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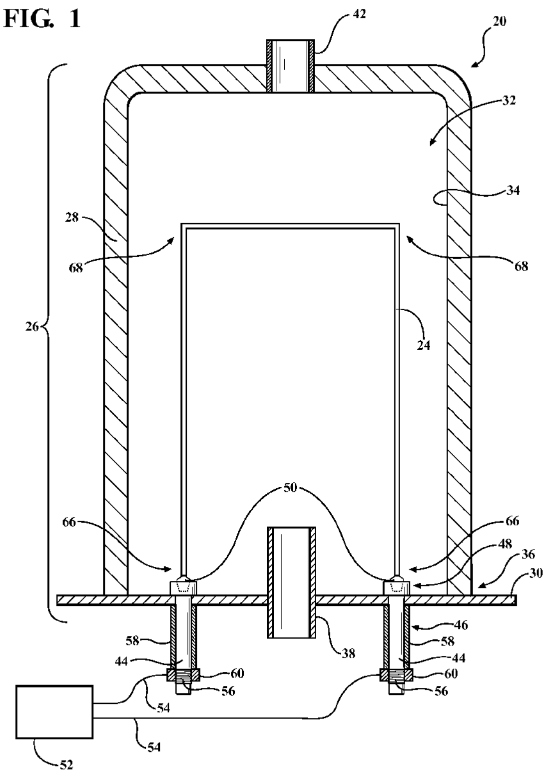
[Continued on next page]

(54) Title: CARRIER BODY FOR COUPLING TO A SOCKET DISPOSED ON AN ELECTRODE WITHIN A REACTOR TO GROW POLYCRYSTALLINE SILICON

FIG. 1



(57) Abstract: A carrier body is used to grow polycrystalline silicon within a reactor. The carrier body is coupled to a socket, which is disposed on an electrode within the reactor. The carrier body includes a body portion comprising silicon and extending along a body axis between a first end and a second end. The body portion terminates at a terminal surface at the first end. The carrier body also includes a transitional element having an interface surface coupled to and in contact with the terminal surface of the body portion. The transitional element extends from the interface surface to a socket end configured to connect with the socket. The terminal element is configured to transfer an electrical current from the electrode through the interface surface of the transitional element and into the terminal surface of the body portion.

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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CARRIER BODY FOR COUPLING TO A SOCKET DISPOSED ON AN ELECTRODE WITHIN A REACTOR TO GROW POLYCRYSTALLINE SILICON

[0001] Disclosed herein is a carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon as well as a method and an apparatus for manufacturing the carrier body.

[0002] Carrier bodies for use in a reactor, such as a Siemens type reactor, for growing polycrystalline silicon are known in the art. In such reactors, the carrier bodies are coupled directly to a socket and the socket is coupled to an electrode within the reactor. An electrical current is passed through the electrode, through the socket, and into the carrier body. Passage of the electrical current through the carrier body results in a heating of the carrier body. A deposition gas containing silicon, or a precursor thereof, is then introduced into the reactor and through a decomposition reaction with the heated carrier body, silicon is deposited or grown onto the carrier body.

[0003] The socket provides a transition between the carrier body and the electrode to promote separation of the carrier body from the electrode after the carrier body has been processed. Said differently, the socket allows the carrier body to be easily separated from the electrode once the polycrystalline silicon is grown on the carrier body.

[0004] Typically, the socket defines a recess for receiving an end of carrier body. As such, a majority of the socket is disposed about the outer periphery of the carrier body. Typically, the end of the carrier body within the recess is spaced from the socket and only the outer periphery of the carrier body is engaged by the socket.

[0005] Additionally, the carrier body typically has an oxide layer disposed on the exterior surface thereof. The oxide layer is a natural result of the carrier body being exposed to oxygen. As the electrical current is applied to the carrier body, the oxide layer diminishes or even begins to breakdown thereby decreasing the resistivity of the oxide layer of the carrier body. However, the diminishing of the oxide layer does not occur uniformly over the contact area of the socket and the carrier body.

[0006] As a result of the uneven diminishing of the oxide layer, passage of the electrical current into the carrier body is localized where the diminishing of the oxide layer first occurs. The localization of the passage of the electrical current is referred to as point firing or spark discharge. Point firing or spark discharge results in damage to the carrier body and premature failure of the carrier body during deposition of the silicon onto the carrier body. Additionally, uneven diminishing of the oxide layer can result in uneven growth of the silicon on the carrier body. As such, there remains a need to provide an improved carrier body that minimizes the occurrence of point firing or spark discharge.

[0007] Disclosed, in various embodiments, are a carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon as well as a method and an apparatus for manufacturing the carrier body.

[0008] A carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon comprises: a body portion extending along a body axis between a first end and a second end, with said body portion terminating at a terminal surface at said first end, and with said body portion comprising silicon; and a transitional element having an interface surface coupled to and in contact with said terminal surface of said body portion, with said transitional element extending from said interface surface to a socket end configured to connect with the socket, and with said terminal element configured to transfer an electrical current from the electrode through said interface surface of said transitional element and into said terminal surface of said body portion.

[0009] A method of forming a carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said method comprises: providing the body portion comprising silicon; providing the transitional element; and coupling the interface surface of the transitional element to the terminal surface of the body portion thereby forming the carrier body.

[0010] A manufacturing apparatus for forming a carrier body to couple to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body comprising silicon and including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said manufacturing apparatus comprises: a processing chamber sealable from an atmosphere surrounding said processing chamber; a first arm disposed within said processing chamber and configured to secure the body portion of the carrier body within said processing chamber; a second arm disposed within said processing chamber and spaced from said first arm with said second arm configured to secure an adaptor of the carrier body within said processing chamber such that the interface surface of the adaptor is aligned with the terminal surface of the body portion; and a heating element movable into and out of alignment with said body axis with said heating element configured to heat the first end of body portion of the carrier body; wherein at least one of said first arm and said second arm is movable along said body axis for bringing said terminal surface of said body portion into contact with said interface surface of said adaptor to couple the adaptor to the body portion thereby forming the carrier body.

[0011] These and other features and characteristics are more particularly described below.

[0012] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0013] Figure 1 is a partial cross-sectional view of a reactor used to grow polycrystalline silicon;

[0014] Figure 2 is another partial cross-sectional view of the reactor with a deposition composition within the reactor;

[0015] Figure 3 is a cross-sectional view of a portion of an electrode used within the reactor with a socket coupled to the electrode and a carrier body coupled to the socket with the carrier body having a body portion and a transitional element;

[0016] Figure 4 is an exploded cross-sectional view of Figure 3;

[0017] Figure 5 is a cross-sectional view of the electrode, the socket, and the carrier body when the transitional element is a coating;

[0018] Figure 6 is a cross-sectional view of the electrode, the socket, and the carrier body when the transitional element is an adaptor;

[0019] Figure 6A is a cross-sectional view of the electrode, the socket, and the carrier body when the transitional element is the adaptor and the coating is disposed on the adaptor;

[0020] Figure 7 is a perspective view of the adaptor;

[0021] Figure 8 is an end view of the adaptor;

[0022] Figure 9 is a cross-sectional view of the body portion coupled to the adaptor via a male-female connection;

[0023] Figure 10 is a partial view of a manufacturing apparatus for forming the carrier body;

[0024] Figure 11 is a partial view of the manufacturing apparatus for forming the carrier body showing a holder and a heating element with the adaptor coupled to the holder;

[0025] Figure 12 is a partial view of the manufacturing apparatus for forming the carrier body showing the body portion in contact with the adaptor;

[0026] Figure 13 is another partial view of the manufacturing apparatus for forming the carrier body showing the body portion in contact with the adaptor;

[0027] Figure 14 is yet another partial view of the manufacturing apparatus for forming the carrier body showing the body portion in contact with the adaptor; and

[0028] Figure 15 is a perspective view of first and second test carrier bodies from a comparative example.

[0029] Referring to the Figures, wherein like numerals indicate like or corresponding parts throughout the several views, a reactor 20 is generally shown in Figure 1. The reactor 20 can be a chemical vapor deposition reactor, such as a Siemens type chemical vapor deposition reactor, for depositing material 22 (see Figure 2) on a carrier body 24 within the reactor 20. In such an example, the reactor 20 is used to produce high purity polycrystalline silicon. Generally, the reactor 20 is used to produce semiconductor grade silicon. By "semiconductor grade silicon," it is meant a material comprising at least 99 percent by weight silicon.

[0030] Polycrystalline silicon serves as a seed material in the production of monocrystalline or multicrystalline silicon, which is used in the production of solar cells for photovoltaic cells. It is desirable to produce monocrystalline or multicrystalline silicon with high purity, e.g., purity exceeding metallurgical grade silicon. Therefore, when the silicon product is polycrystalline silicon for producing the monocrystalline or multicrystalline silicon, it is desirable to produce polycrystalline silicon with high purity to minimize contamination contributed to the monocrystalline or multicrystalline silicon by the polycrystalline silicon.

[0031] Typically, when the polycrystalline silicon is characterized as high purity, an impurity content of the polycrystalline silicon is less than or equal to 1,000 parts per billion atomic (ppba). The term parts per billion atomic as used herein refers to the number of atoms of the impurity per billion atoms of the main component. In this case, the main component is silicon. Impurities, as the term is generally used herein, are defined as elements or compounds the presence of which is undesirable in the polycrystalline silicon. It is to be appreciated that within the class of polycrystalline silicon having high purity, additional distinctions can be made based on sequentially lower impurity contents. While the above threshold for characterizing the polycrystalline silicon as high purity provides an upper limit for the impurity content, the polycrystalline silicon can have a substantially lower impurity content than the threshold set forth above.

[0032] These figures (also referred to herein as "FIG.") are merely schematic representations based on convenience and the ease of demonstrating the present disclosure, and are, therefore, not intended to indicate relative size and dimensions of the devices or components thereof and/or to define or limit the scope of the exemplary embodiments. Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiments selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure. In the drawings and the following description below, it is to be understood that like numeric designations refer to components of like function.

[0033] With reference to Figure 1, the reactor 20 comprises a housing 26. The housing 26 includes a jar 28 and a base plate 30 for coupling to the jar 28 to form the housing 26. The jar 28 of the housing 26 has at least one wall with the wall typically presenting a cylindrical configuration of the housing 26. However, it is to be appreciated that the jar 28 of the housing 26 can have configurations other than cylindrical, such as a cubed configuration. The jar 28 defines a reaction chamber 32. More specifically, the wall of the jar 28 of the housing 26 has an interior surface 34, such that the interior surface 34 of the jar 28 defines the reaction chamber 32. The jar 28 has an end 36 that is open for allowing access to the reaction chamber 32. The base plate 30 is coupled to the end of the jar 28 that is open for covering the end.

[0034] The housing 26 defines an inlet 38 for introducing a deposition composition 40, which comprises the material 22 to be deposited or a precursor thereof, into the reaction chamber 32. Similarly, the housing 26 can define an outlet 42 for allowing the deposition composition 40 (see Figure 2), or a reaction byproduct thereof, to be exhausted from the reaction chamber 32. It is to be appreciated that the inlet 38 and/or the outlet 42 can be defined by either the jar 28 or the base plate 30 of the housing 26.

[0035] The reactor 20 includes at least one electrode 44 disposed through the housing 26. The electrode 44 is at least partially disposed within the reaction chamber 32. For example, the electrode 44 is typically disposed through the base plate 30 with a portion of the electrode 44. However, it is to be appreciated that the electrode 44 can be disposed through the jar 28 of the housing 26. In one embodiment, the electrode 44 has a shaft 46 and a head 48 disposed on the shaft 46. In such an embodiment, the head 48 is disposed within the reaction chamber 32 for supporting the carrier body 24. Generally, the electrode 44 supports the carrier body 24 within the reaction chamber 32.

[0036] A socket 50 is used to connect the carrier body 24 to the electrode 44. The socket 50 provides a transition between the carrier body 24 and the electrode 44 to promote separation of the carrier body 24 from the electrode 44 after the carrier body 24 has been processed. Said differently, the socket 50 allows the carrier body 24 to be easily separated from the electrode 44 once the polycrystalline silicon is grown on the carrier body 24.

