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(71) Applicant (for all designated States except US): **ADVANCED BIONICS AG** [CH/CH]; Laubisruetistrasse 28, CH-8712 Staefa (CH).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **KOESTER, Kurt J.** [US/US]; 1840 S. Barrington Ave., #3, Los Angeles, California 90025 (US).

(74) Agent: **NICHOLS, Steven L.**; Van Cott, Bagley, Cornwall & McCarthy P.C., 36 S. State Street, Suite 1900, Salt Lake City, Utah 84111 (US).

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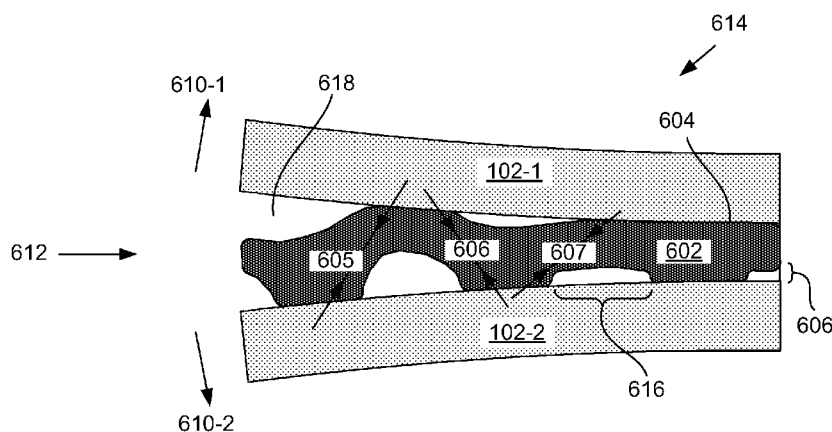


Fig. 6D

(57) Abstract: An electrical feedthrough with a structured interface includes a ceramic body with a first surface and a second surface and a first electrical conductor passing through the ceramic body from the first surface to the second surface. An interface between the ceramic body and the electrical conductor is adapted to exhibit extrinsic toughening mechanisms in the wake of a crack propagating along the interface.



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STRUCTURED INTERFACES IN ELECTRICAL FEEDTHROUGHS

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RELATED DOCUMENTS

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 61/423,378, entitled "Structured Interfaces in Electrical Feedthroughs" to Kurt J. Koester, filed December 15, 2010, which application is incorporated herein by reference in its entirety

BACKGROUND

[0002] Hermetically sealed cases can be used to isolate electronic devices from environmental contamination. To form electrical or physical connections between the interior and the exterior of a hermetically sealed case, a hermetic feedthrough can be used. Ideally this hermetic feedthrough would maintain the integrity of the hermetic sealed case, while allowing electrical signals to pass through. However, the reliability of the hermetic feedthrough can become a limiting factor in some implant designs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The accompanying drawings illustrate various embodiments of the principles described herein and are a part of the specification. The illustrated embodiments are merely examples and do not limit the scope of the claims.

[0004] Fig. 1 is an exploded view of an illustrative hermetically sealed case, according to one example of principles described herein.

5 **[0005]** Fig. 2A is a cross-sectional view of an illustrative electrical feedthrough that includes conductive pins that are hermetically sealed into a ceramic body using a gold braze joint, according to one example of principles described herein.

10 **[0006]** Fig. 2B is a perspective view of the illustrative electrical feedthrough shown in Fig. 2A, according to one example of principles described herein.

15 **[0007]** Figs. 3A and 3B are cross-sectional and cut-away perspective views, respectively, of diagrams showing an illustrative electrical feedthrough that uses partial transient liquid phase bonding to join ribbon conductors to a ceramic body, according to one example of principles described herein.

[0008] Fig. 4A is a cross-sectional diagram of a crack propagating along an illustrative feedthrough interface, according to one example of principles described herein.

20 **[0009]** Figs. 4B-4D are cross-sectional diagrams showing paths of conductors passing through ceramic bodies, according to one example of principles described herein.

[0010] Fig. 4E is a cross-sectional diagram of cracks propagating along illustrative structured interfaces between a conductor and a ceramic body, according to one example of principles described herein.

25 **[0011]** Figs. 5A- 5C are illustrative patterned conductors that pass through a ceramic body, according to one example of principles described herein.

[0012] Fig. 6A shows illustrative patterns in a conductor/ceramic interface, according to one example of principles described herein.

30 **[0013]** Figs. 6B and 6C are cross-sectional diagrams of illustrative micro-patterned conductors, according to one example of principles described herein.

35 **[0014]** Fig. 6D is a cross-sectional diagram that shows a crack propagating through an illustrative feedthrough with a micro-patterned conductor, according to one example of principles described herein.

[0015] Fig. 7 is a flow chart of an illustrative method for forming structured interfaces in electrical feedthroughs, according to one example of principles described herein.

[0016] Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

DETAILED DESCRIPTION

[0017] Hermetically sealed cases are used to protect electronic components from environmental contaminants. An electrical feedthrough maintains the integrity of the hermetically sealed case, while allowing electrical signals to pass through. Human implant technologies often make use of hermetically sealed cases. These hermetically sealed cases prevent body fluids from damaging electronic components contained within the case. In an implanted environment, the hermetically sealed case is subject to a variety of corrosive chemicals and mechanical forces. However, the implanted case must be highly reliable over the lifetime of the biomedical device.

[0018] The electrical feedthrough may include a ceramic body with a number of conductive electrical conductors, vias, or ribbons that pass through the ceramic body. As used in the specification and appended claims the term “ceramic” is used broadly to refer to glass, glass/ceramic, or ceramic materials. The ceramic body may include a number of reinforcing microstructures or phases. The ceramic body has a number of advantages: it is a biocompatible electrical insulator that is substantially impermeable to liquids and gasses, has a relatively high resistance to chemical corrosion, and has high yield strength. However, the ceramic body is brittle and fails by fracture and crack propagation. It is fundamental to the structure of feedthroughs that they include a number of interfaces between dissimilar materials. For example, there are interfaces between the conductors and the ceramic body. Cracks have a tendency to propagate near and along these interfaces. Consequently, the presence of these interfaces can significantly reduce the impact resistance, fracture toughness, and stress corrosion crack-growth resistance. However, by

5 appropriately structuring these interfaces, the toughness and lifetime of the feedthrough can be substantially increased.

[0019] For purposes of explanation, the principles described below are discussed in the context of implanted medical devices. However, the principles are broadly applicable to interfaces in ceramic bodies in a variety of applications. For example, ceramic interfaces may be present in aerospace,
10 industrial, microfluidics, medical equipment, and other applications.

[0020] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present systems and methods. It will be apparent,
15 however, to one skilled in the art that the present apparatus, systems, and methods may be practiced without these specific details. Reference in the specification to “an embodiment,” “an example,” or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment or example is included in at least that one embodiment, but not
20 necessarily in other embodiments. The various instances of the phrase “in one embodiment” or similar phrases in various places in the specification are not necessarily all referring to the same embodiment.

[0021] Fig. 1 is an exploded view of an illustrative hermetic enclosure (100) that houses cochlear implant electronics. In this particular example, the
25 hermetic enclosure (100) includes a case (110) and a case top (115). The case (110) and the case top (115) may be formed from a variety of biocompatible materials. For example, the case (110) and case top (115) may be formed from metals, ceramics, crystalline structures, composites, or other suitable materials. The outer case (110) may be formed from a single piece of material or may
30 include multiple elements. The multiple pieces may be connected through a variety of methods including, but not limited to, brazing, laser welding, adhesive bonding, ultrasonic bonding, or other suitable bonding techniques.

[0022] According to one illustrative example, the case (110) and the case top (115) are formed from titanium. Titanium has a number of desirable
35 characteristics, including high strength, resiliency, biocompatibility, low density, and low gas permeability. The case (110) shown in Fig. 1A is a closed-bottom

5 cylinder that is machined, stamped, or otherwise formed from a single piece of titanium. In this example, the case (110) includes two apertures (111, 112) that are configured to receive hermetic electrical feedthroughs (101, 120). The case top (115) is also made from titanium and can be placed onto a ledge (116) machined into the upper rim of the case (110). The case top (115) can then be
10 laser welded or brazed onto the case (110). Once the case top (115) and hermetic electrical feedthroughs (101, 120) are sealed in place, the hermetic enclosure (100) prevents liquids or gasses from entering the interior of the enclosure (100). As discussed above, this prevents damage to electronics or other components housed in the interior of the hermetic enclosure (100).

15 **[0023]** The electrical feedthroughs (101, 120) may be formed from a variety of materials and have a number of different configurations. According to one illustrative example, the electrical feedthroughs (101, 120) include a set of conductors (108, 109) that are imbedded in ceramic bodies (104, 105). These conductors (108, 109) pass through and are sealed in the ceramic body. The
20 sealing of the conductors into the ceramic body may take place in a variety of ways, including gold brazing or partial transient liquid phase bonding.

[0024] The ceramic body (104, 105) is then joined to the appropriate aperture (111, 112) in the case (110). A variety of techniques, including gold braze joints can be used to join the ceramic body to the case (110). In this
25 illustrative example, the hermetic feedthroughs (101, 120) are on the perimeter of the case (110). The hermetic feedthroughs (101, 120) are well protected by the case (110) to minimize damage from impact loads. Although the feedthroughs (101, 120) are illustrated as being located in the perimeter of the case (110), feedthroughs could additionally or alternatively be located at other
30 sites on the case (110) or the case top (115). Further, the number and size of hermetic feedthroughs (101,120) could be varied according to the design requirements. For example, a single feedthrough could be used to make all the desired electrical interconnections.

