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Electrode Cap with Electrical Insulator and Related Methods

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ELECTRODE CAP WITH ELECTRICAL INSULATOR AND RELATED METHODS

FIELD OF THE INVENTION

[0001] This application relates to resistance spot welding, and, more particularly, to electrodes for resistance spot welding.

BACKGROUND

[0002] Metal manufacturing can involve welding metal sheets or metal alloy sheets together to form various parts or components of a final product. Various techniques or processes, including, for example, resistance spot welding, can be used to weld the metal sheets. Resistance spot welding can involve positioning metal sheets between electrodes and using the electrodes to apply a clamping force and an electric current to the metal sheets. Heat produced from a resistance of the metal sheets to the electric current, along with the clamping force of the electrodes, can be used to join the metal sheets at the interface, forming local cohesive zones known as weld nuggets. Current resistance spot welding processes use copper-based electrodes. However, the life of such electrodes is limited because the electrode tip becomes degraded at least partially due to the electric current flow path and tip temperature of the cap during resistance spot welding, which results in the weld quality over time becoming less consistent. As such, electrodes frequently must be dressed and replaced, which takes time away from the resistance spot welding process and increases the costs associated with resistance spot welding process.

SUMMARY

[0003] According to some examples, an electrode for resistance spot welding includes a cap. The cap includes a cap body having a tip, and the tip includes an outer surface defining a pocket. An electrical insulator is positioned within the pocket.

[0004] According to various examples, a resistance spot welding system includes a first electrode and a second electrode. At least one of the first electrode or the second electrode includes a cap having a tip, and the tip includes an outer surface defining a pocket. An electrical insulator is positioned within the pocket.

[0005] According to certain examples, a method of manufacturing an electrode for resistance spot welding includes forming a pocket in an outer surface of a tip of an electrode cap. The method includes positioning an electrical insulator within the pocket.

[0006] According to various examples, a method of resistance spot welding includes positioning a first metal sheet and a second metal sheet between two electrodes. At least one of the two electrodes includes an electrode cap that includes a cap body with a tip having an outer surface that defines a pocket. The electrode cap includes an electrical insulator positioned within the pocket. The method includes applying a current to the first metal sheet and the second metal sheet through the two electrodes to form a weld nugget. Forming the weld nugget joins the first metal sheet with the second metal sheet.

[0007] According to some examples, a weld nugget joins a first metal sheet with a second metal sheet. The weld nugget includes a center region surrounded by an outer region, and a thickness of the center region is less than a thickness of the outer region.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The features and components of the following figures are illustrated to emphasize the general principles of the present disclosure. Corresponding features and components throughout the figures can be designated by matching reference characters for the sake of consistency and clarity.

[0009] FIG. 1 is a sectional view of an electrode for resistance spot welding according to aspects of the current disclosure.

[0010] FIG. 2 is a top view of the electrode of FIG. 1.

[0011] FIG. 3 is another sectional view of the electrode of FIG. 1 with an electrical insulator.

[0012] FIG. 4 is another sectional view of the electrode of FIG. 1 with another electrical insulator.

[0013] FIG. 5 is a diagram of a resistance spot welding system with the electrode of FIG. 1 according to aspects of the current disclosure.

[0014] FIGs. 6A-D illustrate stages of forming a weld nugget during resistance spot welding with the resistance spot welding system of FIG. 5.

[0015] FIG. 7 illustrates an example of a weld nugget formed by resistance spot welding according to aspects of the current disclosure.

[0016] FIG. 8 illustrates another example of a weld nugget formed by resistance spot welding according to aspects of the current disclosure.

[0017] FIG. 9 is a sectional view of another electrode for resistance spot welding according to aspects of the current disclosure.

[0018] FIG. 10 is a top view of the electrode of FIG. 9.

[0019] FIG. 11 is a sectional view of another example of an electrode for resistance spot welding according to aspects of the current disclosure.

[0020] FIG. 12 is another sectional view of the electrode of FIG. 11 with an electrical insulator.

[0021] FIGs. 13A-B are photographs comparing a weld formed according to aspects of the present disclosure with a traditional weld.

DETAILED DESCRIPTION

[0022] Aspects and features of the present disclosure can be used with any suitable metal substrate, however may be especially useful for bonding aluminum and/or aluminum alloys. In this description, reference is made to alloys identified by aluminum industry designations, such as “series” or “7xxx.” For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” or “Registration Record of Aluminum Association Alloy Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot,” both published by The Aluminum Association.

[0023] FIGs. 1-3 illustrate an example of an electrode 102 for resistance spot welding (“RSW”) according to examples of the present disclosure. The electrode 102 may be constructed from various materials suitable for RSW. As one example, the electrode 102 may be a copper-based electrode 102.

[0024] The electrode 102 includes a cap 104 having a tip 106. The tip 106 includes an outer surface 108. In the example of FIGs. 1-3, the cap 104 is generally cylindrical and the tip 106 is arcuate-shaped. However, the shape or profile of the cap 104 and/or the tip 106 should not be considered limiting on the current disclosure, as the cap 104 and/or the tip 106 may have various suitable shapes or profiles as desired. The cap 104 has a cap width 112 and a central cap axis 116. Optionally, the cap 104 defines a body cavity 110, and a coolant for cooling and controlling the temperature of the electrode 102 may be provided in the body cavity 110 during RSW.

[0025] As illustrated in FIGs. 1-3, the outer surface 108 of the tip 106 defines one or more pockets 114. In the example of FIGs. 1-3, the cap 104 includes a single pocket 114. However, the number of pockets 114 should not be considered limiting on the current disclosure, as in other examples, the tip 106 may include more than one pocket 114. For example, FIGs. 9 and 10 illustrate an example of an electrode 902 with two pockets 114A-B.