[0037] The reactor 20 further includes a power supply device 52 coupled to the electrode 44 for providing an electrical current. Typically, an electric wire or cable 54 couples the power supply device 52 to the electrode 44. It is to be appreciated that the connection of the electric wire 54 to the electrode 44 can be accomplished by different methods.

[0038] Typically, the electrode 44 comprises an electrically conductive material such as copper, silver, nickel, Inconel, gold, and combinations thereof. The electrode 44 is heated within the reaction chamber 32 by passing the electric current through the electrode 44. In particular, the electrical current passes through the electrode 44, through the socket 50 and through the carrier body 24 resulting in the Joule heating of the carrier body 24. As a result of receiving the electric current, the carrier body 24 is heated to a deposition temperature. Typically, the deposition temperature of the carrier body 24 within the reaction chamber 32 is of about 800 to about 1,250, for example about 900 to about 1,150, and for example, about 950 to about 1,100 degrees centigrade (°C).

[0039] As shown in Figure 2, heating the carrier body 24 to the deposition temperature generally facilitates thermal decomposition of the deposition composition 40. As alluded to above, the deposition composition 40 comprises the material 22 to be deposited on the carrier body 24 or a precursor thereof. Therefore, the thermal decomposition of the deposition composition 40 results in the material 22 being deposited on the heated carrier body 24. For example, when the material 22 to be deposited is silicon, the deposition composition 40 can comprise a halosilane, such as a chlorosilane or a bromosilane. However, it is to be appreciated that the deposition composition 40 can comprise other precursors, especially silicon containing molecules such as silane, silicon tetrachloride, tribromosilane, and trichlorosilane. It is also to be appreciated that the reactor 20 can be used to deposit materials other than silicon on the carrier body 24.

[0040] Referring to Figures 1 and 2, threads 56 can be disposed on the electrode 44. A dielectric sleeve 58 is typically disposed around the electrode 44 for insulating the electrode 44. The dielectric sleeve 58 typically comprises a ceramic. A nut 60 is disposed on the threads 56 of the electrode 44 for compressing the dielectric sleeve 58 between the base plate 30 and the nut 60 thereby securing the electrode 44 to the housing 26. It is to be appreciated that the electrode 44 can be secured to the housing 26 by other methods.

[0041] As alluded to above, the carrier body 24 is coupled to the socket 50, which is disposed on the electrode 44 within the reactor 20. The socket 50 typically defines a recess 61 (see Figures 3 and 4) for receiving the carrier body 24. For example, the carrier body 24 can be disposed within the recess 61 of the socket 50.

[0042] As is known with the Siemens Method, the carrier body 24 can have a substantially U-shaped configuration, as shown in Figures 1 and 2. However, it is to be appreciated that the carrier body 24 can have configurations other than the U-shaped configuration.

[0043] With reference to Figures 3 and 4, the carrier body 24 comprises a body portion 62. The body portion 62 of the carrier body 24 is the intended targeted area for growing the material 22 on the carrier body 24. As such, the body portion 62 comprises silicon. The silicon comprising body portion 62 can also be referred to as a silicon slim rod, which are used for producing high purity polycrystalline silicon.

[0044] The carrier body 24 extends along a body axis 64 between a first end 66 and a second end 68 (see Figure 1). The body portion 62 terminates at a terminal surface 70 at the first end 66. As mentioned above, as the carrier body 24 is heated, silicon is deposited or grows on the carrier body 24 resulting in the formation of polycrystalline silicon. Typically, the silicon is deposited on the body portion 62 of the carrier body 24.

[0045] The carrier body 24 also comprises a transitional element 72 for disposing between the body portion 62 and the socket 50. The transitional element 72 has an interface surface 74 coupled to and in contact with the terminal surface 70 of the body portion 62. The transitional element 72 extends from the interface surface 74 to a socket end 76 configured to connect with the socket 50. Typically, the socket end 76 is disposed within the recess 61 of the socket 50. The transitional element 72 is configured to transfer the electrical current from the electrode 44 through the interface surface 74 of the transitional element 72 and into the terminal surface 70 of the body portion 62. It is believed that transferring the electrical current through the terminal surface 70 of the body portion 62 provides for a more efficient transfer of the electrical current relative to transferring the electrical current through an outer periphery 78 of the body portion 62. The improved efficiency in transferring the electrical current minimizes, or even eliminates, the occurrence of point firing and spark discharges. Additionally, the terminal surface 70 of the body portion 62 can be free of an oxide layer, which also helps to ensure an even distribution of the electric current into the terminal surface 70 of the body portion 62 of the carrier body 24. The oxide layer can be removed by any suitable method. For example, the oxide layer can be removed by chemical etching.

[0046] The connection between the transitional element 72 and the body portion 62 increases a contact area between the transitional element 72 and the body portion 62 relative to body portions that are coupled directly to the socket 50. More specifically, the terminal surface 70 defines a cross-sectional area of the body portion 62 at the first end 66 of the body portion 62 and the interface surface 74 defines a cross-sectional area of the transitional element 72. The cross-sectional area of the interface surface 74 can be equal to or greater than the cross-section area of the terminal surface 70.

[0047] With reference to Figure 5, in one embodiment, the transitional element 72 is further defined as a coating 80 disposed on the terminal surface 70 of the body portion 62 of the carrier body 24. It is to be appreciated that common features between the transitional element 72 and the coating 80 are referred to with common terms and reference numerals. For example, when the transitional element 72 is the coating 80, the coating 80 has the interface surface 74 for contacting the terminal surface 70 of the body portion 62 and the socket end 76 for coupling to the socket 50.

[0048] The coating 80 can be disposed on only the terminal surface 70 of the body portion 62. Alternatively, in addition to be disposed on the terminal surface 70, the coating 80 can also be on the outer periphery 78 of the body portion 62 to ensure that the coating 80 is disposed between the point of contact between the socket 50 and the body portion 62. Typically, the coating 80 comprises an electrically conducive material. For example, the coating 80 can comprise a material selected from the group of titanium, tungsten, tantalum, niobium, molybdenum, and combinations thereof.

[0049] With reference to Figures 6-8, in another embodiment, the transitional element 72 is further defined as an adaptor 82 (see e.g., Figure 7). It is to be appreciated that common features between the transitional element 72 and the adaptor 82 are referred to with common terms and reference numerals. For example, when the transitional element 72 is the adaptor 82, the adaptor 82 has the interface surface 74 for contacting the terminal surface 70 of the body portion 62 and the socket end 76 for coupling to the socket 50.

[0050] Generally, the adaptor 82 is coupled to the body portion 62 of the carrier body 24. More specifically, the adaptor 82 is bonded to the terminal surface 70 of the body portion 62. When coupled to the body portion 62, the adaptor 82 extends along an adaptor axis 84 between the socket end 76 and the interface surface 74. As with the transitional element 72, the socket end 76 of the adaptor 82 is typically disposed with the recess 61 of the socket 50. The adaptor axis 84 is typically aligned with the body axis 64 of the body portion 62 of the carrier body 24. Said differently, the adaptor 82 is typically aligned with the body portion 62.

[0051] The adaptor 82 comprises a material to promote the transfer of the electrical current from the electrode 44 to the body portion 62 of the carrier body 24 through the adaptor 82. As such, the adaptor 82 can comprise a carbon based material. However, the adaptor 82 typically comprises a material selected from the group of graphite, silicon carbide, silicon, and combinations thereof.

[0052] With reference to Figure 6A, when the adaptor 82 is present, the adaptor 82 can include the coating 80. Said differently, the adaptor 82 can include the coating 80, which is described above. In such an embodiment, the coating 80 is applied on at least the socket end 76 of the adaptor. Additionally, the coating 80 can be applied to an outer surface 81 of the adaptor 82. Adding the coating 80 to the adaptor 82 allows for the same benefits as applying the coating 80 directly to the body portion 62 of the carrier body 24 described above. However, because the body portion 62 of the carrier body 24 can be quite long, directly applying the coating 80 to the body portion 62 can be difficult to accomplish. As such, the coating 80 can be applied to the adaptor 82, which has a shorter length as compared to the body portion 62, and the adaptor 82 can be coupled to the body portion 62 for forming the carrier body 24. In such an embodiment, the adaptor 82 can comprise silicon and the body portion 62 also comprises silicon. Coupling the adaptor 82 to the body portion 62 can result in direct silicon to silicon bonding, which can reduce the resistance at the terminal surface 70 of the body portion 62. Therefore, applying the coating 80 to the adaptor 82 reduces contact resistance between the socket 50 and the carrier body 24 and coupling the adaptor 82 to the body portion 62 reduces resistance between the adaptor 82 and the body portion 62.

[0053] The coating 80 can be applied to the body portion 62 or the adaptor 82 in any suitable manner. For example, the coating 80 can be applied using Physical Vapor Deposition. Typically, the coating 80 has a uniform thickness of about 1 to about 10 microns.

[0054] The bonding of the adaptor 82 to the body portion 62 can be accomplished in a variety of ways. For example, the adaptor 82 can be welded to the body portion 62. Alternatively, the adaptor 82 could be bonded to the body portion 62 using an adhesive. Additionally, the adaptor 82 can be bonded to the body portion 62 by a melt bond. For example, the first end 66 of the body portion 62 can be heated to a melting point and the adaptor 82 pressed against the first end 66 of the body portion 62 while at the melting point. The body portion 62 is then allowed to cool and solidify to bond the adaptor 82 to the body portion 62. As such, the adaptor 82 can be embedded within the body portion 62 for bonding the adaptor 82 to the body portion 62 thereby forming the carrier body 24.

[0055] With reference to Figure 9, the adaptor 82 and the body portion 62 can be bonded together through a male-female connection 88. For example, the interface surface 74 of the adaptor 82 can define a bore 90 and the body portion 62 can define a pin element 92 extending from the terminal surface 70. In such an embodiment, the pin element 92 is disposed within the bore 90 to embed the adaptor 82 within the body portion 62. As such, a diameter of the pin element 92 is typically less than a diameter of the body portion 62. Said differently, a cross-sectional area of the body portion 62 is reduced at the pin element 92 relative to the body portion 62.

[0056] Although not required, the adaptor 82 typically has a length to allow the terminal surface 70 of the adaptor 82 to extend beyond the socket 50. As such, the length of the adaptor 82 can be of about 0.5 to about 2.5 inches. However, it is to be appreciated that the adaptor 82 can be of any suitable length. The body portion 62 has a length that is greater than said length of said adaptor 82.

[0057] The carrier body 24 described above is formed by an inventive method which is described below. The method comprises providing the body portion 62 and providing the transitional element 72. The interface surface 74 of the transitional element 72 is coupled to the terminal surface 70 of the body portion 62 thereby forming the carrier body 24.

[0058] When the transitional element 72 is the coating 80, as described above, the method includes etching the terminal surface 70 of the body portion 62 to remove an oxide layer and applying the coating 80 to the terminal surface 70 of the body portion 62. The oxide layer natural forms on the silicon of the body portion 62. Because the presence of the oxide layer on the terminal surface 70 would interfere with the subsequent transfer of the electrical current, it is beneficial to remove the oxide layer before applying the coating 80. However, it is to be appreciated that the oxide layer can be present when the coating 80 is applied to the terminal surface 70 of the body portion 62 such that the coating 80 is actually applied to the oxide layer. It is also to be appreciated that the oxide layer can be removed by any suitable method besides etching. For example, the oxide layer could be removed using plasma or ion cleaning methods.

[0059] To prevent the subsequent formation of the oxide layer after etching in complete, the body portion 62 can be placed within an inert environment when completing etching the terminal surface 70 and applying the coating 80. The inert environment would limit the presence of oxygen in the environment surrounding the body portion 62 to minimize the exposure of the body portion 62 to oxygen. As such, the body portion 62 can be placed within a vessel sealed off from the surrounding atmosphere and filled with an inert gas. An inert gas would be any gas that does not negatively react with the silicon of the body portion 62, such as any of the noble gasses. For example, the inert gas could be nitrogen, argon, and combinations thereof.

