



(51) International Patent Classification:
A61N 1/375 (2006.01) *H01G 4/35* (2006.01)

(21) International Application Number:
PCT/US2011/064821

(22) International Filing Date:
14 December 2011 (14.12.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/423,337 15 December 2010 (15.12.2010) US

(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).

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

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on next page]

(54) Title: CRACK DIVERSION PLANES IN CERAMIC FEEDTHROUGHS

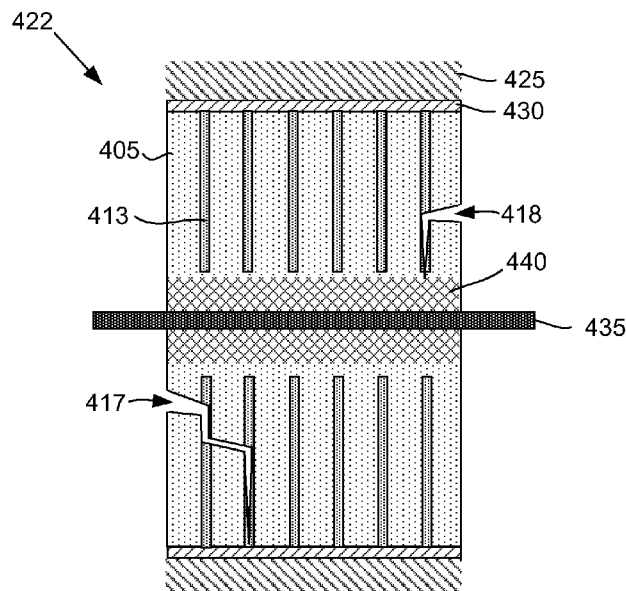


Fig. 4D

(57) Abstract: A hermetic feedthrough assembly including a ceramic body having an exterior surface and an interior surface and being joined around a perimeter surface to a hermetic case. The ceramic body includes a ceramic matrix and a diversion plane disposed within the ceramic matrix, the orientation of the diversion plane being selected to increase resistance of the ceramic matrix to crack propagation from the exterior surface to the interior surface and vice versa. A plurality of electrical conductors passes through the ceramic body from the exterior surface to the interior surface.



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Declarations under Rule 4.17:

- *as to the identity of the inventor (Rule 4.17(i))*
- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

- *with international search report (Art. 21(3))*

5

CRACK DIVERSION PLANES IN CERAMIC FEEDTHROUGHS

10

RELATED DOCUMENTS

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 61/423,337, entitled "Crack Diversion Planes in Ceramic 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 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. Ceramic can be used to form the body of the feedthrough, with a number of electrically conductive pins passing through the ceramic. Ceramic has a number of benefits, including resistance to chemical corrosion, high strength, and fluid and vapor impermeability. However, crack propagation through the ceramic can reduce the reliability of the hermetic feedthrough.

30

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.

35

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

[0005] Fig. 2 is a cross sectional diagram of an illustrative electrical feedthrough that includes a ceramic body with conductive pins passing through the body, according to one example of principles described herein.

[0006] Fig. 3 is a perspective view of the illustrative feedthrough shown in Fig. 2, according to one example of principles described herein.

[0007] Figs. 4A-4F are diagrams showing illustrative crack diversion planes in ceramic bodies, according to one example of principles described herein.

[0008] Figs. 5A and 5B show illustrative steps in creating crack diversion planes in ceramic bodies, according to one example of principles described herein.

[0009] Throughout the drawings, identical reference numbers designate similar, but not necessarily identical, elements.

DETAILED DESCRIPTION

[0010] Human implant technologies often make use of implanted electronic devices. Hermetically sealed cases are used to protect electronic components in the implanted devices from bodily fluids and various mechanical forces. As mentioned above, a feedthrough is often used to form an electrical or physical connection between the interior and the exterior of a sealed case. An electrical feedthrough maintains the integrity of the hermetically sealed case, while allowing electrical signals to pass through.

[0011] The electrical feedthrough is often constructed as a separate element and then sealed into an aperture in a wall of an implant housing. One of the determining factors for the impact resistance of the implant is the toughness of the feedthrough. For example, an implanted processor of a cochlear implant is typically located above and behind the external ear. Impacts to the head of the user can create significant loads on the implanted processor and the feedthroughs.

5 **[0012]** As used in the specification and appended claims, the term
“ceramic” is used broadly and does not distinguish between glass, glass
ceramic, ceramic composites and other types of ceramic materials. Ceramic
can form the body of the feedthrough, with a number of electrically conductive
pins passing through the ceramic. The ceramic has a number of benefits,
10 including resistance to chemical corrosion, high strength, fluid and vapor
impermeability, and other advantages. However, ceramic can exhibit low
fracture toughness. This can lead to failures of the ceramic from crack
propagation. Toughening the ceramic by including engineered microstructures
can significantly reduce failure of the feedthrough.

15 **[0013]** 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,
however, to one skilled in the art that the present apparatus, systems, and
methods may be practiced without these specific details. Reference in the
20 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
necessarily in other embodiments. The various instances of the phrase “in one
embodiment” or similar phrases in various places in the specification are not
25 necessarily all referring to the same embodiment.

[0014] Fig. 1 is an exploded view of an illustrative hermetic enclosure
(100) that houses cochlear implant electronics. In this particular example, the
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
30 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
include multiple elements. The multiple pieces may be connected through a
variety of methods including, but not limited to, brazing, laser welding, or
35 bonding.

5 **[0015]** According to one illustrative example, the case (110) and the case top (115) are formed from titanium. Titanium has a number of desirable characteristics, including high strength, resiliency, biocompatibility, low density, and low permeability. The case (110) shown in Fig. 1 is a closed-bottom 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 laser welded or brazed onto the case (110). Once the case top (115) and hermetic electrical feedthroughs (101, 120) are 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).

20 **[0016]** 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). The conductors (108, 109) pass through and are sealed in the ceramic body. The sealing of the conductors to the ceramic body may take place in a variety of ways, including gold brazing or partial transient liquid phase (pTLP) bonding.

25 **[0017]** The ceramic body (104, 105) is then joined to the appropriate aperture (111, 112) in the case (110). A variety of techniques, including gold brazing, can be used to join the ceramic body to the case (110). In this illustrative example, the hermetic feedthroughs (101, 120) are on the perimeter of the case (110). 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 sites on the case (110) or the case top (115).

30 **[0018]** Figs. 2 and 3 illustrate a feedthrough (101) that includes cylindrical pins (200) that are sealed into the ceramic body (104) using a gold braze joint (202). Fig. 2 is a cross-sectional view of a portion of the case (110) that includes the feedthrough (101). The left side of the pin (200) is connected

5 to components that are internal to the case (110) and the right side of the pin (200) is connected to components that are external to the case (110). As discussed above, the pin (200) may have a variety of geometries and may be formed from a variety of materials. In this example, the pins (200) are cylindrical and formed from platinum or a platinum alloy such as platinum
10 iridium.

[0019] Fig. 3 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 pins (200) that are sealed with a gold joint (202). The braze joint (202) may be formed in a variety of ways. For example,
15 the gold braze joint (202) may be formed by placing the platinum pins through holes in a fully densified ceramic body (104). The platinum pins (200) and ceramic body (104) are heated and melted gold or gold alloy is drawn by capillary action into the gap between the platinum pin (200) and the ceramic body (104).

