



(51) International Patent Classification:

H01H 85/08 (2006.01) H01H 85/06 (2006.01)

H01H 37/76 (2006.01) H01H 85/18 (2006.01)

H01H 85/04 (2006.01) H01H 85/38 (2006.01)

(21) International Application Number:

PCT/US2019/031607

(22) International Filing Date:

09 May 2019 (09.05.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/669,129 09 May 2018 (09.05.2018) US

(71) Applicant: LITTELFUSE, INC. [US/US]; 8755 West Higgins Road, Suite 500, Chicago, Illinois 60631 (US).

(72) Inventors: YURKANIN, Matthew David; c/o Littelfuse, Inc., 8755 West Higgins Road, Suite 500, Chicago, Illinois 60631 (US). SWAIN, K. Matthew; c/o Littelfuse, Inc., 8755 West Higgins Road, Suite 500, Chicago, Illinois 60631 (US).

(74) Agent: DAISAK, Daniel N.; c/o Kacvinsky Daisak Bluni PLLC, 101 Carnegie Center, Suite 106, Princeton, New Jersey 08540 (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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, SM,

(54) Title: CIRCUIT PROTECTION DEVICES FORMED BY ADDITIVE MANUFACTURING

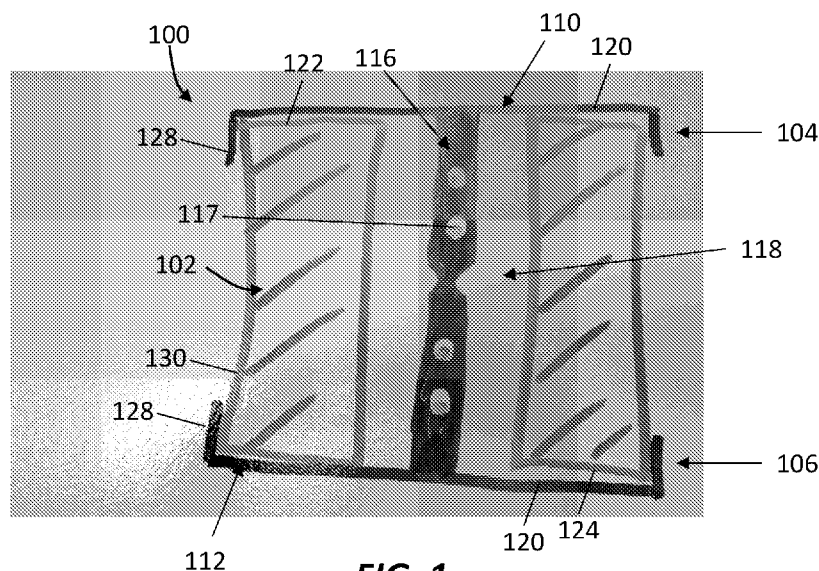


FIG. 1

(57) Abstract: Provided herein are circuit protection devices, such as fuses, formed using additive manufacturing processes. In some embodiments, a circuit protection device includes a fuse body including a hollow interior, a fusible element disposed within the hollow interior, and a set of endcaps disposed on opposite ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive.

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

Published:

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

Circuit Protection Devices Formed by Additive Manufacturing

Related Applications

[0001] This Application claims priority to U.S. provisional patent application 62/669,129, filed May 9, 2018, entitled Circuit Protection Devices Formed by Additive Manufacturing and incorporated by reference herein in its entirety.

Field of the Disclosure

[0002] The disclosure relates to the field of circuit protection devices and, more particularly, to fuses formed by additive manufacturing.

Background of the Disclosure

[0003] Circuit protection devices, such as fuses, are commonly used as circuit protection devices and are typically installed between a source of electrical power and a component in a circuit that is to be protected. One type of fuse, commonly referred to as a “cartridge fuse” or “tube fuse,” includes a tubular, electrically insulating fuse body containing a fusible element that extends between electrically conductive, metallic endcaps that cover opposing longitudinal ends of the fuse body. Upon the occurrence of a specified fault condition, such as an overcurrent condition, the fusible element melts or otherwise separates to interrupt the flow of electrical current between the electrical power source and the protected component.

[0004] The endcaps of a fuse are commonly fastened to the ends of a fuse body using solder or electrically conductive adhesive, which also connects the fusible element of the

fuse to the endcaps and provides an electrically conductive pathway therebetween. When the fuse is operatively installed, such as on a printed circuit board (PCB), the endcaps may be soldered to respective terminals on the PCB, placing the fuse in electrical communication with various other circuit components (e.g., a source of electrical power and a protected load).

[0005] A shortcoming associated with traditional cartridge fuses is that when such a fuse is soldered to a PCB, heat from the soldering process can cause the endcaps of the fuse, as well as solder that fastens the endcaps to the fuse body of the fuse (hereinafter “the endcap solder”), to undergo thermal expansion at a rate greater than that of the fuse body. This is due to a mismatch between the coefficient of thermal expansion of the insulative fuse body and the coefficients of thermal expansion of the conductive endcaps and endcap solder. Thus, the heated endcaps and endcap solder may expand away from the fuse body, resulting in the formation of gaps therebetween. Solder that is being applied to the endcaps during installation of the fuse on a PCB may, in its fluid state, migrate through these gaps and may infiltrate the interior of the fuse body. It has been observed that such infiltration can have deleterious effects on the performance of fuses.

[0006] It is with respect to these and other considerations that the present improvements may be useful.

Summary of the Disclosure

[0007] In one approach according to the present disclosure, a circuit protection device may include a fuse body including a hollow interior, a fusible element disposed within the hollow interior, and a set of endcaps disposed on opposite ends of the fuse body, the

set of endcaps integrally formed with the fusible element without an electrically conductive adhesive.

[0008] In another approach according to the present disclosure, a circuit protection device may include a fuse body including a first end, a second end, a first side, and a second side, a fusible element disposed within a hollow interior of the fuse body, and a set of endcaps disposed on the first and second ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive present within the set of endcaps or the hollow interior.

[0009] In another approach according to the present disclosure, a fuse may include a fuse body including a first end, a second end, a first side, and a second side. The fuse may further include a fusible element disposed within a hollow interior of the fuse body, and a set of endcaps disposed on the first and second ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive present along the set of endcaps or within the hollow interior.

Brief Description of the Drawings

[0010] The accompanying drawings illustrate exemplary approaches of the disclosed embodiments so far devised for the practical application of the principles thereof, and in which:

[0011] **FIG. 1** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0012] **FIG. 2** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0013] **FIG. 3** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0014] **FIG. 4** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0015] **FIG. 5** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0016] **FIG. 6A** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0017] **FIG. 6B** illustrates a perspective view of the exemplary circuit protection device of **FIG. 6A** according to a first embodiment of the present disclosure;

[0018] **FIG. 6C** illustrates a perspective view of the exemplary circuit protection device of **FIG. 6A** according to a second embodiment of the present disclosure;

[0019] **FIG. 7** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0020] **FIG. 8** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0021] **FIG. 9** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0022] **FIG. 10** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0023] **FIG. 11** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0024] **FIG. 12A** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0025] **FIG. 12B** illustrates an end view of the exemplary circuit protection device of **FIG. 12A** according to embodiments of the present disclosure;

[0026] **FIG. 13** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0027] **FIG. 14** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0028] **FIG. 15** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0029] **FIG. 16** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0030] **FIG. 17** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure;

[0031] **FIG. 18** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure; and

[0032] **FIG. 19** illustrates a cross-sectional view of an exemplary circuit protection device according to embodiments of the present disclosure.

[0033] The drawings are not necessarily to scale. The drawings are merely representations, not intended to portray specific parameters of the disclosure. The drawings are intended to depict typical embodiments of the disclosure, and therefore should not be considered as limiting in scope. In the drawings, like numbering represents like elements.

[0034] Furthermore, certain elements in some of the figures may be omitted, or illustrated not-to-scale, for illustrative clarity. Cross-sectional views may be in the form of "slices", or "near-sighted" cross-sectional views, omitting certain background lines otherwise visible in a "true" cross-sectional view, for illustrative clarity. Furthermore, for clarity, some reference numbers may be omitted in certain drawings.

Detailed Description

[0035] Circuit protection devices, fuses, and methods in accordance with the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the device and method are shown.

The devices, fuses, and methods, however, may be embodied in many different forms and

should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the system and method to those skilled in the art.

[0036] Provided herein are approaches for forming circuit protection devices and fuses using additive manufacturing processes (e.g., 3-D printing). Approaches of utilizing multi-material additive manufacturing technology to construct a fuse that eliminates the need for solder connections to the endcaps in traditional cartridge fuse designs. By printing both conductive element/caps as a single structure, and at the same time printing a non-conductive body, a two-part fuse can be created. This differs from the fuse designs used today, which contain a combination of multiple, separate components, such as a fuse body, two end-caps, and a fusible element, the latter being joined together by solder. Embodiments herein are applicable to both sealed and unsealed fuses. Embodiments of the present disclosure also include techniques to print multiple fuse in an array, and are not limited to the printing of single fuses.

[0037] Circuit protection devices of the present disclosure may include one or more components formed using an additive manufacturing process, such as 3-D printing. In particular, the present disclosure relates to a system and process for printing 3-D features of fuses in a layer-by-layer manner from digital representations of the 3-D component (e.g., additive manufacturing file format (AMF) and stereolithography (STL) file format) using one or more additive manufacturing techniques. Examples of additive manufacturing techniques include extrusion-based techniques, jetting, selective laser sintering, powder/binder jetting, electron-beam melting, and stereolithographic processes.

For each of these techniques, the digital representation of the 3-D part is initially sliced into multiple horizontal layers. For each sliced layer, a tool path is then generated, which provides instructions for the particular additive manufacturing system to print the given layer.

[0038] In one example, components of the present disclosure may be formed using an extrusion-based additive manufacturing system in which a 3-D component may be printed from a digital representation of the 3-D component in a layer-by-layer manner by extruding a flowable part material. The part material is extruded through an extrusion tip carried by a print head of the system, and is deposited as a sequence of roads on a platen in planar layers. The extruded part material fuses to previously deposited part material, and solidifies upon a drop in temperature. The position of the print head relative to the substrate is then incremented, and the process is repeated to form a 3-D part resembling the digital representation.

[0039] In another example, components of the present disclosure may be formed via fused deposition modeling (FDM), which places the material in layers. A plastic filament or metal wire may be unwound from a coil and placed in order to produce a component. FDM further involves a computer processing a STL file for the component. During operation, FDM employs a nozzle to extrude beads of material. The nozzle may be heated to melt the material or otherwise make the material more pliable. An extrusion head may be coupled to the nozzle for depositing the beads. The nozzle may be movable in horizontal and vertical directions. The nozzle may be controlled by a robotic mechanism, for example a robotic mechanism having a rectilinear design or a delta robot.

The extrusion head may be moved by stepper motors, servo motors, or other types of motors. The nozzle and extrusion head may be controllable by the computer, which may, for example, send control directives to the robotic mechanism and the motor.

[0040] In yet another example, components of the present disclosure are formed using a selective laser sintering (SLS) process. SLS may involve the use of a laser, for example, a carbon dioxide laser, to fuse particles of a material into a desired three-dimensional shape. Example materials may include plastics, metals, and ceramics. SLS may be applied using several materials, for example, using layers of different material or by mixing different materials together. Materials may include polymers such as nylon (neat, glass-filled, or with other fillers) or polystyrene, metals including steel, titanium, alloy mixtures, and composites and green sand. The materials may be in the form of a powder.

[0041] SLS may involve using the laser to selectively fuse material by scanning cross-sections generated from a 3-D digital description of the component (for example, from a CAD file) on the surface of a powder bed. After each cross-section is scanned, the powder bed may be lowered based on a predetermined layer thickness, a new layer of material may be applied on top, and the process is repeated. This may continue until the component is fully fabricated.

[0042] In fabricating 3-D parts by depositing layers of a part material, supporting layers or structures may be built underneath overhanging portions or in cavities of 3-D parts under construction, which are not supported by the part material itself. A support structure may be built utilizing the same deposition techniques by which the part material

is deposited. The host computer generates additional geometry acting as a support structure for the overhanging or free-space segments of the 3-D part being formed. The support material is then deposited pursuant to the generated geometry during the printing process. The support material adheres to the part material during fabrication, and is removable from the completed 3-D part when the printing process is complete.

[0043] Referring now to **FIG. 1**, an exemplary embodiment demonstrating a cross-sectional view of a circuit protection device (hereinafter “device”) 100 in accordance with the present disclosure will be described in greater detail. The device 100 may include a tubular fuse body 100 having opposing ends 104, 106. The fuse body 102 may be a square cylinder, but embodiments herein are not limited in this regard. Alternative embodiments of the device 100 may have a fuse body 102 that is a round cylinder, an oval cylinder, a triangular cylinder, etc.

[0044] A pair of conductive endcaps 110, 112 are provided over the ends 104, 106 of the fuse body 102, respectively, and may be formed by additive manufacturing. Unlike prior art approaches, the conductive endcaps 110, 112 may not be fastened to the fuse body 102 by solder and/or any type of electrically conductive adhesive. A fusible element 116 (e.g., a fuse wire) may extend through a hollow interior 118 of the fuse body 102 and may be secured to or integrally formed with the endcaps 110, 112 in electrical communication. In exemplary embodiments, the conductive end caps 110, 112 and the fusible element 116 are formed by additive manufacturing. As shown, the fusible element 116 may include one or more apertures 117 formed therein.

