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(54) **MULTI-ELEMENT HYBRID PERFORATING APPARATUS**

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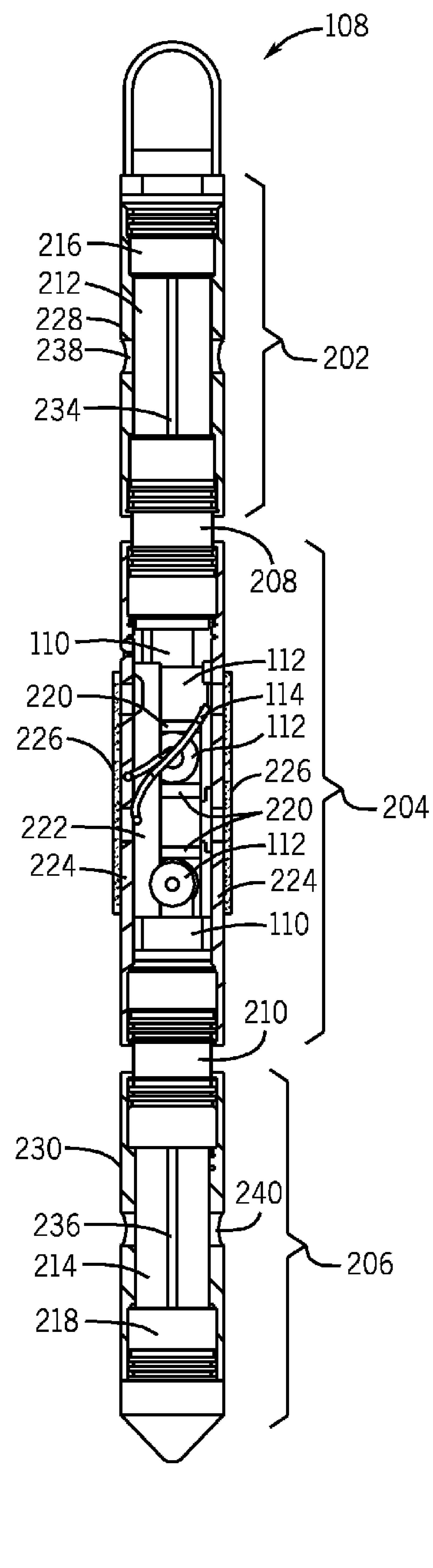
(57) **ABSTRACT**

A perforating apparatus includes a carrier, explosive devices mounted to the carrier, energetic cells arranged among the explosive devices, and a sleeve to receive at least a portion of the carrier, where the sleeve is formed of an energetic material.