[0026] As shown in FIGs. 3-6D, an electrical insulator 118 may be positioned within the pocket 114. In various examples, the electrical insulator 118 may include various suitable electrically insulating materials that block or prevent the flow of electrical current through the portion of the electrode 102 with the electrical insulator 118 during RSW. As discussed below, by blocking or preventing the flow of current through select portions of the electrode 102, the temperature of the material being welded underneath the electrical insulator 118 can be controlled.

[0027] The electrical insulator 118 may be positioned and retained within the pocket 114 through any suitable mechanisms including, but not limited to, brazing, threading, mechanical attachment, adhesives, combinations thereof, or various other suitable mechanisms or methods for retaining the electrical insulator 118 within the pocket 114. In some aspects, the electrical insulator 118 is permanently retained within the pocket 114, meaning that after it is initially positioned within the pocket 114, it cannot be removed without damaging or destroying the electrode 102. In other examples, the electrical insulator 118 may be removably positioned within the pocket 114 such that the electrical insulator 118 can be changed or removed from the electrode 102 as desired.

[0028] One or more controllable characteristics of the pocket 114 and/or the electrical insulator 118 may be controlled and adjusted as desired such that the electrode 102 provides a desired electric current flow path and temperature control of the tip 106 as discussed in detail below. In some aspects, the controllable characteristic may include, but is not limited to, the material used as the electrical insulator 118, a width 120 of the pocket 114 and/or the electrical insulator 118, a depth 122 of the pocket 114 and/or the electrical insulator 118, a shape of the pocket 114 and/or the electrical insulator 118, a position of the pocket 114 and/or the electrical insulator 118 within the outer surface 108, an angle or orientation of a central pocket axis 124 relative to the central cap axis 116, a number of pockets 114 and/or electrical insulators 118, a pattern of a plurality of pockets 114 and/or electrical insulators 118, and/or various other controllable characteristics or combinations of characteristics as desired. In some examples, the controllable characteristics may be controlled or adjusted based on material properties of the materials to be joined through RSW, welding settings, joint configurations, desired weld nugget shapes or properties, etc.

[0029] The electrical insulator 118 may be various materials suitable for blocking or reducing the flow of electrical current through the cap 104. In other examples, the electrical insulator 118 may be omitted, and an empty space is provided in the pocket 114 (or other location) in the cap 104. In certain aspects, the electrical insulator 118 is also a high-temperature insulation material. For example, the electrical insulator 118 may include, but is not limited to, ceramic-based materials, high temperature polymers, combinations thereof, or various other suitable materials. In the example of FIGs. 1-3, the electrical insulator 118 is ceramic, such as a ceramic bar.

[0030] As mentioned, the pocket 114 has the width 120. In various examples, the width 120 of the pocket 114 is less than the width 112 of the cap 104 and/or the width of the body cavity 110. In examples where a plurality of pockets 114 are provided, the widths 120 of the pockets 114 may be substantially the same. However, in other examples, the width of one pocket 114 may be different from the width of another pocket 114.

[0031] The pocket 114 also has the depth 122, which is the extent to which the pocket 114 extends from the outer surface 108 into the cap 104. In some cases, the depth may be about 0.5 mm; however, in other examples, the depth 122 of the pocket 114 may be less than 0.5 mm or greater than 0.5 mm. In some aspects, each pocket has a depth such that a predetermined amount of material of the cap 104 remains between the pocket 114 and the body cavity 110, although it need not in other examples. In cases where the electrode 102 includes a plurality of pockets 114, each pocket 114 may have the same depth 122. However, in other examples, the depth of one pocket 114 may be different from the depth of another pocket 114. As illustrated in FIG. 3, in some aspects, the electrical insulator 118 is retained within the pocket 114 such that the electrical insulator 118 is substantially flush with the outer surface 108. In other examples, as illustrated in FIG. 4, the electrical insulator 118 may be retained within the pocket 114 such that the electrical insulator 118 is recessed relative to the outer surface 108.

[0032] In various examples, the pocket 114 and/or the electrical insulator 118 may have various shapes or profiles as desired. For example, the pocket 114 and/or the electrical insulator 118 may be cylindrical, rectangular, triangular, conical, elliptical, tapered as the pocket 114 extends towards the outer surface 108 or away from the outer surface 108 (i.e., reducing in width), or may have various other shapes or profiles as desired. In examples where a plurality of pockets 114 and/or electrical insulators 118 are provided, the pockets 114 and/or electrical insulators 118 may all have the same shape or profile, or the shape or profile of one pocket and/or electrical insulator may be different from the shape or profile of another pocket and/or electrical insulator. In the example of FIGs. 1-3, the pocket 114 and the electrical insulator 118 are both cylindrical.

[0033] In some examples, the position and orientation of the pocket 114 and/or the electrical insulator 118 may also be controlled. In certain aspects, the pocket 114 is defined in the outer surface 108 such that the central pocket axis 124 is aligned with the central cap axis 116. In other examples, the pocket 114 is defined in the outer surface 108 such that the central pocket axis 124 is substantially parallel to but not aligned with the central cap axis 116. In further examples, the pocket 114 is defined such that the central pocket axis 124 extends at a non-zero angle relative to the central cap axis 116. In the example of FIGs. 1-3, the pocket 114 and the electrical insulator 118 are positioned such that the central pocket axis 124 is aligned with the central cap axis 116.

