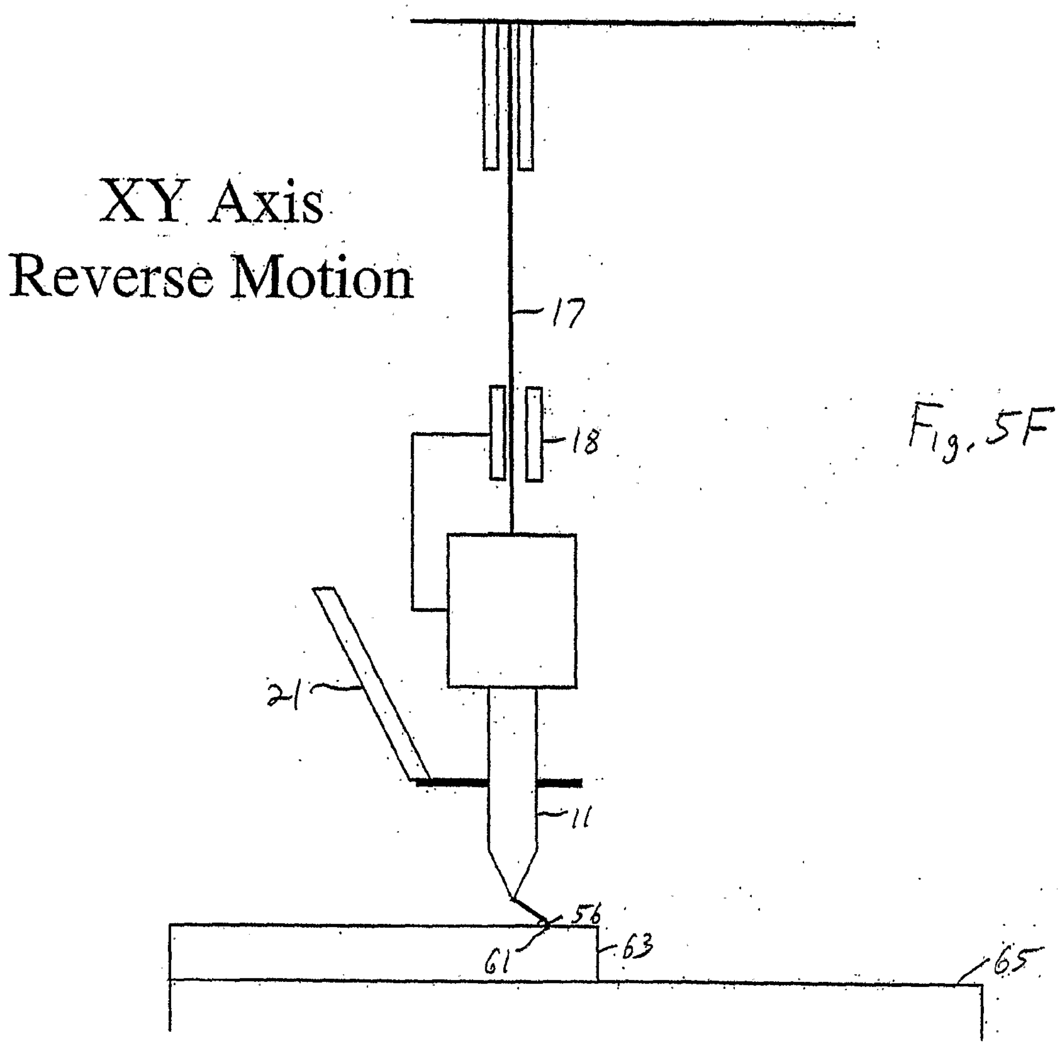


Fig. 5F

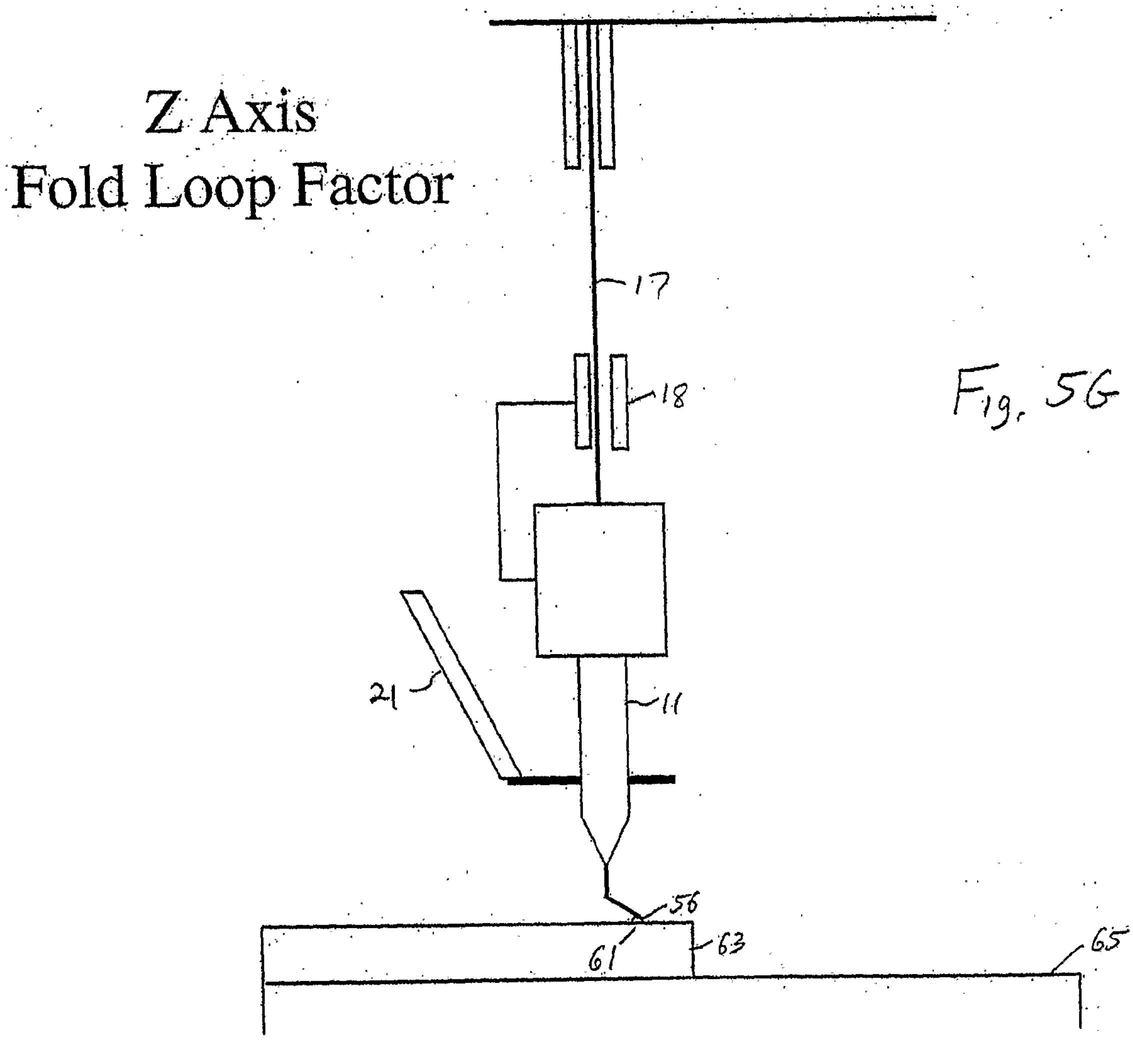


Fig. 5G

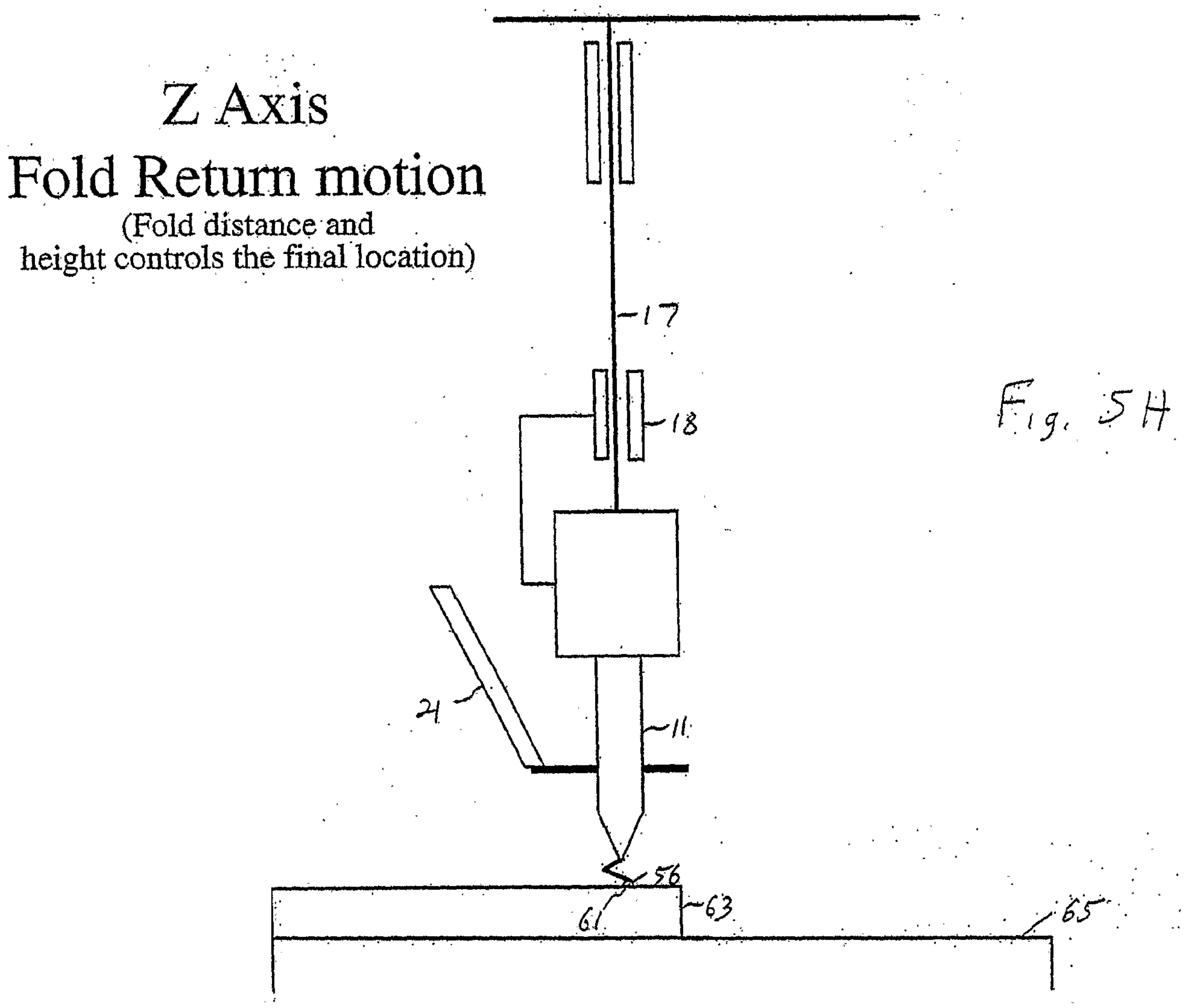

Z Axis
Fold Return motion
(Fold distance and
height controls the final location)
17
18
21
11
56
61
63
65

Fig. 5H

Z Axis
Fold Return motion
(Fold distance and
height controls the final location)