[0025] Figs. 2A and 2B illustrate a feedthrough (101) that includes
35 cylindrical electrical conductors (200) that are sealed into the ceramic body (104) using a gold braze joint (202). Fig. 2A is a cross-sectional view of a

5 portion of the case (110) that includes the feedthrough (101). The left side of the electrical conductor (200) is connected to components that are internal to the case (110) and the right side of the electrical conductor (200) is connected to components that are external to the case (110). The electrical conductor (200) may have a variety of geometries and may be formed from a variety of materials. In this example, the electrical conductors (200) are cylindrical and may be formed from platinum, gold, gold alloy, or a platinum alloy such as platinum iridium. Platinum has a number of desirable characteristics, including a relatively low electrical resistance, high malleability, biocompatibility, and ability to be alloyed with a number of other elements.

15 **[0026]** Fig. 2B is a perspective view of a portion of the hermetic case (110) that includes part of the hermetic feedthrough (101). As discussed above, the ceramic body (104) surrounds the electrical conductors (200) that are sealed with a braze joint (202). In this example, the braze joint (202) becomes part of the conductive pathway through the feedthrough (101).

20 **[0027]** The braze joint (202) between the electrical conductor (200) and the ceramic body may be formed in a variety of ways. For example, a gold braze joint may be formed by placing the platinum electrical conductors through holes in a fully densified ceramic body (104). The platinum electrical conductors (200) and ceramic body (104) are heated and melted gold or gold alloy is drawn by capillary action into the gap between the platinum electrical conductor (200) and the ceramic body (104).

[0028] The ceramic body (102) can be joined to the case (110) in a number of ways, including brazing, active metal brazing, ceramic/glass/metal joining, transient liquid phase bonding, or other suitable techniques.

30 **[0029]** Figs. 3A and 3B are diagrams showing an illustrative electrical feedthrough that uses partial transient liquid phase bonding to join ribbon conductors to a ceramic body. Fig. 3A is a cross-sectional diagram of the hermetic case (110) and feedthrough (101). This figure shows ribbon vias (300) passing through the ceramic body (102) and extending from both sides of the ceramic body (102). The braze joint (108) seals the ceramic body (102) to the case (110). The case (110) may be formed from any biocompatible material

5 that has the desired impermeability and mechanical characteristics. For example, titanium may be used to form the case.

[0030] The ceramic body (102) may be formed from a variety of materials. For example, the ceramic body (102) may be formed from alumina. The ribbon vias (300) may also be formed from a range of materials that have
10 the desired characteristics. For example, the ribbon vias (300) may be formed from platinum.

[0031] In this illustrative example, the platinum ribbon vias (300) could be sealed into the ceramic body (102) using transient liquid eutectic bonding. A number of methods and feedthroughs that use platinum ribbon vias sealed into
15 a ceramic body using transient liquid phase bonding are described in U.S. Pat. App. No. 12/836,831, entitled "Electrical Feedthrough Assembly," to Kurt Koester, filed on July 15, 2010, which is incorporated herein by reference in its entirety.

[0032] Ceramic is typically considered a brittle material. Brittle
20 materials exhibit very little plastic deformation prior to failure. Cracks tend to propagate long distances through brittle materials with little warning. Further, predicting where and when brittle materials will fail is difficult. There are a number of crack propagation mechanisms through which cracks can propagate in a ceramic.

[0033] As discussed above, cracks tend to propagate along
25 interfaces, discontinuities, or other areas of weakness within the feedthrough structure. The interface or other discontinuity creates stress concentrations when the ceramic is subject to internal or external forces. For example, the interface between a metallic electrical conductor and the surrounding ceramic
30 may be particularly susceptible to cracking. This susceptibility may reduce the toughness of the ceramic feedthrough to only a fraction of theoretical strength of the ceramic matrix.

[0034] The forces that drive crack propagation may arise in a variety of ways. Internal forces may due to temperature changes, differences in
35 material properties, or other factors. External forces may be due to impact loading, interaction with surrounding structures, fatigue, chemical corrosion, and

5 other factors. When the stress level at a flaw in the ceramic exceeds the strength of the material, a crack forms. The crack tip then concentrates the stress. Continued application of stress that generates forces greater than the strength of the material at the crack tip results in propagation of the crack. Large cracks can compromise the sealing, electrical, and mechanical functions
10 of the feedthrough.

[0035] Intrinsic toughening mechanisms are typically active in ductile materials and are damage mechanisms that primarily occur ahead of the crack tip and increase the material's resistance to fracture, e.g., plasticity. Extrinsic toughening mechanisms are active in brittle materials and are principally
15 present in the wake of a crack and reduce the driving force for crack extension at the tip of the crack, e.g., bridging, deflection, twist, or microcracking. Bridging refers to a ductile material that spans a crack and resists the further spreading of the crack. Deflection refers to an in-plane redirection of the crack that shifts the crack away from a plane of maximum driving force. Twist refers to an out-
20 of-plane rotation of the crack that also shifts the crack away from a plane of maximum driving force. Microcracking refers to a localized expansion of the crack tip by a number of small cracks. This expansion spreads the plastic deformation at the crack tip over a wider area. The expansion is resisted by the bulk material that surrounds the crack tip.

[0036] Ceramics are primarily toughened through extrinsic mechanisms. Figs. 4A-6D show a number of illustrative techniques for enhancing these extrinsic toughening mechanisms or introducing new toughening mechanisms in ceramic feedthroughs. These techniques can significantly increase the fracture resistance and stress corrosion crack-growth
25 resistance of the ceramic feedthroughs.

[0037] Fig. 4A shows an electrical conductor (401) that passes straight through a ceramic body (102). The interfaces between the electrical conductor (401) and the body (102) have linear interfaces (403), which may be more susceptible to cracking. In this example, the plane of maximum driving
35 force for crack propagation (410) is parallel to this interface. Additionally, the interface between the electrical conductor and ceramic body is coincident with

5 the plane of maximum driving force (410). Consequently, when the driving force exceeds a yield strength threshold, a crack (408) forms at the interface and continues to propagate along the interface in the preferred cracking direction (410). The interface (403) may facilitate the propagation of the crack (408) for a number of reasons, including but not limited to, low bond strength at the
10 interface, differences in material properties between the electrical conductor and the body, or other factors.

[0038] Figs. 4A-4E describe a number of illustrative examples of structured conductor/ceramic interfaces in an XZ plane that extrinsically toughen a ceramic body. According to one illustrative example, there are several
15 methods for mitigating crack propagation through ceramic feedthroughs. One method comprises orienting a plane of weakness, *i.e.*, the interface, out of the plane of maximum driving force for crack extension. This constrains the crack to reside in the higher-toughness plane of maximum driving force or deflect and propagate near or at the interface. Either crack path will be observed as higher
20 toughness. A variety of microstructures that toughen ceramics are discussed in U.S. Prov. App. No. 61/423,355, filed December 15, 2010 entitled "Particulate Toughened Ceramic Feedthroughs," to Kurt J. Koester and U.S. Prov. App. No. 61/423,337, filed December 15, 2010, entitled "Crack Diversion Planes in Ceramic Feedthroughs," to Kurt J. Koester, both of which are incorporated
25 herein by reference in their entirety.

[0039] According to one illustrative example, the geometry and interfaces between the ceramic body and the electrical conductors can be engineered to impede crack propagation. Figs. 4B-4D are cross-sectional diagrams of electrical feedthroughs with structured interfaces between the
30 ceramic body and the electrical conductor that are adapted to exhibit extrinsic toughening mechanisms in the wake of a crack propagating along the interface. In some embodiments, the electrical conductor geometry is altered to impede crack propagation along the interface between the ceramic body and the electrical conductors by rotating at least a portion of the interface away from a
35 plane of maximum driving force. As used in the specification and appended claims, the term "plane of maximum driving force" is used to describe a plane

5 with a location and orientation defined by the maxima of forces applied to the ceramic body that tend to encourage crack initiation and propagation. The location and orientation of the plane of maximum driving force varies with the loading. For example, the plane of maximum driving force could be different in between successive impact events.

10 **[0040]** If at least a portion of the interface (413, 414, 415) between the ceramic (102) and conductor (402, 404, 406) is not in the plane of maximum driving force, the continued crack propagation can occur through one of several mechanisms. First, the crack (408) can leave the interface and travel through the tougher ceramic body (102) in a direction that is closer to the plane of
15 maximum driving force. Second, the crack can continue along the interface in a direction that reduces the available crack driving force. Third, the crack can propagate across conductor to the other side. This leaves the conductor (402, 404, 406) as a bridge across the crack. Any of these mechanisms can significantly increase the resistance of the feedthrough to fracture. Thus,
20 engineering the interface between the ceramic and conductor to take advantage of these mechanisms can significantly toughen the feedthrough and prevent hermetic failure.

[0041] According to another illustrative example, the spacing between the electrical conductors can be selected to mitigate crack propagation. The
25 farther apart the conductors are spaced, the less influence the interfaces of the conductors have on the strength of the feedthrough. As the conductors are spaced further apart, the strength of the feedthrough becomes primarily limited by the bulk properties of the ceramic. However, there is a significant motivation to closely space the conductors and to reduce the size of the feedthrough. This
30 can result in a smaller implanted device. Additionally, the location of the conductors within the ceramic can be offset so that it is more difficult for a crack to propagate along adjacent conductors.

[0042] The electrical conductors are designed to conduct a desired level of electrical current with an acceptable voltage drop across the conductor,
35 while maintaining an acceptably small feedthrough size. However, the size of the electrical conductors can also be engineered to improve the strength of the

5 feedthrough. For example, the thickness or diameter of the electrical conductor should be at least as great as the zone of plastic deformation at a crack tip in the conductor material. This maximizes the crack resistance by efficiently diffusing stresses at the crack tip without making the electrical conductor any larger than necessary. For example, the conductors' diameter or thickness may
10 be less than 0.010 inches and the space between adjacent conductors may be less than 0.020 inches.