[0060] When the transitional element 72 is further defined as the adaptor 82, the method includes placing the body portion 62 and the adaptor 82 within a processing chamber 94 (see Figure 10) and filling the processing chamber 94 with the inert gas. The processing chamber 94 is similar to the vessel in that it is sealed off from the surrounding atmosphere. The adaptor 82 is aligned with the body portion 62 within the processing chamber 94. More specifically, the adaptor axis 84 is aligned with the body axis 64 within the processing chamber 94. The interface surface 74 of the adaptor 82 is brought into contact with the terminal surface 70 of the body portion 62 and the adaptor 82 is bonded to the body portion 62 to form the carrier body 24.

[0061] The bonding of the adaptor 82 to the body portion 62 can be further defined as embedding the interface surface 74 of the adaptor 82 within the first end 66 of the body portion 62.

[0062] When the bore 90 and pin element 92 are employed, the method can include forming a bore 90 within the adaptor 82; forming a pin element 92 extending from the terminal surface 70 of the body portion 62; and inserting the pin element 92 within the bore 90 to bond embed the adaptor 82 within the body portion 62.

[0063] The method can comprise heating the terminal surface 70 of the body portion 62 to a melting point of silicon prior to contacting the interface surface 74 of the adaptor 82 with the terminal surface 70 of the body portion 62. Heating the terminal surface 70 of the body portion 62 to the melting point of silicon allows the adaptor 82 to be embedded within the body portion 62. It is also believed that heating the terminal surface 70 of the body portion 62 eliminates the oxide layer at the terminal surface 70 thereby allowing for more uniform transfers of the electrical current. Once the adaptor 82 is embedded, the body portion 62 is allowed to cool such that the silicon of the body portion 62 returns to a solid state with a portion of the adaptor 82 embedded therein.

[0064] Heating of the first end 66 of the body portion 62 can comprise heating the first end 66 of the body portion 62 to a first temperature that is lower than the melting point of silicon and inductively heating the first end 66 of the body portion 62 to the melting point of silicon. It is to be appreciated that the first end 66 of the body portion 62 can be heated to the melting point of silicon by any suitable method. For example, a radio frequency system 108 (see Figure 10) can be activated to generate radio waves and the inductive heating of the first end 66 of the body portion 62 is accomplished by use of the radio waves. As best shown in Figure 13, the radio frequency system 108 can be a coil.

[0065] With reference to Figures 10-14, the process of forming the carrier body 24 with the adaptor 82 can be accomplished by using a manufacturing apparatus 98. The manufacturing apparatus 98 comprises the processing chamber 94 sealable from the atmosphere surrounding the processing chamber 94. Notably, in Figure 10 the processing chamber 94 is only partially shown to allow the components of the manufacturing apparatus 98 within the processing chamber 94 to be seen. The processing chamber 94 is fillable with the inert gas for providing an oxygen free environment within the processing chamber 94 to prevent oxidation, and formation of the oxide layer, on the body portion 62.

[0066] The manufacturing apparatus 98 includes a first arm 100 disposed within the processing chamber 94 and configured to secure the body portion 62 of the carrier body 24 within the processing chamber 94. The manufacturing apparatus 98 also includes a second arm 102 disposed within the processing chamber 94 and spaced from the first arm 100. The second arm 102 is configured to secure the adaptor 82 of the carrier body 24 within the processing chamber 94 such that the interface surface 74 of the adaptor 82 is aligned with the terminal surface 70 of the body portion 62.

[0067] At least one of the first arm 100 and the second arm 102 can be movable relative to each other within the processing chamber 94 for aligning the adaptor 82 with the body portion 62. Additionally, at least one of the first arm 100 and the second arm 102 is movable along the body axis 64 for bringing the terminal surface 70 of the body portion 62 into contact with the interface surface 74 of the adaptor 82 to couple the adaptor 82 to the body portion 62 thereby forming the carrier body 24. As such, the manufacturing apparatus 98 can include at least one actuator 104 aligned with the at least one of the first and second arms 100, 102 for moving either the body portion 62 along the body axis 64 or the adaptor 82 along the adaptor axis 84. Alternatively, the body portion 62 and the adaptor 82 can just be clamped into place.

[0068] As shown in Figure 11, the manufacturing apparatus 98 can include a holder 106 coupled to at least one of the first and second arms 100, 102 for holding either the body portion 62 or the socket 50 within the processing chamber 94. The holder 106 allows for adaptor 82 and body portion 62s of different lengths to be accommodated within the processing chamber 94 without having to modify the first and second arms 100, 102.

[0069] The manufacturing apparatus 98 also includes a heating element 96 (see Figure 10) movable into and out of alignment with the body axis 64 of the body portion 62. The heating element 96 is configured to heat the first end 66 of body portion 62 of the carrier body 24. In addition to the heating element 96, the manufacturing apparatus 98 can include the radio frequency system 108 for generating the radio waves to inductively heat the first end 66 of the body portion 62.

[0070] The following example is merely illustrative of the device and method disclosed herein and is not intended to limit the scope hereof.

[0071] A comparative example was conducting using two different carrier bodies 24A, 24B. More specifically, a first test carrier body 24A was made by bonding a socket 50A to the terminal surface 70A of the body portion 62A of a carrier body 24A. The first test carrier body 24A was coupled to a first socket 50A by inserting the socket end 76A into a recess of the first socket 50A. Adaptor 82A was also present. A second test carrier body 24B was made using only the body portion 62B of another carrier body 24B such that the adaptor 82 was not used. The second test carrier body 24B was coupled to a second socket 50B by directly inserting the body portion 62 into a recess 61B of the second socket 50B.

[0072] Both the first and second test carrier bodies 24A, 24B were inserted into a reactor 20 and the test carrier bodies 24A, 24B were energized using the electrical current. Once the test carrier bodies 24A, 24B reached the deposition temperature, the reactor 20 was run for two hours and the growth of the test carrier bodies 24A, 24B was observed. With reference to Figure 15, the test carrier bodies 24A, 24B are shown after being removed from the reactor 20. As is readily appreciable, the first test carrier body 24A (top carrier body in Figure 15) did not experience much growth of the silicon on the adaptor 82A such that the growth did not reach the first socket 50A. Alternatively, the growth on the second test carrier body 24B (bottom carrier body in Figure 15) extending all the way down to the second socket 50B. Additionally, the growth of the silicon on the first test carrier body 24A was more even as compared to the growth on the second test carrier body 24B. It is believed that the even growth on the first test carrier body 24A was due to the adaptor 82A providing a uniform distribution of the electrical current into the body portion 62A of the first test carrier body 24A.

[0073] The results of the comparative example shown in Figure 15 make it clear that use of the adaptor 82A coupled to the body portion 62A of the carrier body 24A results in even growth on the carrier body 24A with the adaptor 82A. Additionally, the uneven growth on carrier body 24B suggest the electrical current is passing into the carrier body 24B a specific location resulting in uneven heating of the carrier body 24B and suggest point firing or spark discharge during the heating of the carrier body 24B.

[0074] The carrier body, method, and apparatus as disclosed herein include at least the following embodiments:

[0075] Embodiment 1: A carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, said carrier body comprising: a body portion extending along a body axis between a first end and a second end, with said body portion terminating at a terminal surface at said first end, and with said body portion comprising silicon; and a transitional element having an interface surface coupled to and in contact with said terminal surface of said body portion, with said transitional element extending from said interface surface to a socket end configured to connect with the socket, and with said terminal element configured to transfer an electrical current from the electrode through said interface surface of said transitional element and into said terminal surface of said body portion.

[0076] Embodiment 2: A carrier body as set forth in Embodiment 1, wherein said terminal surface of said body portion is free of an oxide layer.

[0077] Embodiment 3: A carrier body as set forth in Embodiment 1 or Embodiment 2, wherein said terminal surface defines a cross-sectional area of said body portion at said first end and said interface surface defines a cross-sectional area of said transitional element with said cross-sectional area of said interface surface equal to or greater than said cross-section area of said terminal surface.

[0078] Embodiment 4: A carrier body as set forth in any of Embodiments 1 to 4, wherein said terminal element is further defined as an adaptor bonded to said terminal surface of said body portion with said adaptor extending along an adaptor axis between said socket end and said interface surface, and with said adaptor axis aligned with said body axis.

[0079] Embodiment 5: A carrier body as set forth in Embodiment 4, wherein said adaptor includes a coating disposed on at least said socket end of said adaptor.

[0080] Embodiment 6: A carrier body as set forth in Embodiment 5, wherein said coating comprises a material selected from the group of titanium, tungsten, tantalum, niobium, molybdenum, and combinations thereof.

[0081] Embodiment 7: A carrier body as set forth in Embodiment 4, wherein said adaptor includes a coating disposed on at least said socket end of said adaptor, wherein said coating comprises a material selected from the group of titanium, tungsten, tantalum, niobium, molybdenum, and combinations thereof.

[0082] Embodiment 9: A carrier body as set forth in any of Embodiments 4 to 8, wherein said adaptor comprises a material selected from the group of graphite, silicon carbide, silicon, and combinations thereof.

[0083] Embodiment 10: A carrier body as set forth in any of Embodiments 4 to 8, wherein said adaptor is embedded within said body portion for bonding said adaptor to said body portion thereby forming said carrier body.

[0084] Embodiment 11: A carrier body as set forth in any of Embodiments 4 to 8, wherein said interface surface of said adaptor defines a bore and said body portion has a pin element extending from said terminal surface with said pin element disposed within said bore to embed said adaptor within said body portion.

[0085] Embodiment 12: A carrier body as set forth in Embodiment 11, wherein a diameter of said pin element is less than a diameter of said body portion such that a cross-sectional area of said body portion is reduced at said pin element.

[0086] Embodiment 13: A carrier body as set forth in any of Claims 4 to 10, wherein said interface surface of said adaptor defines a bore and said body portion has a pin element extending from said terminal surface with said pin element disposed within said bore to embed said adaptor within said body portion and wherein a diameter of said pin element is less than a diameter of said body portion such that a cross-sectional area of said body portion is reduced at said pin element.

[0087] Embodiment 14: A carrier body as set forth in any of Embodiments 1 to 13, wherein said transitional element has a length configured to allow said terminal surface of said transitional element to extend beyond the socket.

[0088] Embodiment 15: A method of forming a carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said method comprising: providing the body portion comprising silicon; providing the transitional element; and coupling the interface surface of the transitional element to the terminal surface of the body portion thereby forming the carrier body.

[0089] Embodiment 16: A method as set forth in Embodiment 15, wherein the transitional element is further defined as an adaptor extending along an adaptor axis between the socket end and the interface surface and said method includes: placing the body portion and the adaptor within a processing chamber; optionally filling the processing chamber with an inert gas; aligning the adaptor axis with the body axis within the processing chamber; contacting the interface surface of the adaptor with the terminal surface of the body portion; and bonding the adaptor to the body portion to form the carrier body.

[0090] Embodiment 17: A method as set forth in Embodiment 15 or Embodiment 16, further comprising applying a coating to the socket end of the adaptor.

[0091] Embodiment 18: A method as set forth in Embodiment 17, wherein the coating comprises a material selected from the group of titanium, tungsten, tantalum, niobium, molybdenum, and combinations thereof.

[0092] Embodiment 19: A method as set forth in any of Embodiments 15 to 18, wherein the adaptor comprises a material selected from the group of graphite, silicon carbide, silicon, and combinations thereof.

[0093] Embodiment 20: A method as set forth in any of Embodiments 15 to 19, wherein bonding the adaptor to the body portion is further defined as embedding the interface surface of the adaptor within the first end of the body portion.

[0094] Embodiment 21: A method as set forth in any of Embodiments 15, 16, 18, and 19, further comprising applying a coating to the socket end of the adaptor and wherein bonding the adaptor to the body portion is further defined as embedding the interface surface of the adaptor within the first end of the body portion.

[0095] Embodiment 22: A method as set forth in any of Embodiments 15 to 21, further comprising: forming a bore within the adaptor; forming a pin element extending from the terminal surface of the body portion; and inserting the pin element within the bore to bond embed the adaptor within the body portion.