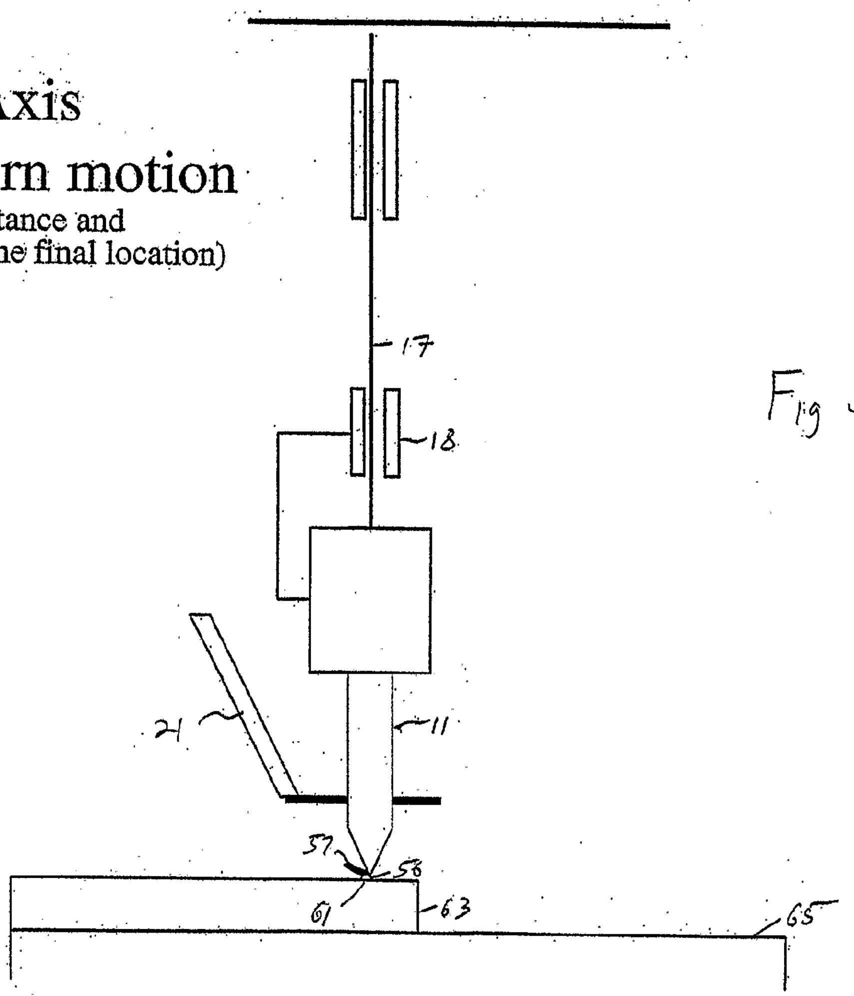


Fig 5I

Z Axis
Rise to top motion

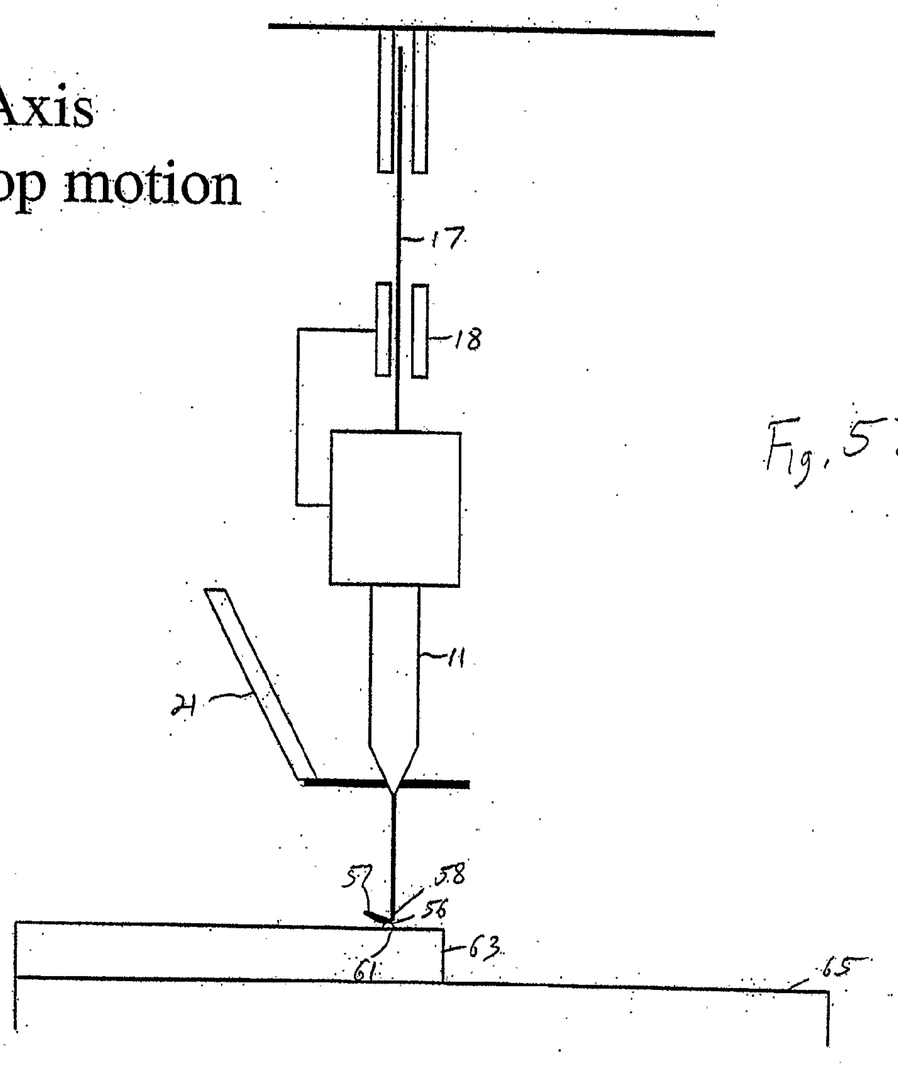


Fig. 5J