[0043] Fig. 4B shows a feedthrough (405) with a conductor (402) passing into a ceramic body (102) from its first surface (401-1) to a second opposite surface (401-2). The conductor (402) enters the ceramic and then
15 turns abruptly and passes through the ceramic (102) at an angle, then exits perpendicularly to the right surface (401-2) of the feedthrough (405). The angled path of the conductor (402) may increase the overall fracture toughness by exhibiting several extrinsic toughening mechanisms. First, the angled path can be selected such it does not coincide with the plane of maximum driving
20 force for crack propagation. For example, a feedthrough may be prone to a particular impact loading, which generates the driving force for crack propagation. For example, this impact loading may be limited to a particular angle or range of angles. In that case, the angled path of the conductor is selected such that the interface between the conductor and the ceramic does
25 not coincide with the range of anticipated planes of maximum driving force.

[0044] Additionally, an engineered interface can be created by angling the path of the conductor (402) as illustrated in Fig. 4B. This can increase the fracture toughness of the feedthrough by increasing the length of the conductor/ceramic interface (413). A longer conductor/ceramic interface (413)
30 means that if a crack propagates along the interface (413), it must travel a greater distance before exiting the opposite side and compromising the hermetic seal of the feedthrough.

[0045] Fig. 4C is a cross sectional diagram feedthrough (407) that includes a conductor (404) that curves as it passes through the ceramic body (102). The continuous curve in the conductor (404) creates a constantly
35 changing slope. Because of the constantly changing slope, only a small portion

5 of the conductor/ceramic interface (414) will be directly aligned with any given plane of maximum driving force. Consequently, for a crack to propagate along the curved interface (414), it must follow a path that does not coincide with the plane of maximum driving force. This reduces the force available to drive the crack propagation and consequently increases the toughness of the
10 feedthrough (407).

[0046] Fig. 4D is a cross sectional diagram of a feedthrough (409) that includes a conductor (406) with multiple curves. This creates a long serpentine conductor/ceramic interface (415) that may significantly strengthen the feedthrough (409). This serpentine interface (415) may act in a number of ways
15 to toughen the feedthrough. First, the interface (415) may deflect crack propagation out of the plane of maximum driving force. As discussed above, this increases the toughness of the feedthrough by increasing amount of driving force required to continue crack propagation. Second, the interface (415) may direct the crack to terminate an upper or lower edge of the feedthrough (409)
20 rather than propagating through the entire feedthrough. A crack that terminates at the upper or lower edge of the feedthrough (409) does not pass through the thickness of the hermetic feedthrough or compromise the hermetic seal. Third, the crack may jump cross the conductor (406). The ductile conductor (406) then serves a bridge across the crack. This reduces the crack propagation
25 force. Fourth, the length of the interface (415) is significantly longer than a linear path between the first surface and second surface. Consequently, if a crack propagates along the interface, it must propagate significantly farther than it would across a straight interface. Each of these mechanisms can be used separately or in combination with other mechanisms to toughen the feedthrough
30 (409). The specific mechanism or combination of mechanisms can be selected based on specific designs, materials, expected loads, and other factors.

[0047] Fig. 4E illustrates two cracks (411, 416) propagating through the feedthrough (409) with a serpentine conductor/ceramic interface illustrated in Fig. 4D. In this example, the plane of maximum driving force (410) is oriented
35 horizontally. As discussed above, the plane of maximum driving force (410) can be influenced by a number of factors, including the direction and magnitude of

5 forces that are applied to the feedthrough. A first crack (411) begins to propagate from the left side of the feedthrough (409) along the interface (415). Because the interface (415) is not aligned with the plane of maximum driving force (410), the crack (411) initially propagates along an angled path (412) that follows the interface (415). In this example, the angled path (412) is at
10 approximately a 45 degree angle from the plane of maximum driving force (410). Consequently, the angled path (412) may reduce the crack propagation force to approximately $\frac{3}{4}$ of the original value. As the crack (411) continues along the interface (415), the crack crosses the conductor (406) to take a path that is more closely aligned to the plane of maximum driving force (410). When
15 the crack (411) crosses the conductor (406), the conductor (406) bridges the crack. The bridges (414) across the crack (411) are identified by the dashed circles. In the first bridge (414-1), the conductor (406) shows some ductile necking as it absorbs a portion of the crack propagation energy. These bridges (414) resist further widening of the crack (411) and limit its propagation.

20 **[0048]** Fig. 4E also illustrates a second crack (416) initiated by a different impact force directed into the ceramic, rather than directly at an interface. A second crack (416) propagates through the feedthrough (409) from the right hand side. This crack is deflected by the interface (415) and terminates at the edge of the feedthrough. As discussed above, this edge is
25 brazed into the titanium can. The growth may stop when it encounters the ductile braze material. In this example, the crack terminates at the edge of the feedthrough and does not propagate through the remainder of the ceramic body. Consequently, the ceramic body maintains a hermetic seal between the interior and exterior of the implanted device. In at least these ways, the
30 structured interface (415) can provide significant toughening of the feedthrough.

[0049] The embodiments described above are only illustrative examples of the principles described herein. A number of variations of these principles could also be used. As described above, the ceramic body may be an alumina ceramic and the conductor may be platinum. According to one
35 illustrative example, the feedthrough may be formed by laying down a first green ceramic tape and then laying the conductors over the first green ceramic tape.

5 A second green ceramic tape is placed on top of the first green ceramic tape so that the conductor is sandwiched between the two ceramic tapes. The assembly is then fired to densify the ceramic and produce the ceramic body.

[0050] The first green ceramic tape could be formed by stamping, rolling, or extrusion. According to one illustrative example, the green ceramic
10 tape may be formed by die-pressing. The upper surface of the first green ceramic tape then has the desired shape. The platinum conductor is draped over the shaped upper surface and the second green ceramic tape is laid over the platinum conductor. When firing the assembly, pressure may be applied as well as heat to ensure that the ceramic tapes join and that there are no voids in
15 the resulting ceramic body. A variety of post firing processes can be used, such as machining, lapping, polishing, grinding, or other processes. These post firing processes produce the feedthrough in its final form and prepare it to be joined to an aperture in the hermetic case.

[0051] In an alternative example, the first green ceramic tape may be
20 partially fired and then machined to the desired shape. Alternatively, the first green ceramic tape may be formed and then partially fired. The conductor is placed over the partially fired tape and the second green ceramic tape is then pressed into place. Because the partially fired tape is significantly more structural than the second green ceramic tape, it will not plastically deform
25 during subsequent operations. This can result in the conductor path more precisely following the desired path.

[0052] In yet another example, the conductor may be sandwiched between two green ceramic sheets to form a pliable assembly. The entire assembly is then formed into the desired configuration. For example, the
30 assembly could be rolled or stamped to produce the desired rotation of the conductor. The assembly is then fired and machined into the desired finished shape. In this example, the green ceramic sheets may be thicker and/or wider than in previous examples to allow for deformation during the stamping or rolling process. These thicker sheets can then be machined to the final dimensions.

35 [0053] The conductor path may also be varied in an X-Y plane that passes through the length of the feedthrough. Figs. 5A and 5B are cross

5 sections of taken along the X-Y plane of the feedthroughs (500, 501) and show
plan views of a number of illustrative shapes of ribbon vias (502, 504). In these
examples, the ribbon vias (502, 504) are formed prior to being incorporated into
the ceramic body (102). For example, the ribbon vias (502, 504) may be laser
micromachined, stamped, or cut into the desired shapes. The ribbon vias (502,
10 504) are then sandwiched between the green ceramic sheets. The shaping
operations described above with respect to Figs. 4B-4D can also be performed
using the ribbon vias (502, 504). The shaped ribbon vias (502, 504) vary the
path in the X-Y plane, and the paths shown in Figs. 4B-4D can vary the
conductor path in the X-Z plane. For example, Fig. 5 C shows a shaped ribbon
15 via (504) that takes a curved path through a ceramic body (102). This results in
a three dimensional path of conductors through the ceramic body.

[0054] In addition to engineering the macro structure of the
conductors, a number of microstructural features of the conductor surfaces can
be used to enhance the fracture toughness of feedthrough. Figs. 6A-6C are
20 diagrams that show etched patterns on the surface of a conductor that alter the
conductor/ceramic interface to form localized weak or strong bonding regions
along the interface. This enhances the extrinsic fracture toughness of the
feedthrough by inducing crack jumping. Crack jumping occurs where a ductile
layer between two brittle materials causes a crack propagating along the
25 interface to alternately jump from one side of the ductile layer to the other. This
forms a bridging zone behind the crack tip where ductile layer bridges the crack
and dissipates energy by plastic deformation. This acts to hold the crack tip
closed and decreases the driving force for crack extension. A number of
illustrative structured interfaces that promote crack jumping are shown below in
30 Fig. 6A-6D.

[0055] Fig. 6A shows a number of patterns (600) formed by extrinsic
toughening features (616) in the surfaces of conductors or ceramic prior to
joining the conductor and ceramic to form the feedthrough. A first pattern (600-
1) includes a number of angled ellipses formed over the interface surface. A
35 second pattern (600-2) is a modified checkerboard pattern. A third pattern (600-
3) includes a number of horizontal segments extending from the borders of the

5 interface surface. A fourth pattern (600-4) includes horizontal bars extending across the entire width of the interface surface.