20 [0020] In an alternative example, two or more green ceramic layers are used to form the ceramic body. These green ceramic layers could be formed in a variety of ways, including, but not limited to, tape casting, ceramic injection molding, or die pressed ceramic. The pins (200) are coated with a layer of gold around their circumference and laid on a bottom green ceramic
25 layer. An upper green ceramic layer is laid over the pins (200) and the bottom layer. This sandwiches the gold coated pins between two layers of green ceramic. The green ceramic is then densified by the application of heat and pressure. During this process, the upper and lower layers are joined and the gold forms a seal between the ceramic (104) and the pins (200). The ceramic
30 body (104) can be joined to the case (110) in a number of ways, including brazing, active metal brazing, ceramic/metal joining, transient liquid phase bonding, or other suitable techniques.

[0021] Ceramic is typically considered a brittle material. Brittle materials exhibit very little plastic deformation prior to failure. Cracks tend to
35 propagate long distances through brittle materials with little warning. Further, predicting where and when brittle materials will fail is difficult. As discussed

5 above, the reliability of the ceramic body can become a limiting factor in some
implant designs. For example, the ceramic body can be fractured through its
thickness. This can destroy the hermetic seal and create an opening for the
passage of fluids and/or gasses into the case. There are a number of
mechanisms through which cracks can propagate in a ceramic. A first crack
10 propagation mechanism results from the application of forces that exceed the
local yield strength of the ceramic material. For example, these forces may be
generated by mechanical impact or temperature changes that cause differential
expansion of components in the device.

[0022] Crack propagation typically begins at a flaw or discontinuity in
15 the ceramic. The flaw or discontinuity may be a scratch, indentation, inclusion,
devitrified region, bubble, edge, corner, grain boundary, or other discontinuity in
the ceramic. The flaw or discontinuity creates stress concentrations when the
ceramic is subject to mechanical stress. These stress concentrations create
situations where the ceramic body fails at stresses that are far below levels
20 predicted by the ceramic's theoretical strength.

[0023] When the stresses concentrated by the flaw exceed the local
yield strength of the ceramic material, the crack forms at the flaw and begins to
propagate through the ceramic. The crack tip then concentrates the stress.
Continued application of stresses that cause forces greater than the fracture
25 strength of the material at the crack tip results in propagation of the crack.
Large cracks in the ceramic can compromise the sealing, electrical, and
mechanical properties of the feedthrough. The fracture toughness of a ceramic
material is a measure of its resistance to fracture when forces are applied.

[0024] A number of illustrative examples of structures and methods for
30 toughening ceramic bodies used in feedthroughs are described below. These
methods include the creation of crack diversion planes in a ceramic material.
The principles described below with respect to crack diversion planes are
broadly applicable to ceramics. However, for purposes of illustration, the crack
diversion planes are discussed in the context of ceramic feedthrough bodies.

35 **[0025]** Intrinsic toughening mechanisms are typically active in ductile
materials and are damage mechanisms that primarily occur ahead of the crack

5 tip and increase the material's resistance to fracture, *e.g.*, plasticity. Extrinsic toughening mechanisms are active in brittle materials and are principally 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, microcracking, etc. Ceramics can be extrinsically toughened materials and their fracture resistance
10 and stress corrosion crack-growth resistance can be improved by enhancing these extrinsic toughening mechanisms or introducing new toughening mechanisms.

[0026] According to one illustrative example, the ceramic feedthrough bodies can be toughened by providing extrinsic toughening mechanisms that
15 mitigate crack propagation through the ceramic. As used in the specification and appended claims the term "mitigate" or "mitigating" crack propagation refers to inhibiting, deflecting, arresting, or otherwise reducing crack propagation through the ceramic.

[0027] Figs. 4A and 4B show structures that exhibit increased
20 toughness by diverting and arresting cracks. Fig. 4A shows a multilayer ceramic structure that includes matrix layers (405) and a number of microstructural diversion planes (410). In general, any material can be used that creates an interface that is stronger or weaker than adjacent matrix material. In some embodiments, the planes could be formed from insulating, conductive, or
25 semiconducting materials in a matrix of insulating or semiconducting materials. For example, silicon nitride planes in an alumina matrix could be used. The plane of maximum driving force (415) is shown by a chevron shaped line (415) that enters multilayer structure (400) from the left. The diversion planes (410) are oriented out of the plane of crack propagation.

[0028] As used in the specification and appended claims, the term
30 "plane of maximum driving force" is used to describe a plane 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
35 plane of maximum driving force could be different in between successive impact events. For the feedthrough configurations shown, the plane of maximum

5 driving force may be on one of the two free surfaces of the feedthrough—the other faces are protected, bonded to, and supported by the surrounding case. Consequently, the bonded ceramic faces may not experience as high of forces as the two free faces and the likelihood of a crack beginning at these bonded ceramic faces is low.

10 **[0029]** There is a significant advantage in deflecting the crack propagation direction away from the plane of maximum driving force. The amount of driving force available to drive the crack through the ceramic can be dramatically lower when the crack direction is different than the plane of maximum driving force. Consequently, when cracks are deflected away from
15 the plane of maximum driving force, the ceramic body is “tougher” because it can withstand higher applied loads without failure of the hermetic seal. The deflection mechanism achieves this toughening even when the crack diversion planes are weaker than the ceramic matrix.

[0030] Fig. 4B shows a multilayer feedthrough (420) that has been
20 formed from alternating layers of ceramic matrix (405) and diversion planes (410). The multilayer feedthrough (420) has been joined to a hermetic case (425) by a braze joint (430). The multilayer feedthrough (420) has a first free face (403) on the left side of the feedthrough and a second free face (404) on the right side of the feedthrough. When a crack propagates from the first free
25 face (403) to the second free face (404) or vice versa, the hermetic seal is compromised. For example, the first free face (403) may be an exterior surface on the tissue side of the hermetic case and the second free face (404) may be an interior surface on the component side of the hermetic case.

[0031] In this example, a crack (415) has formed in the leftmost layer
30 of the feedthrough (420). As the crack (415) propagated through the multilayer feedthrough (420) it encountered several diversion planes (410). These diversion planes (410) are configured to divert the crack. After passing through two of the matrix layers (405), the crack (415) is diverted by a diversion plane (410) to the ductile braze joint (430). The ductile braze joint (430) plastically
35 deforms and diffuses the force at the crack tip. This prevents further propagation of the crack (415). In this case, although a crack (415) formed in

5 the feedthrough (420), the crack (415) was diverted so that it did not pass through the thickness of the feedthrough (420) and did not compromise the hermetic seal.

[0032] Fig. 4C shows a number of diversion planes (411) placed at an angle to the front surface of the feedthrough. These diversion planes (412) are
10 more likely to divert a crack (416) that is advancing from the exterior of the feedthrough (421) because the angle of the diversion plane is closer to the plane of maximum driving force. Further, because the diversion planes are oriented at an angle, the cracks are diverted away from the conductor (435). In some configurations, the interface between the conductor and ceramic matrix
15 may be relatively weak compared to the ceramic matrix and allow for preferential crack growth. Diverting cracks away from the conductor (435) can be advantageous to preserve the function of the conductor and to prevent crack propagation along the interface between the conductor and ceramic matrix.