[0034] In certain aspects with a plurality of pockets 114 and electrical insulators 118, the pattern of the pockets 114 and/or electrical insulators 118 may also be controlled. The pattern of the pockets 114 and/or the electrical insulators 118 may include the particular physical arrangement on the tip 106, as well as the particular combinations of the other controllable characteristics (e.g., material of the electrical insulator, widths, depths, angles, etc.).

[0035] By controlling the one or more controllable characteristics of the pocket 114 and/or the electrical insulator 118, the electrode 102 controls an electric current flow path in the tip 106 and thus a temperature of the material being joined. For example, the electrode 102 controls the electric current flow path by controlling what portions of the electrode 102 through which the current can flow (i.e., the portions of the electrode 102 that do not have the electrical insulator 118). Those portions of the electrode 102 without the current do not produce heat in the material to be joined, and corresponding portions of the material to be joined may thus have a reduced temperature compared to other portions of the material.

[0036] As such, by controlling one or more of the controllable characteristics of the pocket 114 and/or the electrical insulator 118, the electrode 102 controls how much current can flow, where the current can flow, etc. through the tip 106 depending on the characteristic of the pocket 114 and/or the electrical insulator 118, and thus controls the temperature in the material to be joined. For example, in the electrode 102 of FIGs. 1-3, the positioning of the pocket 114 and the electrical insulator 118 along the central cap axis 116 prevents the flow of current through the center of the electrode 102. In this example, the temperature of the material being welded beneath the electrical insulator will be less than the temperature of the material beneath another portion of the electrode 102 without the electrical insulator 118. In some aspects, different flow paths may be desirable depending on the type of material to be joined, welding settings, joint configurations, etc.

[0037] Optionally, the electrode 102 with the electrical insulator 118 limits the temperature of the tip 106 to certain temperatures to reduce or avoid electrode sticking during RSW, which increases the usable life of the electrode 102. As one example, the electrode 102 may control the electrical current such that the temperature of the surface of the material being welded is less than or equal to about 450 °C. In other examples, the electrode 102 may control the electrical current such that the temperature does not exceed a temperature less than 450 °C or exceed a temperature greater than 450 °C. In some cases, the electrode 102 with the electrical insulator 118 may at least double the usable tip life of the electrode 102 compared to traditional electrodes. In certain cases, the electrode 102 with the electrical insulator 118 may at least triple the usable tip life of the electrode 102 compared to traditional electrodes.

[0038] FIG. 4 illustrates an example of an electrode 402 that is substantially similar to the electrode 102 except that the electrical insulator 118 is positioned within the pocket 114 such that the electrical insulator 118 is recessed relative to the outer surface 108. In some examples, positioning the electrical insulator 118 at a recessed position may allow for improved dressing of the electrode 402.

[0039] FIG. 5 illustrates a system 500 for enhanced RSW, FIGs. 6A-D illustrate various steps of RSW using the system 500, and FIG. 7 illustrates the weld formed by the steps of FIGs. 6A-D.

[0040] As illustrated in FIG. 5, the RSW system 500 includes two of the electrodes 102 (one as an upper electrode 102A and the other as a lower electrode 102B). Any number of electrodes 102 in any configuration may be used as desired. In some examples, the electrode 102 may only be provided on one side of the system 500, and the opposing electrode 102 (or other electrode) may not include the electrical insulator 118 or otherwise be different from the electrode 102.

[0041] In the example of FIG. 5, the controllable characteristics (e.g., number, pattern, depth, width, etc.) of the pocket 114 and electrical insulator 118 are the same for both electrodes 102A-B. However, in other examples, a controllable characteristic of the pocket 114 and/or the electrical insulator 118 of the upper electrode 102A may be different from a corresponding characteristic of the pocket 114 and/or the electrical insulator 118 of the lower electrode 102B. For example, the number, pattern, depth, width, angle, etc. of the pocket 114 and/or the electrical insulator 118 of the upper electrode 102A may be different from the pattern, depth, width, angle, etc. of the pocket 114 and/or the electrical insulator 118 of the lower electrode 102B.

[0042] The RSW system 500 is used to join a first metal sheet 502 to a second metal sheet 504. As used herein, a sheet generally refers to a product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than 4 mm, less than 3 mm, less than 2 mm, less than 1 mm, less than 0.5 mm, less than 0.3 mm, or less than 0.1 mm. A sheet plate generally has a thickness of from about 4 mm to about 15 mm. For example, a sheet plate may have a thickness of 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, or 15 mm. The disclosed systems and methods may also be used to join sheet plates.

[0043] In various examples, the first metal sheet 502 includes a first aluminum alloy and/or the second metal sheet 504 includes a second aluminum alloy. In such cases, the first aluminum alloy and/or the second aluminum alloy can be cast using various suitable casting methods including, but not limited to direct chill casting (including direct chill co-casting) or semi-continuous casting, continuous casting (including, for example, by use of a twin belt caster, a twin roll caster, a block caster, or any other continuous caster), electromagnetic casting, hot top casting, or any other casting method. In some examples, the first metal sheet 502 and/or the second metal sheet 504 may be selected from the group comprising a 1xxx series aluminum alloy, a 2xxx series aluminum alloy, a 3xxx series aluminum alloy, a 4xxx series aluminum alloy, a 5xxx series aluminum alloy, a 6xxx series aluminum alloy, a 7xxx series aluminum alloy, or an 8xxx series aluminum alloy. In some examples, the first aluminum alloy is different from the second aluminum alloy (e.g., the first aluminum alloy is a 7xxx series aluminum alloy and the second aluminum alloy is a 6xxx series aluminum alloy). In other examples, the first aluminum alloy and the second aluminum alloy are both the same series aluminum alloy (e.g., both the first and second aluminum alloys are a 7xxx series aluminum alloy). In certain examples, the first aluminum alloy and the second aluminum alloy may be the same aluminum alloy (e.g., both the first and second aluminum alloys are a 7075 aluminum alloy).