[0056] The patterns described above and illustrated in Fig. 6A are only illustrative examples. A wide range of other patterns could be used, including random patterns, staggered arrays, arbitrary geometries, and other
10 configurations. The patterns may be formed by a variety of additive or subtractive methods. Subtractive methods may include localized ablation, etching, or machining of portions of the conductor or ceramic surface. Additive methods may include selective deposition of cladding, coatings, or adhesion layers. For example, the localized regions can be formed by local ablation
15 before joining, by patterning of a cladding and using a pTLP (partial transient liquid phase) approach, selective deposition of higher adhesion layer, or selective deposition of a low adhesion layer. A number of other adhesion promoting agents could be used at the interface including chromium and titanium. The adhesion promoting agents could be deposited on the conductor
20 using a variety of techniques and patterns. Each of these methods creates microstructural variations in the interface that interfere with crack propagation.

[0057] According to one illustrative example, the conductor is platinum foil, and a layer of niobium is selectively deposited over one or more surfaces of the platinum foil. Areas of the platinum foil with a niobium overcoat form
25 stronger bonds with the surrounding ceramic using a pTLP (partial transient liquid phase) approach. An illustrative pTLP bonding approach is described in U.S. Pat. App. Pub. No. 12/836,831, entitled "Electrical Feedthrough Assembly," to Kurt Koester, filed on July 15, 2010, which was incorporated by reference above. Depending on the properties of these structures it may be desirable to
30 use different structures on the top and the bottom of the ribbons. For example, if an Nb layer on the Pt foil is an effective adhesion layer for the Pt, it may be patterned on top and bottom to promote crack jumping.

[0058] Fig. 6B shows a cross section of a portion of a feedthrough. In this example, the conductor (602) passes linearly through the ceramic body
35 (102). The upper conductor/ceramic interface (604) is uniform, while the lower conductor/ceramic interface (606) has a number of extrinsic toughening features

5 (616). In this example, the extrinsic toughening features are actually small voids or areas of bonding weakness in the lower conductor ceramic interface (606) that promote crack jumping. This patterned interface may be created in a number of ways including using partial transient liquid phase bonding. For example, the conductor (606) may be platinum. A niobium coating is deposited
10 on both sides of the conductor (606) and then selectively removed from portions of the lower interface (606). The conductor is sandwiched between two ceramic bodies (102-1, 102-2) and heated. The niobium/platinum interface melts and the liquid niobium platinum alloy wets and flows into the ceramic. The niobium rapidly diffuses into the main portion of the platinum conductor, altering the
15 composition of the liquid niobium platinum alloy, which then rapidly solidifies. Consequently, in the areas where the niobium layer is deposited on the platinum conductor, strong bonds with the ceramic are formed. In areas (616) where the niobium layer is removed, a much weaker bond is formed. As shown below, these weaker bond areas (616) mitigate crack propagation and produce an
20 overall increase in the toughness of the feedthrough.

[0059] Fig. 6C shows a cross section of a portion of a feedthrough (624) with a conductor (662) with patterned upper and lower surfaces (625, 626). In this example, strong bond areas (628) are illustrated with a zigzag line at the interface while weaker bond areas (626) are recessed and have a straight
25 interface. This type of interface can be formed in a number of ways, including patterning the ceramic layers (102-1, 102-2) and pressing a malleable conductor (622) between the two layers. In some examples, the conductor and ceramic may also be heated to facilitate the bonding and conformation of the conductor to the pattern in the ceramic.

30 [0060] In addition to forming a structure that promotes crack jumping, the textured interfaces have a greater surface area and length than a straight interface. The larger surface area and length inhibit crack growth in several ways. First, the larger surface area promotes stronger bonding between the conductor and ceramic. Second, the texture creates interlocking elements that
35 have high bond strength. Third, for a crack to follow the textured interface, the crack must make numerous turns that are out of the plane of maximum driving

5 force. Fourth, the increased length of the interface requires that the crack must propagate a longer distance before compromising the feedthrough (624).

[0061] Fig. 6D shows a crack that has propagated along the lower interface of the feedthrough (614) shown in Fig. 6B. In this example, a separating force (610) is illustrated as two approximately vertical arrows. The
10 separating force (610) results in a preferred crack propagation direction (612). A crack (618) has started to propagate along the upper and lower interfaces (604, 606). In this example, the upper interface (604) is less strongly bonded to the metal than the strongest portions of the lower interface. Alternatively, the upper interface (604) may be bonded more strongly than the lower interface
15 (606) or have equal strength.

[0062] The extrinsic toughening features (616) have produced crack jumping along the interfaces (604, 606). In this example, the crack jumping occurs on both interfaces and the crack (618) jumps across the conductor (602) from one interface to the other. The ductile conductor (602) forms a bridging
20 zone behind the crack tip where uncracked metal dissipates energy by plastic deformation and acts to hold the crack tip closed. This creates a number of ductile bridges (605, 606, 607) across the crack (618). As shown in Fig. 6D, the bridges (605, 606, 607) exert forces that tend to draw the upper ceramic layer (102-1) and lower ceramic layer (102-2) together and resist the expansion of the
25 crack. This bridging decreases the driving force for crack extension.

[0063] The thickness and properties of the ductile metal conductor (602) can be designed to maximize the effectiveness of the structured interfaces. For example, the thickness of the conductor (602) could be designed to be approximately equal to the natural plastic zone, or process zone,
30 of a growing crack in this material. This would provide the minimum thickness while still providing the maximum possible benefits of the plastic deformation of the ductile phase. The plastic zone size can be varied by changing the yield stress of the metallic conductor. For example, adding iridium to the platinum will increase the yield stress and decrease the size of the plastic zone.
35 Consequently, the optimal thickness of a platinum iridium alloy conductor may be different than that of a platinum conductor.

5 **[0064]** There are a variety of ways to create, combine, and apply the principles described above. For example, the principles described above could also be applied to the interface between the ceramic and the aperture in the titanium case.

10 **[0065]** Fig. 7 is an illustrative method for creating microstructured interfaces in an electrical feedthrough. A patterned layer is formed on a first surface of an electrical conductor and includes areas of adhesion promoting agent and areas without an adhesion promoting agent (step 705). The pattern may be formed in a variety of ways including depositing an adhesion promoting agent over a surface of the electrical conductor and then using subtractive
15 patterning to remove portions of the adhesion promoting agent from the first surface. For example, a layer of niobium, chromium, or titanium may be deposited over the surface of the conductor. The subtractive patterning may be etching, laser ablation, or other suitable technique. In other examples, the pattern may be formed using additive techniques to deposit the adhesion
20 promoting agent on the surface. For example, the pattern may be formed by masking portions of the surface, depositing the adhesion promoting agent, and then removing the masking to expose bare portions of the surface. A patterned layer can also be formed on the opposite surface of the electrical conductor.

25 **[0066]** The surface of the electrical conductor is bonded to a ceramic body to create an interface with areas of differential adhesion between the electrical conductor and the ceramic body (710), configuring the areas of differential adhesion to promote crack jumping. For example, the electrical conductor may be platinum, the adhesion promoting agent may be niobium, and bonding to the surface of the electrical conductor may include partial transient
30 liquid phase bonding. Areas patterned with a niobium overcoat are strongly adhered to the ceramic and areas without niobium are weakly adhered to the ceramic. This creates the pattern of differential adhesion that promotes crack jumping.

35 **[0067]** In sum, interfaces between electrical conductors and ceramic bodies in a feedthrough can be particularly susceptible to cracking. However, by appropriately structuring these interfaces, the toughness and lifetime of the

5 feedthrough can be substantially increased. As shown above, an electrical
feedthrough may include a ceramic body with a first surface and a second
surface and a continuous electrical conductor that passing through the ceramic
body from the first surface to the second surface. Forces applied to the
feedthrough form a plane of maximum driving force. The structured interface
10 between the ceramic body and the electrical conductor is configured so that at
least a portion of the structured interface is oriented in a different plane than the
plane of maximum driving force. The microstructure of the interface can also be
modified to strengthen the interface and/or promote crack jumping.

[0068] The preceding description has been presented only to illustrate
15 and describe embodiments and examples of the principles described. This
description is not intended to be exhaustive or to limit these principles to any
precise form disclosed. Many modifications and variations are possible in light
of the above teaching.

5

CLAIMS

WHAT IS CLAIMED IS:

- 10 1. An electrical feedthrough with a structured interface comprises:
a ceramic body with a first surface and a second surface;
a first electrical conductor passing through the ceramic body from the first
surface to the second surface; and
a structured interface between the ceramic body and the electrical
15 conductor adapted to exhibit extrinsic toughening mechanisms in the wake of a
crack propagating along the interface.
2. The feedthrough of claim 1, in which the structured interface has a
constant slope between the first surface and second surface.
- 20 3. The feedthrough of claim 1, in which the structured interface between the
first surface and second surface is a continuous curve with a constantly
changing slope.
- 25 4. The feedthrough of claim 1, in which the structured interface has a
serpentine shape.
5. The feedthrough according to any of the above claims, in which the
structured interface is plane of weakness configured to divert crack propagation
30 away from a linear path between the first surface and second surface.
6. The feedthrough according to any of the above claims, further comprising
a second electrical conductor adjacent to the first conductor, in which a
structured interface of the second electrical conductor comprises a different
35 geometric profile than the structured interface of the first electrical conductor.

5 7. The feedthrough according to any of the above claims, in which the conductor is a platinum foil that is micromachined to create geometric variations in the structured interface between the conductor and the ceramic.

10 8. The feedthrough according to any the above claims, in which the structured interface comprises a platinum niobium alloy adhered to the ceramic body using partial transient liquid phase bonding.

15 9. The feedthrough according to any of claims 1-7, in which the structured interface is a gold braze joining a platinum conductor to the ceramic body.

20 10. The feedthrough according to any of the above claims, in which the structured interface comprises defined areas with different adhesion strengths, the defined areas being configured to promote crack jumping across the conductor.

25 11. The feedthrough of claim 10, in which the defined areas comprise low adhesion strength areas distributed over the structured interface in a geometric pattern and high adhesion strength areas of niobium/platinum alloy that are bonded to the ceramic using partial transient liquid phase bonding.