[0045] The fuse body 102 of the device 100 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. The endcaps 110, 112 may be formed of an electrically conductive material, including, but not limited to, copper or one of its alloys, and may be plated with nickel or other conductive, corrosion resistant coatings. The fusible element 116 may be formed of an electrically conductive material, including, but not limited to, tin or copper, and may be configured to melt and separate upon the occurrence of a predetermined fault condition, such as an overcurrent condition in which an amount of current exceeding a predefined maximum current flows through the fusible element 116. The fusible element 116 may be any type of fusible element suitable for a desired application, including, but not limited to, a fuse wire, a corrugated strip, a fuse wire wound about an insulating core, etc. In some embodiments, the fusible element 116 may extend diagonally through the hollow interior 118 of the fuse body 102. In some embodiments, the hollow interior 118 of the fuse body 102 may be partially or entirely filled with an arc-quenching material, including, but not limited to, sand, silica, etc.

[0046] In this non-limiting embodiment, each end cap 110, 112 may include a main section 120 extending across respective end surfaces 122, 124 of the ends 104, 106 of the fuse body 102. The main section 120 may extend perpendicular, or substantially perpendicular, to the fusible element 116. As further shown, each end cap 110, 112 may include a wrap-around section 128 extending from the main section 120. The wrap-around section 128 may extend substantially along an outer surface 130 of the fuse body 102. In the non-limiting embodiment shown, the wrap-around section 128 may extend perpendicular, or substantially perpendicular from the main section 120. To form each

wrap-around section 128, one or more temporary or permanent shelves may be employed during the additive manufacturing process. Alternatively, the device 100 may be flipped/rotated as required to form the wrap-around section 128 during the additive manufacturing process.

[0047] **FIG. 2** demonstrates the device 100 of **FIG. 1** including an arc-arresting or arc-quenching material 135 disposed within the hollow interior 118 of the fuse body 102. The arc-quenching material 135 may include sand, silica, etc. In this non-limiting embodiment, the arc-quenching material 135 is added to the device 100 using additive manufacturing. Printing the arc-quenching material 135 in an intentional array provides a good combination of material and air within the hollow interior 118 for arc quench.

[0048] **FIG. 3** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 200 in accordance with the present disclosure. The device 200 includes many of the features previously described above in relation to the device 100 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the fuse body 202 is printed to add support at ends 204, 206 to increase the break rating of the fuse body 202. As shown, a pair of conductive endcaps 210, 212 are provided over the ends 204, 206 of the fuse body 202, respectively, and may be formed by additive manufacturing. A fusible element 216 (e.g., a fuse wire) may extend through a hollow interior 218 of the fuse body 202 and may be secured to or integrally formed with the endcaps 210, 212 in electrical communication. In exemplary embodiments, the conductive end caps 210, 212 and the fusible element 216 are formed by additive

manufacturing without the presence of any electrically conductive adhesive, such as solder, at an intersection of the endcaps 210, 212 and the fusible element 216.

[0049] The fuse body 202 of the device 200 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. In this non-limiting embodiment, the hollow interior 218 does not extend completely through the device 200, e.g., between the ends 204, 206. Instead, the hollow interior 218 is completely enclosed or embedded by the material of the fuse body 202. Although not limited to any particular shape, the hollow interior 218 may be oval-shaped. In some embodiments, the hollow interior 218 of the fuse body 202 may be partially or entirely filled with an arc-quenching material (not shown), including, but not limited to, sand, silica, etc.

[0050] **FIG. 4** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 300 in accordance with the present disclosure. The device 300 includes many of the features previously described above in relation to the devices 100, 200, and, as such, may not be described in full detail for the sake of brevity. In this embodiment, a set of non-conductive support structures 340 may be part of the device 300 to improve manufacturability of the fusible element 316. As shown, a pair of conductive endcaps 310, 312 are provided over the ends 304, 306 of the fuse body 302, respectively, and may be formed by additive manufacturing. The fusible element 316 (e.g., a fuse wire) may extend through a hollow interior 318 of the fuse body 302 and may be secured to or integrally formed with the endcaps 310, 312 in electrical communication. In exemplary embodiments, the conductive end caps 310, 312 and the

fusible element 316 are formed by additive manufacturing without the presence of any electrically conductive adhesive, such as solder, at an intersection of the endcaps 310, 312 and the fusible element 316.

[0051] The fuse body 302 of the device 300 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. In this non-limiting embodiment, the device 300 may further include the set of non-conductive support structures 340 extending from the fuse body 302. As shown, the support structures 340 may extend horizontally, or substantially horizontally into the hollow interior 318 from an interior sidewall 342 of the fuse body 302. In some embodiments, the support structures 340 may include one or more loops 344 configured to extend around and support the fusible element 316. The support structures 340 may be formed according to an additive manufacturing process in which a set of permanent or temporary framing elements are employed. The support structures 340 may initially be deposited on temporary framing elements, which are subsequently removed prior to the completion of the device 300.

[0052] **FIG. 5** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 400 in accordance with the present disclosure. The device 400 includes many of the features previously described above in relation to the devices 100, 200, 300 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, a set of micro-rebar structures 444 are added within the fuse body 402. As shown, the rebar structures 444 may be embedded within the fuse body 402, and surround the hollow interior 418 in a circular or helical configuration. In some embodiments, the

rebar structures 444 include a set of vertical elements 444A connected with a set of horizontal elements 444B. The set of rebar structures 444 may be a different material than the fuse body 402, and may be formed by additive manufacturing. In various embodiments, the set of rebar structures 444 are conductive or non-conductive.

[0053] The fusible element 416 (e.g., a fuse wire) may extend through a center of a set of horizontal elements 444B and may be secured to or integrally formed with the endcaps 410, 412 in electrical communication. In exemplary embodiments, the conductive end caps 410, 412 and the fusible element 416 are formed by additive manufacturing without the presence of any electrically conductive adhesive, such as solder, at an intersection of the endcaps 410, 412 and the fusible element 416.

[0054] **FIG. 6A** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 500 in accordance with the present disclosure. The device 500 includes many of the features previously described above in relation to the devices 100, 200, 300, 400 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the conductive area needed to connect the square or cylindrical fuse body 502 has been minimized to reduce cost and weight. For example, as shown, a pair of conductive endcaps 510, 512 are provided embedded within the ends 504, 506 of the fuse body 502, respectively, and may be formed by additive manufacturing. In this embodiment, the conductive endcaps 510, 512 are not wrapped around respective end surfaces 522, 524 of the ends 504, 506. Instead, a portion 548 of the fuse body 502 is provided between the conductive endcaps 510, 512 and respective end surfaces 522, 524.

[0055] In this non-limiting embodiment, each end cap 510, 512 may include a main section 520 extending between the outer surface(s) 530 of the fuse body 502. The main section 520 may extend perpendicular, or substantially perpendicular, to the fusible element 516. As further shown, each end cap 510, 512 may include a set of electrically conductive end tabs or end strips 552 extending from the main section 520. As shown, the end strips 552 may extend outside of the fuse body 502. In the non-limiting embodiment shown, the end strips 552 may extend perpendicular, or substantially perpendicular from the main section 520 and from the outer surface(s) 530 of the fuse body 502. To form each of the end strips 552, one or more temporary shelves may be employed during the additive manufacturing process. Alternatively, the device 500 may be flipped/rotated as required to form end strips 552 during the additive manufacturing process.

[0056] As further shown, the fusible element 516 may extend through a hollow interior 518 of the fuse body 502 and may be secured to or integrally formed with the endcaps 510, 512 in electrical communication. In exemplary embodiments, the conductive end caps 510, 512 and the fusible element 516 are formed by additive manufacturing without the presence of any electrically conductive adhesive.

[0057] As shown in the non-limiting embodiment of **FIG. 6B**, the end strips 552 may extend beyond the outer surface(s) 530 of the fuse body 502 at multiple positions. Although not limited to any specific number or configuration, the device 500 may include eight (8) end strips 552. In another embodiment, as shown in **FIG. 6C**, each end strip

552 may be a band of electrically conductive material extending fully or partially around the outer surface 530 of the device 500.

[0058] **FIG. 7** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 600 in accordance with the present disclosure. The device 600 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the fuse body 602 has a geometry printed in shape to prevent a straight path for arcing. The fusible element 616 may be printed following a same or similar geometry to the fuse body 602, yet may be formed so as to avoid contact with an interior sidewall 642 of a hollow interior 618 of the fuse body 602.

[0059] As shown, a pair of conductive endcaps 610, 612 are provided over the ends 604, 606 of the fuse body 602, respectively, and may be formed by additive manufacturing. The fusible element 616 may extend through the hollow interior 618 of the fuse body 602 and may be secured to or integrally formed with the endcaps 610, 612 in electrical communication. In exemplary embodiments, the conductive end caps 610, 612 and the fusible element 616 are formed by additive manufacturing.

[0060] The fuse body 602 of the device 600 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. In this non-limiting embodiment, the fuse body 602 may include a set of irregular features or projections 660, 661 extending generally towards the first side 669 of the fuse body 602. The hollow interior 618 may have a correspondingly irregular shape defining an embedded curvilinear channel 665. The fusible element 616 may also have a

correspondingly irregular or curvilinear shape. In other embodiments, the shape of the fusible element 616 and/or the hollow interior 618 do not track with the shape of the fuse body 602. As shown, the embedded curvilinear channel 665 may include a first section 667 extending toward the first and/or second ends 622, 624 of the fuse body 602, and a second section 668 extending towards first and/or second sides 669, 671 of the fuse body 602.

[0061] FIG. 8 demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 700 in accordance with the present disclosure. The device 700 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the fuse body 702 may include one or more vents 765 for releasing/relieving pressure within the fuse body 702. As shown, the vents 765 may be printed so as to extend from the hollow interior 718 to an exterior sidewall 730 of the fuse body 702 to relieve pressure, and thus prevent arcing. Vent shapes may be selected to prevent materials/debris from escaping.

[0062] As shown, a pair of conductive endcaps 710, 712 are provided over the ends 704, 706 of the fuse body 702, respectively, and may be formed by additive manufacturing. The fusible element 716 may extend through the hollow interior 718 of the fuse body 702, and may be secured to or integrally formed with the endcaps 710, 712 in electrical communication. In exemplary embodiments, the conductive end caps 710, 712 and the fusible element 716 are formed by additive manufacturing, for example,

without the use of a conductive adhesive, such as solder, at the interface of the conductive end caps 710, 712 and the fusible element 716.

[0063] The fuse body 702 of the device 700 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. In this non-limiting embodiment, the vents 765A, 765B may be straight or substantially straight, while the vent(s) 765C may take on a curved or meandering shape. As shown, the vent 765C is an embedded curvilinear channel configured to extend both vertically and horizontally within the fuse body 702. Said differently, vent 765C may include a first section 767 extending toward the first and/or second ends 722, 724 of the fuse body 702, and a second section 768 extending towards first and/or second sides 769, 771 of the fuse body 702. The first and second sections 767, 768 may be fluidly connected. With additive manufacturing processes, the vents 765 may take on virtually any shape, size, and/or configuration throughout the fuse body 702. In exemplary embodiments, the fuse body 702 is formed as a single component.

[0064] **FIG. 9** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 800 in accordance with the present disclosure. The device 800 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the fuse body 802 may be printed to include internal shadow features. For example, a set of printed geometric projections or geometric shapes 868 inside the fuse body 802 may create shadows for debris and vaporized materials, thus

quenching arcing faster and breaking the conductive path, e.g., for high open state resistance (OSR).

[0065] As shown, a pair of conductive endcaps 810, 812 are provided over the ends 804, 806 of the fuse body 802, respectively, and may be formed by additive manufacturing. The fusible element 816 may extend through the hollow interior 818 of the fuse body 802, and may be secured to or integrally formed with the endcaps 810, 812 in electrical communication. In exemplary embodiments, the conductive end caps 810, 812 and the fusible element 816 are formed by additive manufacturing, for example, without the use of a conductive adhesive, such as solder, at the interface of the conductive end caps 810, 812 and the fusible element 816.

[0066] The fuse body 802 of the device 800 may be formed of an electrically insulating and preferably heat resistant material, including, but not limited to, ceramic or glass. In this non-limiting embodiment, the geometric shapes 868 may be printed/formed along an interior sidewall 842 of the hollow interior 818 of the fuse body 802. As shown, the geometric shapes 868 may define a series of points, indentations, cavities, etc., which provide shadows for debris and vaporized materials. Embodiments herein are not limited to any particular shape or configuration for the geometric shapes 868.

[0067] The hollow interior 818 may have a correspondingly irregular shape defining an embedded curvilinear channel 865. The fusible element 816 may also have a correspondingly irregular or curvilinear shape. For example, the fusible element 816 may contain one or more protrusions 888 extending laterally. As shown, the embedded curvilinear channel 865 may include a first section 867 extending toward the first and/or

second ends 822, 824 of the fuse body 802, and a second section 864 extending towards first and/or second sides 869, 871 of the fuse body 802.

[0068] **FIG. 10** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 900 in accordance with the present disclosure. The device 900 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, a plurality of printed anchors 970 may join together the fuse body 902 and one or more of the pair of conductive endcaps 910, 912. For example, the anchors 970, which may be conductive, help connect the non-conductive materials of the fuse body 902 and the conductive materials of the pair of conductive endcaps 910, 912, thus allowing for a higher break rating and minimization of the conductive material (i.e., thinner metal acting as the end caps).

[0069] As shown, the pair of conductive endcaps 910, 912 are provided over the ends 904, 906 of the fuse body 902, respectively, and may be formed by additive manufacturing. The fusible element 916 may extend through the hollow interior 918 of the fuse body 902, and may be secured to or integrally formed with the endcaps 910, 912 in electrical communication. In exemplary embodiments, the conductive end caps 910, 912 and the fusible element 916 are formed by additive manufacturing, for example, without the use of a conductive adhesive, such as solder, at the interface of the conductive end caps 910, 912 and the fusible element 916.