[0044] In other examples, the first metal sheet 502 and/or the second metal sheet 504 include a metal other than aluminum or an aluminum alloy. As one non-limiting example, the first metal sheet 502 includes an aluminum alloy and the second metal sheet 504 includes steel, or vice versa. As another non-limiting example, both the first metal sheet 502 and the second metal sheet 504 may include steel.

[0045] In other examples, the first metal sheet 502 and/or the second metal sheet 504 may include various other metals or types of metal sheets including, but not limited to, an aluminum cladded alloy sheet, a monolithic alloy (aluminum, steel, etc.), a roll bonded alloy, or various other types of metal sheets to be welded together. In some non-limiting examples where the first metal sheet 502 includes aluminum and the second metal sheet 504 includes steel or some other dissimilar metal, the first metal sheet 502 may be brazed to the second metal sheet 504 where the second metal sheet 504 would not experience melting.

[0046] To weld the first metal sheet 502 to the second metal sheet 504, at least a portion of the first metal sheet 502 and at least a portion of the second metal sheet 504 are positioned between the electrodes 102A-B such that the first metal sheet 502 and the second metal sheet 504 at least partially overlap. During the RSW process, the electrodes 102A-B are clamped together such that the electrodes contact opposing surfaces of the first metal sheet 502 and the second metal sheet 504, as illustrated in FIG. 5.

[0047] While the electrodes 102A-B are clamped together, an electric current is applied via the electrodes 102A-B. Heat is generated at the interface of the metal sheets 502 and 504, which causes the metal sheets 502 and 504 to heat up and form a weld nugget 506. As the current is applied, the weld nugget 506 grows and elongates within the metal sheets 502 and 504. When the current through the electrodes 102A-B is stopped, the molten metal forming the weld nugget may cool to form a weld.

[0048] In certain cases, because the electrical insulator 118 blocks or reduces the flow of electrical current to reduce the heat in certain portions of the sheets 502 and 504, the electrodes 102A-B can produce the weld nugget 506 with an improved shape compared to traditional RSW weld nuggets. Moreover, by controlling one or more of the controllable characteristics, the shape and/or other properties of the weld nugget can further be controlled as desired.

[0049] In the example of FIGs. 5, 6A-D, and 7, the weld nugget 506 is dog-bone shaped, meaning that, as shown in FIG. 7, a thickness of a center portion 702 is less than a thickness of an outer region 704 of the weld nugget 506. Referring to the steps of weld nugget formation illustrated in FIGs. 6A-D, when the electrical current is initially supplied, the weld nugget 506 does not form in the area below the electrical insulators 118 because the temperature is reduced (see FIG. 6A). As the RSW process continues, the center region starts to heat up and the weld nugget size increases (see FIGs. 6B and 6C). Eventually, the center region is heated to some extent such that the weld nugget is formed in the center region (see FIG. 6D).

[0050] As mentioned, in other examples, the electrode 102 may be controlled such that the weld nugget has a different shape. For example, FIG. 8 illustrates another example of a weld nugget 806 having a different dog-bone shape. Compared to traditional RSW weld nuggets that are egg-shaped or generally elliptical, the dog-bone shaped weld nugget 506 (or a weld nugget having another shape) may have improved strength because an adjustable larger weld nugget size can be made. As one non-limiting example, a weld nugget size of 12 mm in diameter can be achieved with a center hole having an 8 mm diameter in a stack of two 1.1 mm thick sheets of the aluminum alloy 5182-O. By comparison, traditional RSW cannot make a weld nugget size of 8 mm in the same stack of sheets due to expulsion occurrence.

[0051] FIGs. 9 and 10 illustrate another example of an electrode 902. The electrode 902 is substantially similar to the electrode 102 except that the electrode 902 includes two pockets 114A-B each having an electrical insulator 118A-B, respectively. In addition, both pockets 114A-B of the electrode 902 include axes 124A-B, respectively, that are offset but substantially parallel to the central cap axis 116.

[0052] FIGs. 11 and 12 illustrate another example of an electrode 1102. The electrode 1102 is substantially similar to the electrode 102 except that the electrode 1102 includes a diffusive coating 1104 within the pocket 114. In some cases the diffusive coating 1104 may provide improved resistance to wear, aluminum sticking, and erosion at the interface between the electrical insulator 118 and the cap 104.

[0053] FIGs. 13A-B are photographs showing a weld 1300 formed with a traditional electrode and a weld 1302 formed with the electrode 102 described herein. The photograph of FIG. 13A was taken after twenty welds were completed. As illustrated in FIG. 13A, after twenty welds, the sheet surface is contaminated and cracks 1304 are beginning to form in the weld, which indicates that the traditional electrode is degrading. The photograph of FIG. 13B was taken after 40 welds were completed. As illustrated in FIG. 13B, the sheet surface is not visibly affected yet even though double the number of welds were formed.