30 12. The feedthrough of claim 11, in which the defined areas with different adhesion strengths are arranged in a periodic geometric pattern configured to promote crack jumping.

35 13. The feedthrough according to any of the above claims, in which a thickness of the first electrical conductor is at least as great as a zone of plastic deformation at a crack tip in the conductor material.

 14. The feedthrough according to any of the above claims, in which the conductor comprises a first surface and a second surface, the first surface patterned with areas having differential levels of adhesion between the

5 conductor and ceramic and the second surface patterned with areas having differential levels of adhesion between the conductor and ceramic.

15. The feedthrough according to any of the above claims, further comprising: a plane of maximum driving force; and

10 a plane of weakness formed by the structured interface, the plane of weakness oriented in a different plane than the plane of maximum driving force, the plane of weakness being configured to divert crack propagation away from the plane of maximum driving force.

15 16. A method for creating structured interfaces in electrical feedthroughs, comprising:

forming a patterned layer on a first surface of an electrical conductor which comprises areas of adhesion promoting agent and areas without the adhesion promoting agent; and

20 bonding the surface of the electrical conductor to a ceramic body to create an interface with areas of differential adhesion between the electrical conductor and the ceramic body, the areas of differential adhesion being configured to promote crack jumping.

25 17. The method of claim 16, in which forming a patterned layer comprises: depositing an adhesion promoting agent over the first surface of the electrical conductor; and

using subtractive patterning to remove portions of the adhesion promoting agent from the first surface.

30

18. The method of claim 17, in which the electrical conductor is platinum, the adhesion promoting agent is niobium, and bonding the surface of the electrical conductor comprises partial transient liquid phase bonding.

35 19. The method of claim 16, further comprising:

forming a patterned layer on a second opposing surface of the electrical conductor; and

5 bonding the second opposing surface of the electrical conductor to the ceramic body.

20. An electrical feedthrough with a structured interface comprises:

 a ceramic body with a first surface and a second surface;

10 a first electrical conductor passing through the ceramic body from the first surface to the second surface;

 a plane of maximum driving force; and

 a structured interface between the ceramic body and the electrical conductor, at least a portion of the structured interface comprising a plane of
15 weakness oriented in a different plane than the plane of maximum driving force, the plane of weakness being configured to divert crack propagation away from the plane of maximum driving force.

20

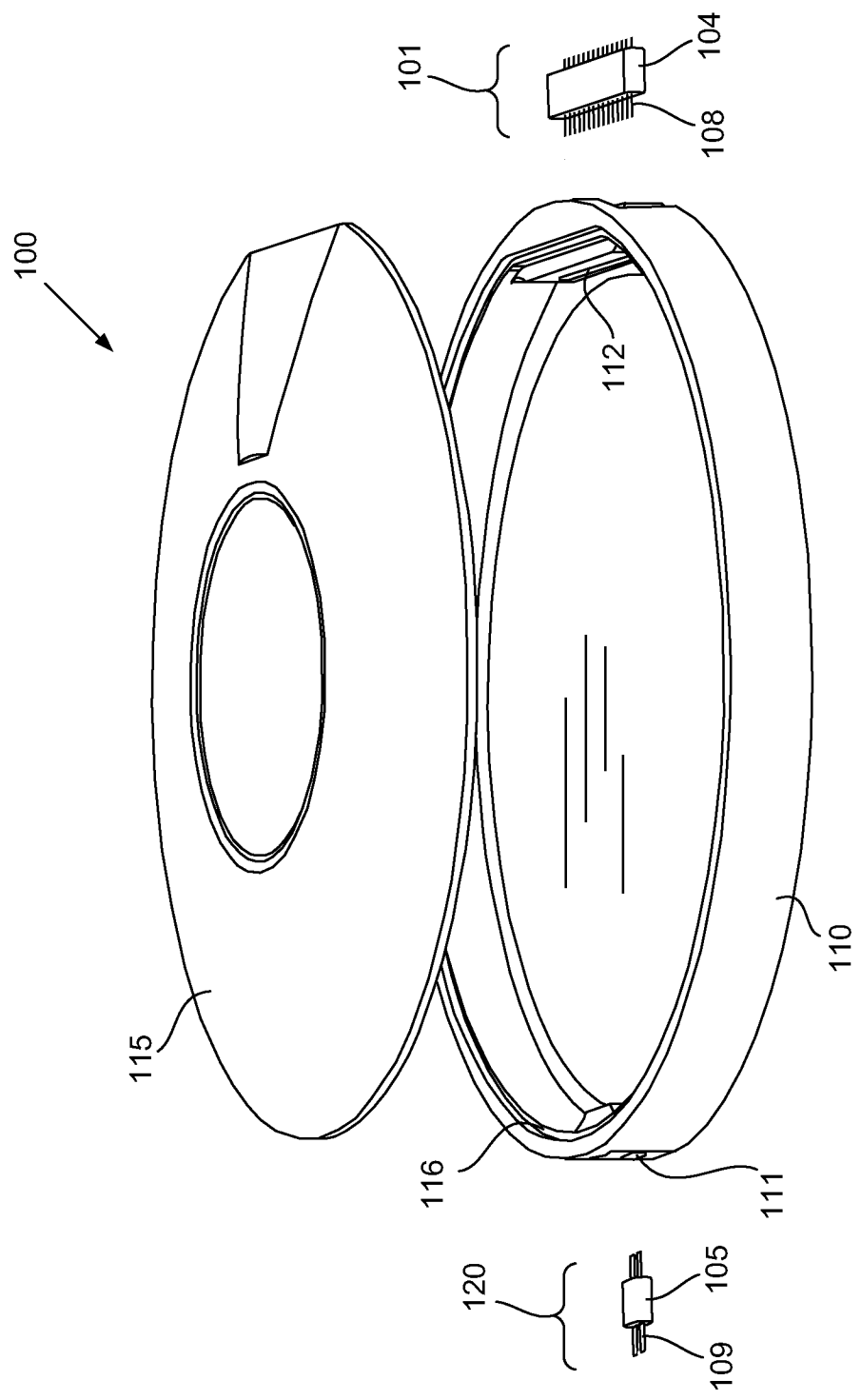


Fig. 1

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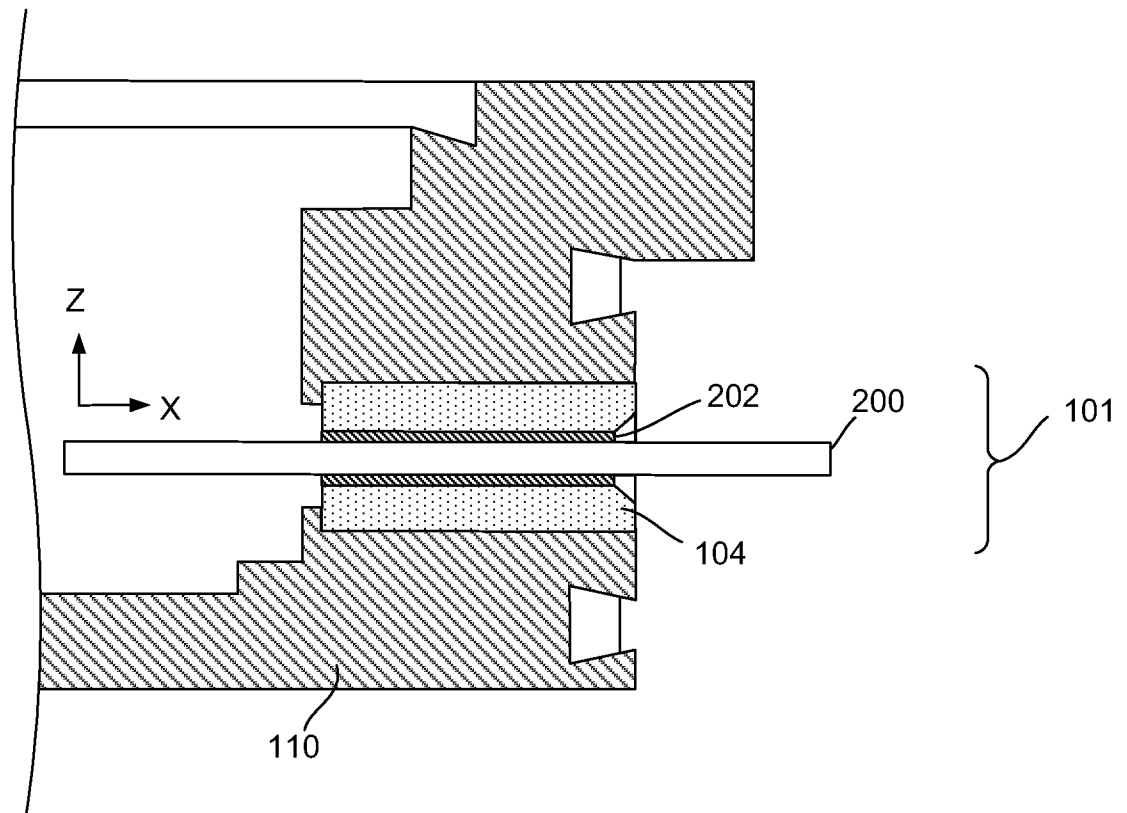