[0033] Fig. 4D shows a feedthrough (422) that uses a combination of
20 dispersed particles (440) and diversion planes to prevent crack growth from compromising the hermetic integrity of the feedthrough (422). In this example, the dispersed particles (440) are concentrated in an area immediately adjacent to the conductor. These dispersed particles (440) are formed from a ductile material and provide both intrinsic and extrinsic mechanisms that reduce the
25 likelihood that a crack will encounter the conductor (435). The dispersed particles intrinsically strengthen the ceramic by reducing the stress concentration at a crack tip and extrinsically strength the ceramic by bridging the crack behind the crack tip. The use of particulates to strengthen ceramic bodies is described in U.S. Prov. Pat. App. No. 61/423,337, filed December 15, 2010,
30 entitled "Particulate Toughened Ceramic Feedthrough," to Kurt J. Koester, which is incorporated herein by reference in its entirety. The dispersed particles (440) help prevent the crack from propagating along the interface between the conductor (435) and the surrounding ceramic. In some examples, techniques such as partially transient liquid phase bonding and fully transient liquid phase
35 bonding can be used to create strong bonds between the dispersed particles

5 and the ceramic. In some examples, the particles may also employ or activate self-healing chemistry to mitigate crack propagation.

[0034] One example of partially transient liquid phase bonding is the use of platinum particles coated with niobium embedded in the ceramic matrix. The platinum has a high melting point and the niobium has a lower melting
10 point. During processing, the niobium melts and forms a liquid phase of a niobium/platinum alloy on the surface of the platinum. This liquid phase wets the ceramic and creates a strong bond between the ceramic and the platinum particle. The niobium then rapidly diffuses from the surface of the platinum into the platinum particle. This changes the composition of the liquid phase and
15 raises its melting point. Consequently, the liquid phase solidifies after a short period of time. Niobium is just one example of an additive that can be used at grain boundaries between the ductile particles and the ceramic matrix. A variety of other additives could be used.

[0035] Fig. 4D shows diversion planes (413) that are parallel to the
20 interior and exterior surfaces of the feedthrough and perpendicular to the conductor (435). When a crack encounters a diversion plane (413) that is perpendicular to its propagation direction, the crack can propagate in either direction along the diversion plane. Two cracks (417, 418) are illustrated in the ceramic feedthrough (422). The trajectories of both cracks (417, 418) are
25 altered by the diversion planes (413). A first crack (417) enters the ceramic body (405) from the left and is diverted into the braze joint (430). A second crack (418) enters the ceramic body (405) from the right surface and propagates toward the conductor (435). However, it may not be desirable for the crack (418) to actually encounter the conductor (435). To prevent this, a
30 concentration of ductile particulates (440) is formed around the conductor (435). As discussed above, the dispersed particles can strengthen the ceramic by reducing the stress concentration at a crack tip and extrinsically strengthen the ceramic by bridging the crack behind the crack tip. Consequently, the growth of the crack (418) can be arrested by the particles (440) before encountering the
35 conductor (435).

5 **[0036]** Fig. 4E is a perspective view of a portion of a feedthrough (470) with a number of parallel diversion planes (410) that are configured as a crack divider. Crack dividers increase the toughness of a ceramic or glass material by incorporating a number of diversion planes that divide the crack and energy driving the crack. Orienting the diversion planes out of the plane of maximum driving force (415) causes an increase in the toughness of the material even if the diversion planes are weaker than the ceramic matrix. In this example, the diversion planes are oriented substantially perpendicular to a free face of the feedthrough. If the crack rotates and is deflected into a diversion plane then it must grow with diminished driving force. Because the crack is propagating outside of the plane of maximum driving force for crack propagation, only a fraction of the total driving force is then available to further the crack growth. If the crack does not deflect then it must continue to grow on the higher toughness path where it is divided into multiple sub-cracks (472) by the parallel diversion planes (410). As the crack (415) is divided into many separate sub-cracks (472), the amount of driving force available to advance a given sub-crack (472) is substantially diminished. The smaller driving forces significantly reduce the likelihood that any sub-crack (472) will continue to advance. Consequently, a crack divider can significantly increase the fracture toughness of the feedthrough (470).

25 **[0037]** According to one illustrative example, the diversion planes (410) are oriented in the X-Z plane while the plane of maximum driving force is oriented in the X-Y plane. As discussed above, the diversion planes (410) tend to rotate portions of a crack from the X-Y plane to the X-Z plane and/or divide the crack front.

30 **[0038]** Fig. 4F shows a portion of a feedthrough (480) that has a number of diversion planes (410) in a crack arrestor configuration. In a crack arrestor configuration, the diversion planes (410) are oriented orthogonally to the plane of maximum driving force (415). As the crack (482) generated by the driving force (415) moves through the ceramic matrix, (405) it repeatedly encounters perpendicular diversion planes. The crack has a tendency to be

35

5 diverted either up or down by the perpendicular diversion planes. This impedes the crack grown and toughens the feedthrough.

[0039] To most effectively use crack dividers and diversion planes, they should be placed within the ceramic matrix at appropriate locations and orientations. Determining the most effective placement of crack dividers and
10 diversion planes can be difficult for a number of reasons. In many ceramic applications, any type or orientation of cracking can result in failure. For example, a crack propagating in any direction through a ceramic turbine blade can compromise the function of the blade, the turbine, and the aircraft. Similarly, a crack through a ceramic bone prosthesis in any direction could
15 compromise the health and function of the user of the prosthesis.

[0040] Additionally, the orientation of the plane of maximum driving force is not typically known in advance. For example, the plane of maximum driving force created by an impact event is not known until the impact event occurs. The plane of maximum driving force would typically vary from event to
20 event. Consequently, prior knowledge of the plane of maximum driving force cannot typically be relied on to determine the most advantageous configuration of the diversion planes or crack divider.

[0041] The inventor has recognized several characteristics of ceramic feedthroughs that can be used to help determine locations and orientations of
25 diversion planes and crack dividers that provide an advantage in reducing crack propagation. First, the ceramic feedthroughs maintain their hermetic integrity as long as a crack does not propagate from an exterior side of the feedthrough to the interior side of the feedthrough or vice versa. Further, ceramic feedthroughs are typically bounded around a perimeter by a much more crack resistant body.
30 As discussed above, a ceramic feedthrough may be brazed into an aperture of a titanium case. The braze material and titanium surround the ceramic feedthrough around a perimeter surface of the ceramic feedthrough. The sides of the ceramic that are bonded to the titanium case are typically much less prone to cracking. Consequently, one crack propagation direction between the
35 interior and exterior surfaces can be more important to guard against than other directions.

5 **[0042]** The analysis given above is only an example of principles that may be used to select orientation, location, and configuration of diversion planes in ceramic feedthroughs. A variety of other configurations, principles, and methods can be used to determine the most advantageous configuration for a given ceramic body. For example, if a critical plane of maximum driving force
10 can be estimated from the operating environment, the configuration of the diversion planes can be readily determined. Additionally, numerical modeling, such as finite element analysis and Monte Carlo simulations could be used to fine tune the designs.