[0070] In this non-limiting embodiment, the pair of endcaps 910, 912 each include a main section 920, and a wrap-around section 928 extending from the main section 120.

As shown, the wrap-around section 928 may extend substantially along an outer surface 930 of the fuse body 902. In the non-limiting embodiment shown, the wrap-around section 928 may extend perpendicular, or substantially perpendicular from the main section 920. As further shown, the plurality of anchors 970 extending from the main section 920 and from the wrap-around section 928. Although not limited to any particular shape or configuration, each of the plurality of anchors 970 may be T-shaped. A first end 971 of each anchor 970 may be integrally formed with the main section 920 or from the wrap-around section 928, while a second end 972 may extend within the fuse body 902. Furthermore, the anchor(s) 970 extending from the wrap-around section 928 may be oriented perpendicular, or substantially perpendicular, to the anchor(s) 970 extending from the main section 920. This configuration provides added strength to the device 900.

[0071] **FIG. 11** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1000 in accordance with the present disclosure. The device 1000 may include all of the features previously described above in relation to the device 200 of **FIG. 3** and, as such, may not be described in full detail for the sake of brevity. In this embodiment, a secondary material 1073 is printed on the fusible element 1016. For example, the secondary material 1073 may be a metal or alloy integrally connected to the fusible element 1016 in order to take advantage of the M-effect (Metcalf Effect). In exemplary embodiments, the conductive end caps 1010, 1012 and the fusible element 1016 are formed by additive manufacturing, for example, without the use of a conductive adhesive, such as solder, at the interface of the conductive end caps 1010, 1012 and the fusible element 1016.

[0072] **FIG. 12**, demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1100 in accordance with the present disclosure. The device 1100 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 and, as such, may not be described in full detail for the sake of brevity. This non-limiting embodiment demonstrates combined printed and dispensed fuse materials. For example, an arc suppressing material 1175, such as a dielectric gel, may be deposited within the hollow interior 1118 of the device 1100 prior to enclosing/finishing the device 1100 using additive manufacturing.

[0073] As shown, a pair of conductive endcaps 1110, 1112 are provided over the ends 1104, 1106 of the fuse body 1102, respectively, and may be formed by additive manufacturing. The fusible element 1116 may extend through the hollow interior 1118 of the fuse body 1102, and may be secured to or integrally formed with the endcaps 1110, 1112 in electrical communication. In exemplary embodiments, the conductive end caps 1110, 1112 and the fusible element 1116 are formed by additive manufacturing, for example, without the use of a conductive adhesive, such as solder, at the interface of the conductive end caps 1110, 1112 and the fusible element 1116.

[0074] An arc-arresting or arc-quenching material 1135 may be disposed within the hollow interior 1118 of the fuse body 1102. The arc-quenching material 1135 may include sand, silica, etc. In this non-limiting embodiment, the arc-quenching material 1135 is added to the device 1100 using additive manufacturing. Either before or after formation of the arc-quenching material 1135, arc suppressing material 1175 may be deposited within the hollow interior 1118 using any suitable method. For example, in

one non-limiting embodiment, formation may begin with the fuse body 1102 and the endcaps 1110, 1112 by applying a series of successive layers of each material according to any number of additive manufacturing techniques. The fusible element 1116 and the arc-quenching material 1135 may then be formed, also in this fashion. Prior to fully encasing the hollow interior 1118 using the remainder of the fuse body 1102, the arc suppressing material 1175 may then fill the ends of the hollow interior 1118. The fuse body 1102 and the endcaps 1110, 1112 may then be finished, again using additive manufacturing.

[0075] **FIG. 13** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1200 in accordance with the present disclosure. The device 1200 may include all of the features previously described above in relation to the device 200 of **FIG. 3** and of device 1000 of **FIG. 11**. As such, the device 1200 may not be described in full detail for the sake of brevity. In this embodiment, the secondary material 1273 is printed/embedded within the fusible element 1216. For example, the secondary material 1273 may be a metal having a horizontal component 1277 connected to ends 1278, 1279, which may extend around the fusible element 1216. In some embodiments, the secondary material 1273 may connect together two distinct sections of the fusible element 1216. The secondary material 1273 is integrally connected to the fusible element 1216 in order to take advantage of the M-effect (Metcalf Effect). The secondary material 1273 and the fusible element 1216 are formed together using additive manufacturing, along with the rest of the device 1200.

[0076] **FIG. 14** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1300 in accordance with the present disclosure. The device 1300 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the device 1300 includes a conductive material printed for interfacing to an electrical source on the same plane.

[0077] As shown, a pair of conductive endcaps 1310, 1312 are provided at the ends 1304, 1306 of the fuse body 1302, respectively, and may be formed by additive manufacturing. The fusible element 1316 may extend through the hollow interior 1318 of the fuse body 1302, and may be secured to or integrally formed with the endcaps 1310, 1312 in electrical communication. In exemplary embodiments, the conductive end caps 1310, 1312 and the fusible element 1316 are formed by additive manufacturing.

[0078] In this non-limiting embodiment, the pair of endcaps 1310, 1312 each include a main section 1320 extending along a same plane. The fuse body 1302 and the fusible element 1316 each generally have an inverted U-shape. As shown, the hollow interior 1318 defines an embedded curvilinear channel 1365. The fusible element 1316 may also have a correspondingly irregular or curvilinear shape. In some embodiments, the embedded curvilinear channel 1365 may include a first section 1367 extending toward the first and/or second ends 1322, 1324 of the fuse body 1302, and a second section 1368 extending towards first and/or second sides 1369, 1371 of the fuse body 1302.

[0079] **FIG. 15** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1400 in accordance with the present disclosure. The device 1400 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the device 1400 includes an embedded curvilinear channel 1480 for post fuse printing addition of fusible element(s).

[0080] As shown, a pair of conductive endcaps 1410, 1412 are provided at the ends of the fuse body 1402, respectively, and may be formed by additive manufacturing. The arc-quenching material 1435 may disposed within the hollow interior 1418, although embodiments herein are not limited in this context. The fusible element, to be subsequently added, may extend through the embedded curvilinear channel 1480, which meanders through the fuse body 1402 and through the hollow interior 1418. Said differently, the embedded curvilinear channel 1480 may be defined by a hollow tube 1481, which may be made from a non-conductive material the same or similar to the material of the fuse body 1402. As shown, the hollow tube 1481 and the embedded curvilinear channel 1480 extend through the fuse body 1402 and through the hollow interior 1418. The hollow tube 1481 may separate the arc-quenching material 1435 from the interior of the embedded curvilinear channel 1480.

[0081] In this embodiment, a pliable fuse wire (not shown) could be manipulated through the embedded curvilinear channel 1480, or a liquid metal or conductive epoxy layer 1485 could be dispensed within the embedded curvilinear channel 1480 to form the

fusible element 1416. In other embodiments, the fuse wire may and/or the liquid metal or conductive epoxy layer 1485 could be formed by additive manufacturing, taking on the curvilinear shape of the embedded curvilinear channel 1480. As shown, the fusible element 1416 may connect with the pair of conductive endcaps 1410, 1412. In some embodiments, the fusible element 1416 and the pair of conductive endcaps 1410, 1412 connect without the use of a solder.

[0082] In some embodiments, an arc arresting material (not shown), such as a dielectric gel, could be dispensed around the fusible element 1416 within the embedded curvilinear channel 1480. Manufacture of the embedded curvilinear channel 1480 is possible using the additive manufacturing process to print the tunnel structure in multiple materials.

[0083] **FIGs. 16A-16B** demonstrates a circuit protection device (hereinafter “device”) 1500 in accordance with the present disclosure. In this embodiment, the device provides a larger fuse body 1502 in a constrained space. As shown, a slot 1581 may be provided in a printed circuit board (PCB) 1582 in addition to the non-conductive fuse body 1502 design, which allows for a larger fuse in the same space typically used for a smaller diameter fuse. The fusible element 1516 design, which flows into a set of conductive pads 1584, minimizes the amount of conductive material needed for the device 1500. The conductive pads 1584 are electrically connected with the fusible element 1512, which may extend across a hollow interior 1518 of the fuse body 1502.

[0084] As shown, the fuse body 1502 may extend along both a first surface 1549 and a second surface 1551 of the PCB 1582. For example, the first end 1522 may extend

above (in the orientation depicted) the PCB 1582, while the second end 1524 may extend below the PCB 1582. In some embodiments, at least one conductive pads 1584 is directly secured to the first surface 1549 of the PCB 1582.

[0085] As further shown, the fuse body 1502 may include a main body 1590 surrounding the hollow interior 1518, and a set of lateral sections 1592 extending from the main body 1590. In some embodiments, each of the lateral sections 1592 extends along the first surface 1549 of the PCB 1582. The conductive pads 1584 may be formed along opposite sides of the lateral sections 1592.

[0086] **FIG. 17** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1600 in accordance with the present disclosure. The device 1600 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the device 1600 may take on a space saving geometry. For example, the device 1600 may have a low profile and low footprint printed fuse body 1602 with conductive material printed at angle(s).

[0087] As shown, a pair of conductive endcaps 1610, 1612 are provided around the exterior of the fuse body 1602, and may be formed by additive manufacturing. The fusible element 1616 may extend through the hollow interior 1618 of the fuse body 1602, and may be secured to or integrally formed with the endcaps 1610, 1612 in electrical communication. In exemplary embodiments, the conductive end caps 1610, 1612 and the fusible element 1616 are formed by additive manufacturing.

[0088] In this non-limiting embodiment, endcap 1610 includes a main section 1620 and a wrap-around section 1628 extending from the main section 1620. As shown, the wrap-around section 1628 may extend perpendicularly, or substantially perpendicularly, from the main section 1620. In this non-limiting embodiment, the endcap 1610 extends along an entire wall/surface 1692 of the fuse body 1602. The endcap 1612 may include a first section 1691 joined to a second section 1693. As shown, the first and second sections 1691, 1693 may form a 90-degree angle relative to one another. As shown, the fusible element 1616 may connect to the endcap 1612 at the intersection of the first and second sections 1691, 1693. However, this construction is non-limiting.

[0089] **FIG. 18** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1700 in accordance with the present disclosure. The device 1700 may include some of the features previously described above in relation to the devices 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600 and, as such, may not be described in full detail for the sake of brevity. In this embodiment, the device 1700 may take on a space saving geometry. For example, the device 1700 may have a low profile and low footprint printed fuse body 1702 with conductive material printed at angle(s).

[0090] In this non-limiting embodiment, the fusible element 1716 may connect with a set of anchors 1770 extending outside the fuse body 1702. Although not limited to any particular shape or configuration, each of the set of anchors 1770 may be T-shaped. As shown, the set of anchors 1770 may extend along a same plane.

[0091] **FIG. 19** demonstrates a cross-sectional view of a circuit protection device (hereinafter “device”) 1800 in accordance with the present disclosure. The device 1800 includes many of the features previously described above in relation to the other devices of the disclosure and, as such, may not be described in full detail for the sake of brevity. In this embodiment, a fusible element 1816 (e.g., a fuse wire) may extend through a hollow interior 1818 of the fuse body 1802 and may be secured to or integrally formed with endcaps 1810, 1812 in electrical communication. As shown, the fusible element 1816 may take on a helical configuration. In exemplary embodiments, the conductive end caps 1810, 1812 and the fusible element 1816 are formed by additive manufacturing without the presence of any electrically conductive adhesive, such as solder, at an intersection of the endcaps 1810, 1812 and the fusible element 1816. Although not shown, the hollow interior 1818 of the fuse body 1802 may be partially or entirely filled with an arc-quenching material (not shown), including, but not limited to, sand, silica, etc.

[0092] As stated above, any of the devices described herein may be formed using an additive manufacturing process (e.g., 3-D printing) that enables fuse geometries to be manufactured not feasible using traditional subtractive manufacturing techniques, such as drilling. 3-D printing allows not only simple, straight, circular channels, but complex paths and profiles in any material, which permits ideal geometries to be fabricated. Furthermore, electrically conductive element, such as endcaps and the fusible element, may be integrally formed as a single component. As a result, the use of solder to join these electrical components is not necessary. Defects typically found in prior circuit protection devices can therefore be eliminated.

[0093] The foregoing discussion has been presented for purposes of illustration and description and is not intended to limit the disclosure to the form or forms disclosed herein. For example, various features of the disclosure may be grouped together in one or more aspects, embodiments, or configurations for the purpose of streamlining the disclosure. However, it should be understood that various features of the certain aspects, embodiments, or configurations of the disclosure may be combined in alternate aspects, embodiments, or configurations. Moreover, the following claims are hereby incorporated into this Detailed Description by this reference, with each claim standing on its own as a separate embodiment of the present disclosure.

[0094] As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural elements or steps, unless such exclusion is explicitly recited. Furthermore, references to “one embodiment” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0095] The use of “including,” “comprising,” or “having” and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Accordingly, the terms “including,” “comprising,” or “having” and variations thereof are open-ended expressions and can be used interchangeably herein.

[0096] The phrases “at least one”, “one or more”, and “and/or”, as used herein, are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions “at least one of A, B and C”, “at least one of A, B, or C”, “one or more of A, B, and C”, “one or more of A, B, or C” and “A, B, and/or C”

means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

[0097] All directional references (e.g., proximal, distal, upper, lower, upward, downward, left, right, lateral, longitudinal, front, back, top, bottom, above, below, vertical, horizontal, radial, axial, clockwise, and counterclockwise) are only used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of this disclosure. Connection references (e.g., attached, coupled, connected, and joined) are to be construed broadly and may include intermediate members between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to each other.