Fig. 2A

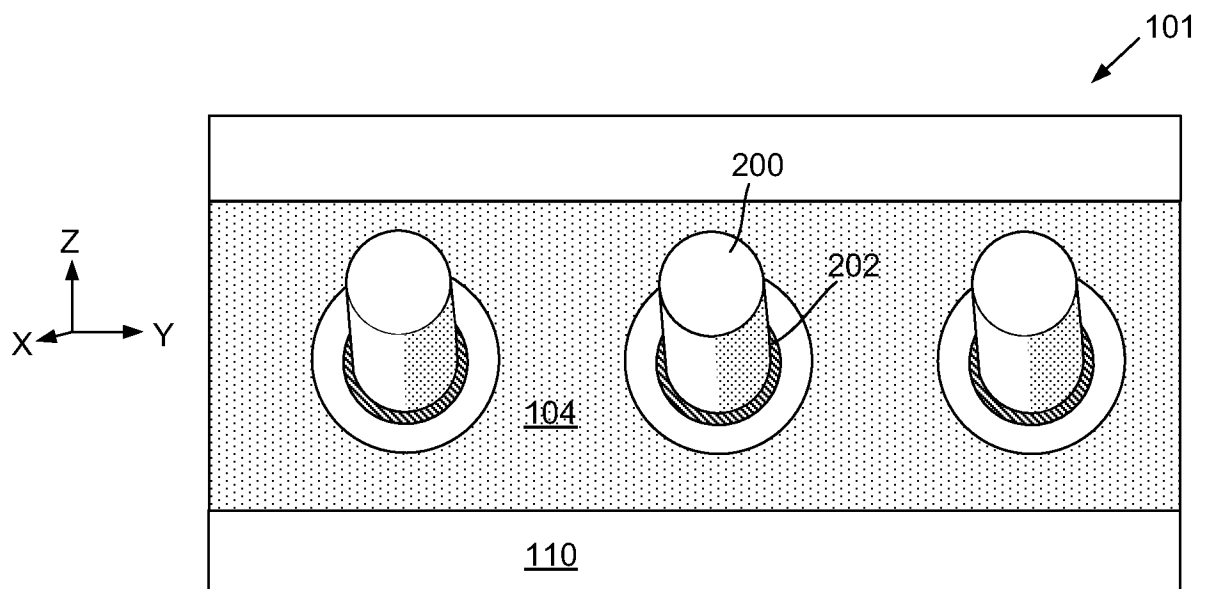
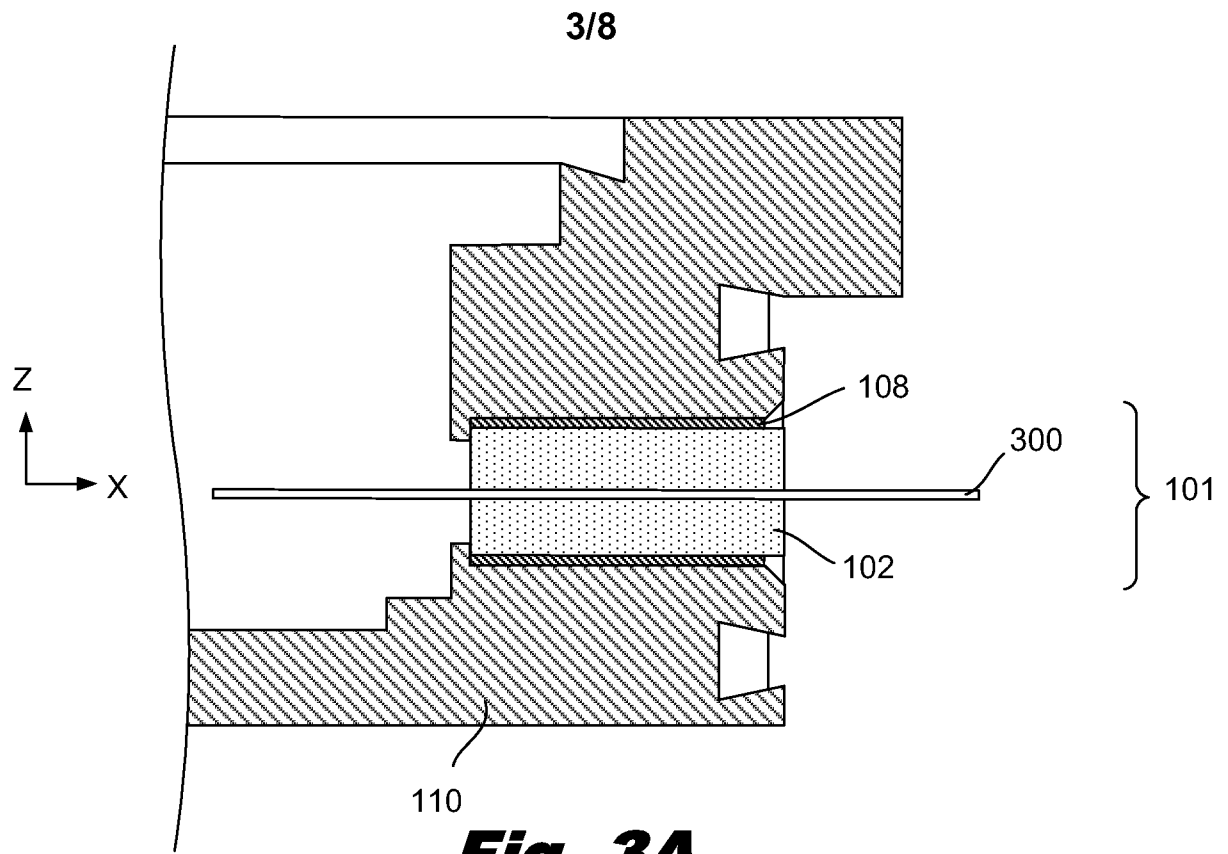
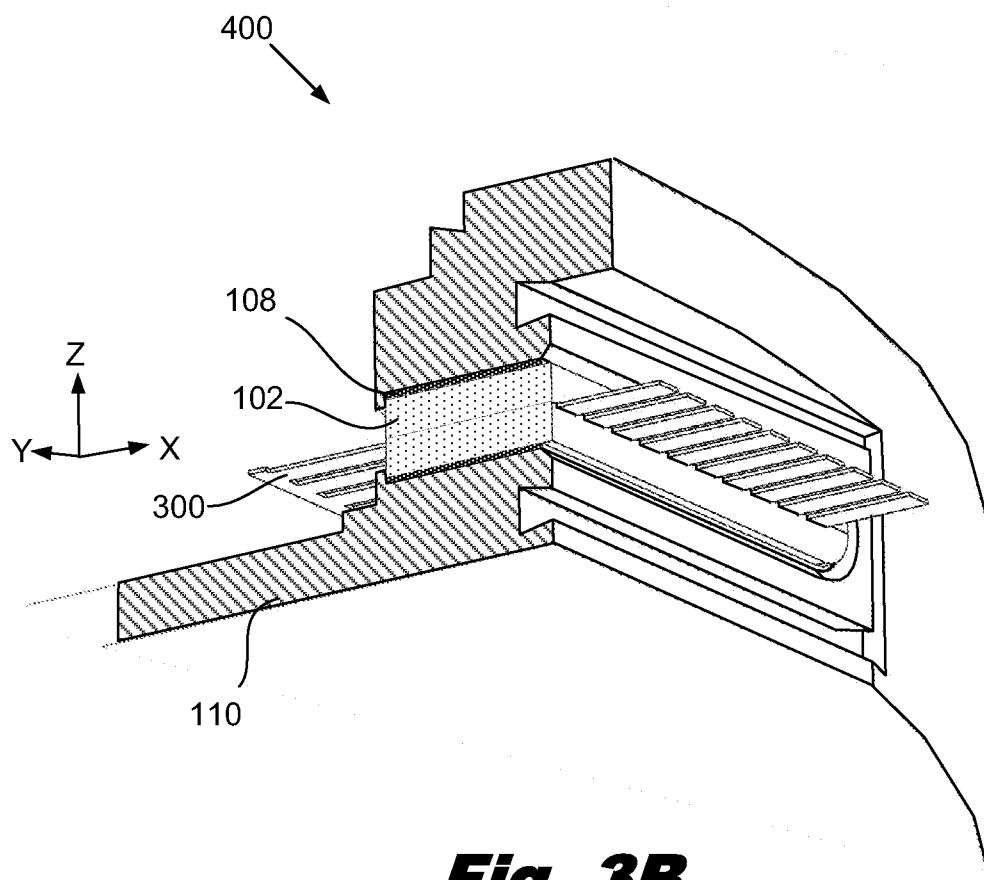