[0096] Embodiment 23: A method as set forth in any of Embodiments 15 to 22, further comprising heating the terminal surface of the body portion to a melting point of silicon prior to contacting the interface surface of the adaptor with the terminal surface of the body portion.

[0097] Embodiment 24: A method as set forth in Embodiment 23, wherein heating the first end of the body portion comprises: heating the first end of the body portion to a first temperature that is lower than the melting point of silicon; activating a radio frequency system to generate radio waves; and inductively heating the first end of the body portion to the melting point of silicon using the radio waves.

[0098] Embodiment 25: A method as set forth in Embodiment 23 or Embodiment 24, further comprising cooling the heated terminal surface of the body portion after contacting the interface surface of the adaptor with the terminal surface of the body portion.

[0099] Embodiment 26: A method as set forth in any of Embodiments 15 to 22, further comprising heating the terminal surface of the body portion to a melting point of silicon prior to contacting the interface surface of the adaptor with the terminal surface of the body portion, wherein heating the first end of the body portion comprises: heating the first end of the body portion to a first temperature that is lower than the melting point of silicon; activating a radio frequency system to generate radio waves; and inductively heating the first end of the body portion to the melting point of silicon using the radio waves, wherein the method further comprises cooling the heated terminal surface of the body portion after contacting the interface surface of the adaptor with the terminal surface of the body portion.

[0100] Embodiment 27: A manufacturing apparatus for forming a carrier body to couple to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body comprising silicon and including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said manufacturing apparatus comprising: a processing chamber sealable from an atmosphere surrounding said processing chamber; a first arm disposed within said processing chamber and configured to secure the body portion of the carrier body within said processing chamber; a second arm disposed within said processing chamber and spaced from said first arm with said second arm configured to secure an adaptor of the carrier body within said processing chamber such that the interface surface of the adaptor is aligned with the terminal surface of the body portion; and a heating element movable into and out of alignment with said body axis with said heating element configured to heat the first end of body portion of the carrier body; wherein at least one of said first arm and said second arm is movable along said body axis for bringing said terminal surface of said body portion into contact with said interface surface of said adaptor to couple the adaptor to the body portion thereby forming the carrier body.

[0101] Embodiment 28: A manufacturing apparatus as set forth in Embodiment 27, wherein said processing chamber is fillable with an inert gas for providing an oxygen free environment within said processing chamber to prevent oxidation of the body portion.

[0102] Embodiment 29: A manufacturing apparatus as set forth in Embodiment 27 or Embodiment 28, further comprising a radio frequency system configured to generate radio waves to inductively heat the first end of the body portion to a melting point of silicon.

[0103] Embodiment 30: A manufacturing apparatus as set forth in any of Embodiments 27 to 29, wherein said first arm and said second arm are movable within said processing chamber for aligning said adaptor with said body portion.

[0104] Embodiment 31: A manufacturing apparatus as set forth in any of Embodiments 27 to 30, wherein said adaptor comprises a material selected from the group of graphite, silicon carbide, silicon, and combinations thereof.

[0105] Embodiment 32: A manufacturing apparatus as set forth in Embodiment 27 or Embodiment 31, wherein said processing chamber is fillable with an inert gas for providing an oxygen free environment within said processing chamber to prevent oxidation of the body portion and wherein said first arm and said second arm are movable within said processing chamber for aligning said adaptor with said body portion, wherein said manufacturing apparatus further comprises a radio frequency system configured to generate radio waves to inductively heat the first end of the body portion to a melting point of silicon.

[0106] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

[0107] In general, the invention may alternately comprise, consist of, or consist essentially of, any appropriate components herein disclosed. The invention may additionally, or alternatively, be formulated so as to be devoid, or substantially free, of any components, materials, ingredients, adjuvants or species used in the prior art compositions or that are otherwise not necessary to the achievement of the function and/or objectives of the present invention. The endpoints of all ranges directed to the same component or property are inclusive and independently combinable (e.g., ranges of “less than or equal to 25 wt%, or 5 wt% to 20 wt%,” is inclusive of the endpoints and all intermediate values of the ranges of “5 wt% to 25 wt%,” etc.). Disclosure of a narrower range or more specific group in addition to a broader range is not a disclaimer of the broader range or larger group. “Combination” is inclusive of blends, mixtures, alloys, reaction products, and the like. Furthermore, the terms “first,” “second,” and the like, herein do not denote any order, quantity, or importance, but rather are used to denote one element from another. The terms “a” and “an” and “the” herein do not denote a limitation of quantity, and are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. “Or” means “and/or.” The suffix “(s)” as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including one or more of that term (e.g., the film(s) includes one or more films). Reference throughout the specification to “one embodiment”, “another embodiment”, “an embodiment”, and so forth, means that a particular element (e.g., feature, structure, and/or characteristic) described in connection with the embodiment is included in at least one embodiment described herein, and may or may not be present in other embodiments. In addition, it is to be understood that the described elements may be combined in any suitable manner in the various embodiments.

[0108] The modifier “about” used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., includes the degree of error associated with measurement of the particular quantity). The notation “+ 10%” means that the indicated measurement can be from an amount that is minus 10% to an amount that is plus 10% of the stated value. The terms “front”, “back”, “bottom”, and/or “top” are used herein, unless otherwise noted, merely for convenience of description, and are not limited to any one position or spatial orientation. “Optional” or “optionally” means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event occurs and instances where it does not. Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this invention belongs. A “combination” is inclusive of blends, mixtures, alloys, reaction products, and the like.

[0109] All cited patents, patent applications, and other references are incorporated herein by reference in their entirety. However, if a term in the present application contradicts or conflicts with a term in the incorporated reference, the term from the present application takes precedence over the conflicting term from the incorporated reference

[0110] While particular embodiments have been described, alternatives, modifications, variations, improvements, and substantial equivalents that are or may be presently unforeseen may arise to applicants or others skilled in the art. Accordingly, the appended claims as filed and as they may be amended are intended to embrace all such alternatives, modifications variations, improvements, and substantial equivalents.

[0111] I/we claim:

CLAIMS

What is claimed is:

1. A carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, comprising:

a body portion extending along a body axis between a first end and a second end, with said body portion terminating at a terminal surface at said first end, and with said body portion comprising silicon; and

a transitional element having an interface surface coupled to and in contact with said terminal surface of said body portion, with said transitional element extending from said interface surface to a socket end configured to connect with the socket, and with said terminal element configured to transfer an electrical current from the electrode through said interface surface of said transitional element and into said terminal surface of said body portion.

2. A carrier body as set forth in Claim 1, wherein said terminal surface of said body portion is free of an oxide layer.

3. A carrier body as set forth in Claim 1 or Claim 2, wherein said terminal surface defines a cross-sectional area of said body portion at said first end and said interface surface defines a cross-sectional area of said transitional element with said cross-sectional area of said interface surface equal to or greater than said cross-section area of said terminal surface.

4. A carrier body as set forth in any of Claims 1 to 3, wherein said terminal element is further defined as an adaptor bonded to said terminal surface of said body portion with said adaptor extending along an adaptor axis between said socket end and said interface surface, and with said adaptor axis aligned with said body axis.

5. A carrier body as set forth in Claim 4, wherein said adaptor includes a coating disposed on at least said socket end of said adaptor, wherein said coating comprises a material selected from the group of titanium, tungsten, tantalum, niobium, molybdenum, and combinations thereof.

6. A carrier body as set forth in Claim 4 or Claim 5, wherein said adaptor comprises a material selected from the group of graphite, silicon carbide, silicon, and combinations thereof.

7. A carrier body as set forth in any of Claims 4 to 6, wherein said adaptor is embedded within said body portion for bonding said adaptor to said body portion thereby forming said carrier body.

8. A carrier body as set forth in any of Claims 4 to 8, wherein said interface surface of said adaptor defines a bore and said body portion has a pin element extending from said

terminal surface with said pin element disposed within said bore to embed said adaptor within said body portion and wherein a diameter of said pin element is less than a diameter of said body portion such that a cross-sectional area of said body portion is reduced at said pin element.

9. A carrier body as set forth in any of Claims 1 to 9, wherein said transitional element has a length configured to allow said terminal surface of said transitional element to extend beyond the socket.

10. A method of forming a carrier body for coupling to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said method comprising:

providing the body portion comprising silicon;

providing the transitional element; and

coupling the interface surface of the transitional element to the terminal surface of the body portion thereby forming the carrier body.

11. A method as set forth in Claim 10 wherein the transitional element is further defined as an adaptor extending along an adaptor axis between the socket end and the interface surface and wherein said method includes:

placing the body portion and the adaptor within a processing chamber;

optionally filling the processing chamber with an inert gas;

aligning the adaptor axis with the body axis within the processing chamber;

contacting the interface surface of the adaptor with the terminal surface of the body portion; and

bonding the adaptor to the body portion to form the carrier body.

12. A method as set forth in Claim 10 or Claim 11, further comprising applying a coating to the socket end of the adaptor and wherein bonding the adaptor to the body portion is further defined as embedding the interface surface of the adaptor within the first end of the body portion.

13. A method as set forth in any of Claims 10 to 12, further comprising heating the terminal surface of the body portion to a melting point of silicon prior to contacting the

interface surface of the adaptor with the terminal surface of the body portion, wherein heating the first end of the body portion comprises:

heating the first end of the body portion to a first temperature that is lower than the melting point of silicon;

activating a radio frequency system to generate radio waves; and

inductively heating the first end of the body portion to the melting point of silicon using the radio waves,

wherein the method further comprises cooling the heated terminal surface of the body portion after contacting the interface surface of the adaptor with the terminal surface of the body portion.

14. A manufacturing apparatus for forming a carrier body to couple to a socket disposed on an electrode within a reactor to grow polycrystalline silicon, with the carrier body comprising silicon and including a body portion extending along a body axis between a first end and a second end, with the body portion terminating at a terminal surface at the first end, and the carrier body including a transitional element having an interface surface and extending from the interface surface to a socket end configured to connect with the socket, with the transitional element configured to transfer an electrical current from the socket through the interface surface of the transitional element and into the terminal surface of the body portion, said manufacturing apparatus comprising:

a processing chamber sealable from an atmosphere surrounding said processing chamber;

a first arm disposed within said processing chamber and configured to secure the body portion of the carrier body within said processing chamber;

a second arm disposed within said processing chamber and spaced from said first arm with said second arm configured to secure an adaptor of the carrier body within said processing chamber such that the interface surface of the adaptor is aligned with the terminal surface of the body portion; and

a heating element movable into and out of alignment with said body axis with said heating element configured to heat the first end of body portion of the carrier body;

wherein at least one of said first arm and said second arm is movable along said body axis for bringing said terminal surface of said body portion into contact with said interface surface of said adaptor to couple the adaptor to the body portion thereby forming the carrier body.

15. A manufacturing apparatus as set forth in Claim 15, wherein said processing chamber is fillable with an inert gas for providing an oxygen free environment within said processing chamber to prevent oxidation of the body portion and wherein said first arm and said second arm are movable within said processing chamber for aligning said adaptor with

said body portion, wherein said manufacturing apparatus further comprises a radio frequency system configured to generate radio waves to inductively heat the first end of the body portion to a melting point of silicon.