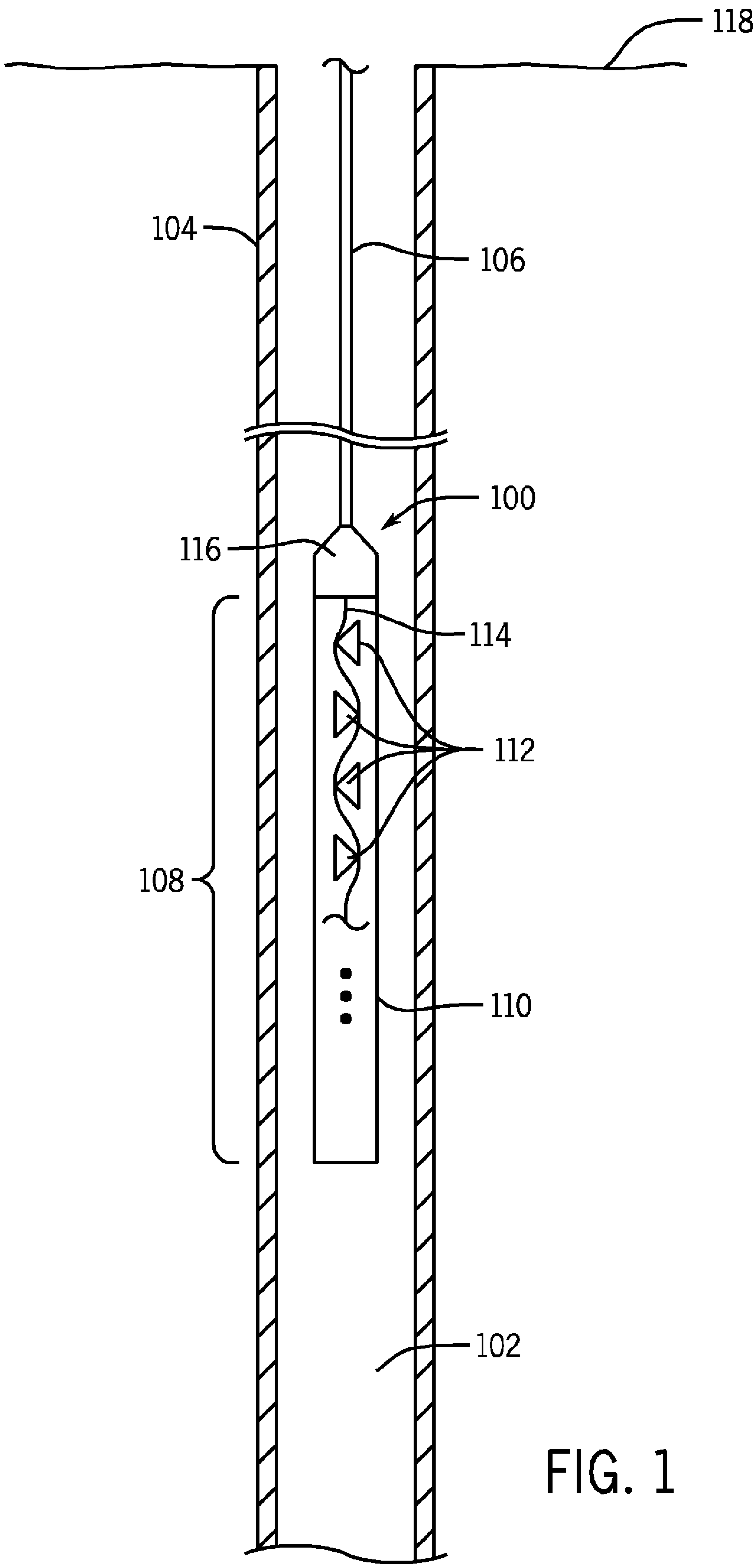


FIG. 1

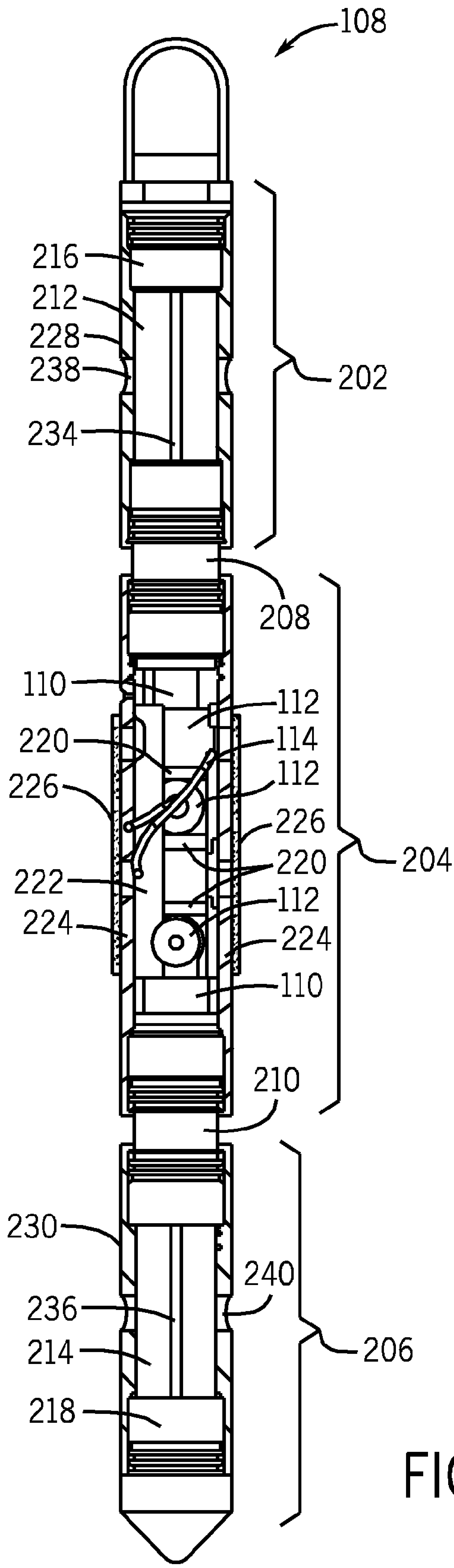

108
216
212
228
238
234
202
208
110
112
220
114
112
226
226
220
222
112
224
224
110
204
210
230
240
236
214
206
218