[0098] Furthermore, identification references (e.g., primary, secondary, first, second, third, fourth, etc.) are not intended to connote importance or priority, but are used to distinguish one feature from another. The drawings are for purposes of illustration only and the dimensions, positions, order and relative sizes reflected in the drawings attached hereto may vary. Furthermore, the terms “substantial” or “substantially,” as well as the terms “approximate” or “approximately,” can be used interchangeably in some embodiments, and can be described using any relative measures acceptable by one of ordinary skill in the art. For example, these terms can serve as a comparison to a reference parameter, to indicate a deviation capable of providing the intended function. Although non-limiting, the deviation from the reference parameter can be, for example,

in an amount of less than 1%, less than 3%, less than 5%, less than 10%, less than 15%, less than 20%, and so on.

[0099] Still furthermore, although the illustrative methods are described above as a series of acts or events, the present disclosure is not limited by the illustrated ordering of such acts or events unless specifically stated. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein, in accordance with the disclosure. In addition, not all illustrated acts or events may be required to implement a methodology in accordance with the present disclosure. Furthermore, the methods may be implemented in association with the formation and/or processing of structures illustrated and described herein as well as in association with other structures not illustrated.

[00100] The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are intended to fall within the scope of the present disclosure. Furthermore, the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose. Those of ordinary skill in the art will recognize the usefulness is not limited thereto and the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Thus, the claims set forth below are to be construed in view of the full breadth and spirit of the present disclosure as described herein.

Claims

What is claimed is:

1. A circuit protection device, comprising:
a fuse body including a hollow interior;
a fusible element disposed within the hollow interior; and
a set of endcaps disposed on opposite ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive.
2. The circuit protection device of claim 1, wherein the set of endcaps is embedded within the fuse body such that a portion of the fuse body is provided between the set of endcaps and respective end surfaces of the fuse body.
3. The circuit protection device of claim 1, wherein the fuse body includes a set of projections extending into the hollow interior.
4. The circuit protection device of claim 1, wherein the fusible element takes on a curvilinear configuration.
5. The circuit protection device of claim 1, further comprising an arc-suppressing material or an arc-quenching within the hollow interior.

6. The circuit protection device of claim 1, further comprising a set of non-conductive support structures extending from an interior sidewall defining the hollow interior, wherein the set of support structures extend around the fusible element.
7. The circuit protection device of claim 1, further comprising a set of micro-rebar structures embedded within the fuse body, wherein the set of micro-rebar structures extend around the hollow interior of the circuit protection device.
8. The circuit protection device of claim 1, wherein each of the set of endcaps includes an end strip extending beyond an outer surface of the fuse body.
9. The circuit protection device of claim 1, further comprising a set of printed anchors extending into the fuse body.
10. The circuit protection device of claim 1, further comprising:
 - a printed circuit board, wherein the fuse body at least partially surrounds the printed circuit board; and
 - a set of conductive pads coupled to the fuse body and to the printed circuit board.
11. A circuit protection device, comprising:
 - a fuse body including a first end, a second end, a first side, and a second side;
 - a fusible element disposed within a hollow interior of the fuse body; and

a set of endcaps disposed on the first and second ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive present within the set of endcaps or the hollow interior.

12. The circuit protection device of claim 11, wherein the set of endcaps is embedded within the fuse body such that a portion of the fuse body is provided between the set of endcaps and respective end surfaces of the fuse body.

13. The circuit protection device of claim 11, wherein the fuse body includes a set of projections extending into the hollow interior.

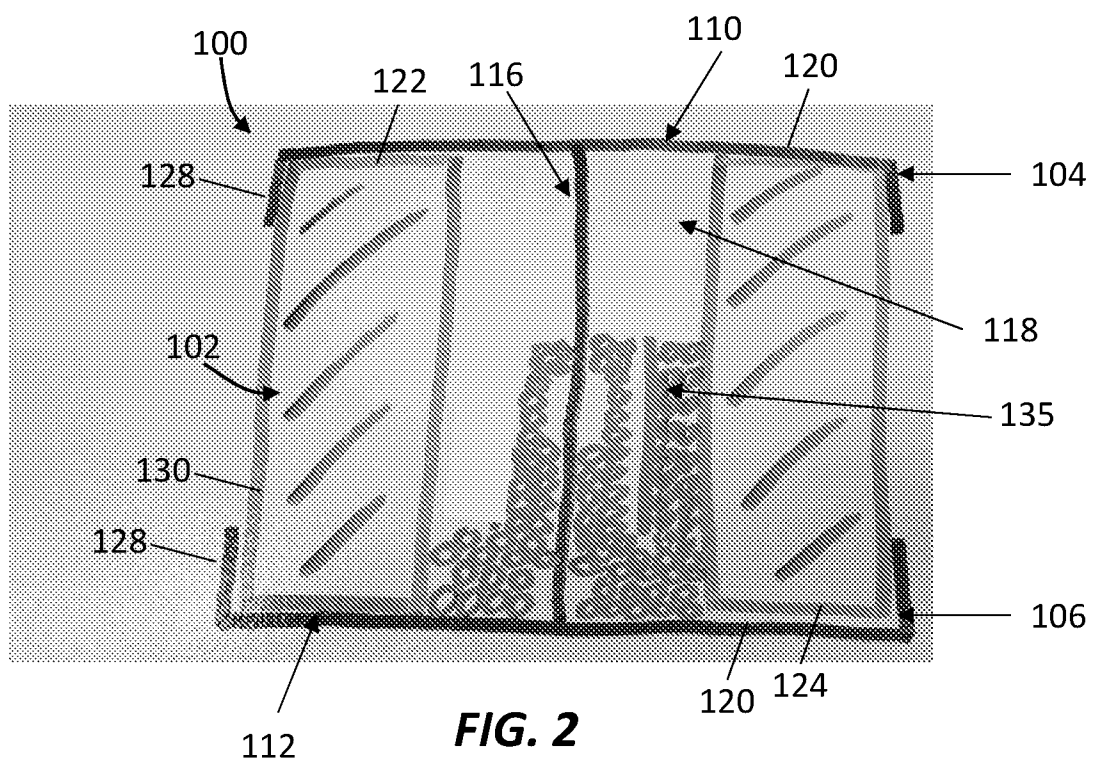
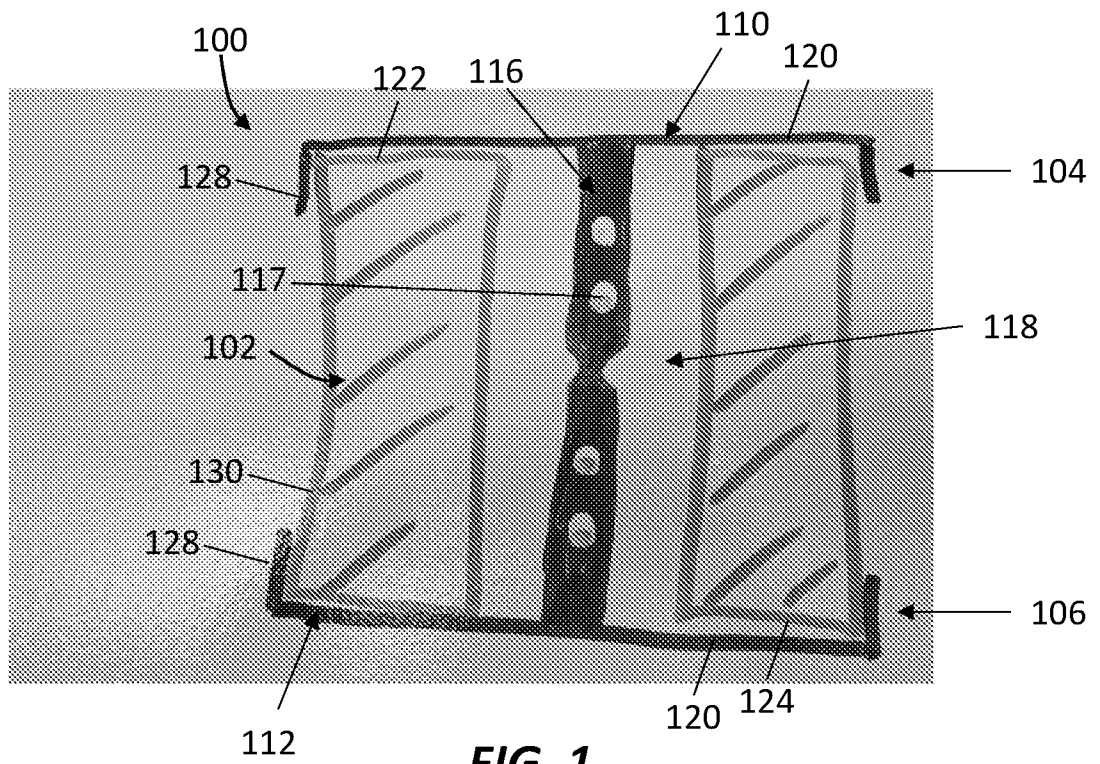
14. The circuit protection device of claim 11, wherein the fusible element takes on a curvilinear configuration.

15. The circuit protection device of claim 11, further comprising a set of non-conductive support structures extending from an interior sidewall defining the hollow interior, wherein the set of support structures each include a loop extending around the fusible element.

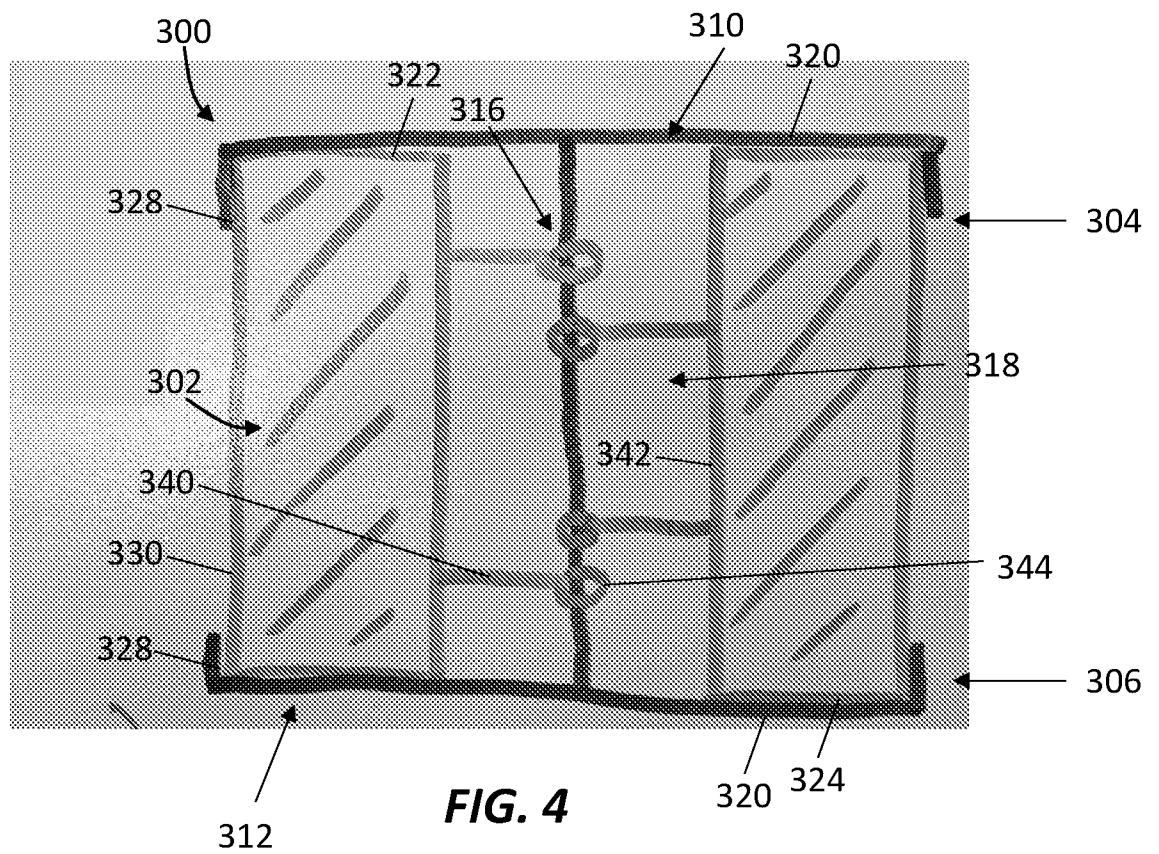
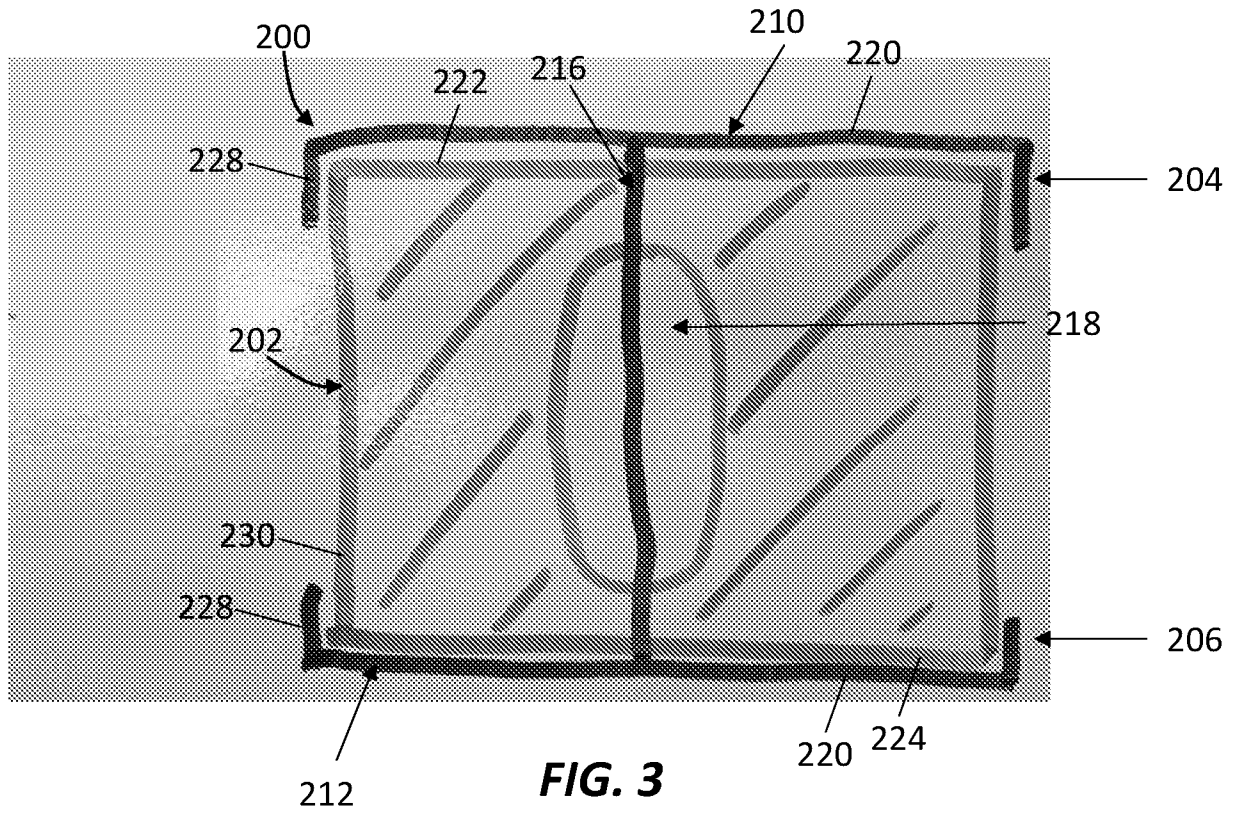
16. The circuit protection device of claim 11, further comprising a set of micro-rebar structures embedded within the fuse body, wherein one or more of the set of micro-rebar structures extends between the first and second ends of the fuse body, and wherein one or more of the set of micro-rebar structures extends around the hollow interior.