FIG. 1

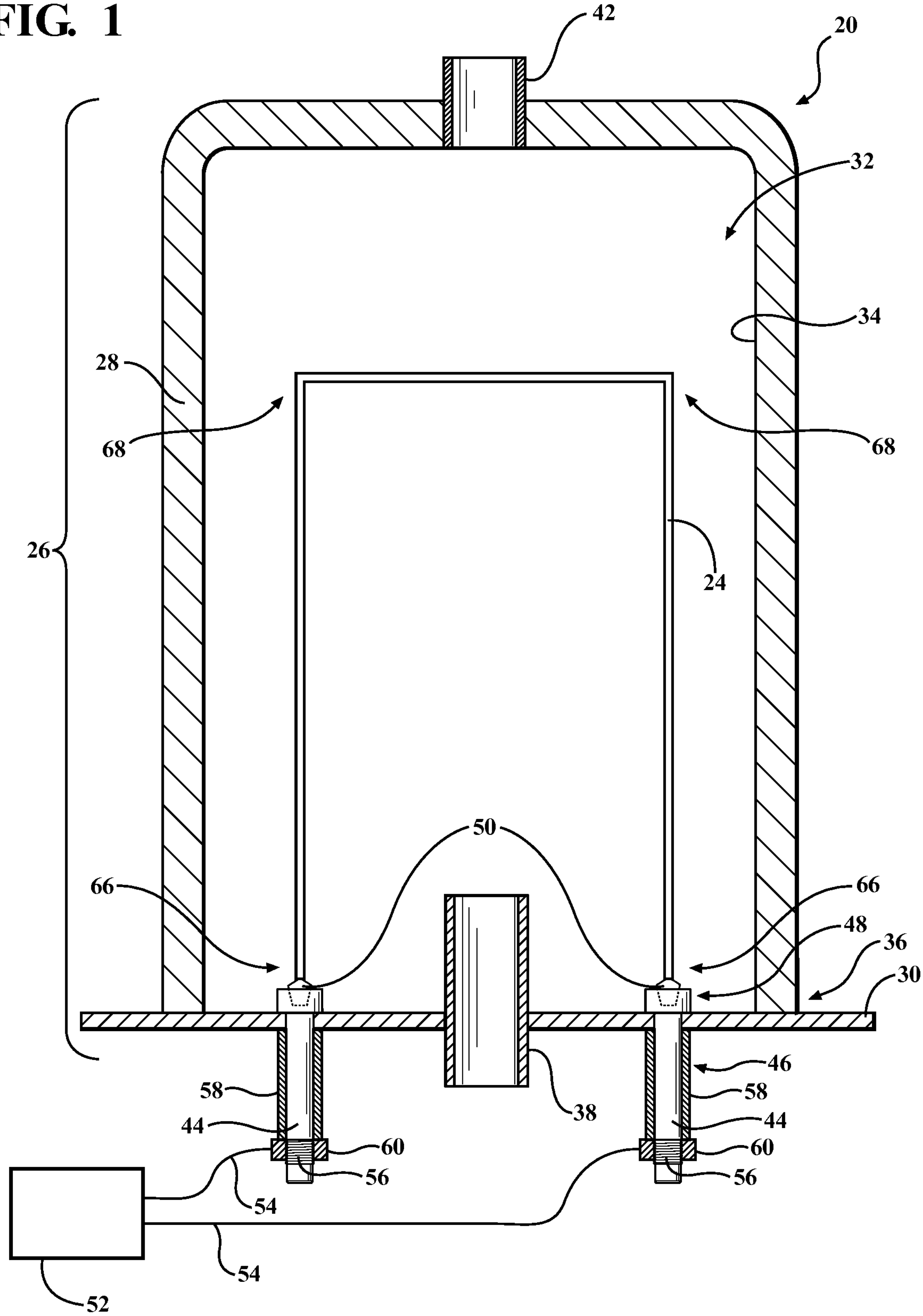
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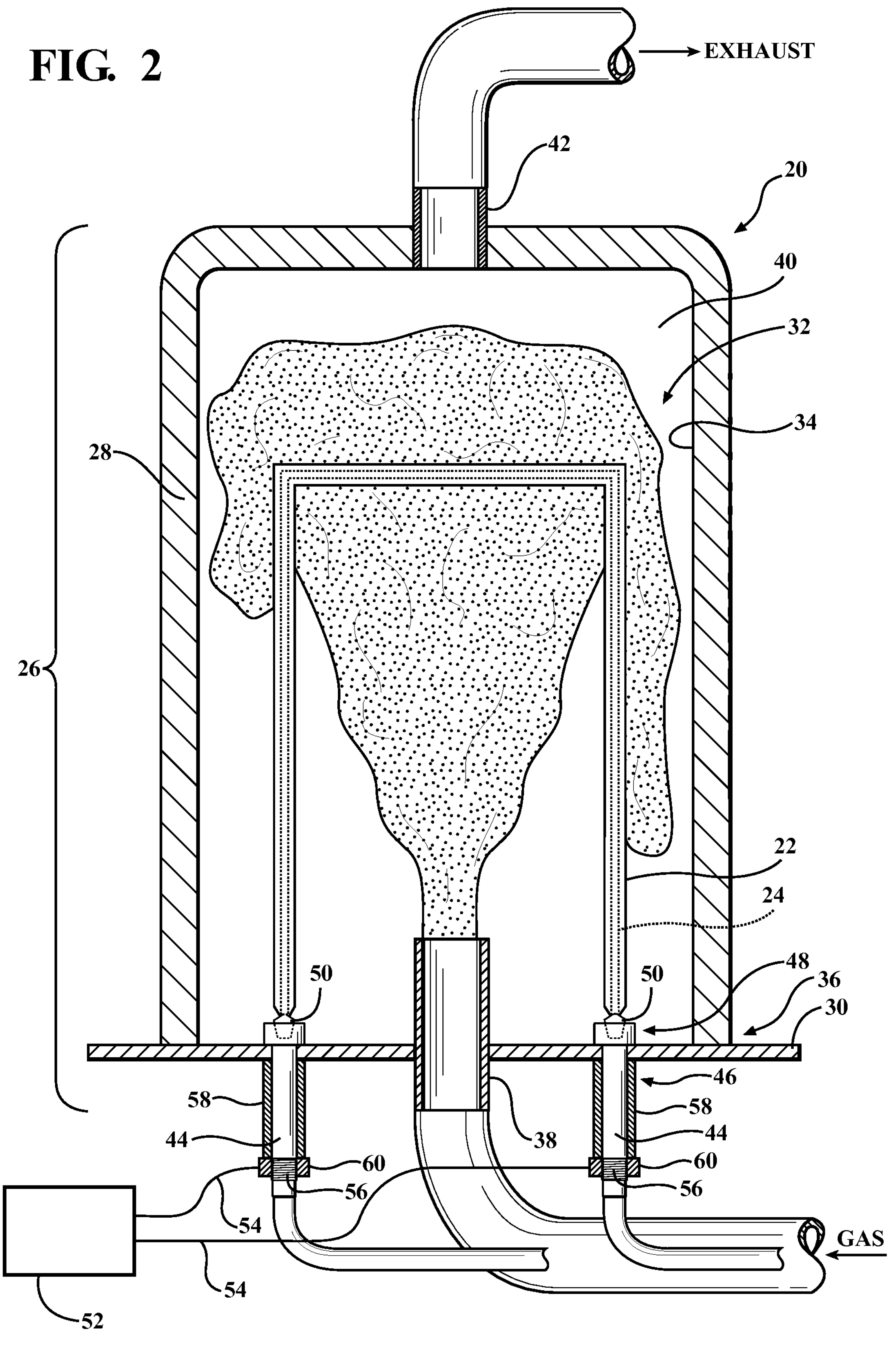
FIG. 2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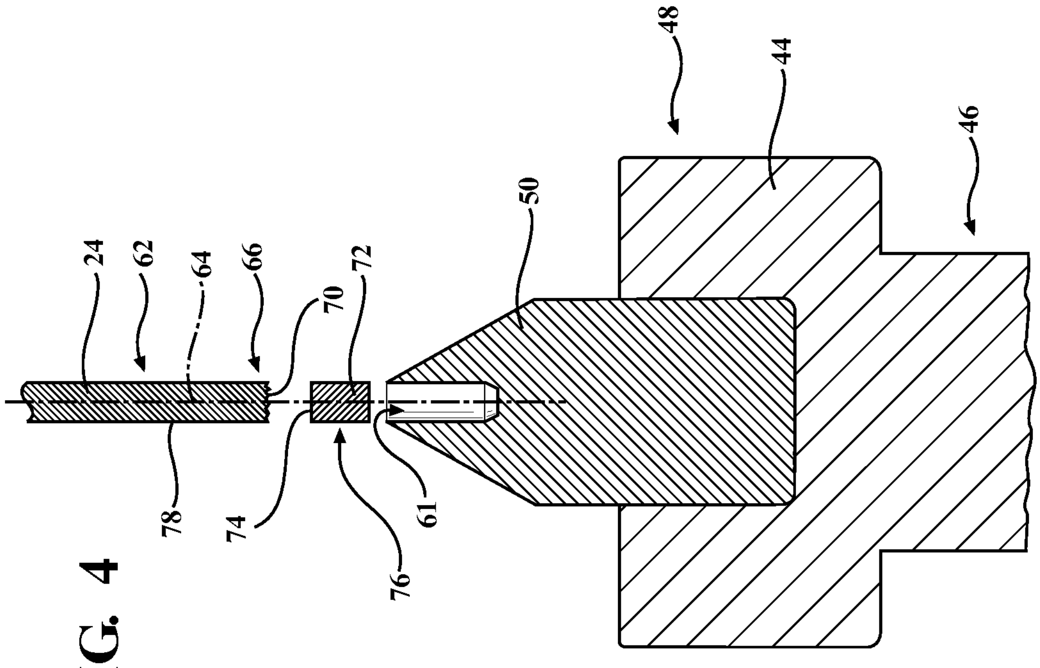