FIG. 2

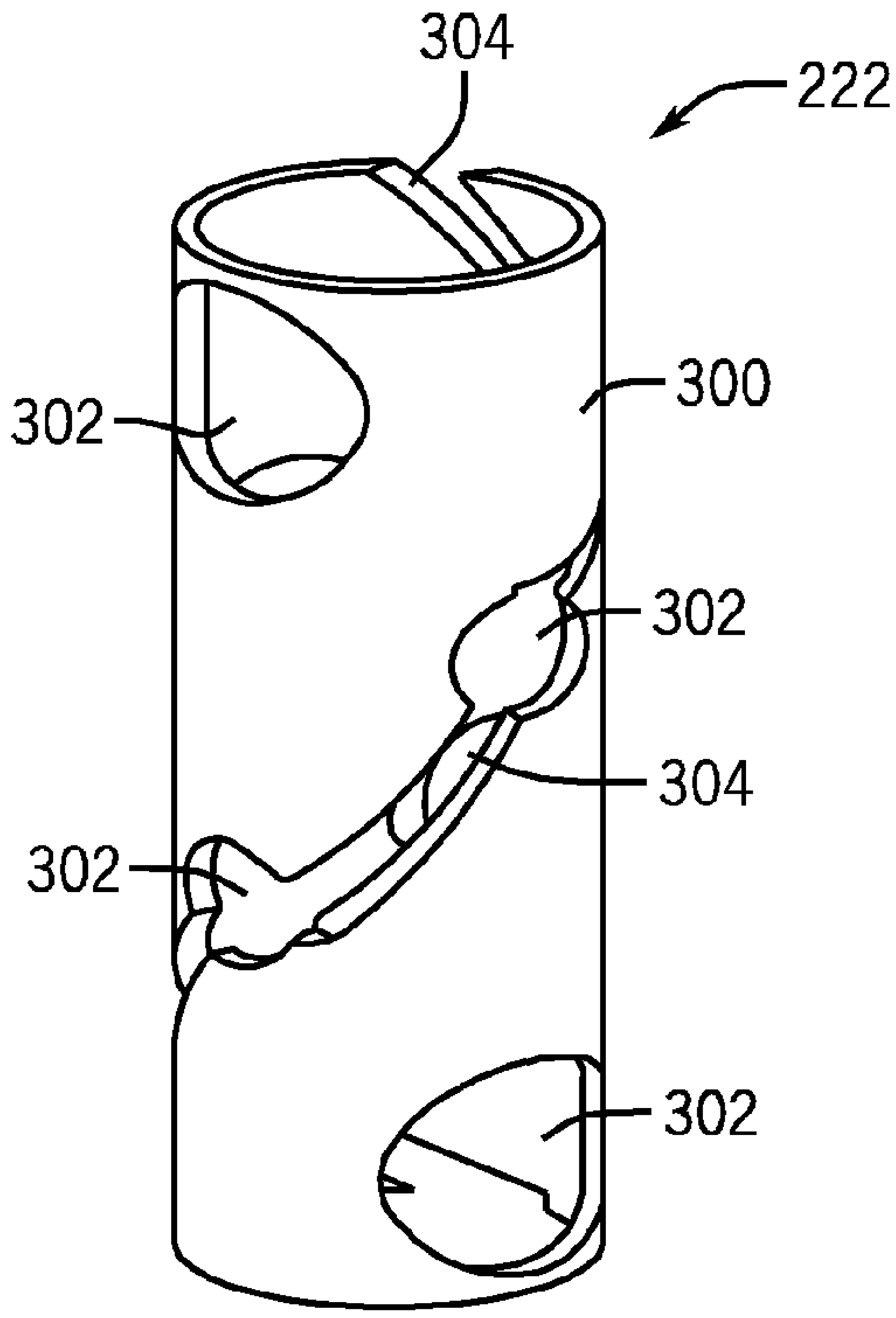


FIG. 3

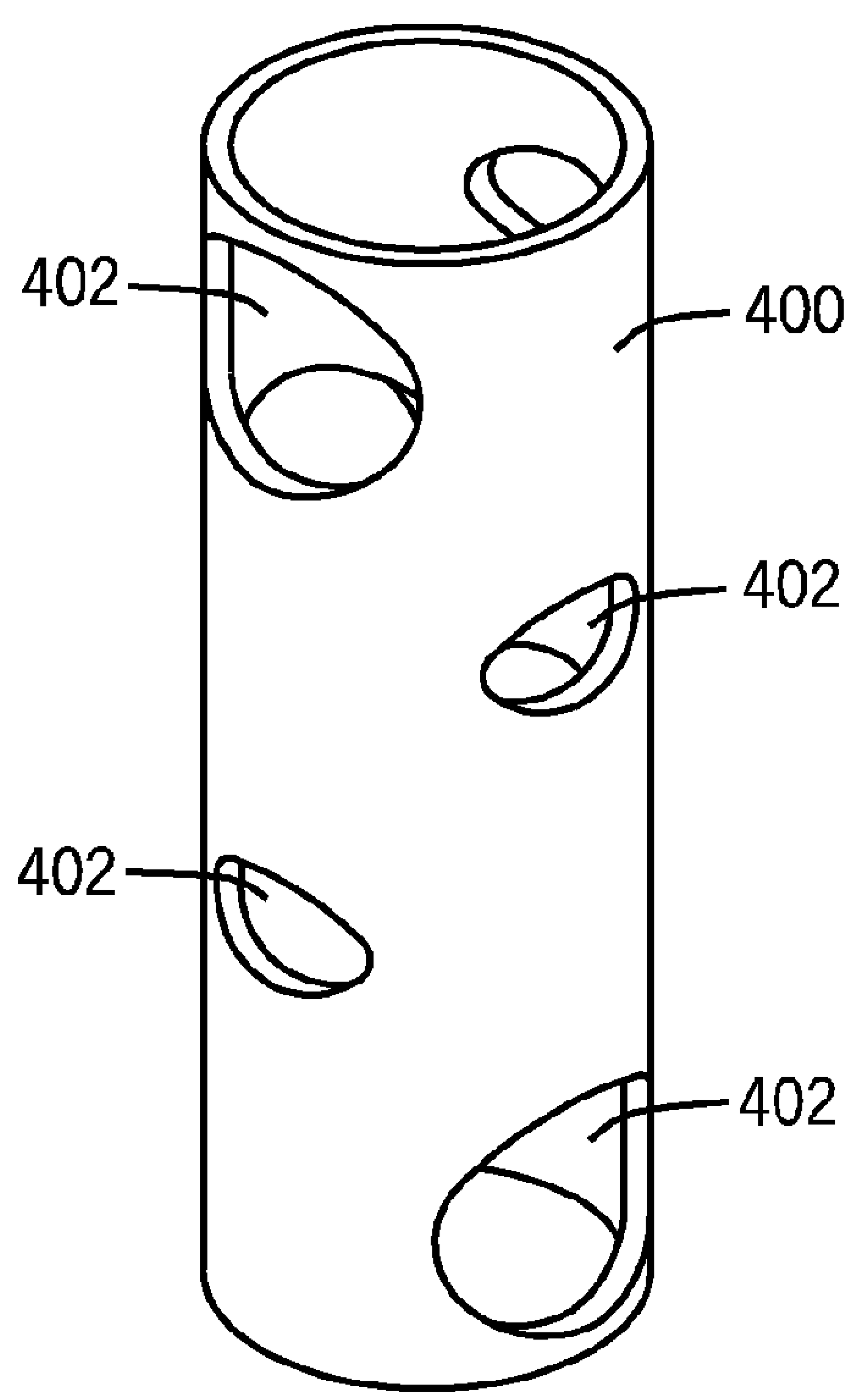


FIG. 4

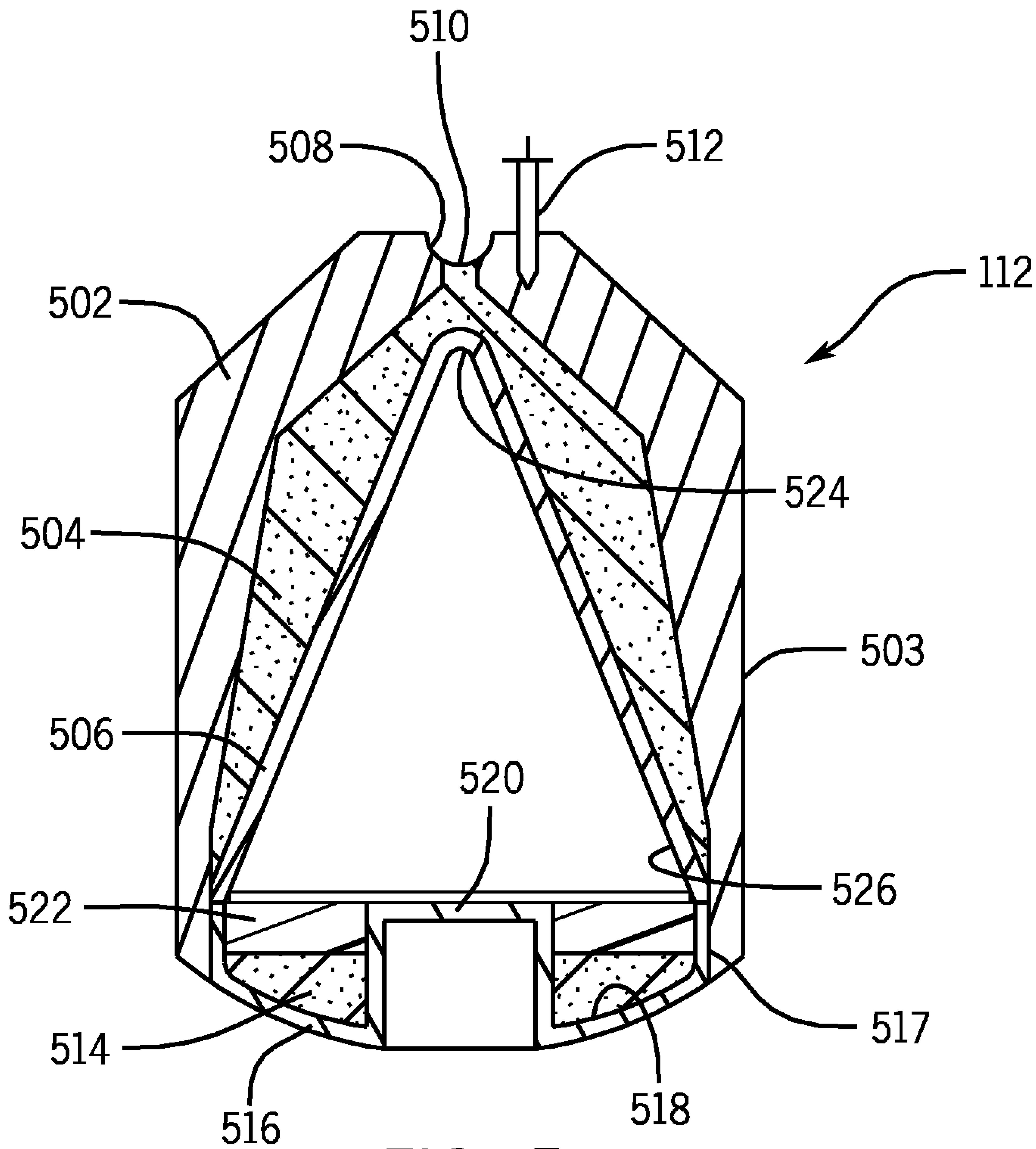

510
508
512
112
502
524
504
503
506
520
526
522
517
514
518
516

FIG. 5

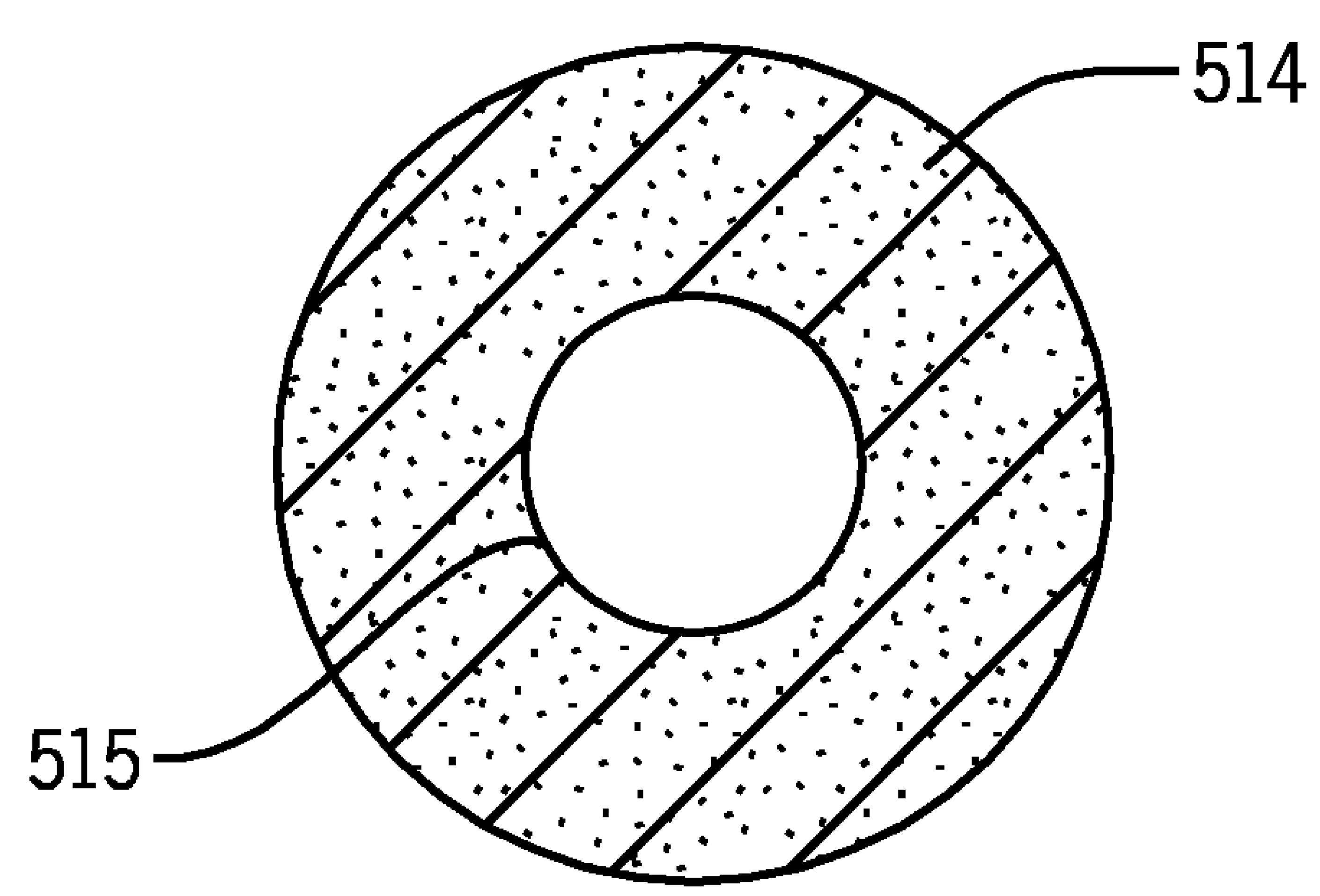

514
515

FIG. 6

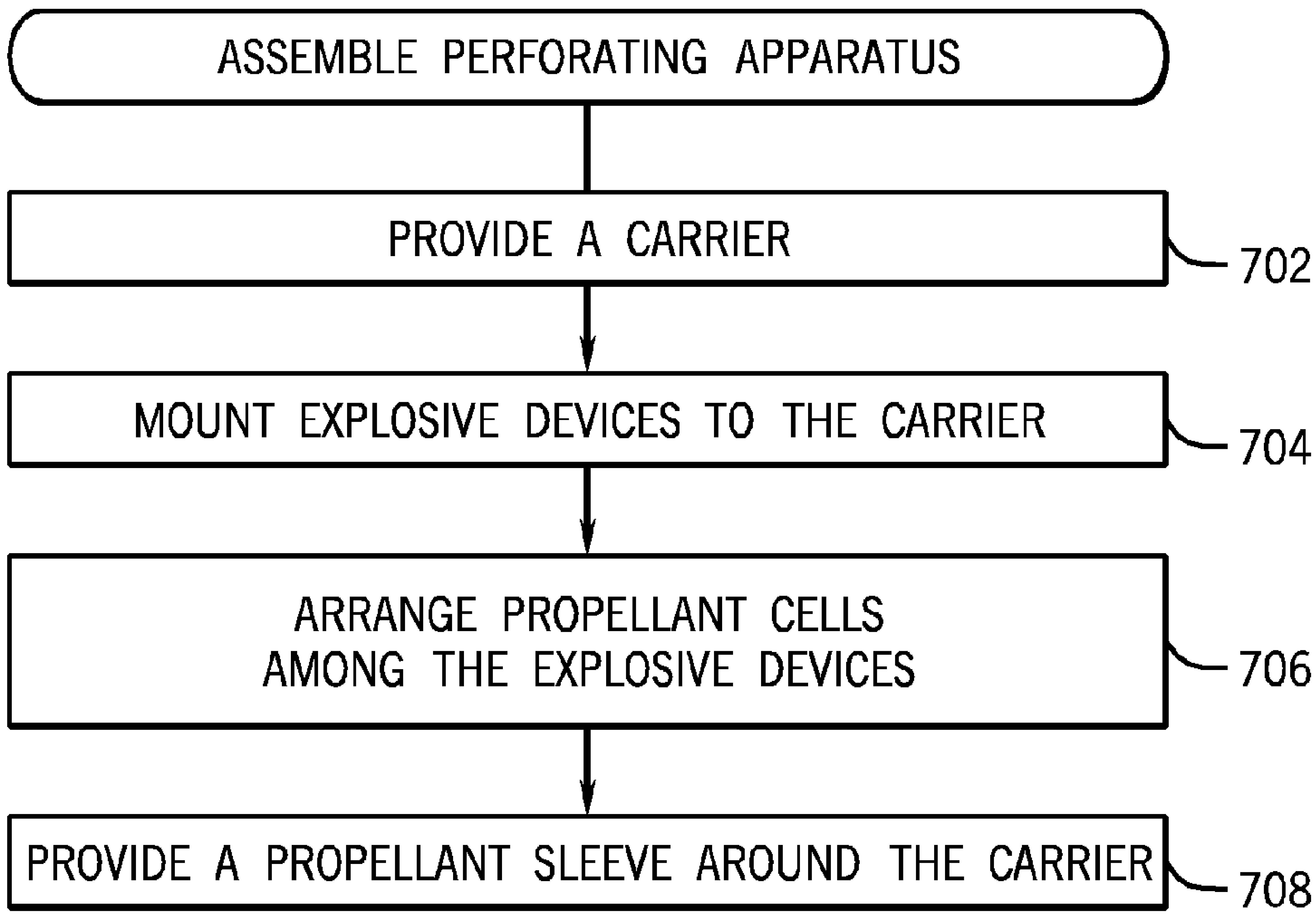

ASSEMBLE PERFORATING APPARATUS
PROVIDE A CARRIER
702
MOUNT EXPLOSIVE DEVICES TO THE CARRIER
704
ARRANGE PROPELLANT CELLS AMONG THE EXPLOSIVE DEVICES
706
PROVIDE A PROPELLANT SLEEVE AROUND THE CARRIER
708

FIG. 7

MULTI-ELEMENT HYBRID PERFORATING APPARATUS

BACKGROUND

[0001] To complete a well for purposes of producing fluids (such as hydrocarbons or other fluids) from a reservoir, or injecting fluids into the reservoir, one or more zones in the well are perforated to allow for fluid communication between a wellbore and the reservoir. Perforation is accomplished by lowering a perforating gun to a target interval within the well. Activation of the perforating gun creates openings in any surrounding casing or liner and extends perforation tunnels into the surrounding subterranean formation.

SUMMARY

[0002] In general, according to some implementations, a perforating apparatus includes a carrier, explosive devices mounted to the carrier, energetic cells arranged among the explosive devices, and a sleeve to receive at least a portion of the carrier, where the sleeve is formed of an energetic material.