[0054] A method of manufacturing an electrode for resistance spot welding is also provided. In some examples, the method includes forming the pocket 114 in the outer surface 108 of the tip 106 of the cap 104. In certain cases, forming the pocket 114 includes drilling the pocket 114, although various other suitable forming techniques may be utilized to form the cap 104 with at least one pocket 114. In certain aspects, forming the pocket 114 includes controlling at least one controllable characteristic of the pocket 114, including, but not limited to, the shape of the pocket, the depth of the pocket, the position of the pocket on the outer surface, the angle of the pocket, and/or the width of the pocket. The method includes positioning the electrical insulator 118 within the pocket 114 and/or filling the pocket 114 with the electrical insulator 118. In some cases, filling the pocket 114 with the electrical insulator includes retaining the electrical insulator 118 within the pocket 114 through brazing, mechanical attachment, or various other suitable mechanisms. Optionally, filling the pocket 114 with the electrical insulator 118 includes lining at least a portion of the pocket 114 with the diffusive coating 1104 before filling the pocket 114 with the electric insulator 118.

[0055] A method of resistance spot welding with an electrode having the electrical insulator is also provided. The method includes positioning the first metal sheet 502 and the second metal sheet 504 between two electrodes. At least one of the electrodes includes the electrical insulator 118. The method includes clamping the two electrodes together against the metal sheets and applying a current to the first metal sheet 502 and the second metal sheet 504 through the two electrodes to form the weld nugget 506. Forming the weld nugget 506 joins the first metal sheet 502 with the second metal sheet 504. In certain cases, forming the weld nugget includes forming the weld nugget with a dog-bone shape such that the center region 702 has a thickness that is less than a thickness of an outer region 704 of the weld nugget.