17. The circuit protection device of claim 11, further comprising:
- a printed circuit board, wherein a main body of the fuse body at least partially surrounds the printed circuit board; and
 - a set of conductive pads coupled to the fuse body and to the printed circuit board.
18. A fuse, comprising:
- a fuse body including a first end, a second end, a first side, and a second side;
 - a fusible element disposed within a hollow interior of the fuse body; and
 - a set of endcaps disposed on the first and second ends of the fuse body, the set of endcaps integrally formed with the fusible element without an electrically conductive adhesive present along the set of endcaps or within the hollow interior.
19. The fuse of claim 18, wherein the set of endcaps is embedded within the fuse body such that a portion of the fuse body is provided between the set of endcaps and respective end surfaces of the fuse body.
20. The fuse of claim 18, further comprising:
- a printed circuit board, wherein a main body of the fuse body at least partially surrounds the printed circuit board; and
 - a set of conductive pads coupled to the fuse body and to the printed circuit board.

1/15



2/15



3/15

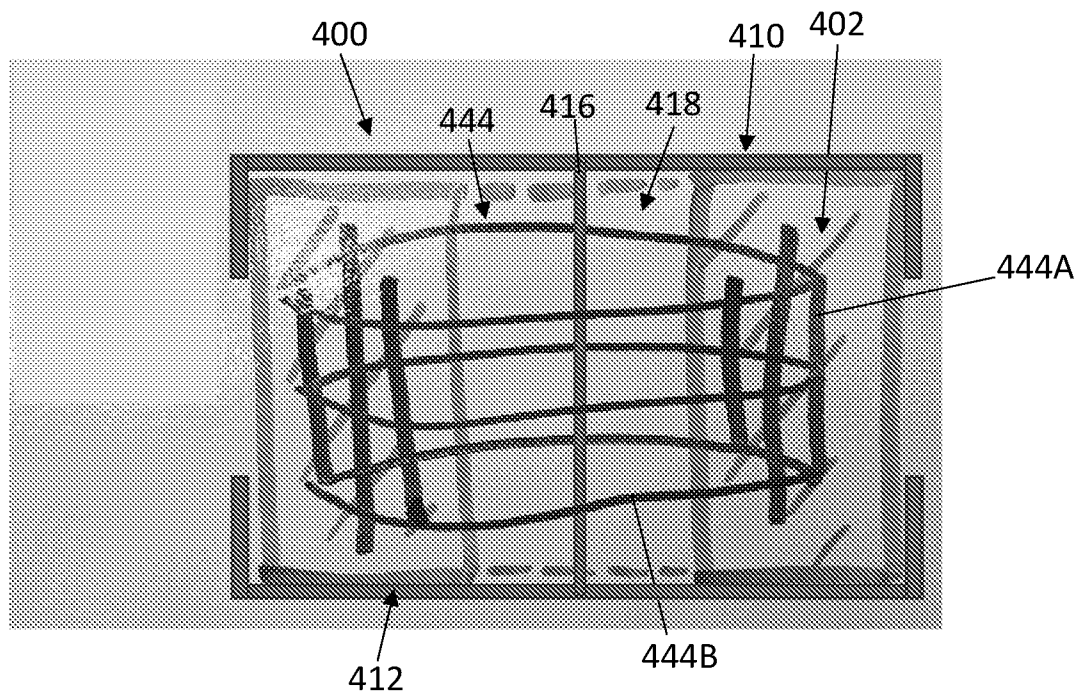


FIG. 5

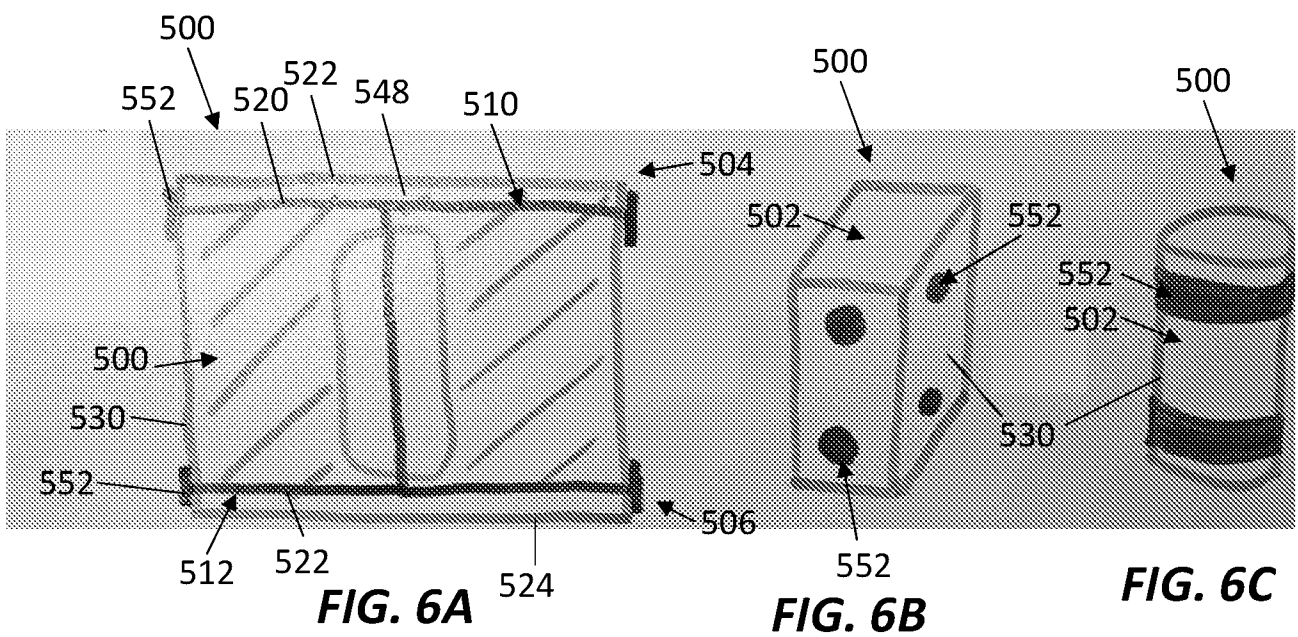


FIG. 6A

FIG. 6B

FIG. 6C

4/15

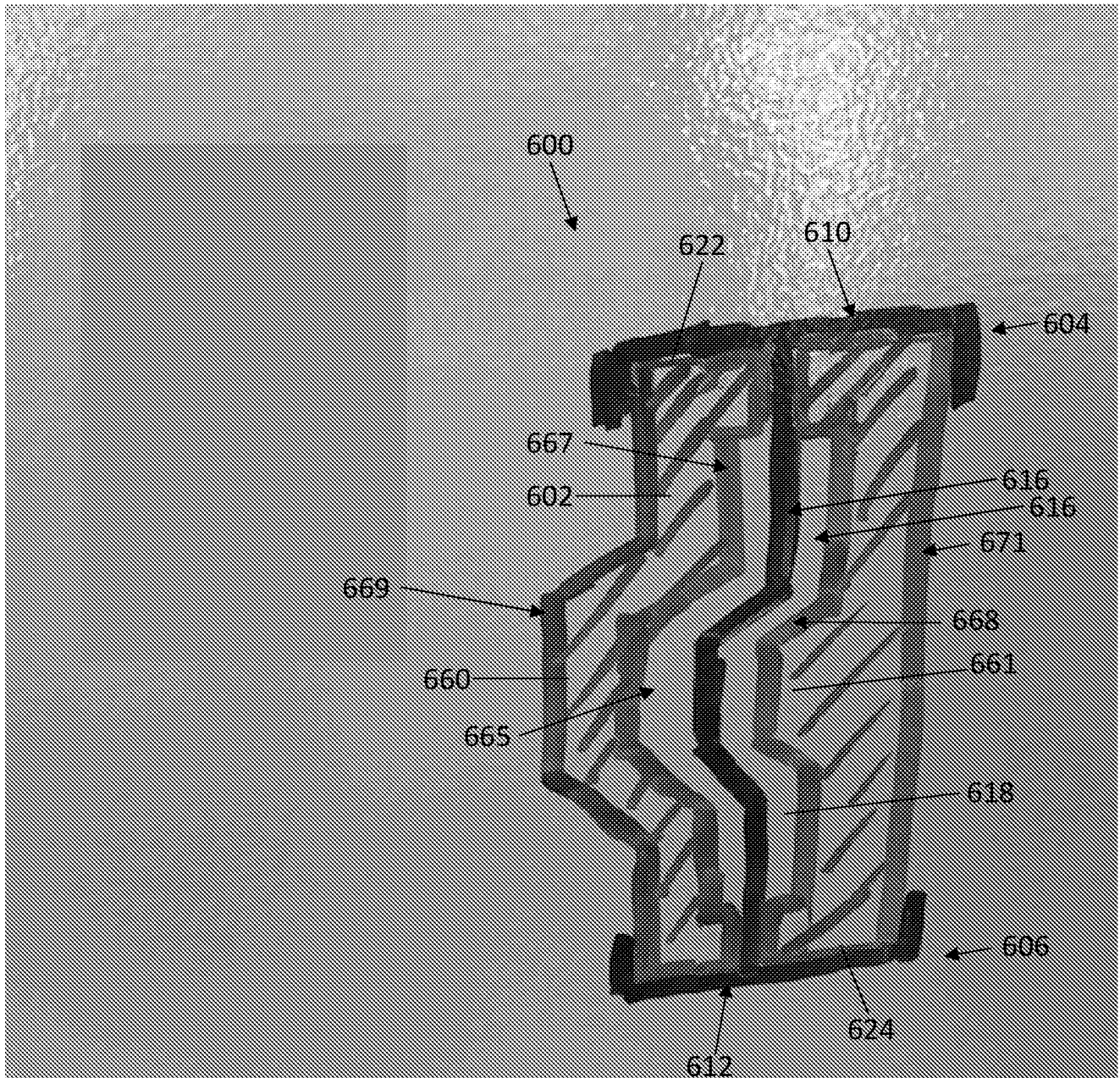


FIG. 7

5/15

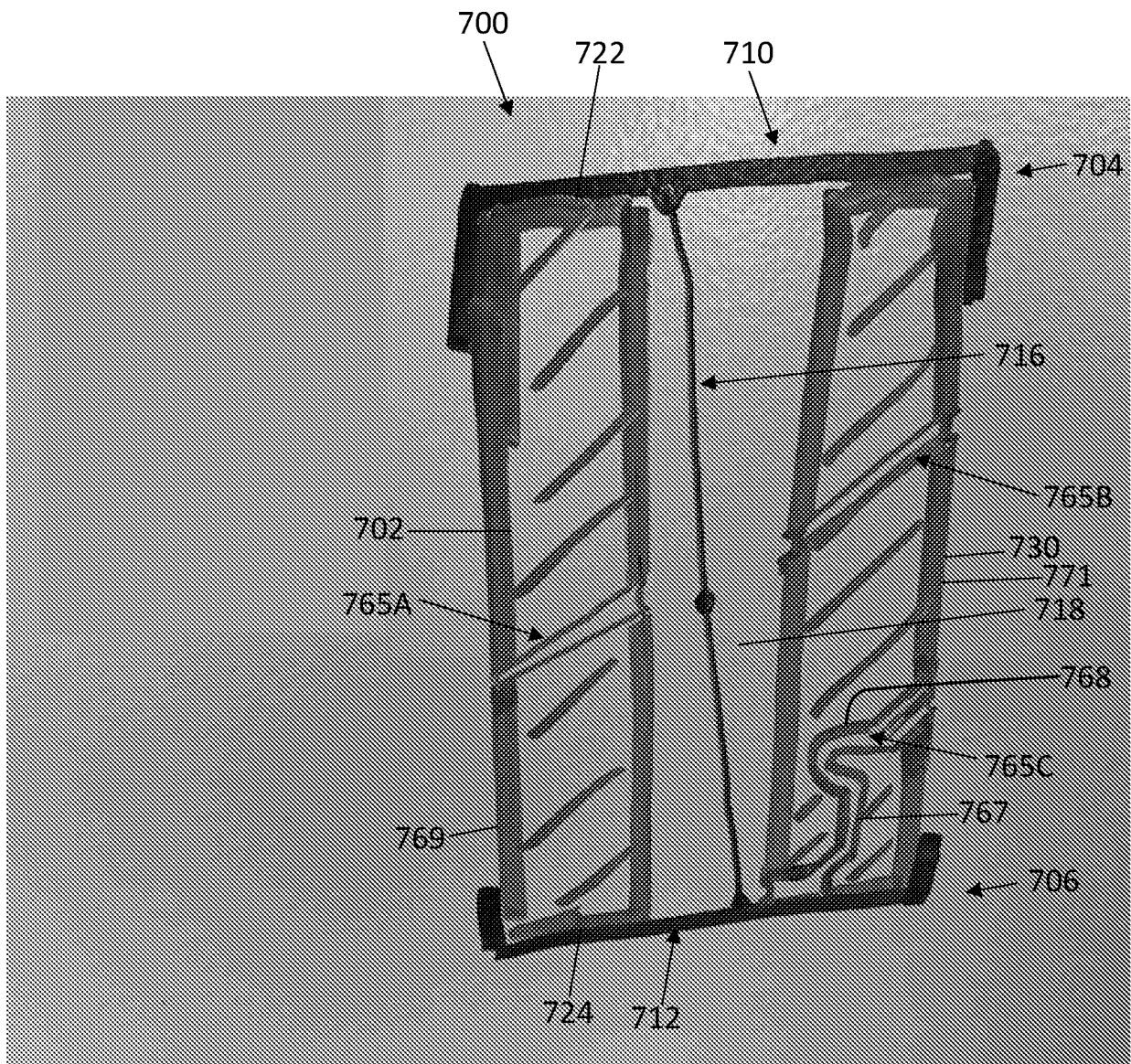


FIG. 8

6/15

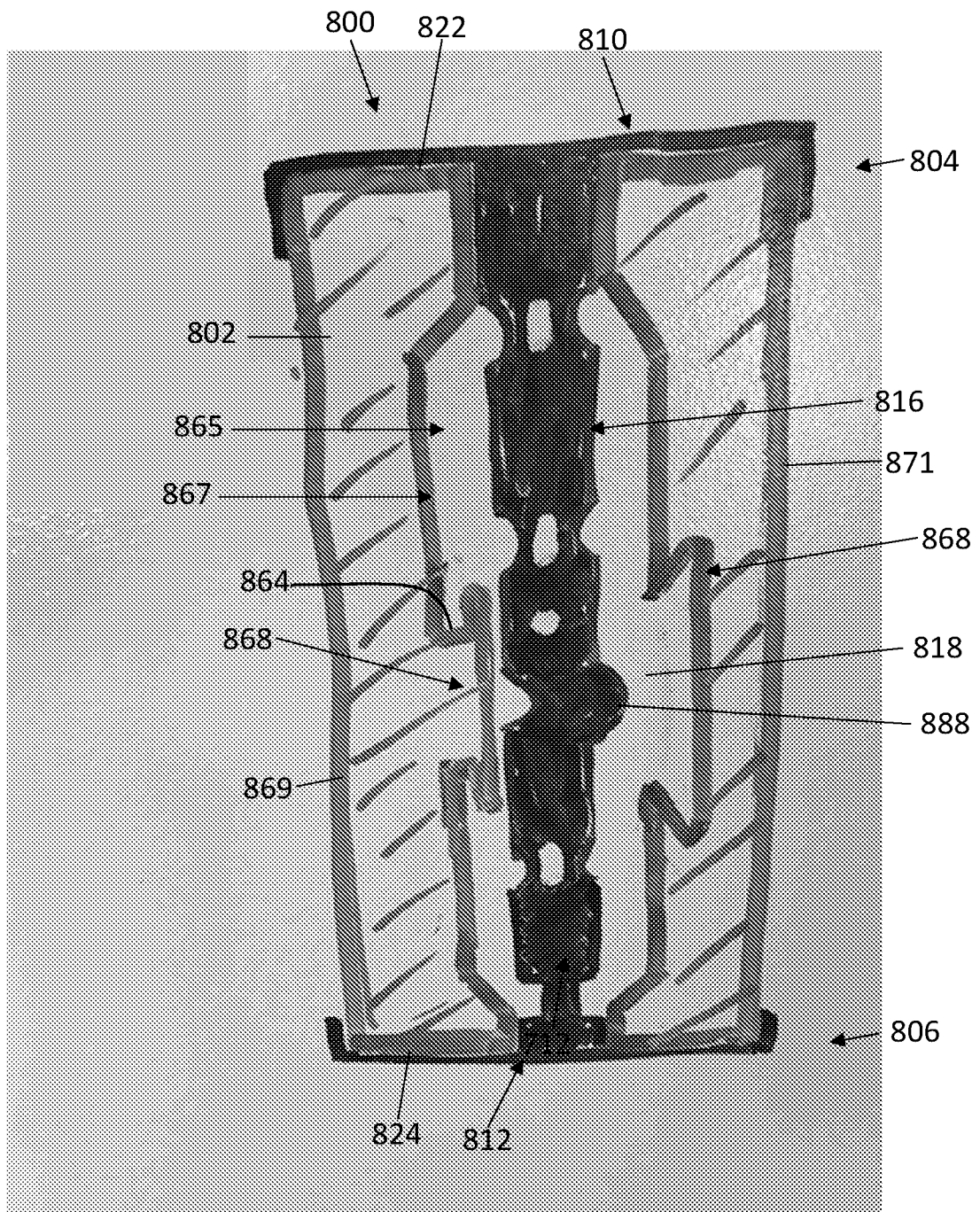


FIG. 9

7/15

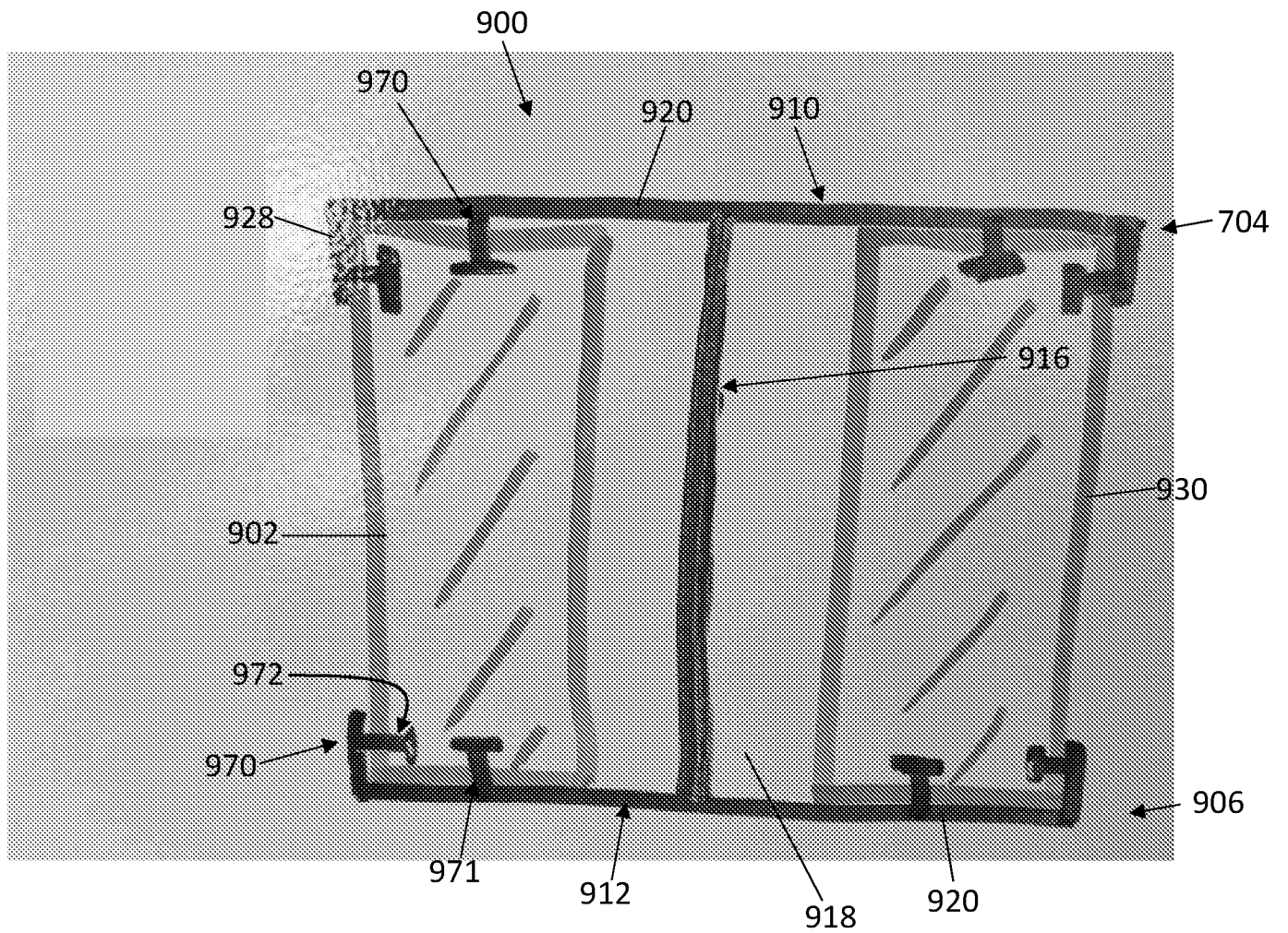


FIG. 10

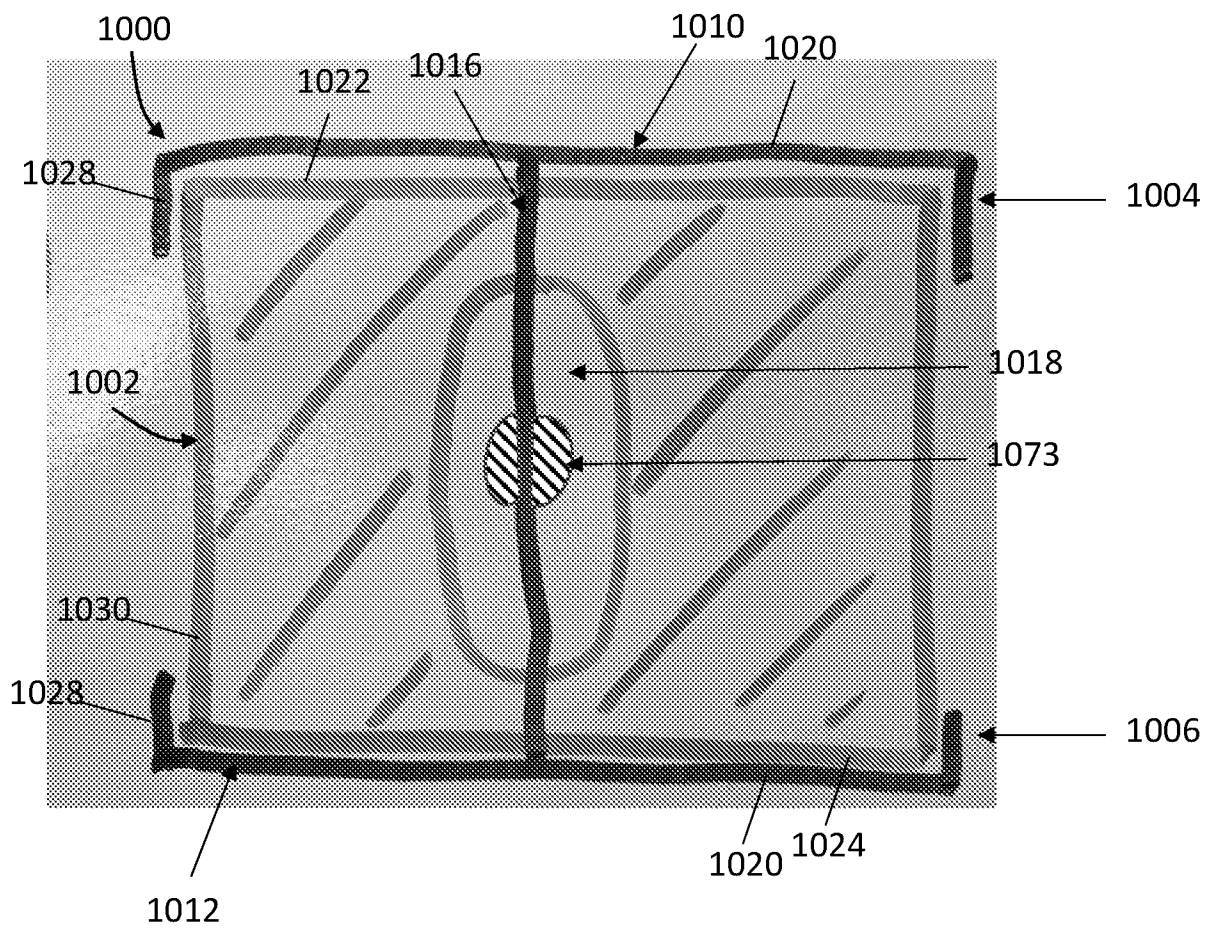


FIG. 11

9/15

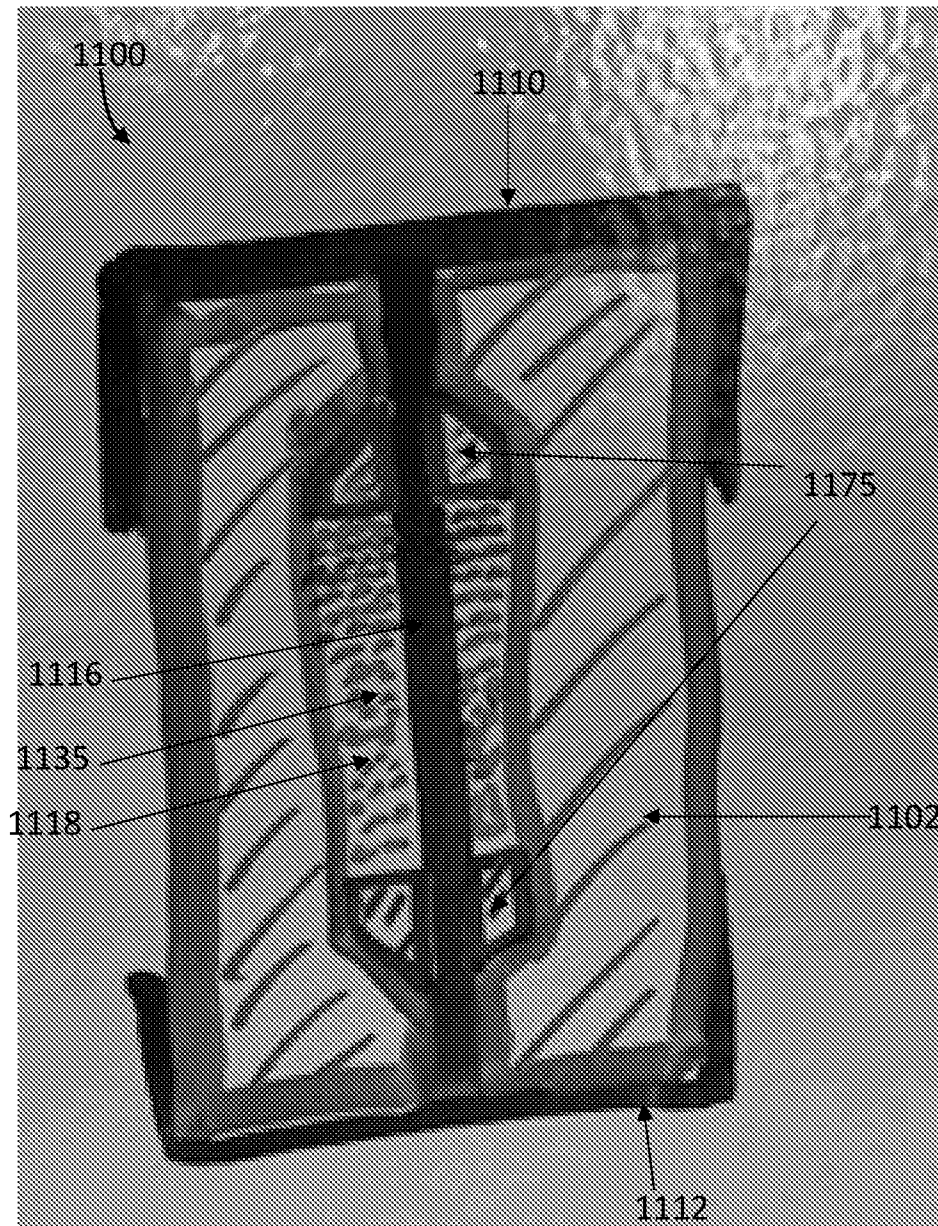


FIG. 12

10/15

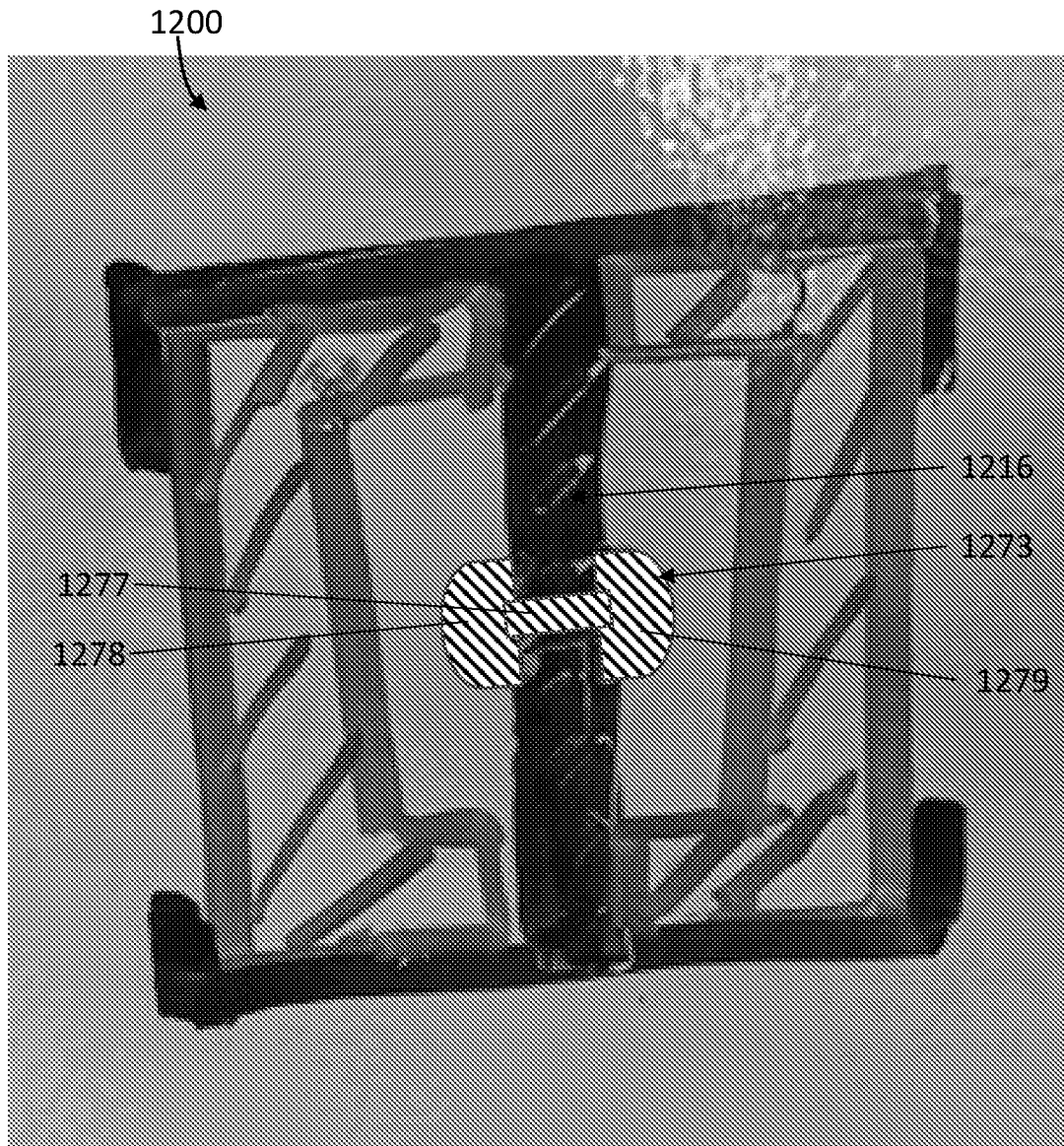
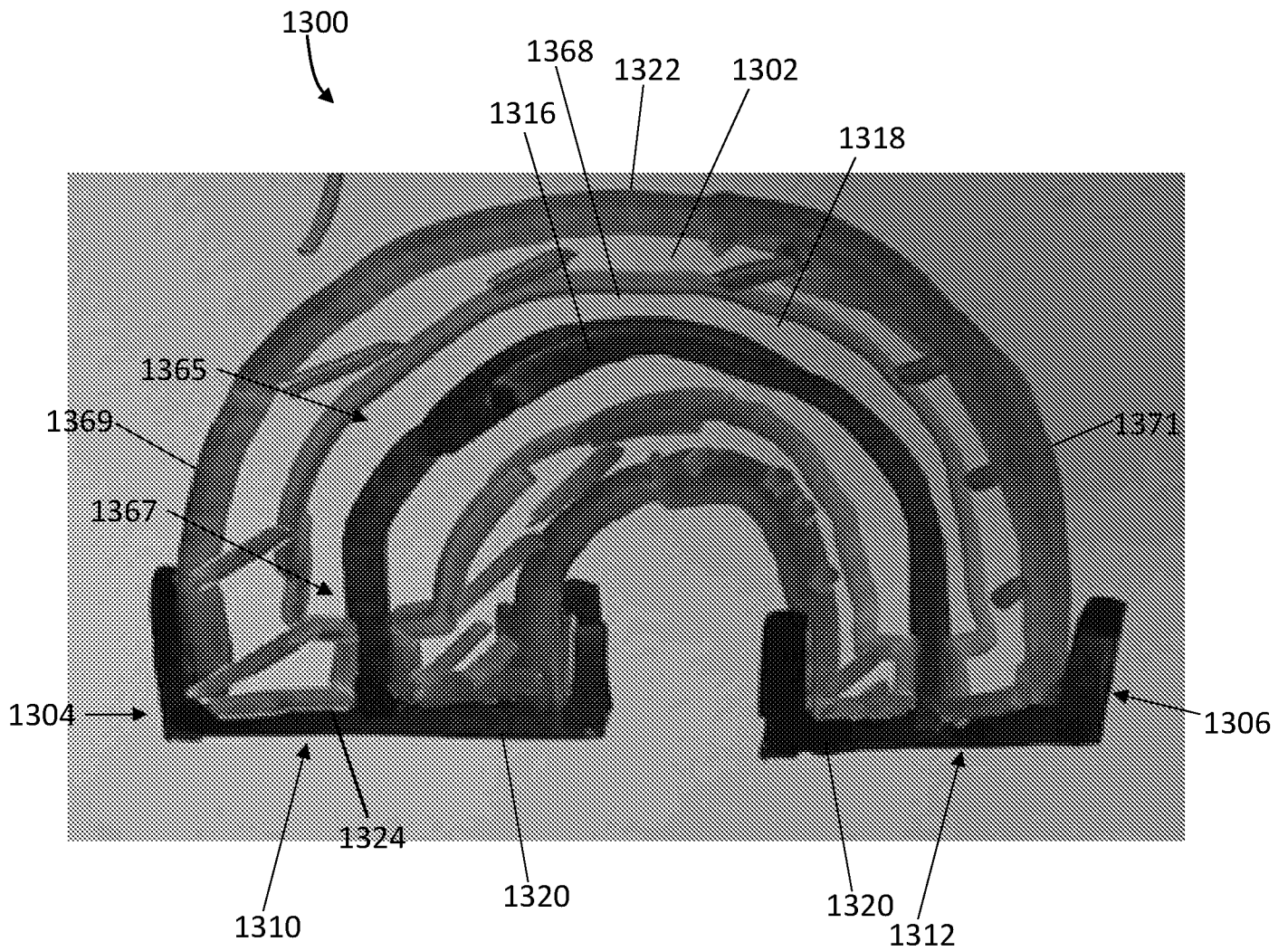
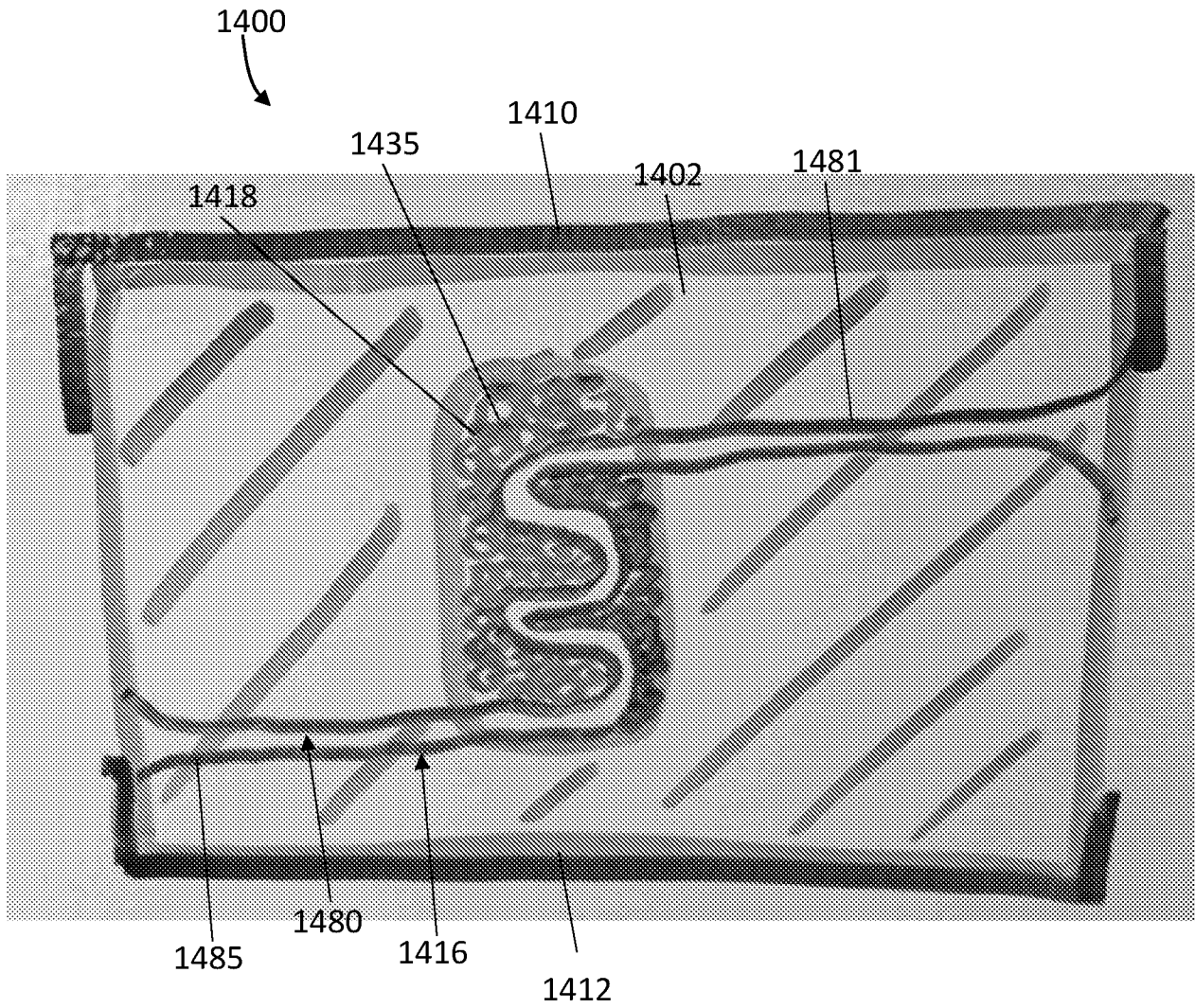