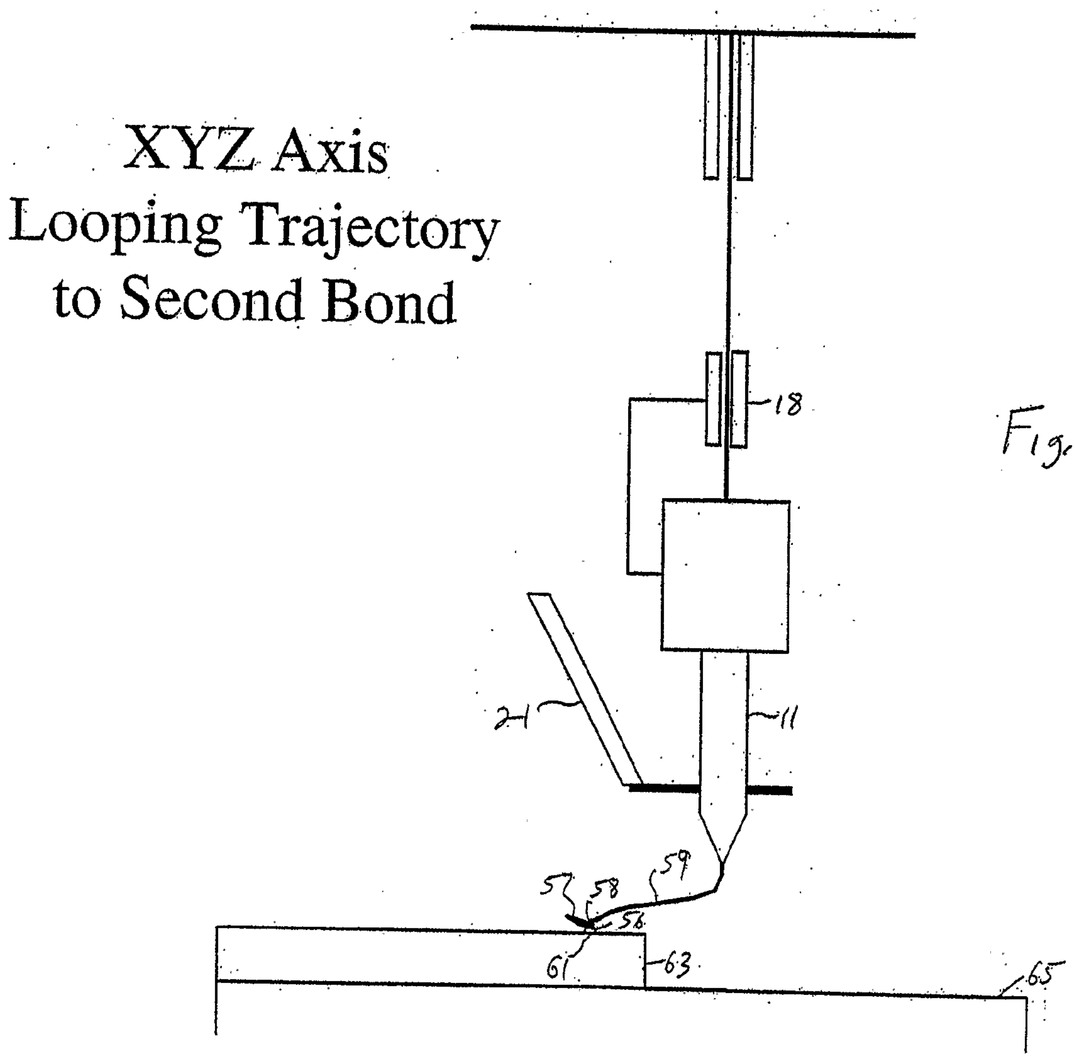

XYZ Axis
Looping Trajectory
to Second Bond
18
21
11
59
57
58
56
61
63
65

Fig. 5K

XYZ Axis