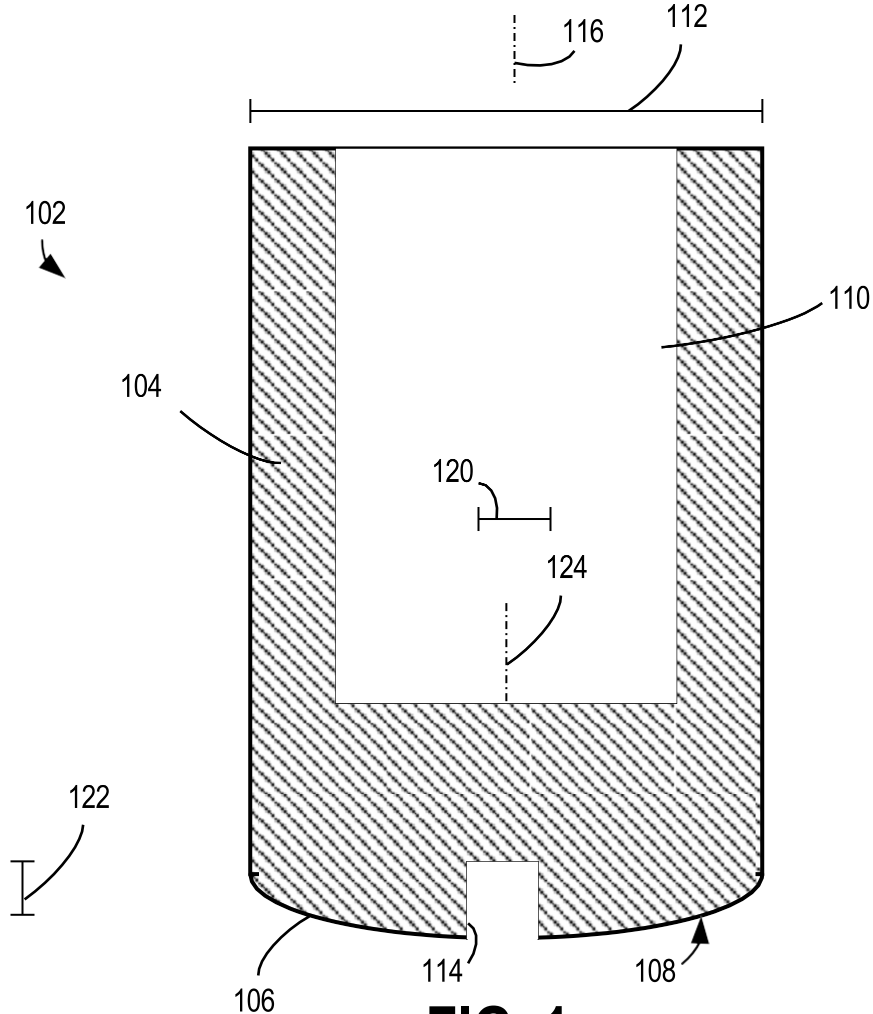

FIG. 1

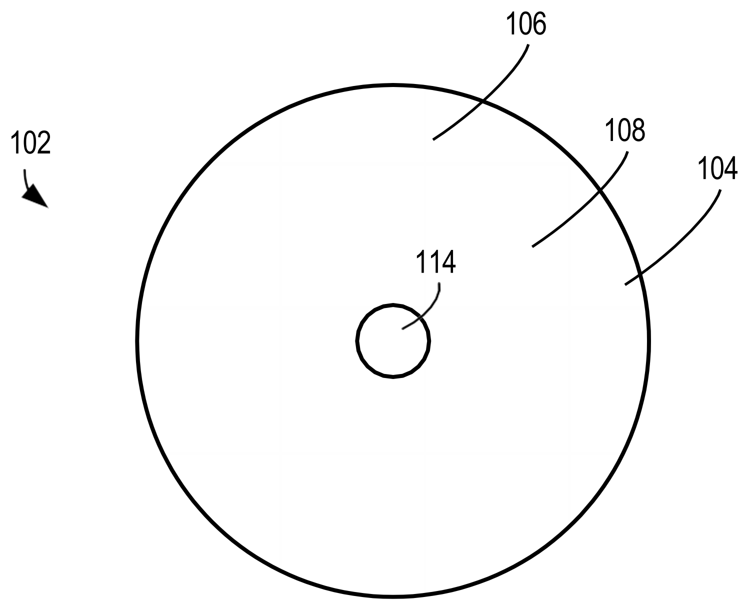

FIG. 2

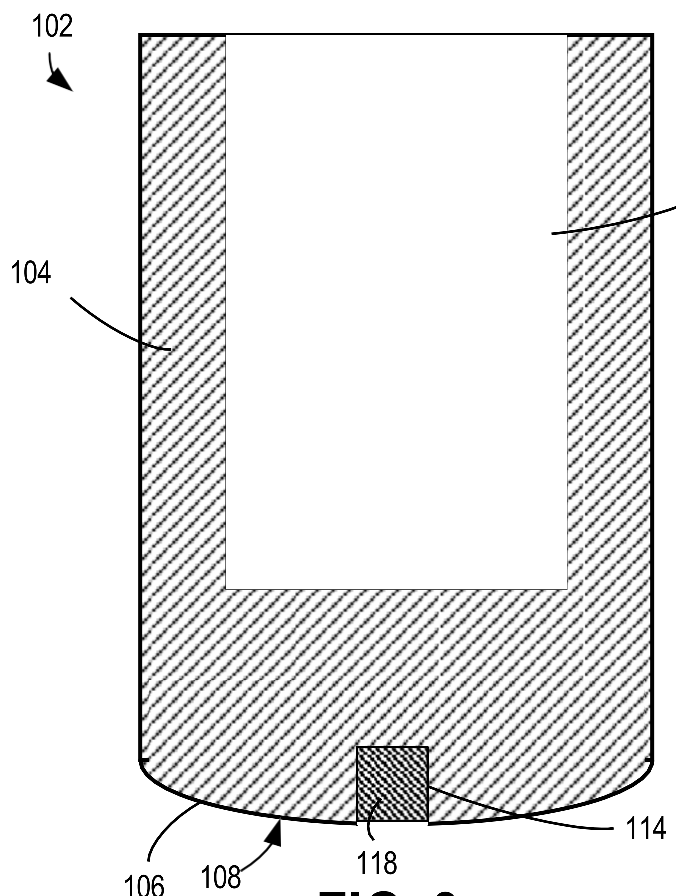

FIG. 3