Fig. 2B

**Fig. 3A****Fig. 3B**

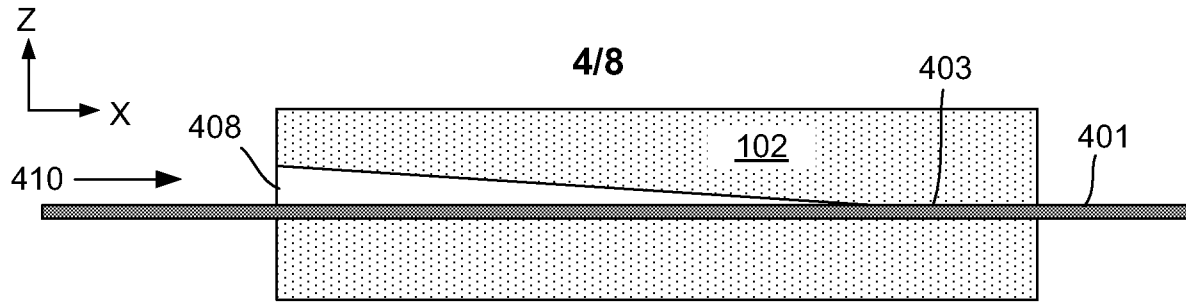


Fig. 4A

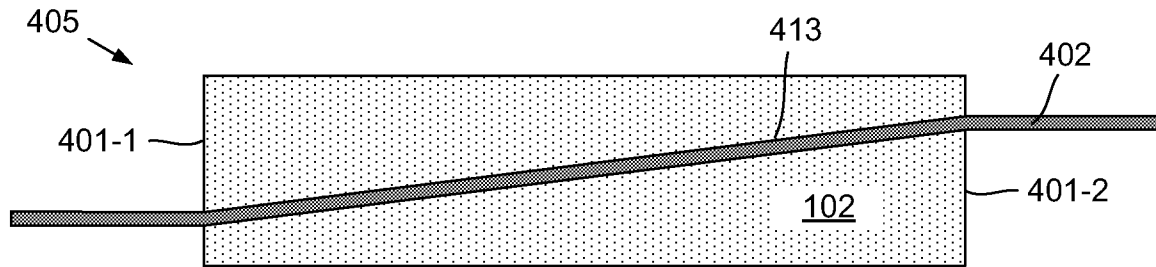


Fig. 4B

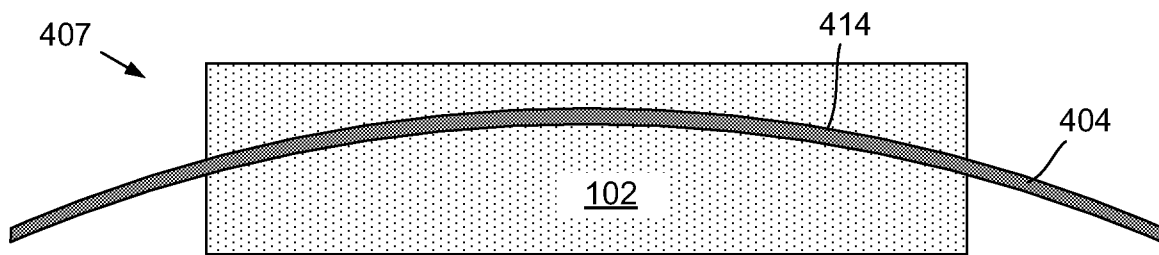


Fig. 4C

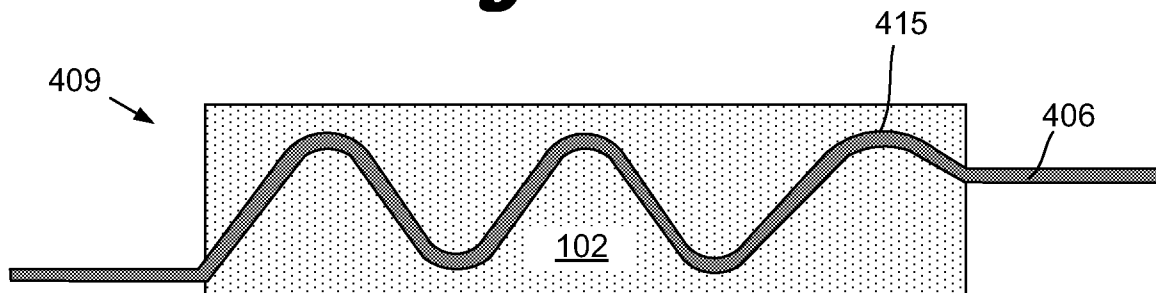


Fig. 4D

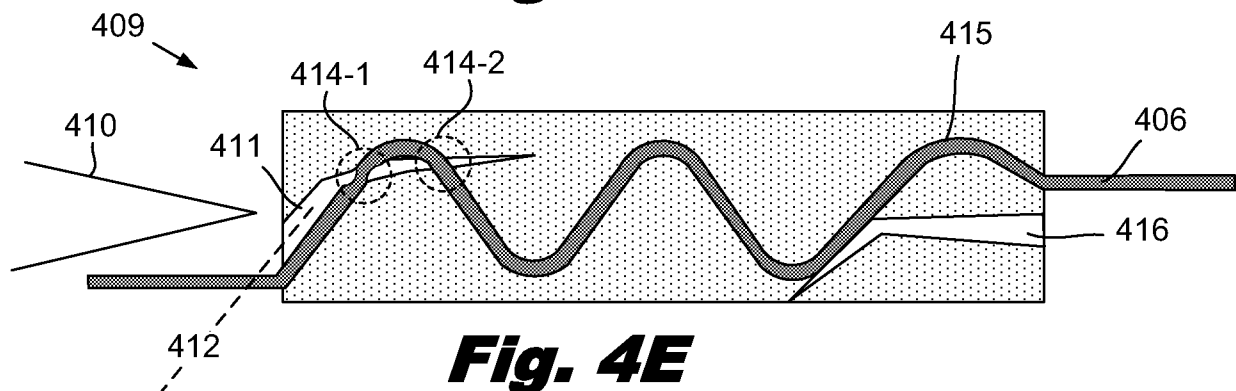


Fig. 4E

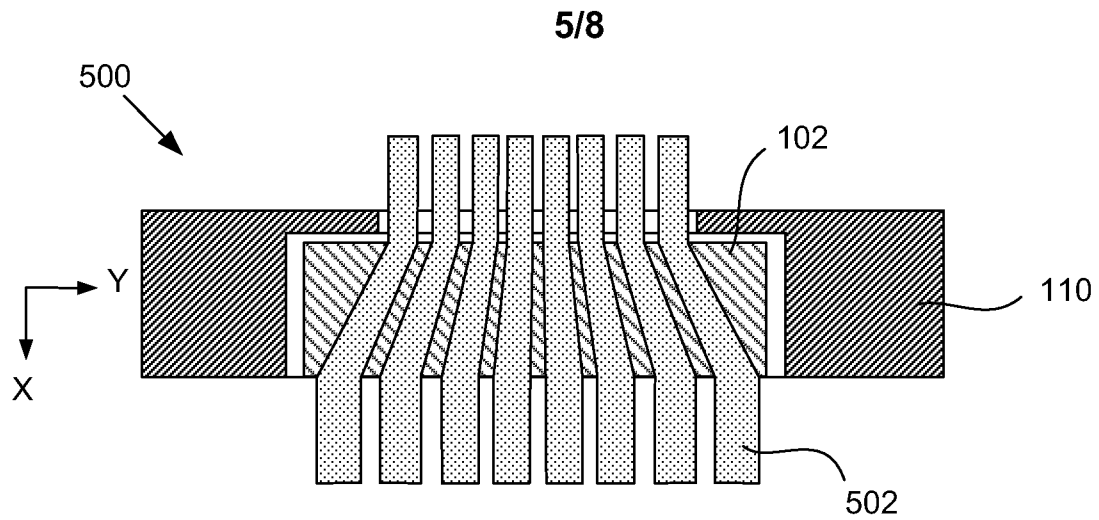


Fig. 5A

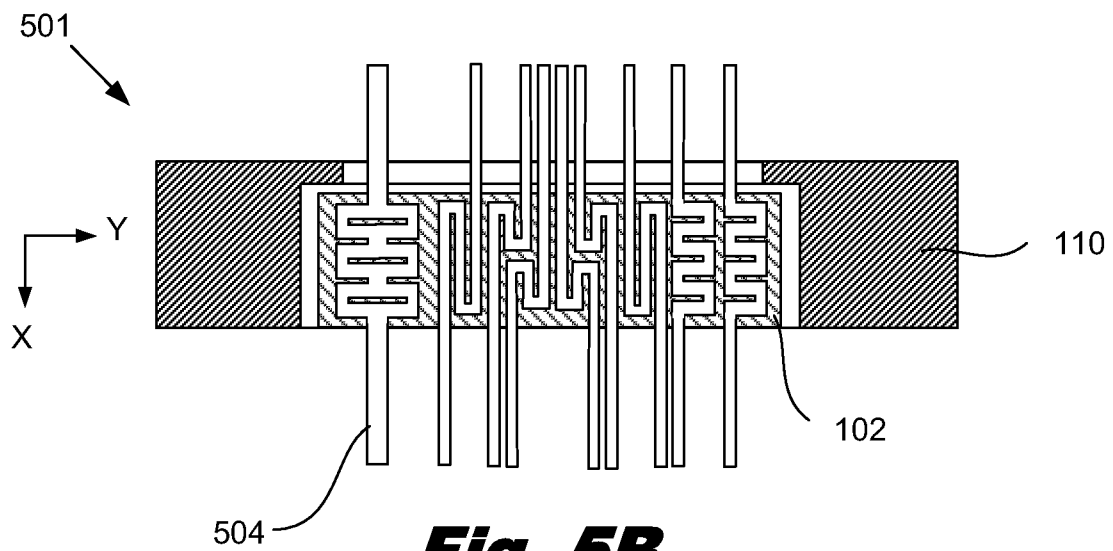