Looping Trajectory
to Second Bond

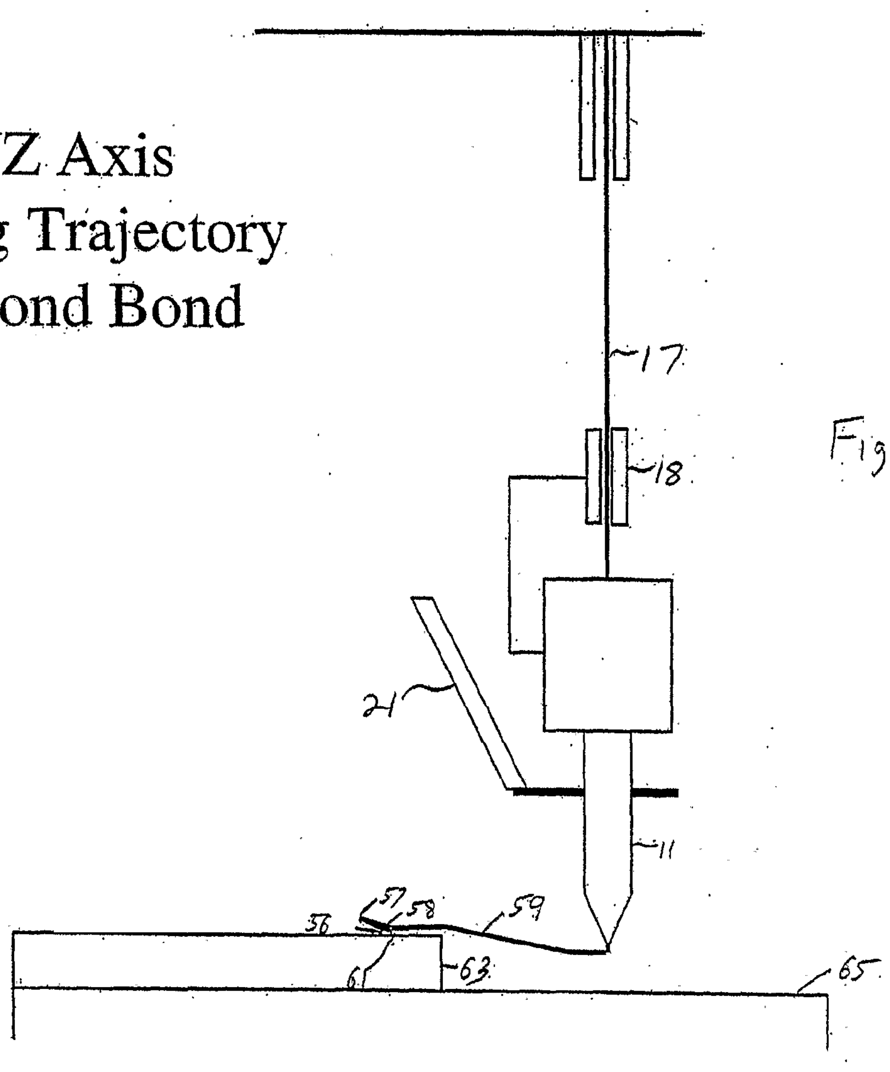


Fig. 5L

2nd Bond

- Z Axis Force
- USG Power
- USG Time