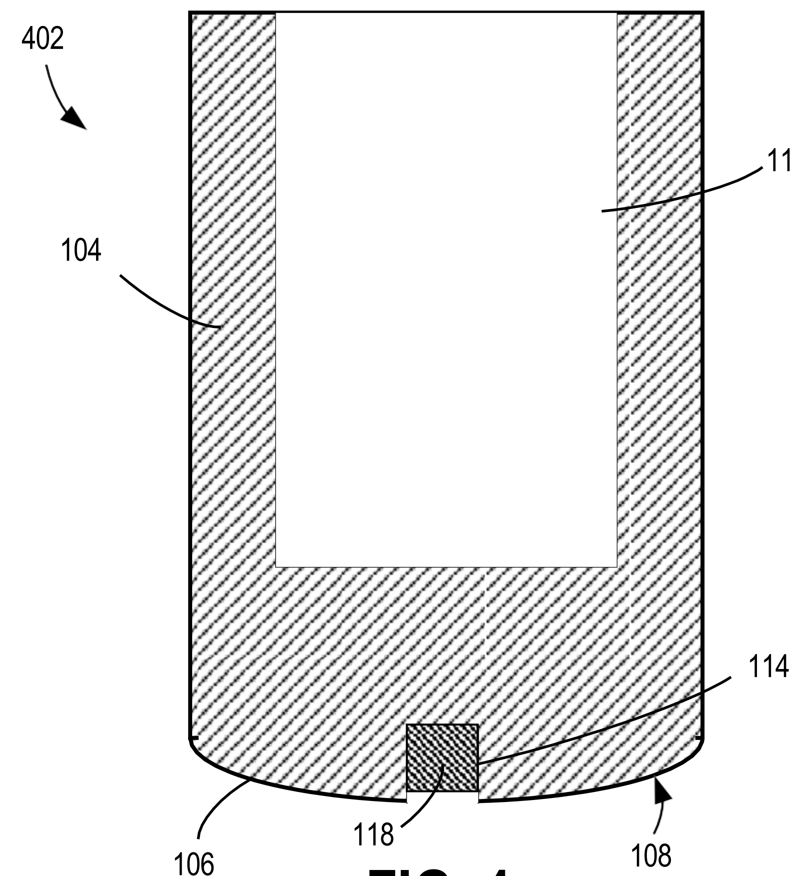

FIG. 4

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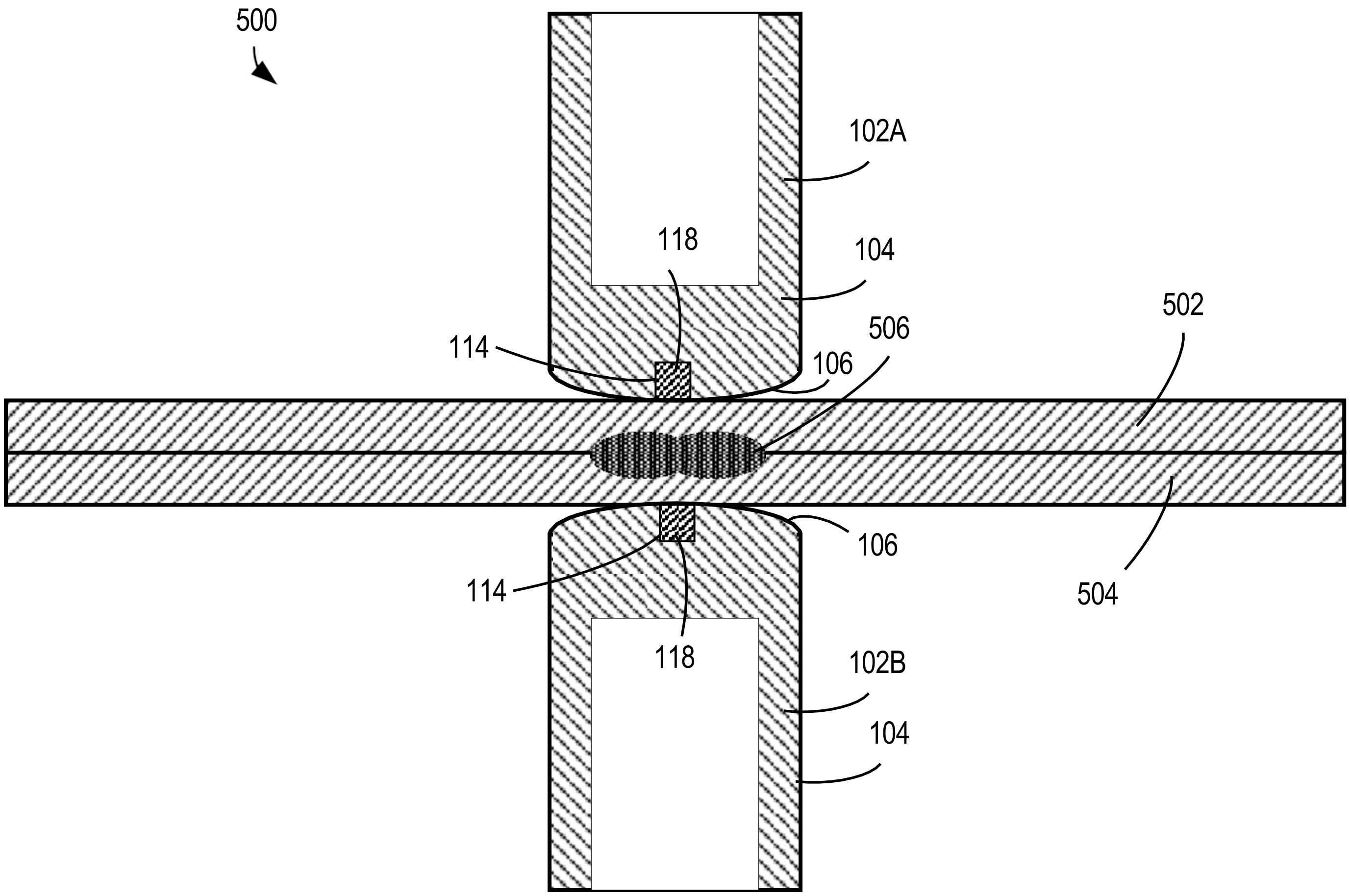