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FIG. 4

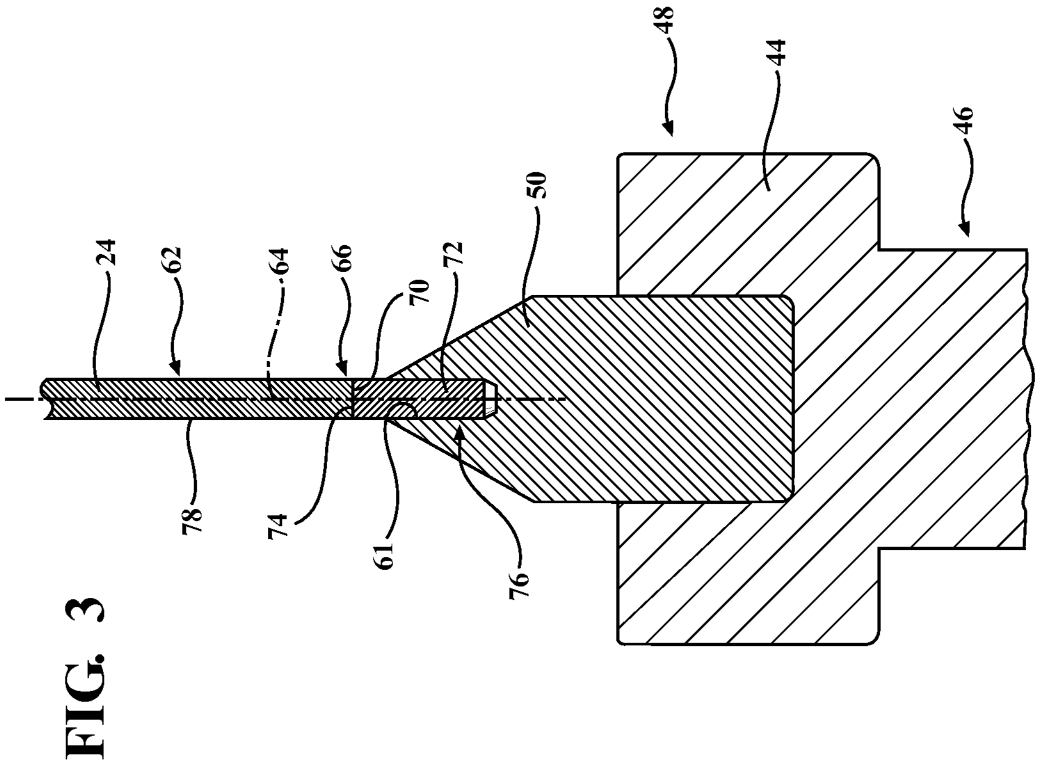

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FIG. 3

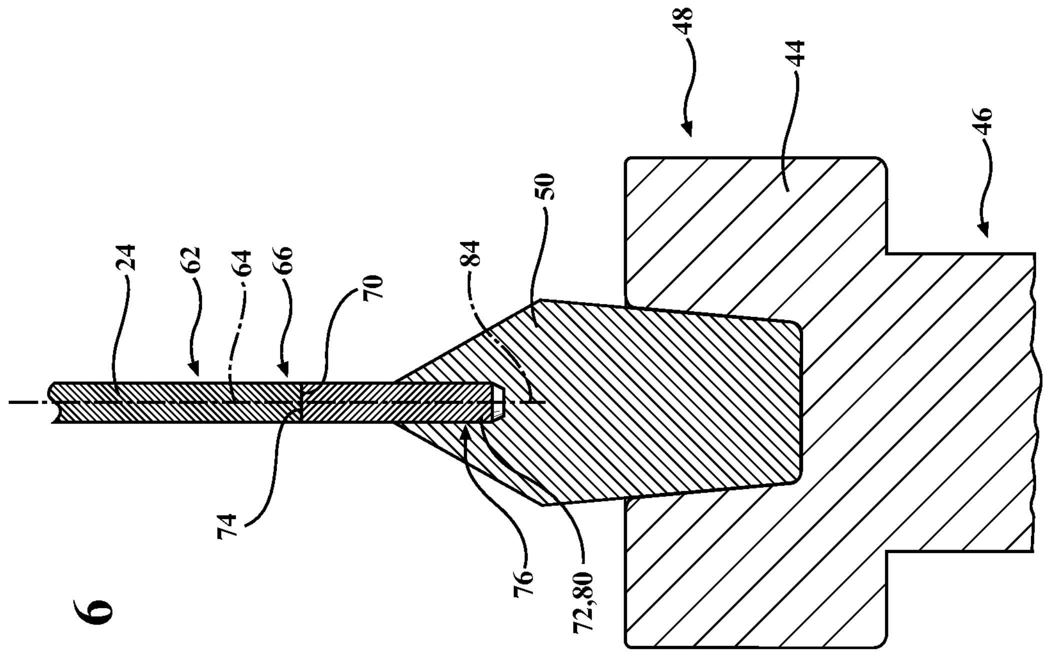
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FIG. 6

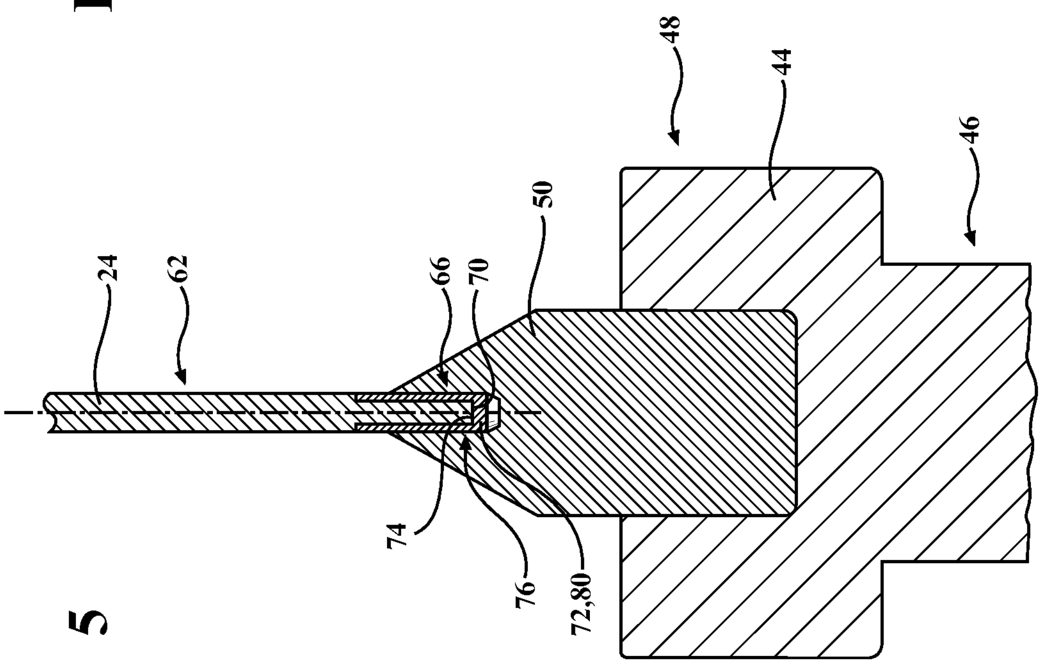
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FIG. 5

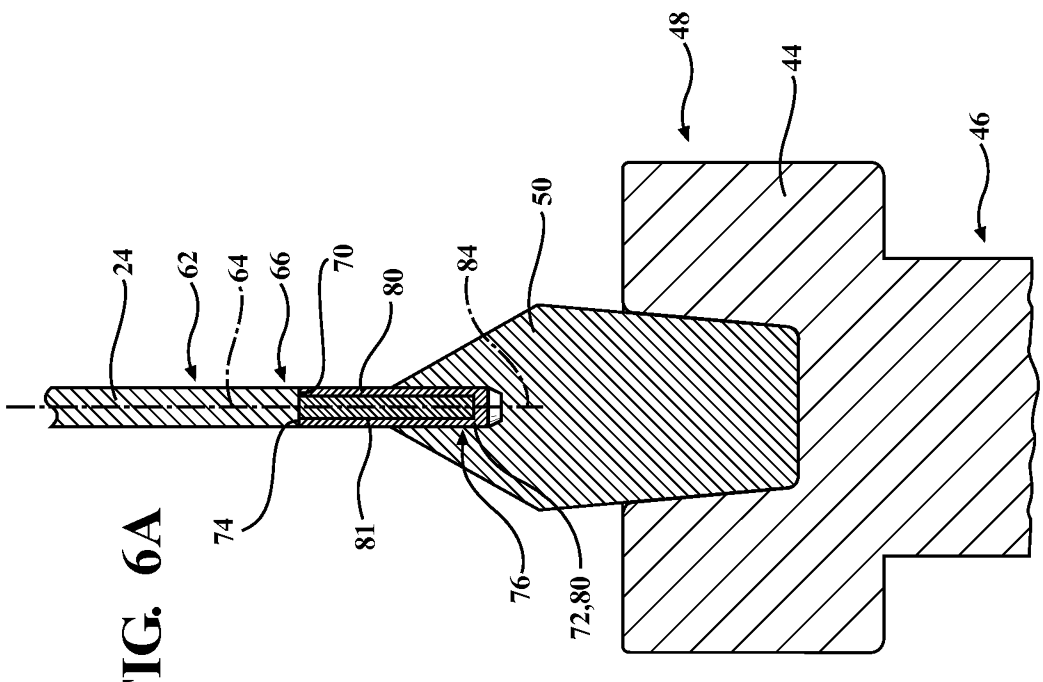
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FIG. 6A

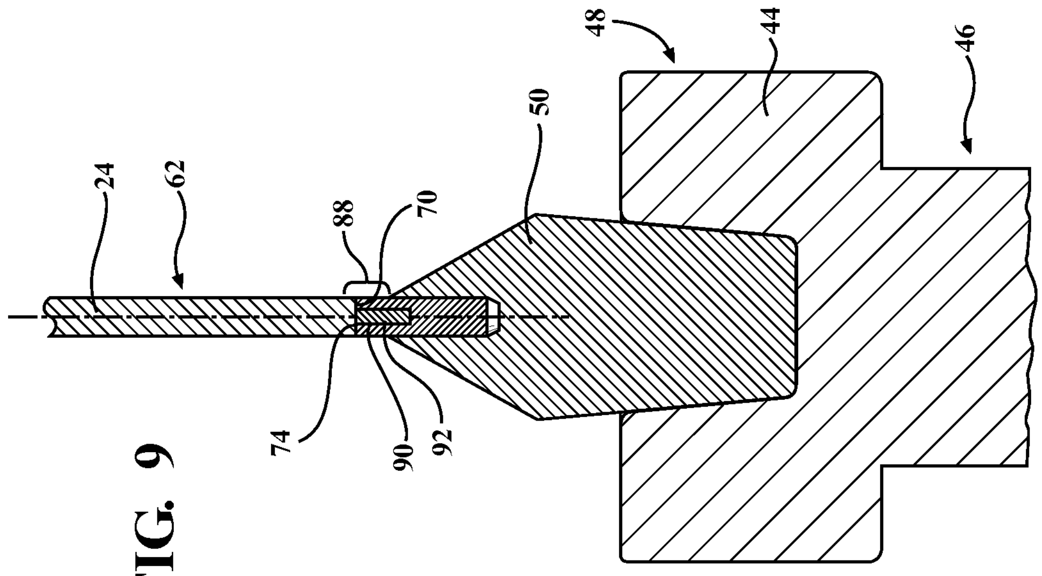
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FIG. 9

FIG. 7

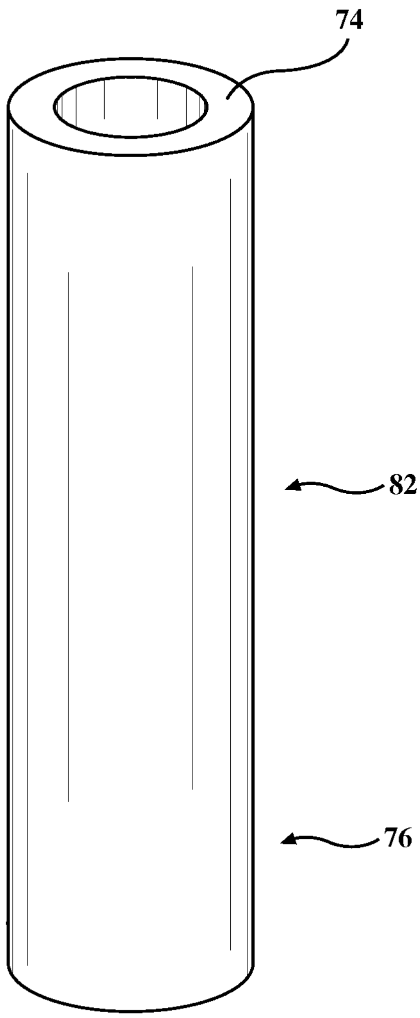
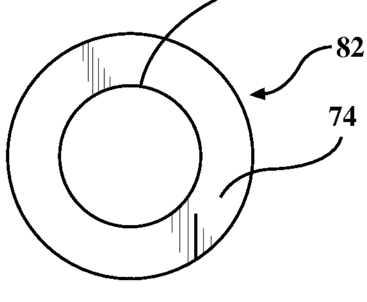