[0043] The diversion planes can be any plane of differential
15 toughness. For example, the principle of diverting crack propagation works both with “planes of weakness” as well as “planes of strength.” Planes of weakness may be formed in a number of ways, including forming a plane of weaker material within a stronger material or forming an interface between two materials that has is relatively weak compared to the surrounding materials. For example,
20 an interface may be formed with a controlled number of defects. These planes of weakness actually increase the overall toughness of the feedthrough because they deflect the trajectory of the crack propagation. When a crack is deflected, the driving force is decreased and the crack is directed toward an edge of the feedthrough where the crack can be terminated by the surrounding metal.

25 **[0044]** A plane of strength may be a strong material or a strong interface that is relatively resistant to crack propagation. As a crack approaches the plane of strength, it can either penetrate the plane or be deflected. In either case, the crack propagation is mitigated. For example, silicon nitride planes may be formed in an alumina matrix. Because silicon nitride is approximately
30 50% tougher than alumina, the silicon nitride forms planes of strength that can be used to preferentially direct crack trajectories.

[0045] In some examples, the orientation of the diversion planes may be selected based on the relative strength or weakness of the diversion plane. For example, a plane of weakness may be perpendicular to a preferred crack
35 propagation direction. For crack to have the same propensity to travel along the perpendicular plane of weakness as to continue through the ceramic matrix, the

5 plane of weakness will have a fracture toughness that is approximately half the fracture toughness of the matrix. For angles that are closer to the preferred crack propagation direction, the plane of weakness can have higher fracture toughness while still influencing the crack propagation trajectory.

10 **[0046]** Figs. 5A and 5B show illustrative steps for forming a multilayer ceramic feedthrough with enhanced toughness. In a first step, a green ceramic body (502) is formed (step 500). The green ceramic body (502) may be a ceramic tape and may be deposited in a number of ways. For example, casting, extrusion, stamping, rolling, or other processes could be used to form the ceramic tape.

15 **[0047]** A second layer or coating (507) is deposited over the green ceramic body (502) (step 505). The coating can be deposited using a variety of coating techniques, including gravure, flexographic, screen printing, knife, roll, curtain, spray, brush, dip, or other suitable coating technique. The resulting green body (502, 507) is then diced as shown by dotted lines (513) (step 510).
20 The diced sections are then stacked into a multilayer assembly (517) (step 515). The conductors (524) are then sandwiched between the multilayer assemblies to form electrical feedthrough assemblies (521, 522) (step 520). The electrical assemblies (521, 522) are fired to densify the green ceramic layers and produce electrical feedthroughs (526, 527) with enhanced toughness (step 525).

25 **[0048]** Figs. 5A and 5B show only one illustrative method for producing electrical feedthroughs with enhanced toughness. A variety of other methods could be used. For example, a multilayer green ceramic structure could be built and then diced into the desired segments. The dicing could occur before or after firing the multilayer structure. Additionally, the layers could be
30 oriented in a number of different ways. It should be noted that it is possible to build a multilayer structure and then dice it into the desired size. It is possible to orient the multilayered structure in a number of ways to obtain the desired geometry. In Fig. 5A, only two orientations are shown, but it is possible to have a combination of these orientations or intermediate orientations. Further, the
35 multilayers may be "capped" with a desired material by using or skipping a final coating process.

5 **[0049]** In sum, the toughness of ceramic materials used for feedthroughs can be improved by creating functional microstructures. These microstructures can include multiple layers to influence the direction of crack propagation and suppress hermetic failures. The individual layers in the multilayer stacks will have different fracture resistances and the resulting
10 diversion planes can be oriented advantageously to deflect cracks and prevent hermetic failures.

[0050] The preceding description has been presented only to illustrate and describe embodiments and examples of the principles described. This description is not intended to be exhaustive or to limit these principles to any
15 precise form disclosed. Many modifications and variations are possible in light of the above teaching.

5

CLAIMS

WHAT IS CLAIMED IS:

1. A hermetic feedthrough assembly comprising:
10 a ceramic body having an exterior surface and an interior surface and being joined around a perimeter surface to a hermetic case, the ceramic body comprising:
a ceramic matrix; and
a diversion plane disposed within the ceramic matrix, the
15 orientation of the diversion plane being selected to increase resistance of the ceramic matrix to crack propagation from the exterior surface to the interior surface and vice versa; and
a plurality of electrical conductors passing through the ceramic body from the exterior surface to the interior surface.
20
2. The assembly of claim 1, in which the diversion plane is configured to influence the trajectory of a crack passing through the ceramic body.
3. The assembly according to any of the above claims, in which the
25 diversion plane is not substantially parallel to the path of the electrical conductors passing through the ceramic body.
4. The assembly according to any of the above claims, in which the diversion plane is angularly oriented within the ceramic matrix to direct a crack
30 away from the electrical conductors.
5. The assembly according to any of the above claims, in which the ceramic body is brazed into an aperture in the hermetic case with a ductile braze material, the diversion plane being angularly oriented to direct a crack to the
35 ductile braze material.

5 6. The assembly according to any of the above claims, in which the diversion plane is a plane of weakness which strengthens the ceramic by diverting the crack away from a plane of maximum driving force.

10 7. The assembly according to any of the above claims, further comprising a plurality of diversion planes configured as a crack divider that divides a propagating crack into multiple cracks and reorients the multiple cracks out of a plane of maximum driving force.

15 8. The assembly of claim 7, in which the diversion planes are oriented substantially parallel to a free face of the feedthrough.

9. The assembly of claim 7, in which the diversion planes are oriented substantially perpendicular to a free face of the feedthrough.

20 10. The assembly according to any of the above claims, in which a portion of the ceramic matrix comprises ductile particulates.

25 11. The assembly of claim 10, in which the ductile particulates comprise platinum with a niobium coating.

12. The assembly of claim 11, in which the ductile particulates are bonded to the ceramic matrix by a partially transient liquid phase bond.

30 13. The assembly according to any of the above claims, in which the diversion planes have greater fracture toughness than the matrix.

35 14. A feedthrough for an implanted electronic device comprising a ceramic body hermetically joined to a metallic case around a perimeter of the ceramic body, the ceramic body comprising a ceramic matrix with diversion planes oriented to selectively direct crack propagation trajectories toward the perimeter of the ceramic body.

- 5 15. A method for forming a multilayer ceramic feedthrough with enhanced toughness comprising:
- forming a green ceramic body;
 - depositing a coating over the green ceramic body;
 - dicing the green ceramic body and coating to form diced sections;
 - 10 stacking the diced sections to form a multilayer assembly;
 - sandwiching the conductors between the multilayer assemblies to form the multilayer ceramic feedthrough; and
 - firing the multilayer ceramic feedthrough.