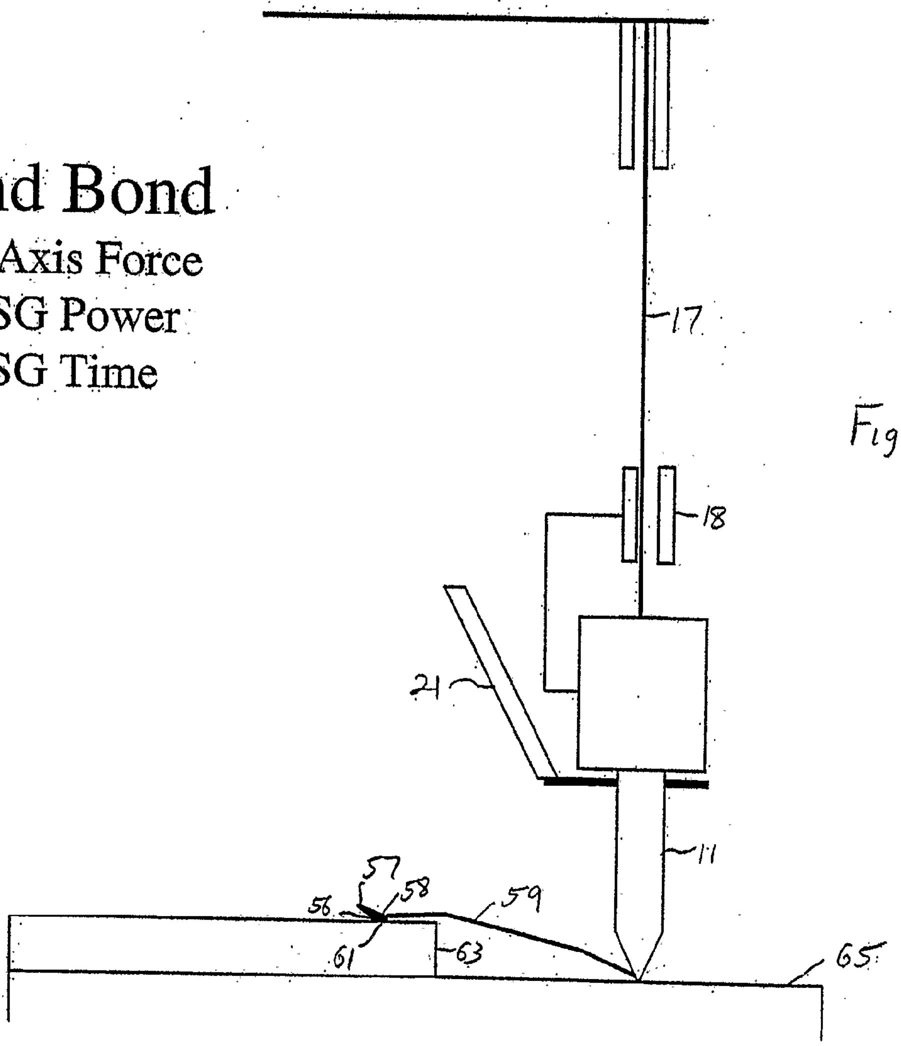


Fig. 5M

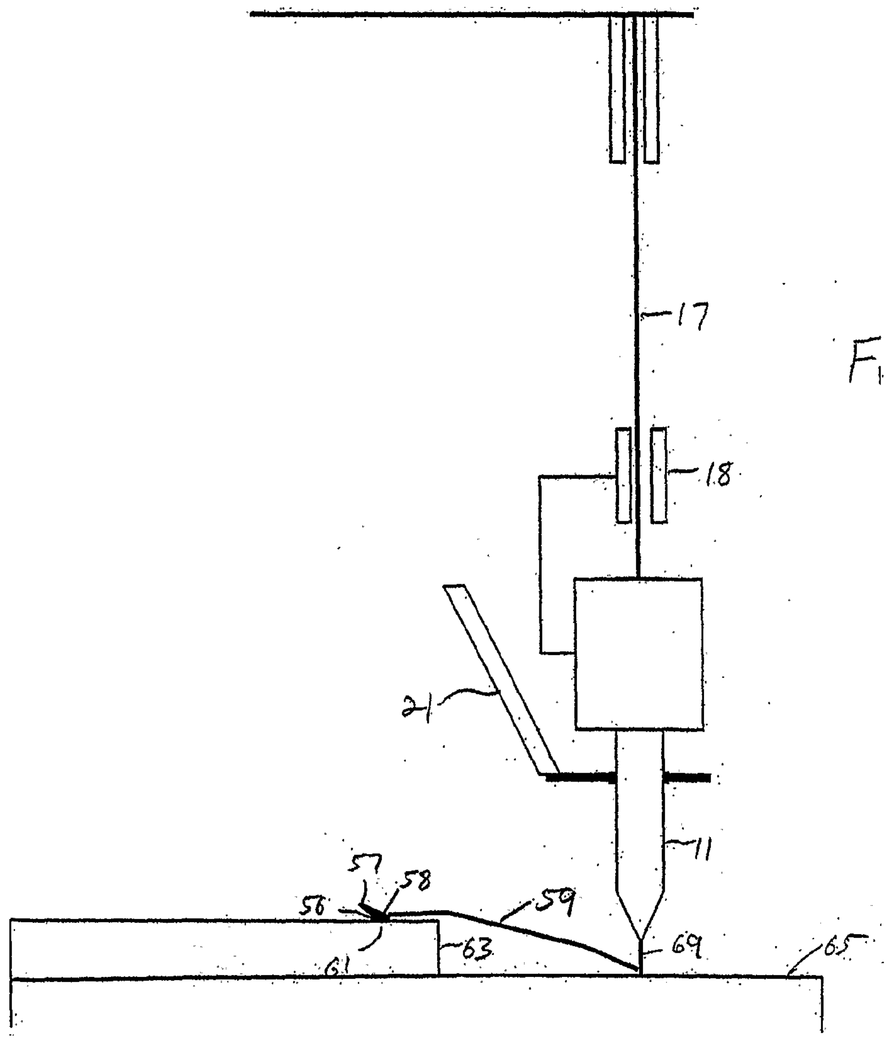


Fig. 5N

XYZ Axis
2nd Bond to Next 1st