FIG. 8



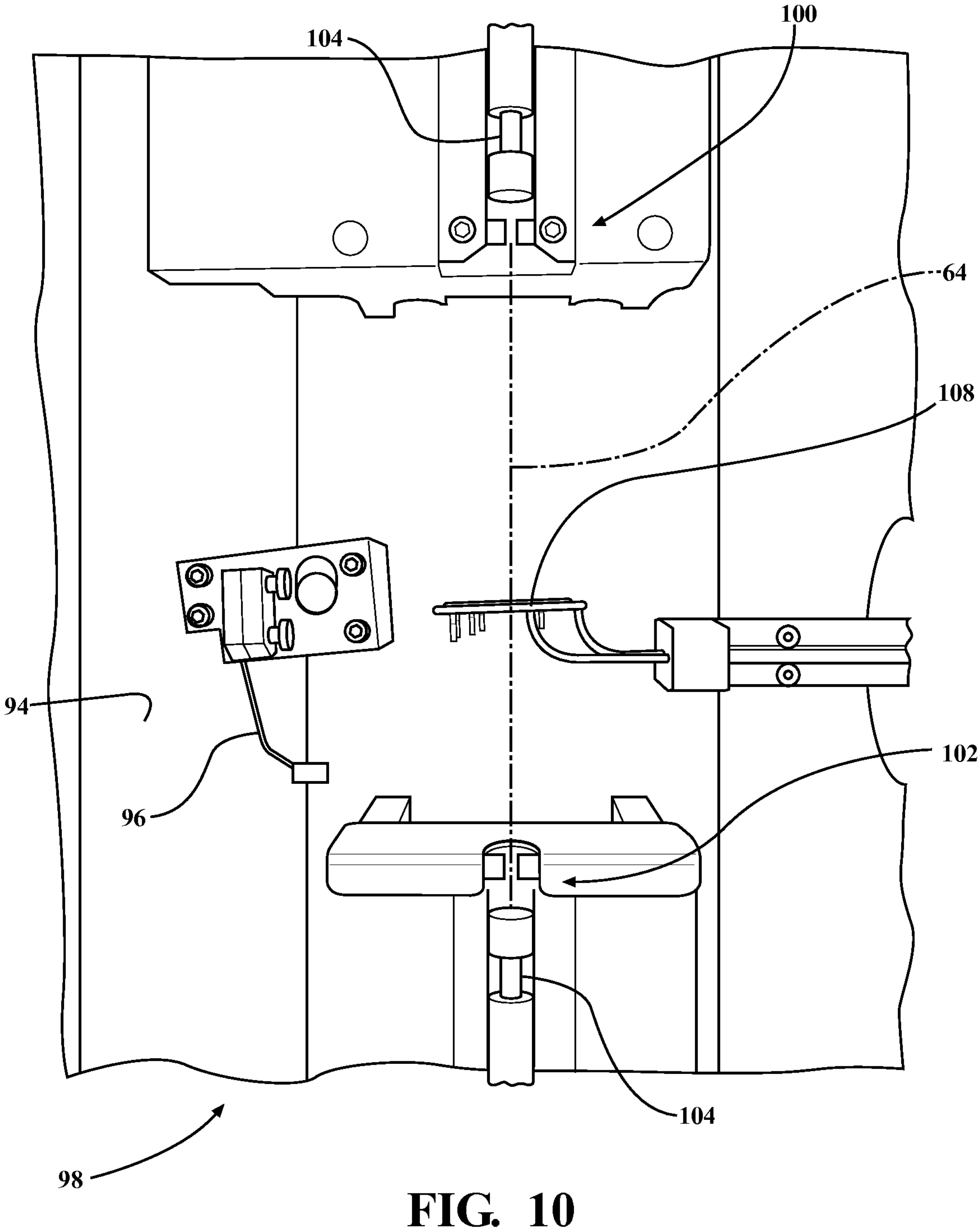


FIG. 10

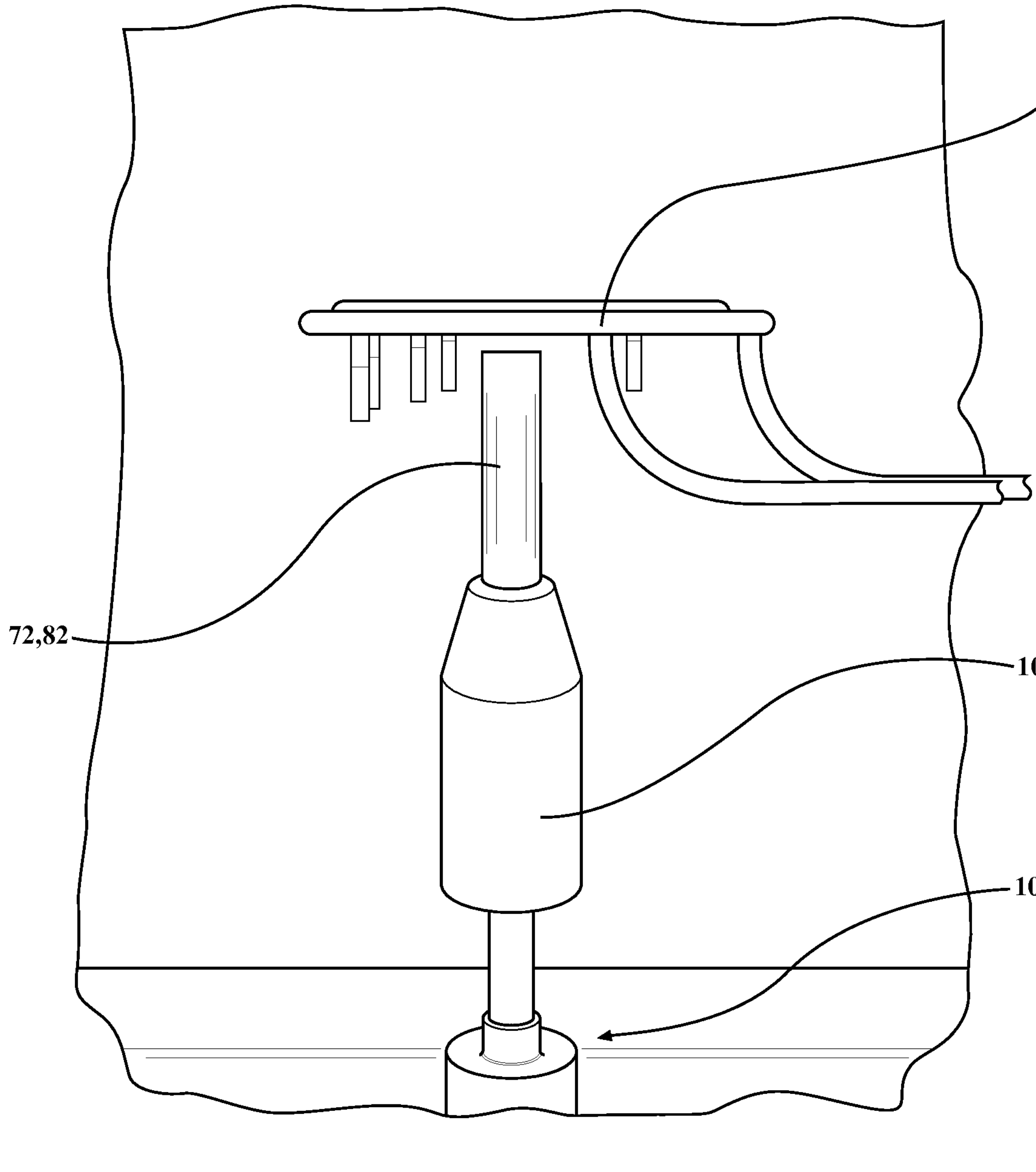


FIG. 11

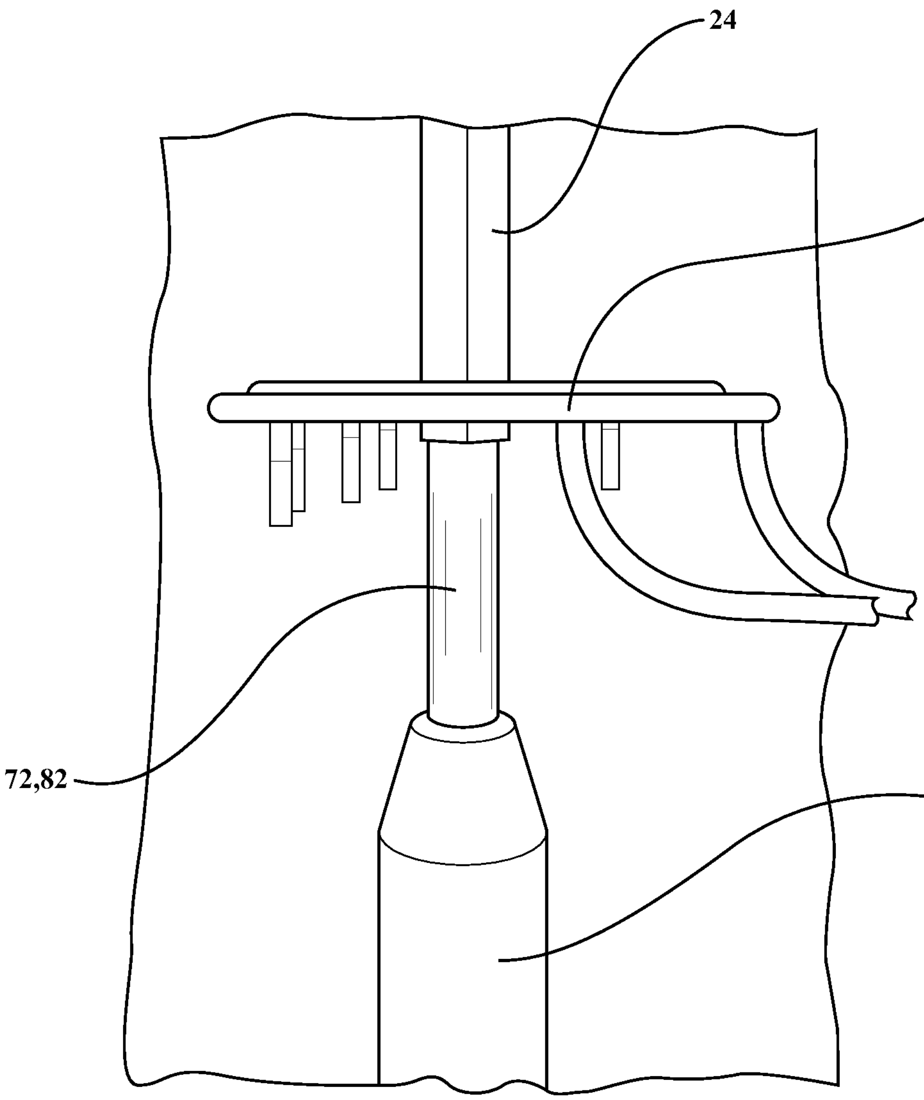


FIG. 12

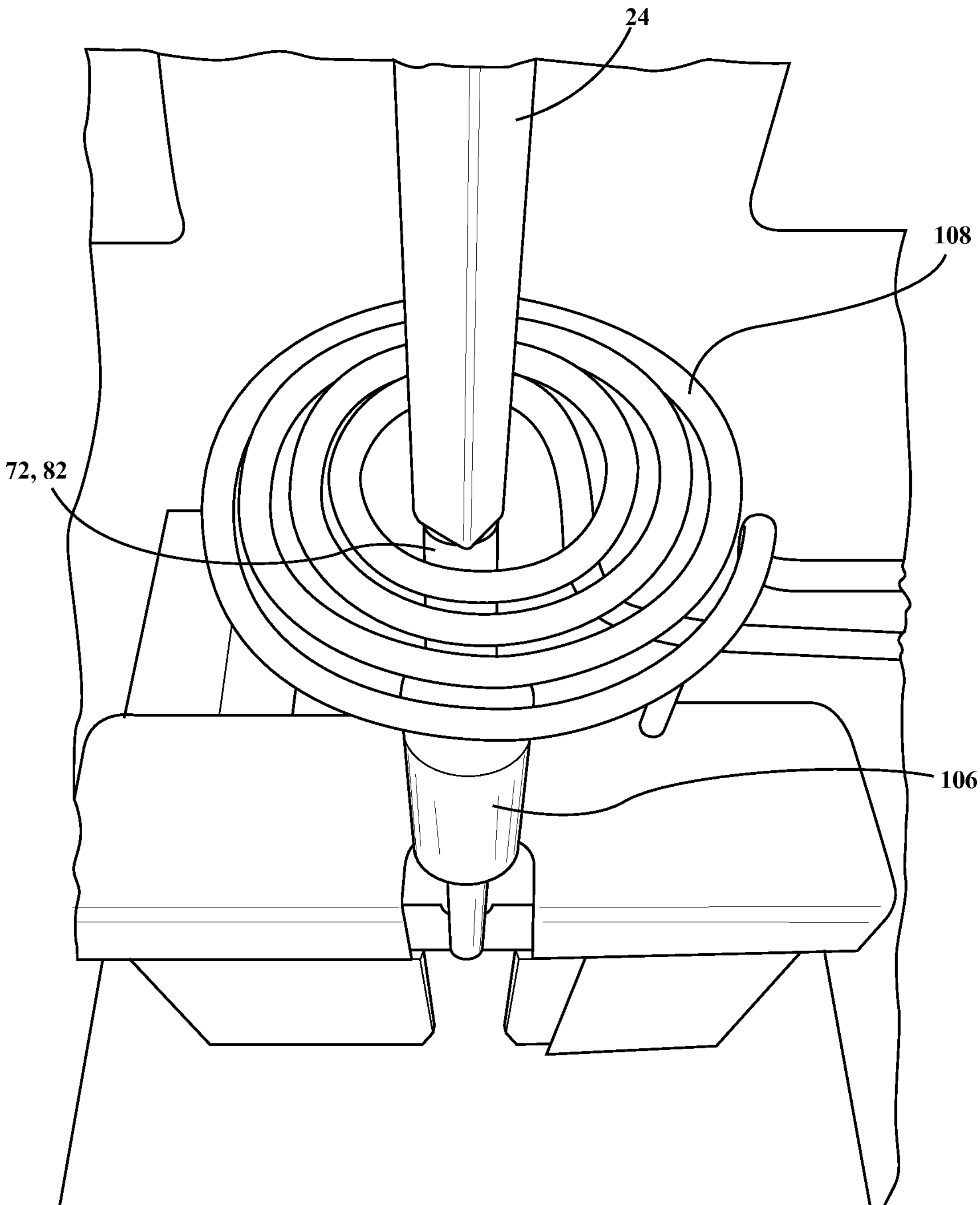


FIG. 13

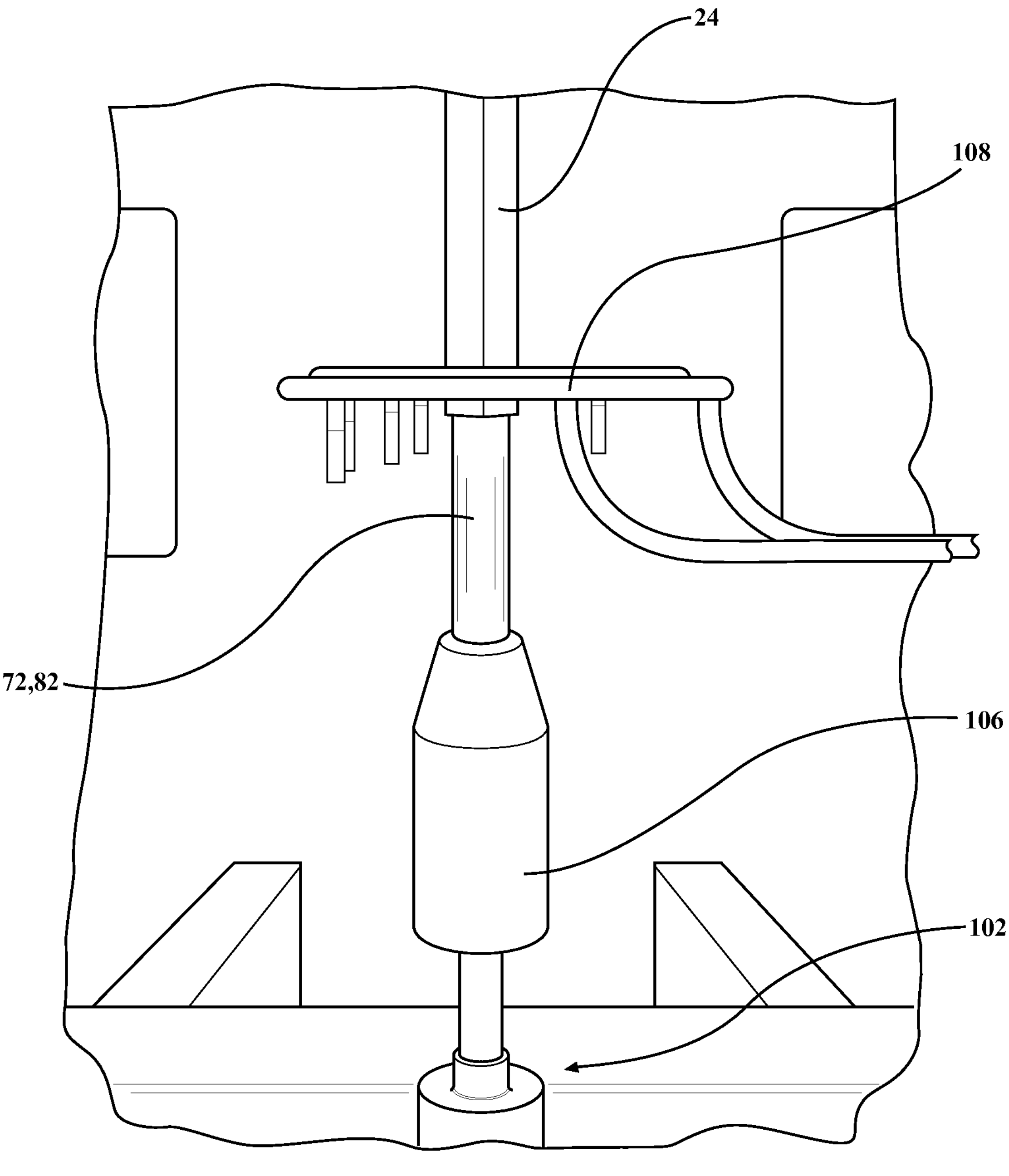


FIG. 14

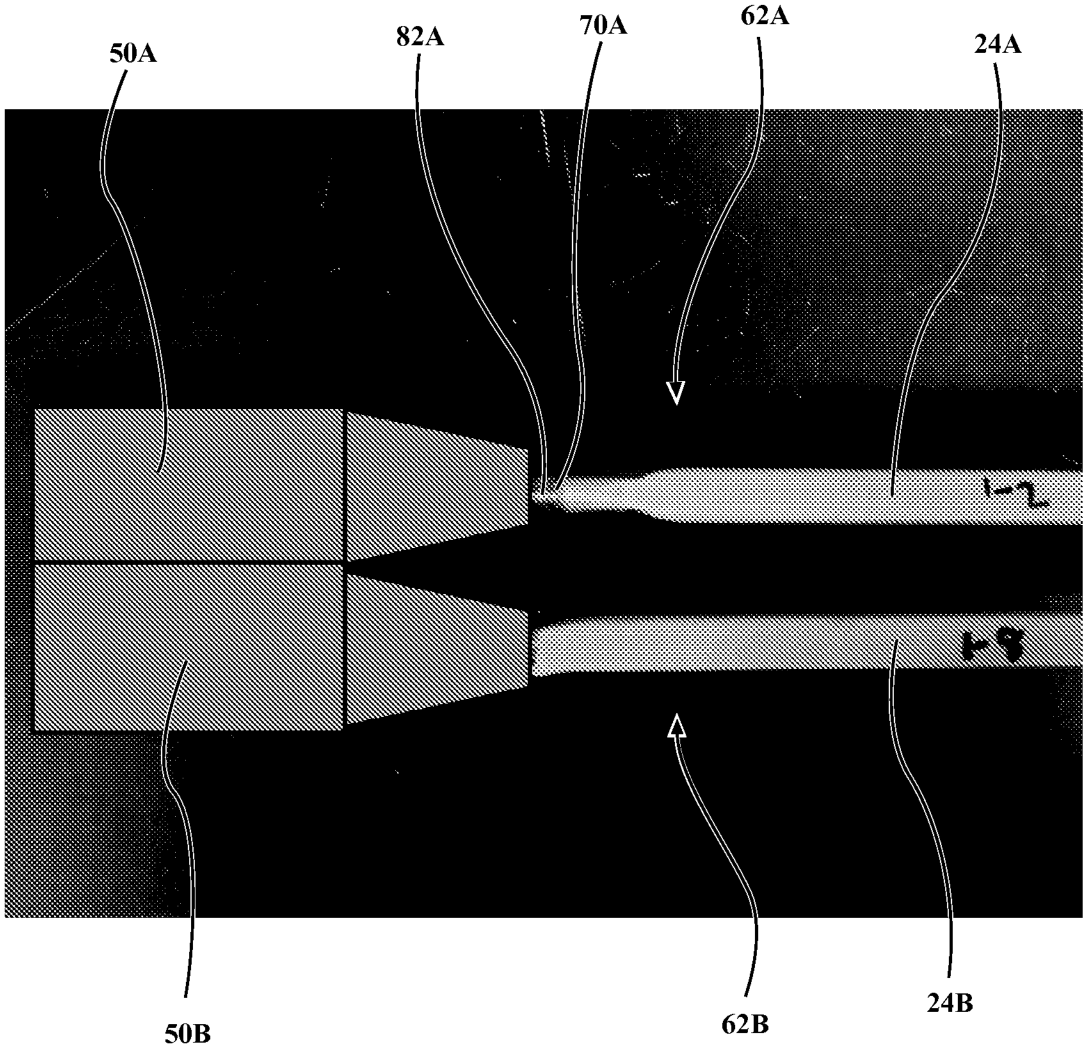


FIG. 15

INTERNATIONAL SEARCH REPORT	International application No. **PCT/US2014/072674**

A. CLASSIFICATION OF SUBJECT MATTER

C01B 33/035(2006.01)i, C30B 28/12(2006.01)i, C30B 29/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C01B 33/035; B23P 11/00; C23C 16/24; C23C 16/50; H05B 3/10; B23H 3/04; H05B 3/08; C23C 16/00; C30B 28/12; C30B 29/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: polycrystalline silicon, deposition, carrier, electrode, socket, transitional element, adaptor, coating

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0203101 A1 (GUM, J. C. et al.) 25 August 2011 See abstract; paragraphs [0008], [0039], [0044]; claim 1; and figures 4-5.	1-3,10
Y		11,12
A		14,15
Y	US 2011-0229658 A1 (KRAUS, H. et al.) 22 September 2011 See abstract; paragraph [0038]; claim 1; and figure 1.	11,12
A		1-3,10,14,15
A	US 2011-0031115 A1 (HILLABRAND, D. et al.) 10 February 2011 See abstract; paragraph [0038]; claim 1; and figures 3-4.	1-3,10-12,14-15
A	US 2003-0021894 A1 (INOUE, S. et al.) 30 January 2003 See abstract; claim 1; and figure 1.	1-3,10-12,14-15
A	US 6639192 B2 (HERTLEIN, H. et al.) 28 October 2003 See abstract; claim 1; and figure 1.	1-3,10-12,14-15

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 April 2015 (10.04.2015)	**13 April 2015 (13.04.2015)**

Name and mailing address of the ISA/KR	Authorized officer
International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea	Han, Inho