15

1/6

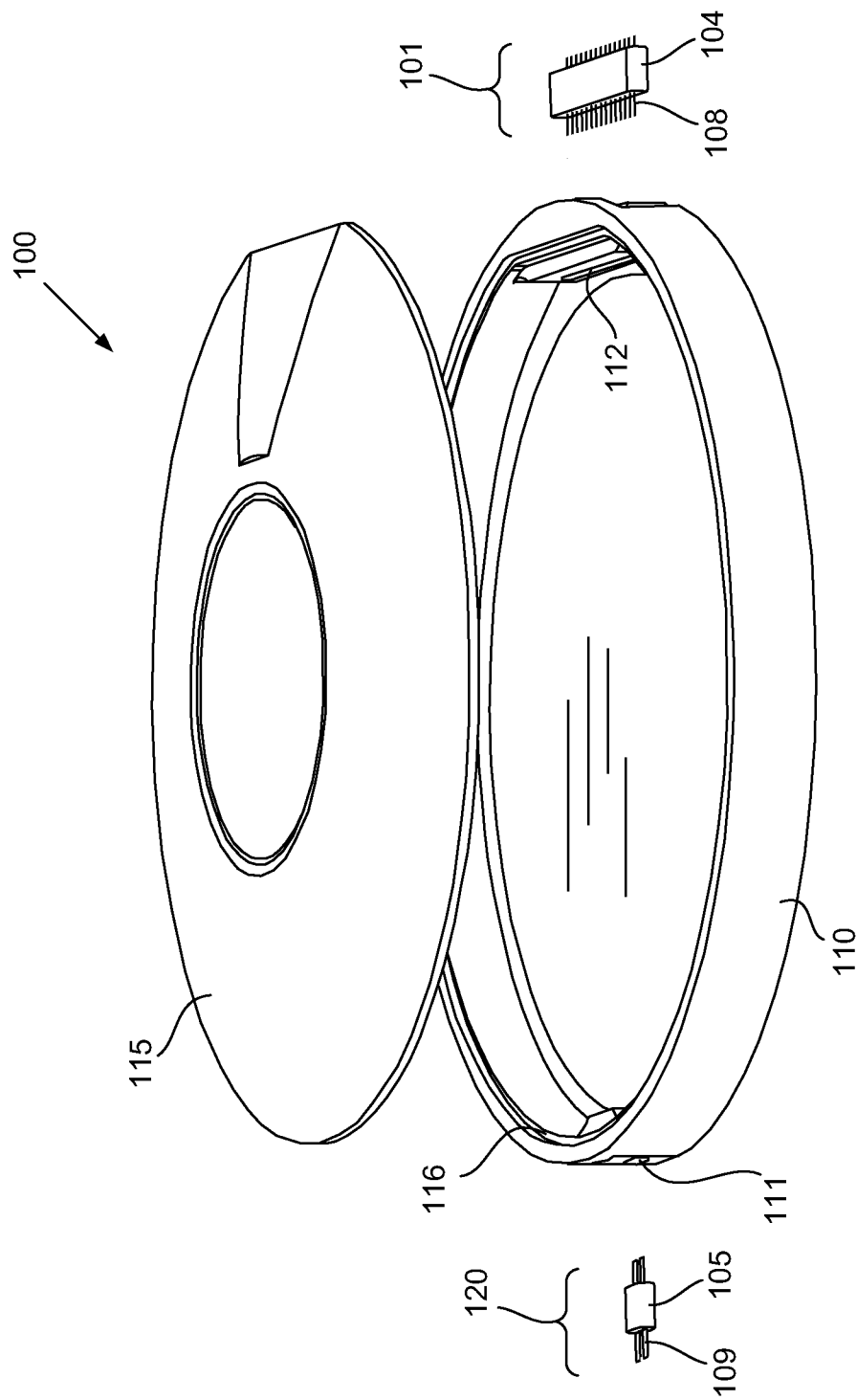
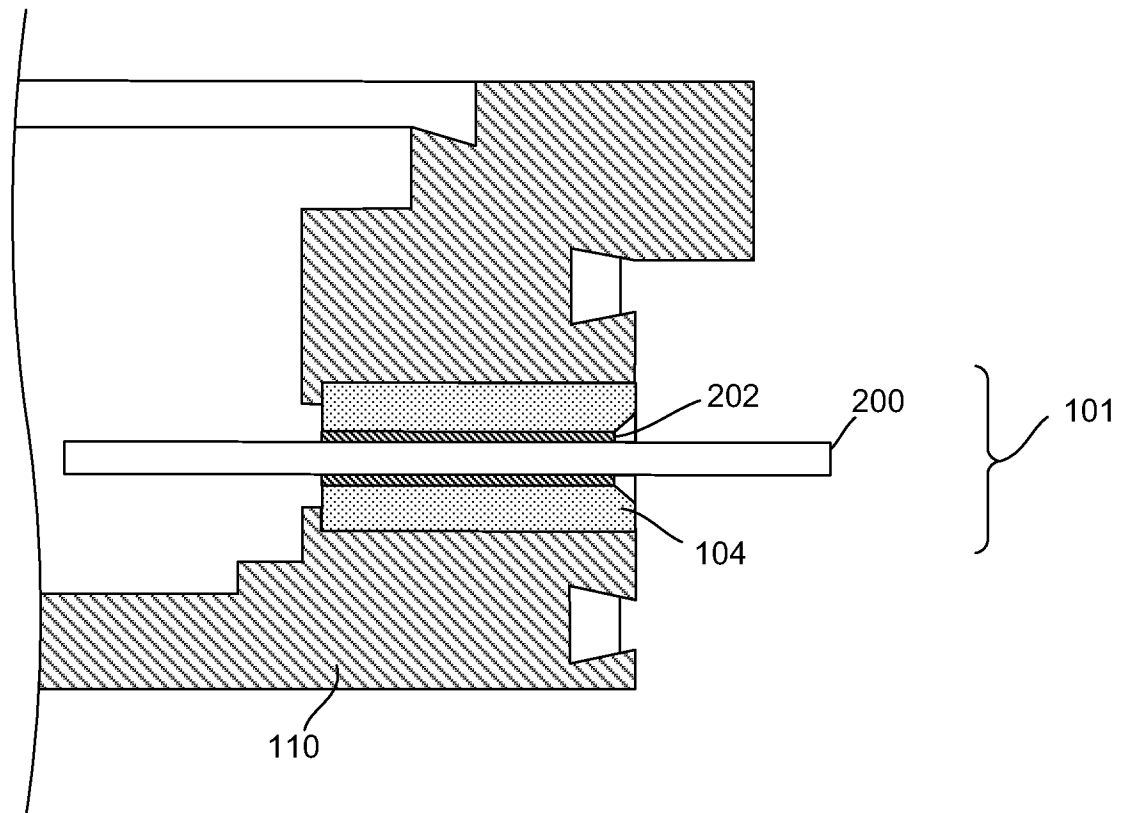
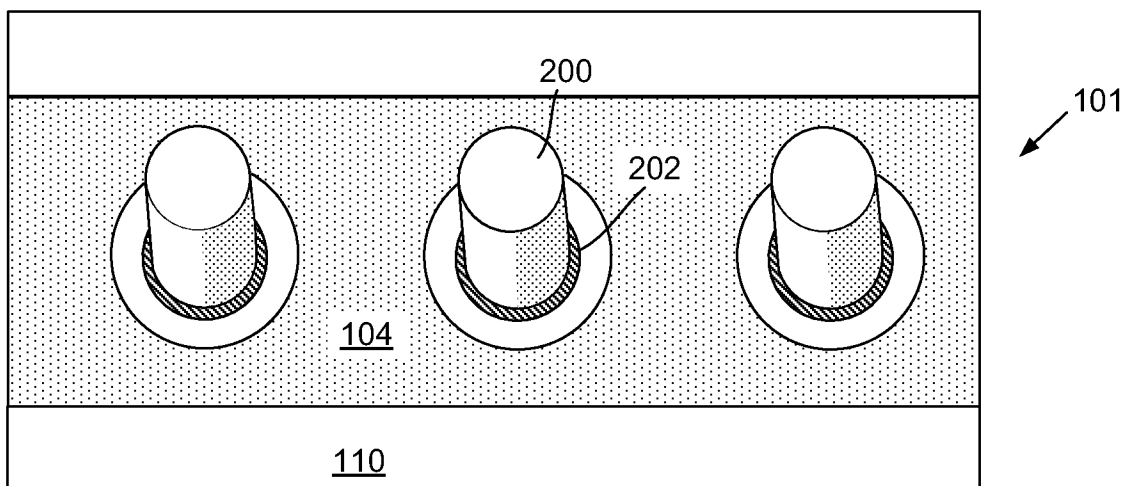