Fig. 5B

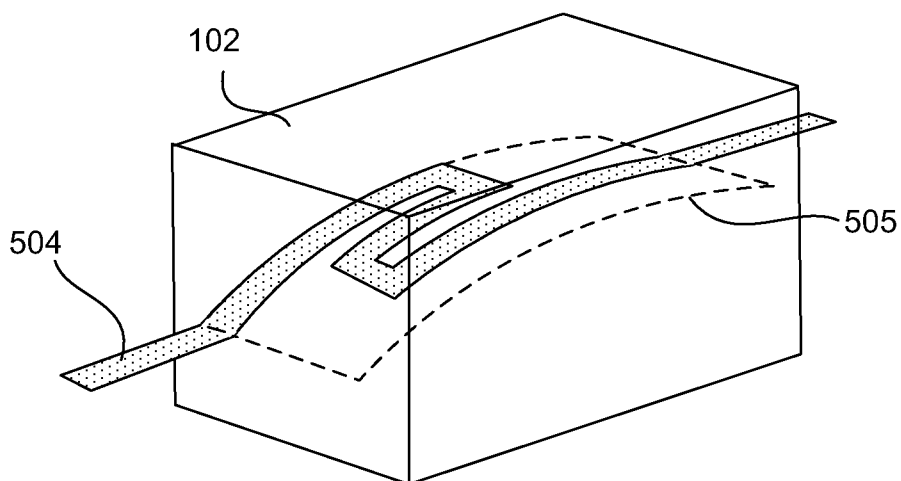


Fig. 5C

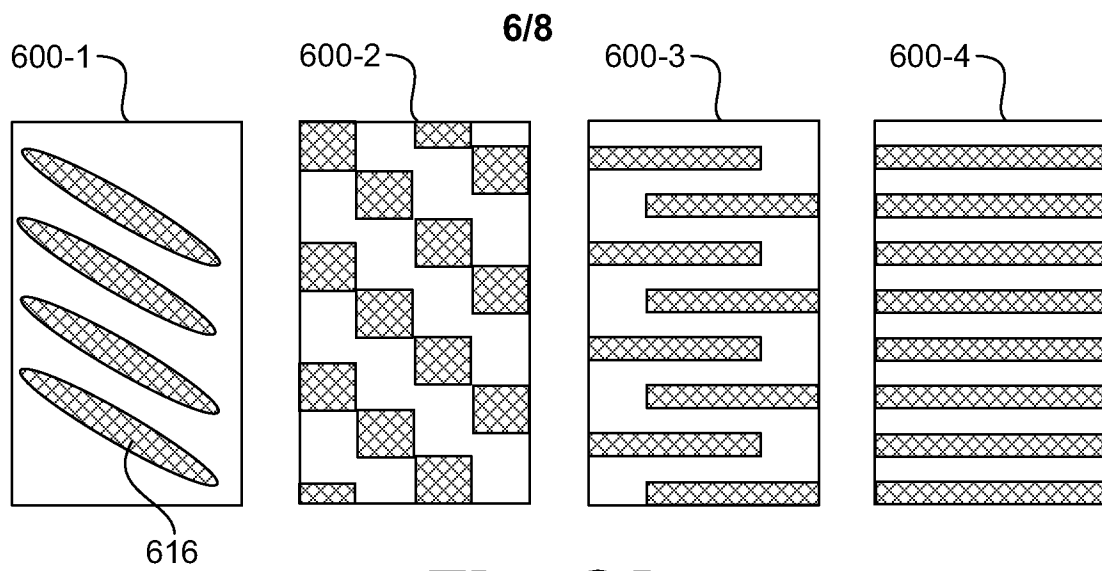


Fig. 6A

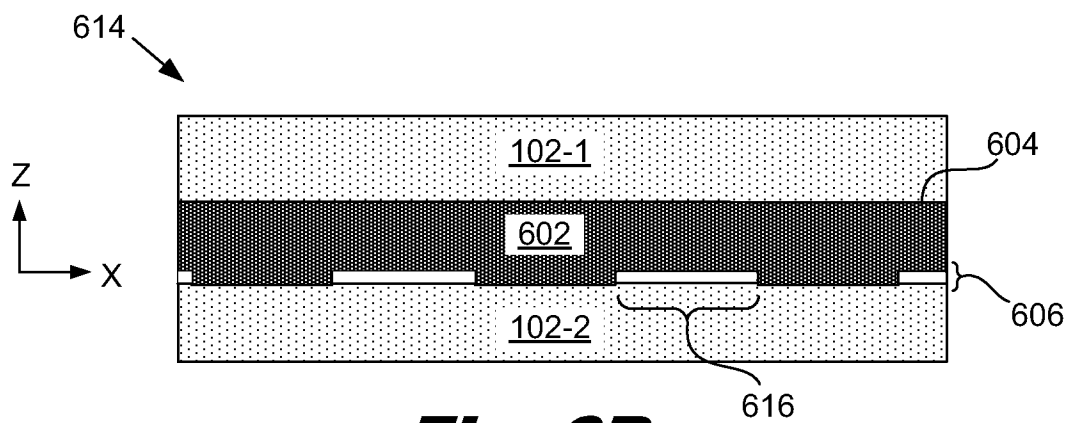


Fig. 6B

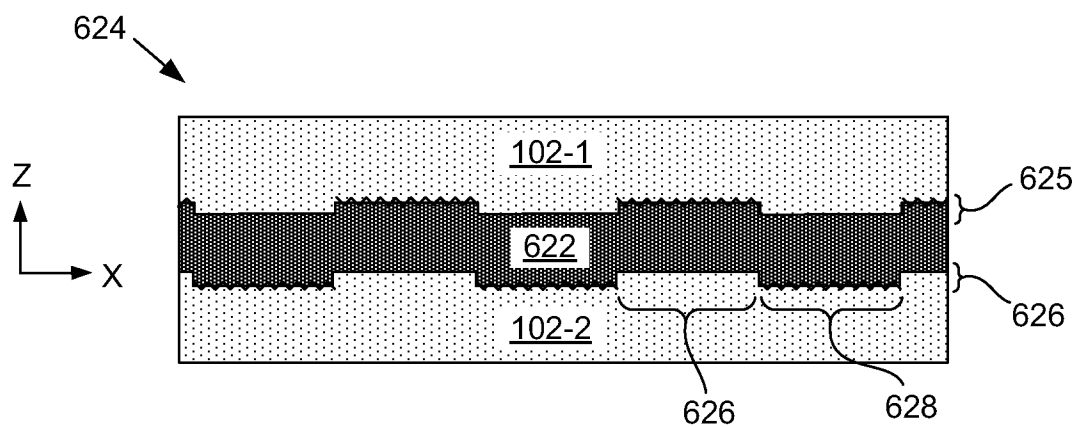


Fig. 6C

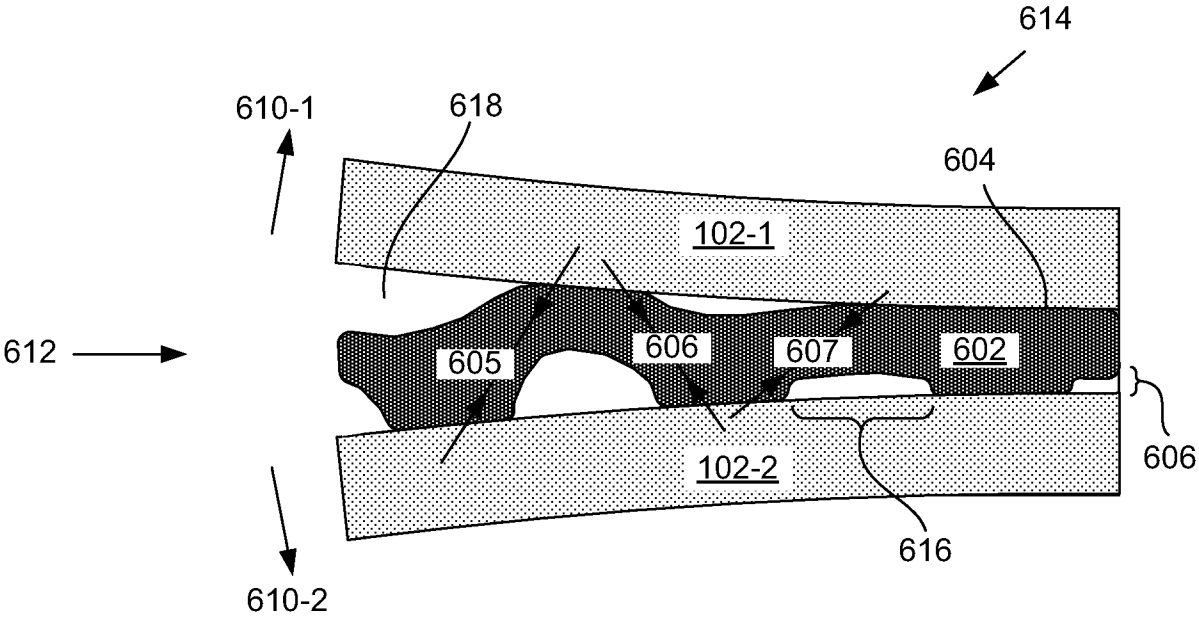
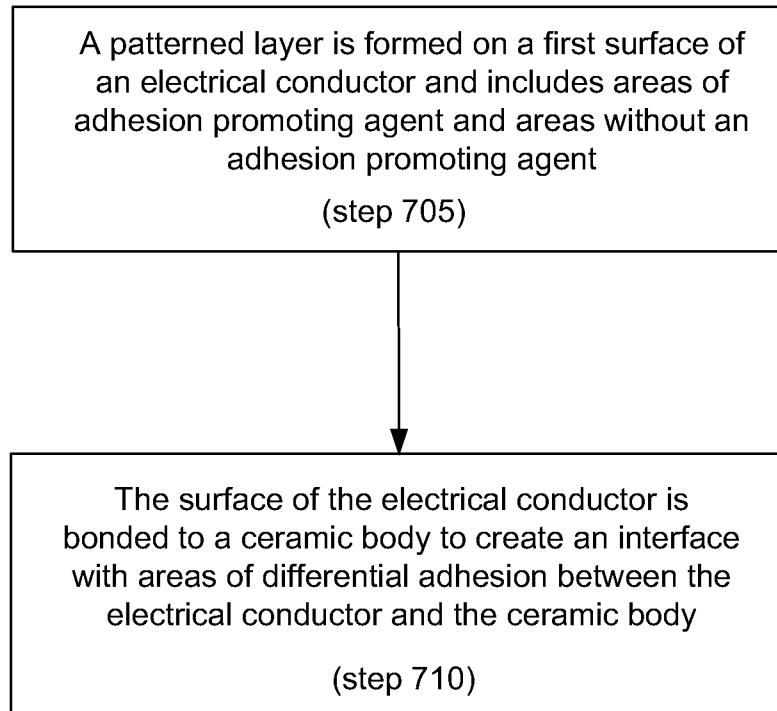


Fig. 6D

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700
**Fig. 7**