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/072674

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 5
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claim 5 is unclear because it refers to an unsearchable claim which does not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 4,6-9,13
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/072674

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011-0203101 A1	25/08/2011	CN 102084028 A	01/06/2011
		CN 102084028 B	16/04/2014
		EP 2321446 A2	18/05/2011
		JP 05636365 B2	03/12/2014
		JP 2011-525472 A	22/09/2011
		KR 10-2011-0081934 A	15/07/2011
		RU 2011102451 A	27/07/2012
		TW 201009111 A	01/03/2010
		WO 2010-008477 A2	21/01/2010
		WO 2010-008477 A3	03/06/2010
US 2011-0229658 A1	22/09/2011	CA 2733313 A1	19/09/2011
		CN 102196611 A	21/09/2011
		CN 102196611 B	14/08/2013
		DE 102010003064 A1	22/09/2011
		EP 2368847 A1	28/09/2011
		EP 2368847 B1	27/02/2013
		JP 05049398 B2	17/10/2012
		JP 2011-195439 A	06/10/2011
		KR 10-1265558 B1	20/05/2013
		KR 10-2011-0105712 A	27/09/2011
		US 8366892 B2	05/02/2013
US 2011-0031115 A1	10/02/2011	AU 2009-236678 A1	22/10/2009
		AU 2009-236678 B2	27/02/2014
		CA 2721194 A1	22/10/2009
		CN 102047750 A	04/05/2011
		CN 102047750 B	06/11/2013
		EP 2266368 A1	29/12/2010
		JP 2011-522959 A	04/08/2011
		KR 10-2011-0008082 A	25/01/2011
		RU 2010146252 A	20/05/2012
		TW 201001596 A	01/01/2010
		US 8784565 B2	22/07/2014
		WO 2009-128887 A1	22/10/2009
US 2003-0021894 A1	30/01/2003	JP 2003-040612 A	13/02/2003
		US 6623801 B2	23/09/2003
US 6639192 B2	28/10/2003	DE 10101040 A1	25/07/2002
		EP 1223146 A1	17/07/2002
		EP 1223146 B1	01/10/2003
		JP 03909242 B2	25/04/2007
		JP 2002-234720 A	23/08/2002
		US 2002-0088401 A1	11/07/2002