[0003] Other or alternative features will become apparent from the following description, from the drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Some embodiments are described with respect to the following figures:

[0005] FIG. **1** illustrates an example tool string having a perforating gun configured according to some implementations;

[0006] FIG. **2** is a partial sectional view of a perforating gun according to some implementations;

[0007] FIGS. **3** and **4** illustrate modular energetic sleeves according to some implementations;

[0008] FIGS. **5** and **6** illustrate components of a perforator charge according to further implementations; and

[0009] FIG. **7** is a flow diagram of a process of forming a perforating gun according to some implementations.

DETAILED DESCRIPTION

[0010] To form perforations in a well (perforations are formed in a surrounding formation as well as in any casing or liner that lines the well), a perforating apparatus can be deployed into the well. An example of a perforating apparatus is a perforating gun that carries explosive devices that when detonated produces explosive jets that extend the perforations into a surrounding formation (in any intermediate casing or liner). Such explosive devices are referred to as perforator charges, and in some cases, are referred to as shaped charges.

[0011] The explosive nature of creating perforation tunnels in the subterranean formation can create a crushed zone in the formation. A "crushed zone" refers to a damaged zone that surrounds a perforation tunnel, where the perforating action has altered the formation structure and its permeability. Also, the perforating action can cause debris to fill perforation tunnels. The crushed zone damage can result in reduced ability to perform production or injection.

[0012] In accordance with some embodiments, a perforating apparatus, such as a perforating gun, is provided that includes various components formed of an energetic material that are able to produce a relatively high energy wave (or waves), such as in the form of a relatively high pressure pulse or pressure pulses. The high energy wave can result in creation of fractures in the subterranean formation, enlargement of a perforation tunnel, and/or removal or reduction of crushed zone damage in the formation. The components formed of the energetic material is activated in response to detonation of the explosive devices (such as perforator charges) in the perforating apparatus.