Fig. 1

2/6

**Fig. 2****Fig. 3**

3/6

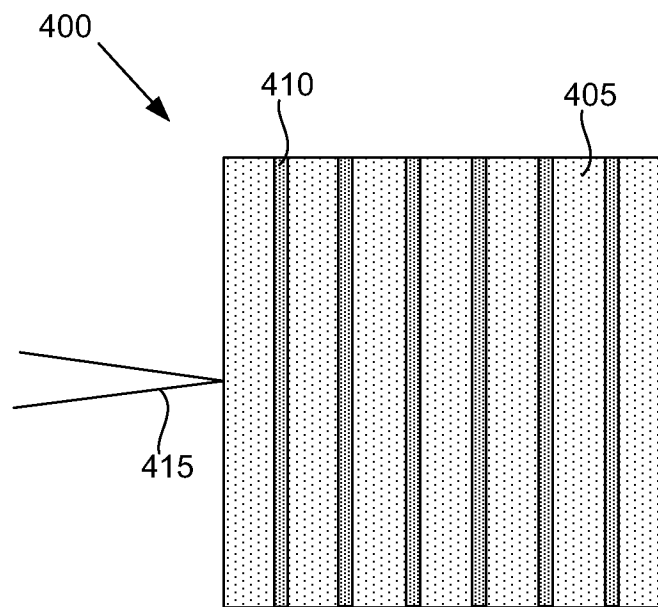


Fig. 4A

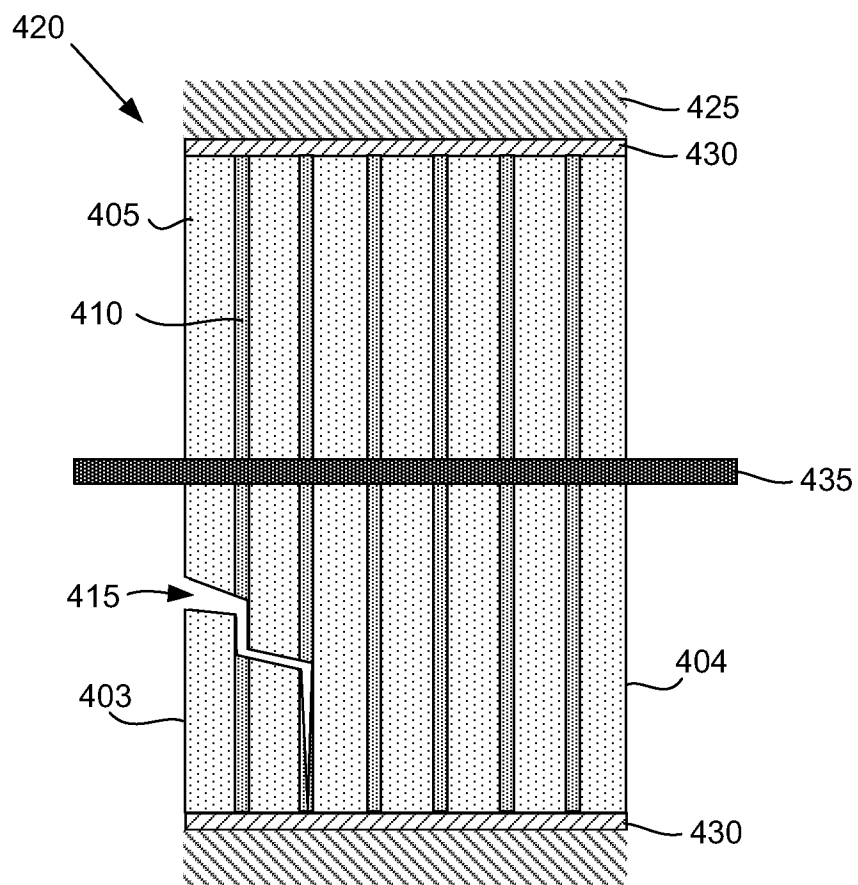


Fig. 4B

4/6

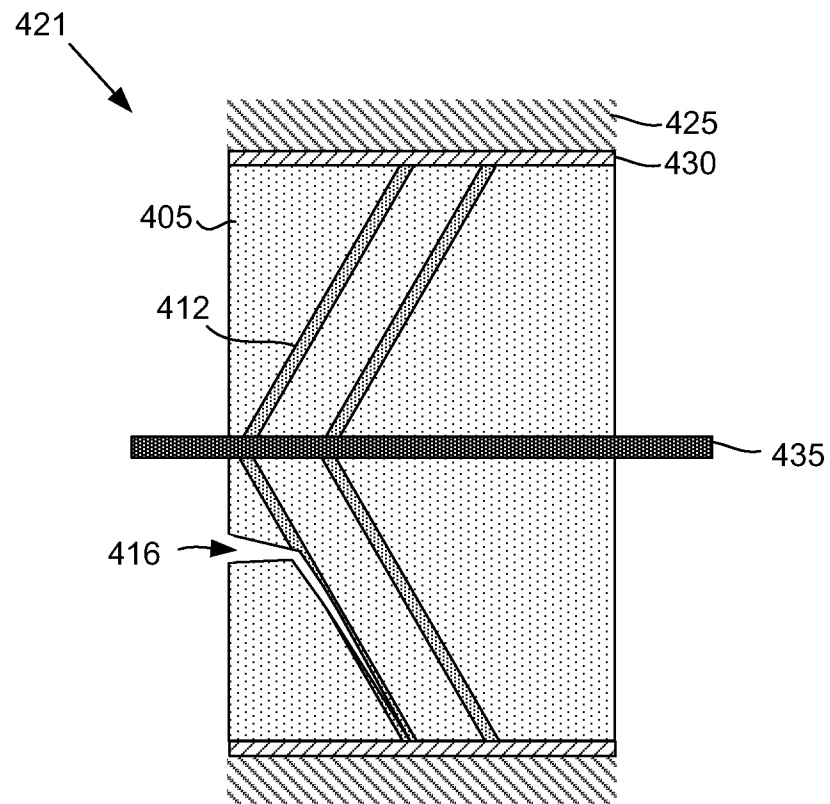


Fig. 4C