FIG. 13

11/15

**FIG. 14**

12/15

**FIG. 15**

13/15

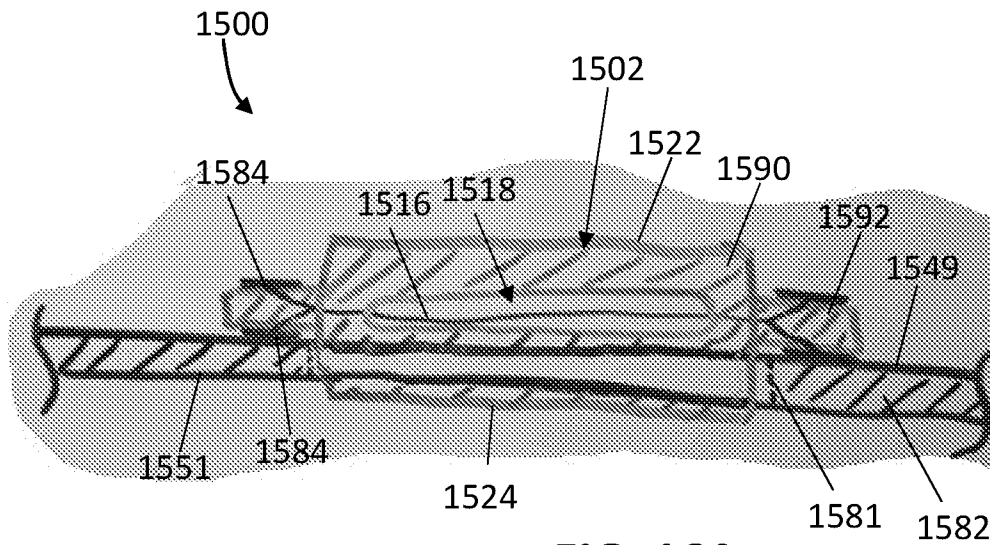


FIG. 16A

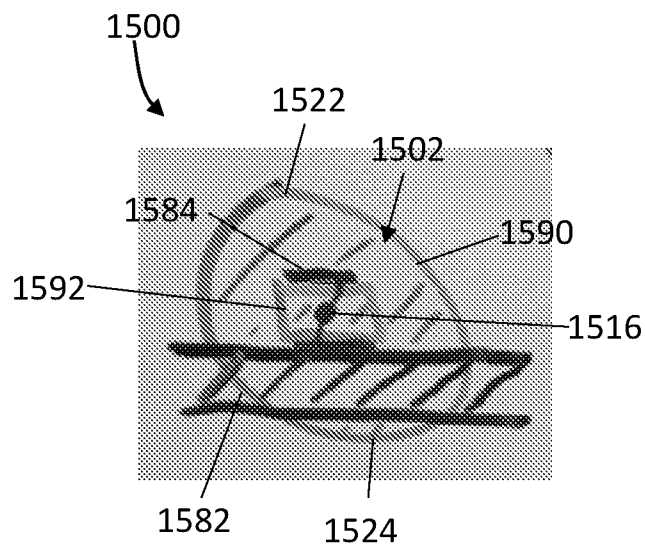


FIG. 16B

14/15

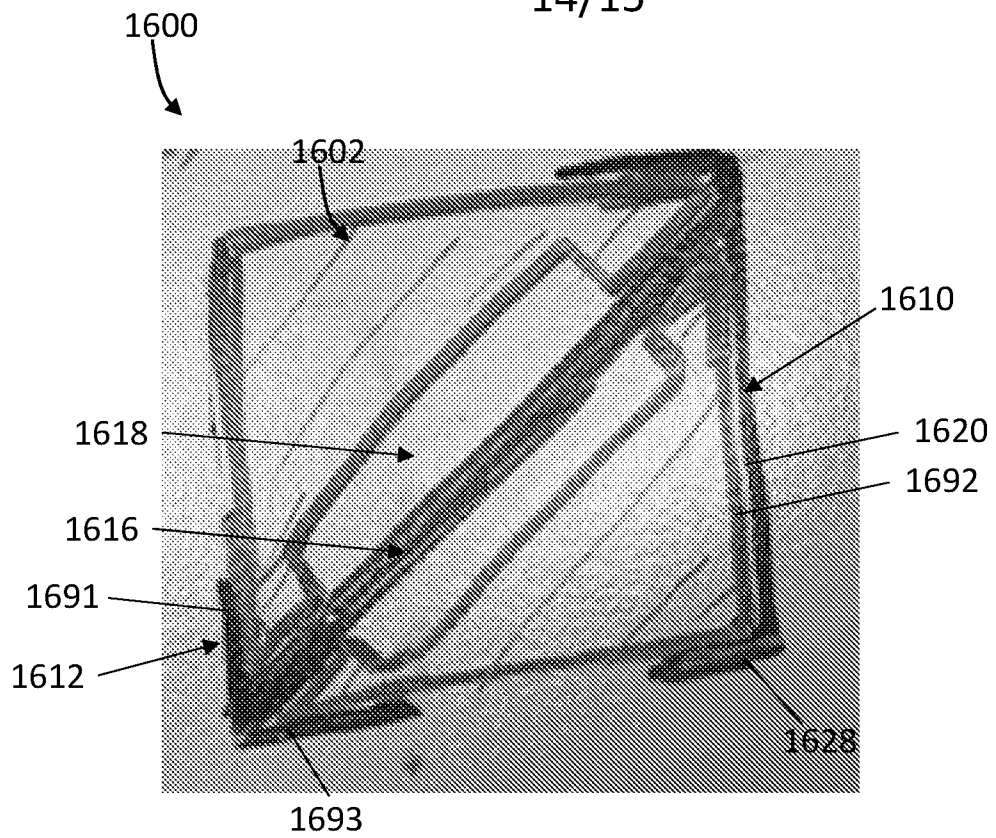


FIG. 17

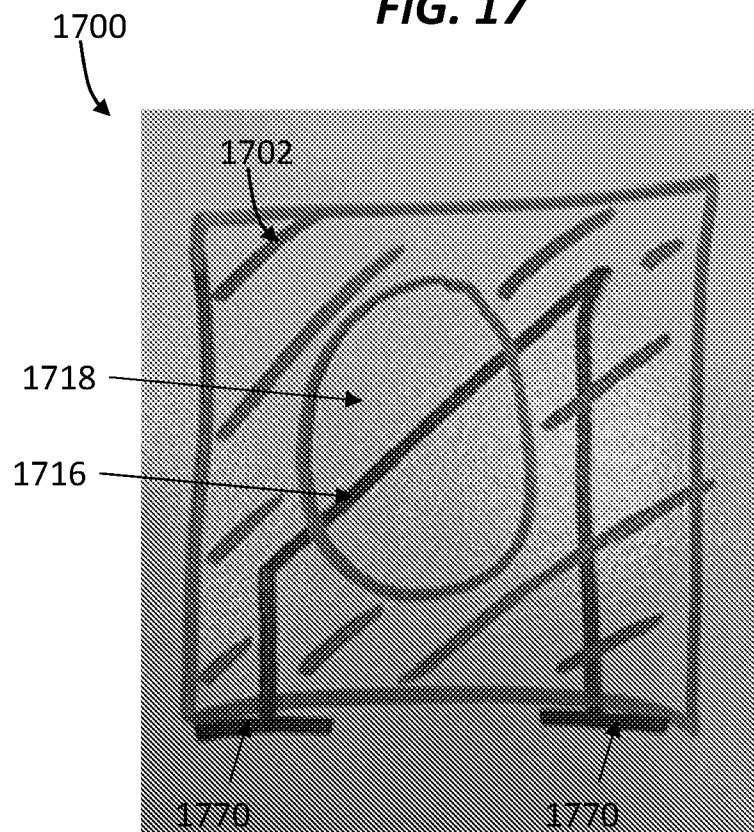


FIG. 18

15/15

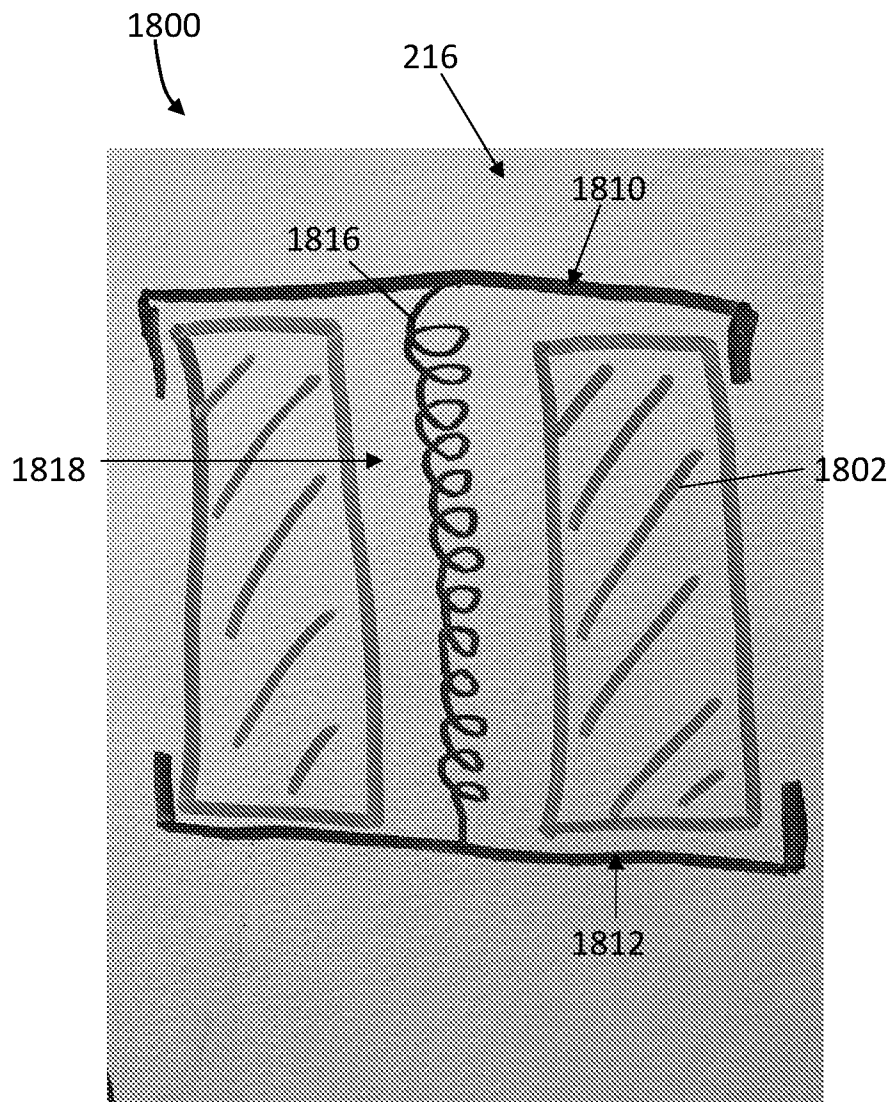


FIG. 19

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2019/031607

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01H 85/08; H01H 37/76; H01H 85/04; H01H 85/06; H01H 85/18; H01H 85/38 (2019.01)

CPC - H01H 85/08; H01H 85/0411; H01H 85/06; H01H 85/143; H01H 85/38 (2019.05)

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)

See Search History document

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

USPC - 29/623; 337/231; 337/273; 337/276; 337/278; 337/290; 337/295; 337/404; 361/93.1 (keyword delimited)

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	WO 2013/041270 A1 (AUTO-KABEL MANAGEMENTGESELLSCHAFT MBH et al) 28 March 2013 (28.03.2013) see machine translation	1, 5, 11, 18 --- 2-4, 8, 10, 12-14, 17, 19, 20
Y	US 2001/0024155 A1 (ENDO et al) 27 September 2001 (27.09.2001) entire document	2-4, 8, 12-14, 19
Y	US 6,873,243 B1 (KARNES et al) 29 March 2005 (29.03.2005) entire document	10, 17, 20
A	US 2016/0064173 A1 (COOPER TECHNOLOGIES COMPANY) 03 March 2016 (03.03.2016) entire document	1-20
A	US 4,441,093 A (OKAZAKI) 03 April 1984 (03.04.1984) entire document	1-20
A	US 6,507,264 B1 (WHITNEY) 14 January 2003 (14.01.2003) entire document	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

02 July 2019

Date of mailing of the international search report

17 JUL 2019

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, VA 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774