[0013] In some implementations, the deployment of multiple components of an energetic material allows for creation of multiple energy waves (such as multiple pressure pulses). In some implementations, the multiple components formed of an energetic material can include some combination of the following: a charge formed of an energetic material provided in a section of a perforating apparatus that is connected (above or below) to the section of the perforating apparatus that includes the explosive devices; energetic cells (formed of an energetic material) arranged among the explosive devices; a modular energetic sleeve formed around an outer surface of a carrier mounted above the explosive devices, where the carrier can include a loading tube or other type of carrier; a sleeve formed of an energetic material that is provided around an outer housing of the perforating apparatus; and a member formed of an energetic material formed as part of an individual explosive device, such as a perforator charge.

[0014] Examples of an energetic material can include any one or more of the following: a propellant, a high explosive, a gun powder, a combustible metallic powder, thermite, or any combination thereof.

[0015] In the ensuing discussion, reference is made to a carrier (to which explosive devices are mounted) that is in the form of a loading tube. Also, reference is made to perforator charges, which are a form of explosive devices. Additionally, reference is made to an energetic material that includes a propellant. Although reference is made to the foregoing example implementations, note that other example components can be employed in other embodiments.

[0016] FIG. **1** illustrates a tool string **100** that is lowered into a wellbore **102**. The wellbore **102** can be lined with casing or liner **104**. The tool string **100** is lowered on a deployment structure **106**, which can be a wireline, tubing (e.g. coiled tubing or other tubing), a pipe, and so forth. The tool string **100** has a perforating gun **108**, which includes a carrier structure **110** to which perforator charges **112** are attached. In some implementations, the carrier structure **110** can be a loading tube defining an inner chamber (which can be sealed from outside well fluids) in which the perforator charges **112** are mounted. Alternatively, the carrier structure **110** can be a strip onto which the perforator charges **112** are mounted. In other examples, the carrier structure **110** can have other forms.

[0017] The perforator charges **112** are ballistically connected to a detonating cord **114**. Initiation of the detonating cord **114** causes detonation of the perforator charges **112**.

[0018] The detonating cord **114** can be connected to a firing head **116**, which can be activated from an earth surface **118**, such as by use of equipment at the earth surface **118**. The activation of the firing head **116** can be in response to electrical commands, acoustic commands, pressure commands, optical commands, and so forth, that can be sent from the equipment at the earth surface **118** to the firing head **116**. In other examples, the activation of the firing head **116** can be performed mechanically.

[0019] FIG. **2** is a partial sectional view of an example perforating gun **108** that has multiple sections **202**, **204**, and

206. Portions of the perforating gun **108** are cut away to illustrate inner components. The upper gun section **202** and intermediate gun section **204** are interconnected by an adapter **208**, and the intermediate gun section **204** and lower gun section **206** are interconnected by an adapter **210**. The intermediate gun section **204** includes the loading tube **110**, perforator charges **112**, and detonating cord **114** discussed above in connection with FIG. **1**.

[0020] The upper gun section **202** includes a propellant charge **212**, which is formed of a propellant (or other energetic material). The propellant charge **212** is contained inside an outer housing **228** of the upper gun section **202** Similarly, the lower gun section **206** includes a propellant charge **214**, which includes a propellant or other energetic material. The propellant charge **214** is contained inside an outer housing **230** of the lower gun section **206**.

[0021] The upper gun section **202** has a gun head **216** to allow the perforating gun **108** to connect to another portion of the tool string **100** shown in FIG. **1**. The lower gun section **206** has a bottom nose piece **218**.

[0022] The intermediate gun section **204** also includes various components formed of a propellant or other energetic material. In some examples, as shown in FIG. **2**, propellant cells **220** are arranged among the perforator charges **112**. Each propellant cell **220** is formed of a propellant or other energetic material. In addition, as shown in FIG. **2**, a modular propellant sleeve **222** is provided around an outer surface of the loading tube **110**. A sleeve provided around the loading tube (or other carrier) can refer to a sleeve that either partially or fully surrounds the outer surface of the loading tube or other carrier.

[0023] The loading tube **110** is positioned inside an outer housing **224** of the intermediate gun section **204**. In some examples, another outer propellant sleeve **226** can be provided around the outer surface of the outer gun housing **224** of the intermediate gun section **204**. The outer propellant sleeve **226** can also include a propellant or other energetic material.

[0024] As further shown in FIG. **2**, a sealed central passageway **234** (sealed from fluids outside the central passageway **234**) is provided in the upper gun section **202** through the propellant charge **212**. The detonating cord **114** for activating the perforator charges **112** can be passed through the central passageway **234** in the upper gun section **202**. The detonating cord **114** extends from the gun head **216** through the central passageway **234** to the intermediate gun section **204**.

[0025] The detonating cord **114** further extends from the intermediate gun section **204** to the lower gun section **206**. The lower gun section **206** includes a central passageway **236** that extends through the perforator charge **214**. The detonating cord **114** extends inside the central passageway **236**.

[0026] In operation, an activation signal (e.g. electrical signal, acoustic signal, optical signal, hydraulic signal, mechanical stimulus, etc.) can be provided to the gun head **216**. In some examples, the gun head **216** can include a firing mechanism that can initiate the detonating cord **114**. Initiation of the detonating cord **114** causes an initiation wave to travel down the detonating cord **114**.

[0027] Initiation of the portion of the detonating cord **114** in the central passageway **234** in the upper gun section **202** causes activation of the propellant charge **212**. A pressure wave caused by the activation of the propellant charge **212** travels through openings **238** in the outer housing **228** of the upper gun section **202**.

[0028] The initiation wave continues to travel along the detonating cord **114** until it reaches the intermediate gun section **204**. Initiation of the portion of the detonating cord **114** in the intermediate gun section **204** causes detonation of the perforator charges **112**, which in turn causes activation of the propellant cells **220**, the modular propellant sleeve **222**, and the outer propellant sleeve **226**. Activation of the propellant cells **220**, the modular propellant sleeve **222**, and the outer propellant sleeve **226** causes resultant pressure waves to be generated, which can be propagated through openings in the outer housing **224** of the intermediate gun section **204**. Such openings in the outer housing **224** are produced by perforating jets generated by the detonated perforator charges **112**.