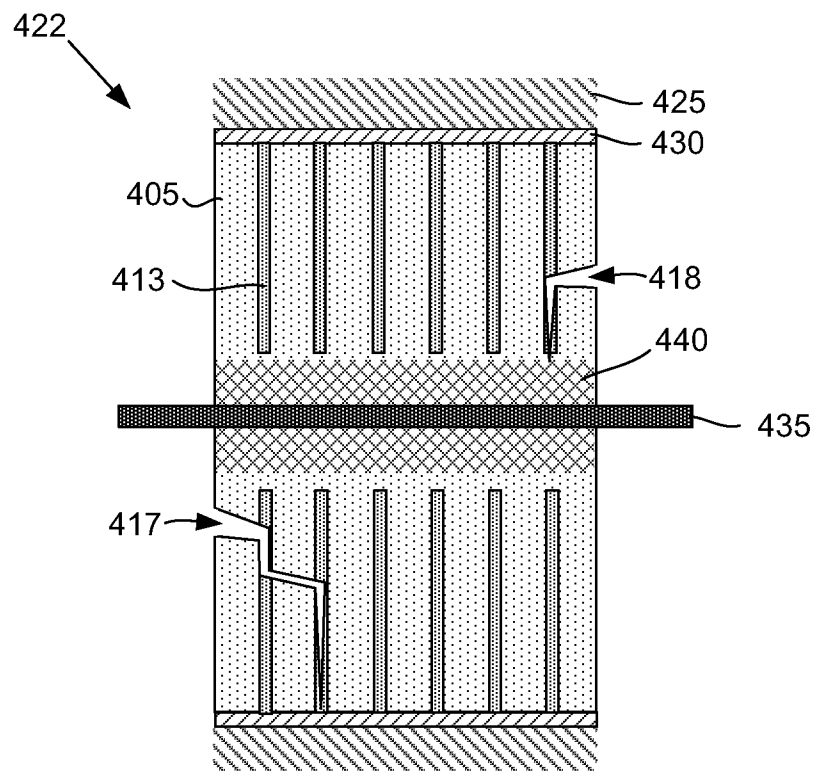
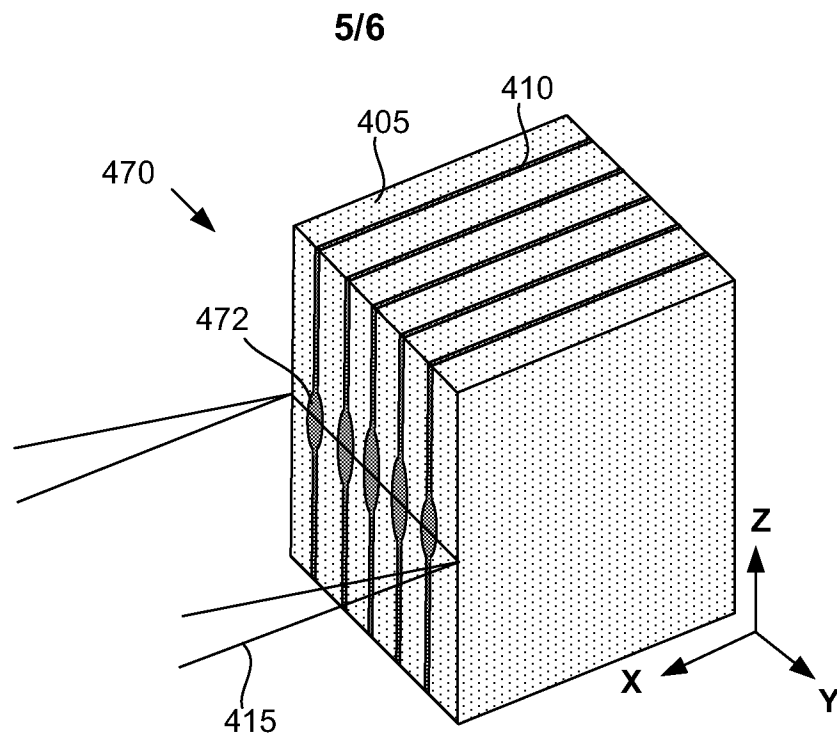
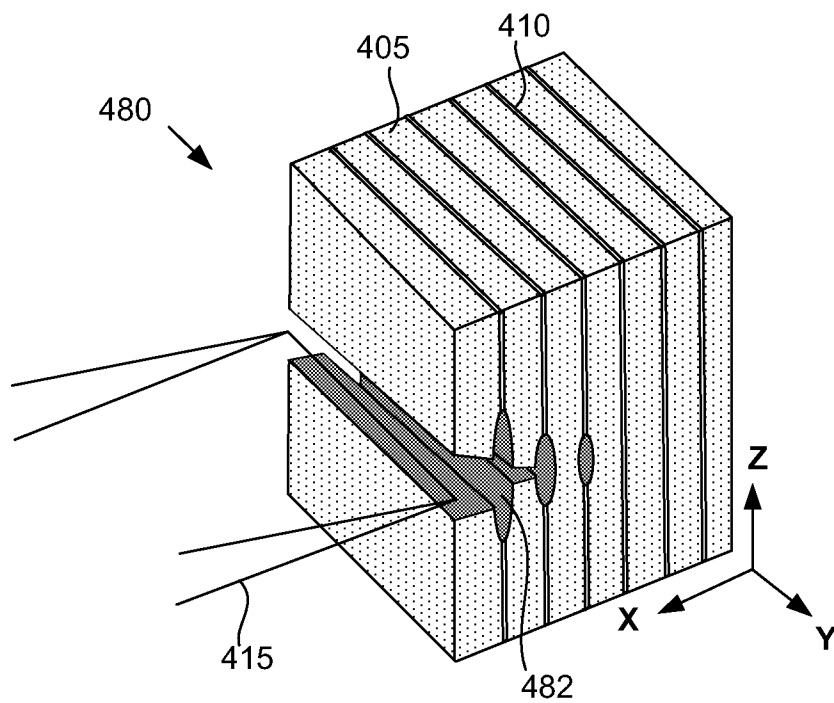
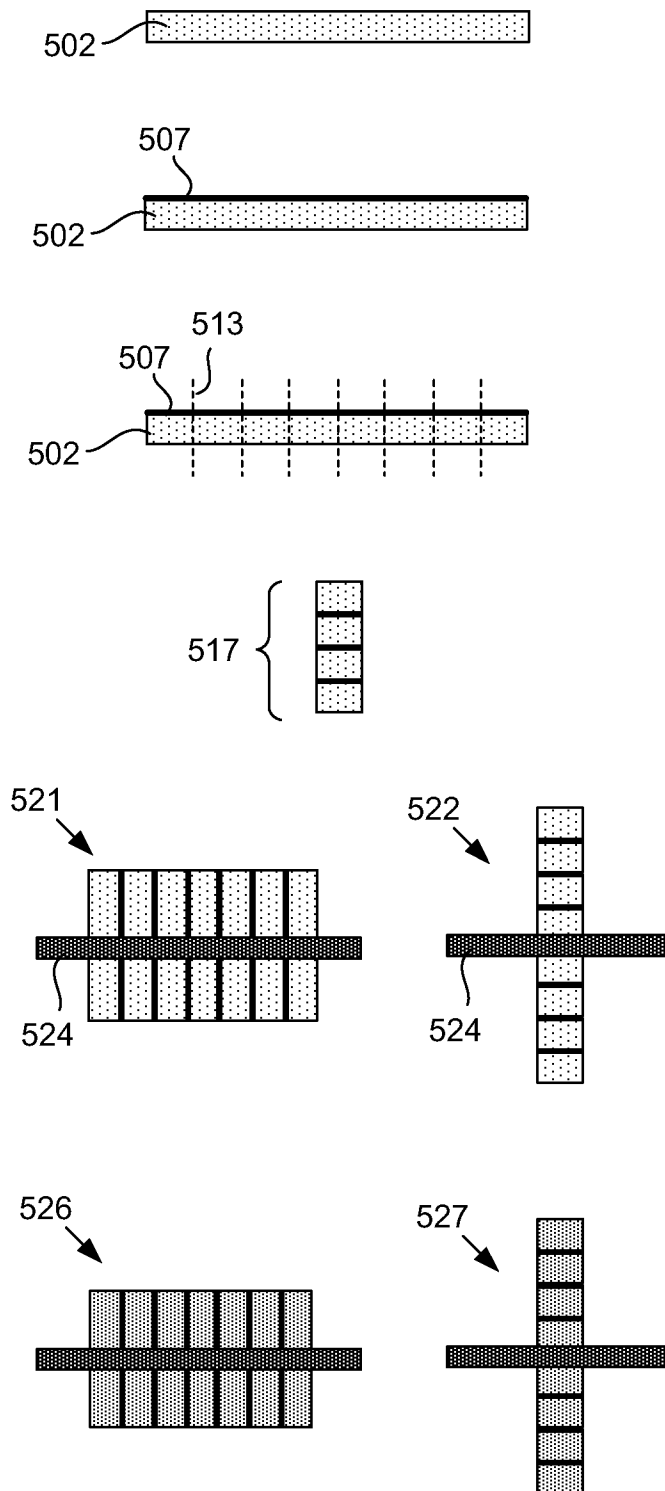
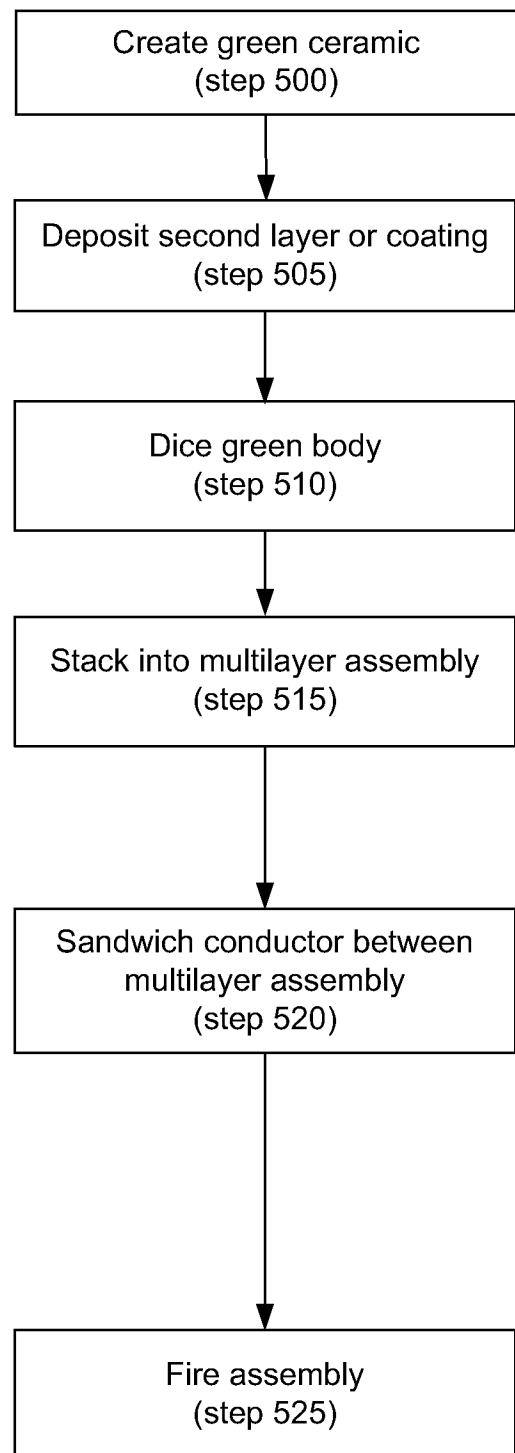