(Z rise to reset)

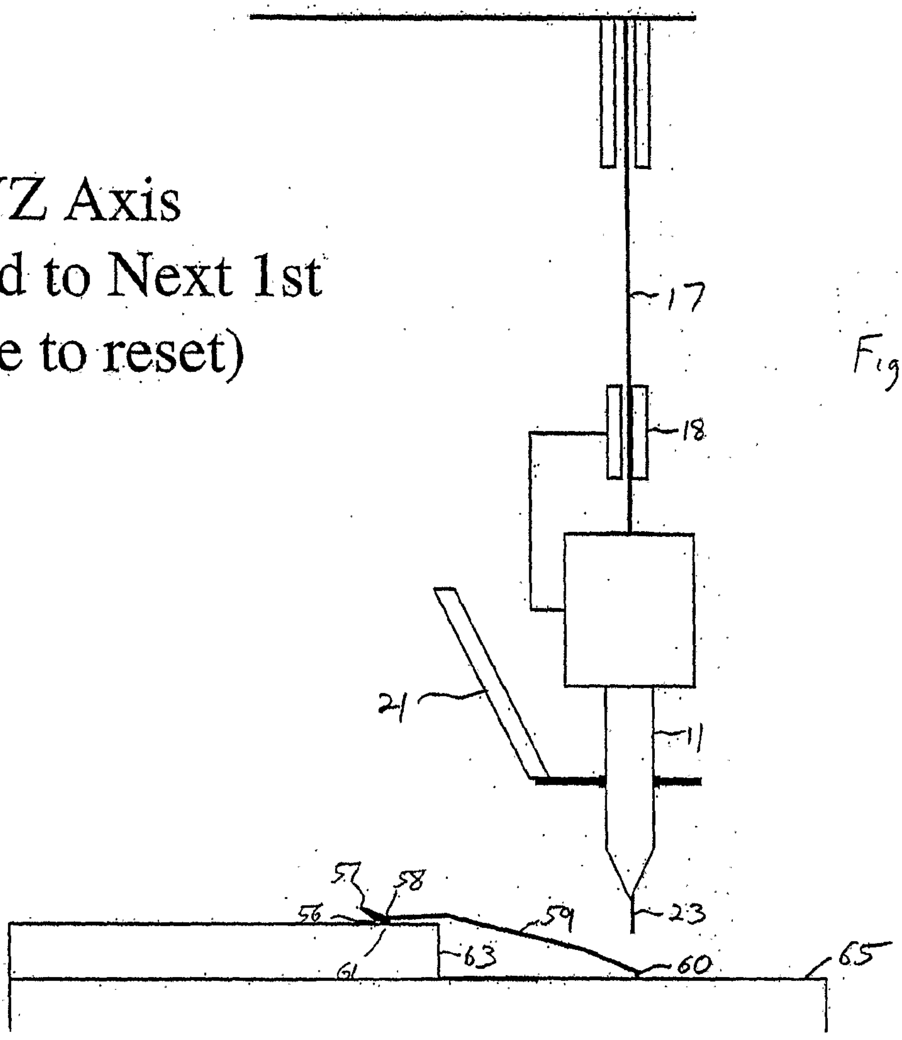
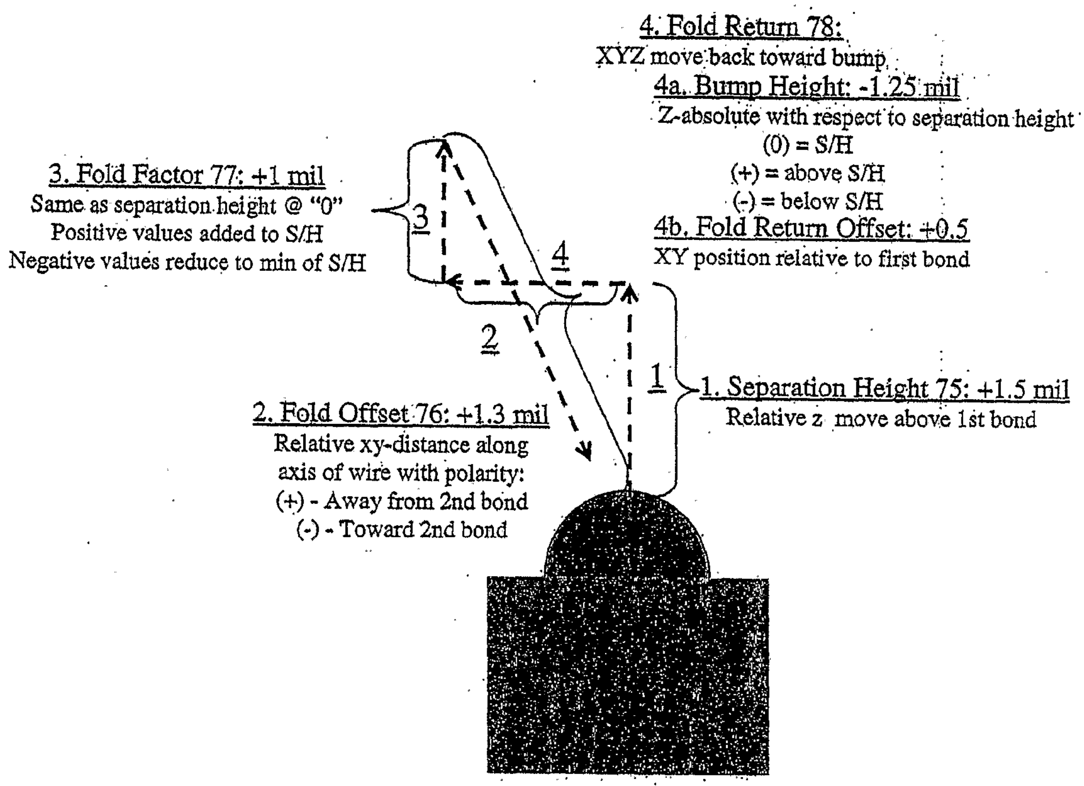
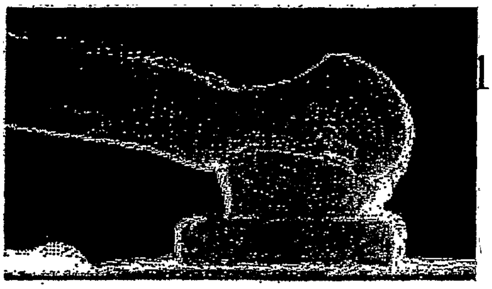