[0029] The initiation wave continues to travel down the detonating cord **114** to the lower gun section **206**. Initiation of the detonating cord **114** in the central passageway **236** of the lower gun section **206** causes activation of the propellant charge **214**, which causes the resultant pressure wave to travel through openings **240** in the outer housing **230** of the lower gun section **206**.

[0030] Although a specific example of the perforating gun **108** is shown in FIG. **2**, note that in other examples, some of the elements depicted in FIG. **2** can be omitted. For example, the outer propellant charge **226** can be omitted in some implementations. As another example, the propellant cells **220** can be omitted in some implementations. As yet another example, the propellant charge **212** and/or propellant charge **214** in the upper and lower gun sections **202** and **206**, respectively, can be omitted.

[0031] More generally, different configurations of the perforating gun **108** can include different combinations of the following propellant elements: propellant charge **212**, propellant charge **214**, propellant cells **220**, modular propellant sleeve **222**, and outer propellant sleeve **226**.

[0032] As discussed further below, in other implementations, the perforator charges **112** can be incorporated with a propellant or other energetic material. Such propellant or other energetic material incorporated into a perforator charge **112** can be used in addition to or in place of any or some combination of the foregoing propellant elements.

[0033] FIG. **3** shows an example configuration of the modular propellant sleeve **222**. In examples according to FIG. **3**, the modular propellant sleeve **222** includes a tubular structure **300** that has openings **302** that correspond to positions of the perforator charges **112** in the loading tube **110** of FIG. **2**. These openings **302** of the propellant sleeve **222** are positioned such that the perforating jet of each perforator charge **112** extends through the corresponding opening **302** of the propellant sleeve **222**. A tubular structure can refer to a structure as generally cylindrical, or that can have different cross-sectional shapes, such as a rectangular shape, or some other shape.

[0034] In addition to the openings **302**, the tubular structure **300** of the propellant sleeve **222** also includes grooves **304** that interconnect adjacent openings **302**. These grooves **304** are arranged to receive the detonating cord **114**. In some examples, the grooves **304** are arranged along a spiral path to allow the detonating cord **114** to be arranged in a spiral pattern around the perforator charges **112**.

[0035] FIG. **4** illustrates a different configuration of the modular propellant sleeve **222**. In FIG. **4**, the modular propellant sleeve **222** includes a tubular structure **400** that has respective openings **402** corresponding to positions of the perforator charges **112** in the loading tube **110**. However, in the configuration of FIG. **4**, grooves (such as grooves **304** in FIG. **3**) are not provided for interconnecting the openings of **402**. Instead, the detonating cord **114** can be arranged along the outer surface of the tubular structure **400**.

[0036] FIG. **5** is a cross-sectional view of an example perforator charge **112** that includes a propellant material as noted above. In other examples, the perforator charge **112** can be implemented without a propellant material.

[0037] The perforator charge **112** includes an outer case **502** that acts as a containment vessel designed to hold the detonation force of the explosion of the perforator charge **112** for a length of time to allow for a perforating jet to form. The outer case **502** can be formed of a metal, such as steel, or some other material. A main explosive **504** is contained inside the outer case **502**. The main explosive **504** is sandwiched between the inner wall of the outer case **502** and a surface of a liner **506**.

[0038] In some examples, the liner **506** is generally conically shaped. As a result of the general conical shape of the liner **506**, the main explosive **504** is also generally conically shaped between an inner wall of the outer case **502** and the liner **506**. In other examples, the liner **506** can be generally bowl-shaped or have a parabolic shape.

[0039] In examples according to FIG. **5**, a rear portion of the outer case **502** has an opening **508**, which can be in the form of a semi-circular slot or a slot having another shape. The opening **508** allows an end portion **510** of the main explosive **504** to be ballistically contacted to a primary explosive, such as the detonating cord **114** shown in FIG. **1**.

[0040] In some examples, a retaining element **512** is attached (e.g. glued, welded, or otherwise attached) to the outer case **502**. The retaining element **512** can be a retaining wire, for example, which is bendable for holding the detonating cord **114** against the rear portion **510** of the main explosive **504**. In other examples, the retaining element **512** can be another type of retaining element, or alternatively, the retaining element **512** can be omitted.

[0041] According to some embodiments, the perforator charge **112** further has an energetic material **514**, which is placed at a front portion of the perforator charge **112**. The "front portion" of the perforator charge **112** is the portion of the perforator charge **112** through which the perforating jet extends upon detonation of the perforator charge **112**. Stated differently, the "front portion" of the perforator charge **112** is at the front opening of the outer case **502**, through which the perforating jet passes.

[0042] The energetic material **514** is generally a discrete segment formed of the energetic material that is placed at the front portion of the perforator charge **112**. A "discrete segment" of energetic material can refer to any layer, piece, or other amount of the energetic material that has a predefined extent such that the energetic material does not surround an outer surface **503** of the outer cover **502**. In some examples, the discrete segment of energetic material **514** does not contact any part of the outer surface **503** of the outer cover **502**.

[0043] The energetic material **514** is retained to the outer case **502** of the perforator charge **112** using a retaining structure that is attached to the outer case **502**. In some implementations, the retaining structure can be a retaining shell (or retaining cap) **516** that covers the discrete segment of energetic material **514**. The retaining shell **516** has a receiving chamber **518** in which the energetic material **514** is positioned. The retaining shell **516** has a protruding portion **520** that extends into an inner opening of the energetic material **514** The retaining shell **516** is attached to the outer case **502** (at **517**). The attachment can be a threaded connection between the retaining shell **516** and the outer case **502**. Alternatively, the retaining shell **516** can be attached to the outer case **502** using another type of attachment mechanism, such as by use of a screw, a rivet, glue, and so forth.

[0044] In examples according to FIG. **5**, the retaining shell **516** has a protruding portion **220** that extends into an inner opening **515** (shown in FIG. **6**) of the energetic material **514**. FIG. **6** is a sectional view of the energetic material **514**, which is generally ring-shaped and has the inner opening **515** formed in the energetic material **514**. The energetic material **514** is "generally" ring-shaped in that the energetic material **514** has a shape resembling a ring—note that manufacturing or design tolerances can cause the energetic material **514** to not have an exact ring shape.