Fig. 4D

**Fig. 4E****Fig. 4F**

6/6

**Fig. 5A****Fig. 5B**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/064821

A. CLASSIFICATION OF SUBJECT MATTER
 INV. A61N1/375 H01G4/35
 ADD.

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)
 A61N H01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/062111 A1 (MORIYA YOICHI [JP]) 3 April 2003 (2003-04-03)	1-3,8,9
Y	paragraphs [0002], [0005], [0018] - [0056]; figures 1,2A-D	4-7, 10-13
Y	US 2005/097892 A1 (CARPER DOUGLAS M [US] ET AL) 12 May 2005 (2005-05-12) paragraphs [0001], [0005], [0007], [0024], [0027], [0030] - [0033]	4,6,7, 10,12-15
Y	US 6 414 835 B1 (WOLF WILLIAM D [US] ET AL) 2 July 2002 (2002-07-02) paragraphs [0022], [0056] - [0061]	5,11,14, 15
A	US 4 816 621 A (HUEBNER ROSA M [DE] ET AL) 28 March 1989 (1989-03-28) the whole document	1-15
	----- -/-	



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 document 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

15 February 2012

Date of mailing of the international search report

24/02/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040,
 Fax: (+31-70) 340-3016

Authorized officer

Schöffmann

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/064821

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 89/08088 A1 (ALLIED SIGNAL INC [US]) 8 September 1989 (1989-09-08) the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2011/064821

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003062111 A1	03-04-2003	JP 2003110238 A	11-04-2003
		US 2003062111 A1	03-04-2003

US 2005097892 A1	12-05-2005	CA 2486024 A1	07-05-2005
		EP 1529950 A1	11-05-2005
		JP 4559191 B2	06-10-2010
		JP 2005201241 A	28-07-2005
		US 2005097892 A1	12-05-2005

US 6414835 B1	02-07-2002	US 6414835 B1	02-07-2002
		US 2002166618 A1	14-11-2002

US 4816621 A	28-03-1989	EP 0269007 A1	01-06-1988
		US 4816621 A	28-03-1989

WO 8908088 A1	08-09-1989	DE 3873929 T2	21-01-1993
		EP 0400005 A1	05-12-1990
		JP H03503754 A	22-08-1991
		WO 8908088 A1	08-09-1989