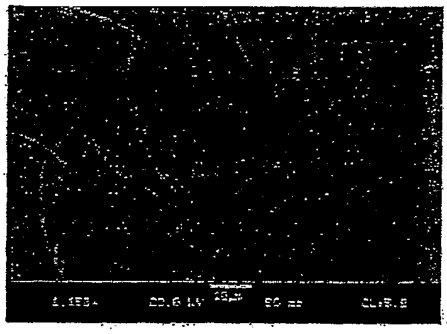
Fig. 50

Figure 6


4. Fold Return 78:
XYZ move back toward bump
4a. Bump Height: -1.25 mil
Z-absolute with respect to separation height
(0) = S/H
(+) = above S/H
(-) = below S/H
4b. Fold Return Offset: +0.5
XY position relative to first bond
3. Fold Factor 77: +1 mil
Same as separation height @ "0"
Positive values added to S/H
Negative values reduce to min of S/H
3
4
2
1
1. Separation Height 75: +1.5 mil
Relative z move above 1st bond
2. Fold Offset 76: +1.3 mil
Relative xy-distance along
axis of wire with polarity:
(+) - Away from 2nd bond
(-) - Toward 2nd bond

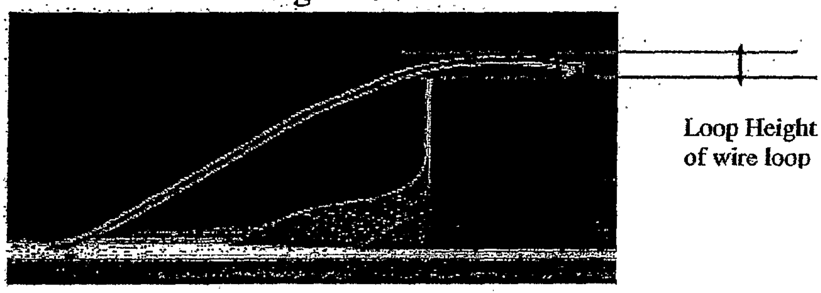


7A



7B

Figure 8A



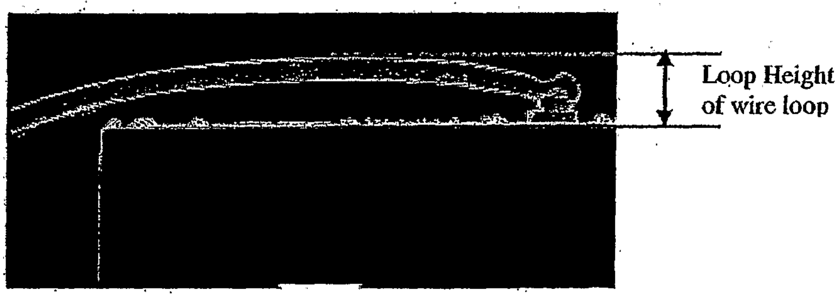


Figure 8B