[0045] In different implementations, rather than providing the generally ring-shaped energetic material **514** that has the inner opening **515**, a generally disk-shaped energetic material can be provided, which does not include the inner opening **515** in an inner portion (e.g. center) of the energetic material. In other examples, instead of providing an energetic material that is generally circular in cross section, energetic materials having other shapes can be employed.

[0046] As further shown in FIG. **5**, the perforator charge **112** can include a shock attenuator **522** positioned between the energetic material **514** and the main explosive **504**. The shock attenuator **522** can be a layer of shock attenuation material, such as a polymer, plastic, a material containing air spaces or other voids, foam, cork, or any other metallic or non-metallic material of relatively low density. The shock attenuator **522** in some examples can also be generally ring-shaped. The shock attenuator **522** is arranged to cause a delay between the detonation of the explosive **504** and activation of the energetic material **514**. This delay allows a perforation tunnel to first be formed by the perforating jet produced by the perforator charge **112**, after which activation of the energetic material **514** creates an energy wave for enlarging the perforation tunnel, creating fractures, and/or removing crushed zone damage.

[0047] In other implementations, the shock attenuator **522** can be omitted.

[0048] In operation, the detonating cord **114** of FIG. **1** is initiated, which causes detonation of the main explosive **504** in the perforator charge **112**. Detonation of the main explosive **504** creates a detonation wave that causes the liner **506** to collapse under the detonation force of the main explosive **504**. Material from the collapsed liner **506** forms a perforating jet which shoots out through the front opening of the outer case **502** and towards the surrounding structure, which can include the casing/liner **104** and the surrounding subterranean formation.

[0049] The collapse of the liner **506** under the detonation force starts near an apex portion **524** of the liner **506**, and proceeds to near the base portion **526** of the liner **506**. The tip of the perforating jet produced from collapse of the liner **506** is formed by the apex portion **524** of the liner **506**, while the tail of the perforating jet is formed by the base portion **526** of the liner **506**.

[0050] In implementations where the energetic material **514** is generally ring-shaped, the perforating jet extends through the opening **515** (FIG. **6**) of the energetic material **514**. After some amount of delay caused by the shock attenuator **522**, the energetic material **514** is activated, which produces an energy wave. Activation of the energetic material **514** is caused by the detonation wave of the main explosive **504**.

[0051] FIG. **7** illustrates a process of assembling a perforating apparatus according to some implementations. The process of FIG. **7** can be performed by a manufacturer or by any other entity that is able to assemble a perforating apparatus. The process provides (at **702**) a carrier (e.g. loading tube **110**), and explosive devices (e.g. perforator charges **112**) are mounted (at **704**) to the carrier. Propellant cells (e.g. **220**) are arranged (at **706**) among the explosive devices. In addition, a propellant sleeve (e.g. **224** or **226**) is provided (at **708**) around the carrier, the sleeve being formed of an energetic material, and the sleeve and energetic cells for activation in response to detonation of the explosive devices.

[0052] In the foregoing description, numerous details are set forth to provide an understanding of the subject disclosed herein. However, implementations may be practiced without some or all of these details. Other implementations may include modifications and variations from the details discussed above. It is intended that the appended claims cover such modifications and variations.

What is claimed is:

1. A perforating apparatus comprising:

a carrier;

explosive devices mounted to the carrier;

energetic cells arranged among the explosive devices; and

a sleeve defining an inner chamber that receives at least a portion of the carrier, the sleeve being formed of an energetic material, the energetic cells and the sleeve for activation in response to detonation of the explosive devices.

2. The perforating apparatus of claim **1**, wherein the carrier is a loading tube containing the explosive devices and the energetic cells.

3. The perforating apparatus of claim **1**, wherein the explosive devices include perforator charges.

4. The perforating apparatus of claim **3**, wherein at least one of the perforator charges includes:

a case;

an explosive inside the case;

a liner to be collapsed by detonation of the explosive to form a perforating jet; and

a member formed of an energetic material for activation in response to detonation of the explosive, wherein the member is retained to the case.

5. The perforating apparatus of claim **1**, further comprising:

an outer housing in which the carrier is contained; and

a second sleeve formed of an energetic material around an outer surface of the outer housing.

6. The perforating apparatus of claim **1**, wherein the energetic material is selected from the group consisting of a propellant, a high explosive, a gun powder, a combustible metallic powder, thermite, or any combination thereof.

7. The perforating apparatus of claim **1**, comprising a plurality of sections, wherein a first of the sections includes the carrier, explosive devices, and sleeve, and wherein a second of the sections connected to the first section includes a charge formed of an energetic material.

8. The perforating apparatus of claim **1**, wherein the sleeve includes openings corresponding to positions of the explosive devices mounted to the carrier.

9. The perforating apparatus of claim **8**, wherein the sleeve further includes grooves interconnecting the openings, and the perforating apparatus further comprises a detonating cord arranged along the grooves, wherein the detonating cord is ballistically connected to the explosive devices.

10. A modular sleeve comprising:

a tubular structure defining an inner chamber to receive a carrier mounted with explosive devices, the tubular structure formed of an energetic material for activation by detonation of the explosive devices,

the tubular structure including openings corresponding to positions of the explosive devices mounted to the carrier.

11. The modular sleeve of claim **10**, wherein the tubular structure further includes grooves interconnecting the openings, the grooves to receive a detonating cord for ballistic coupling to the explosive devices.

12. The modular sleeve of claim **11**, wherein the grooves extend generally along a spiral path along the tubular structure.

13. The modular sleeve of claim **10**, wherein the energetic material is selected from the group consisting of a propellant, a high explosive, a gun powder, a combustible metallic powder, thermite, or any combination thereof.

14. A method of assembling a perforating apparatus, comprising:

providing a carrier;

mounting explosive devices to the carrier;

arranging energetic cells among the explosive devices; and

providing a sleeve around the carrier, the sleeve being formed of an energetic material, and the sleeve and energetic cells for activation in response to detonation of the explosive devices.

15. The method of claim **14**, wherein providing the carrier comprises providing a loading tube containing the explosive devices and energetic cells.

16. The method of claim **14**, further comprising providing the carrier inside an outer housing of the perforating apparatus.

17. The method of claim **16**, further comprising providing a second sleeve around the outer housing, the second sleeve formed of an energetic material for activation in response to detonation of the explosive devices.

18. The method of claim **14**, wherein mounting the explosive devices comprises mounting perforator charges.

* * * * *