FIG. 5

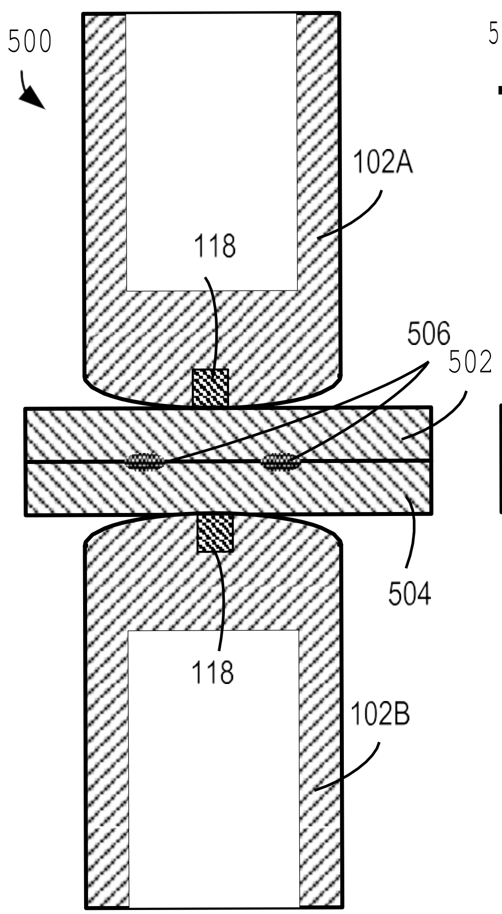

FIG. 6A

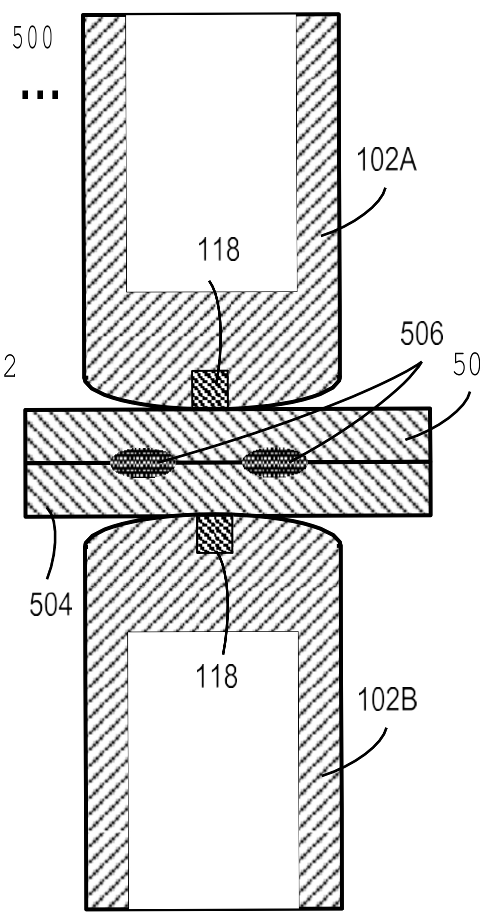

FIG. 6B

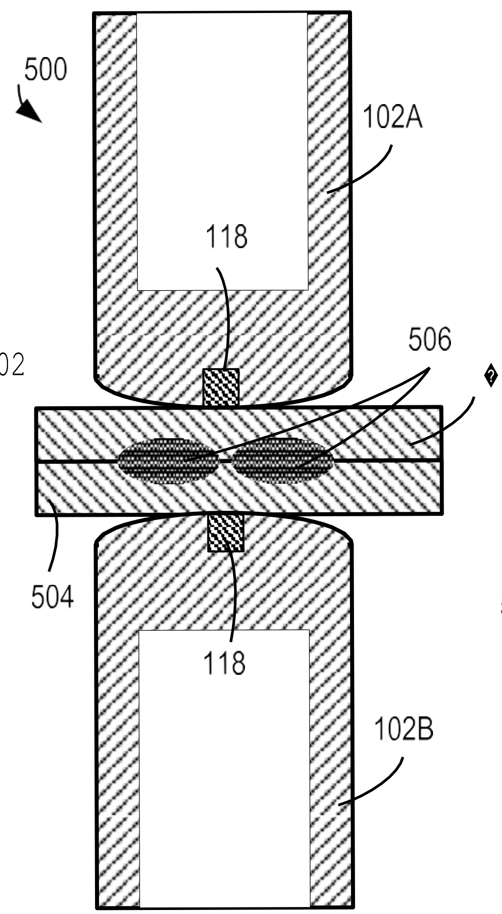

FIG. 6C

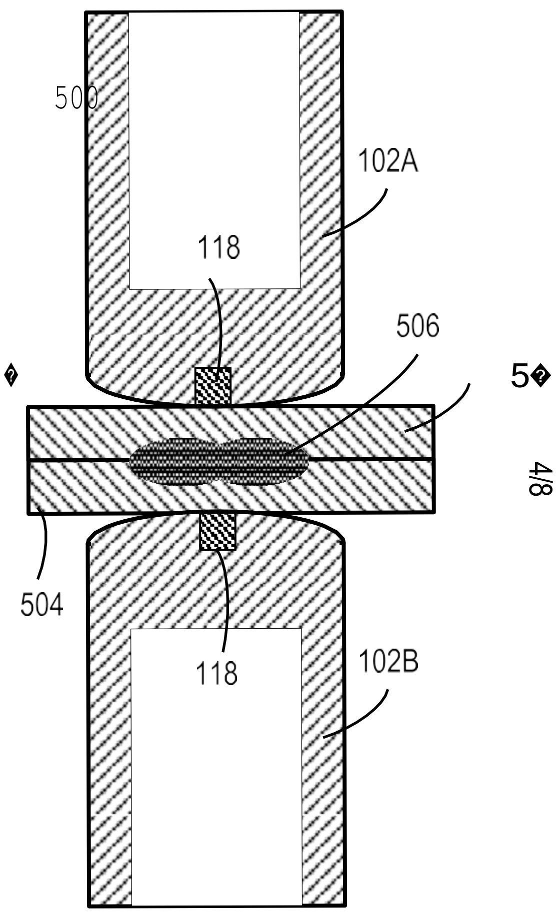

FIG. 6D

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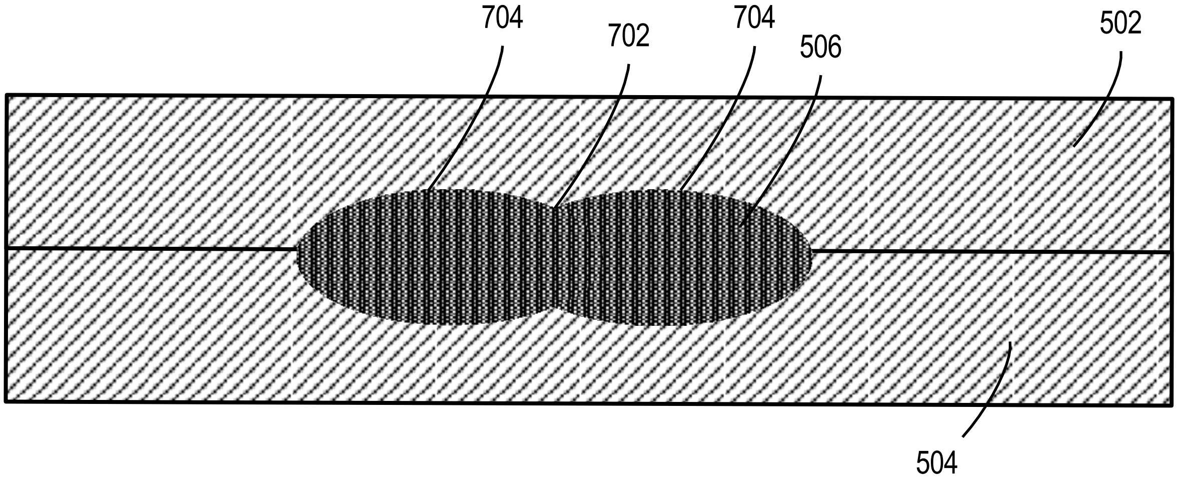

FIG. 7

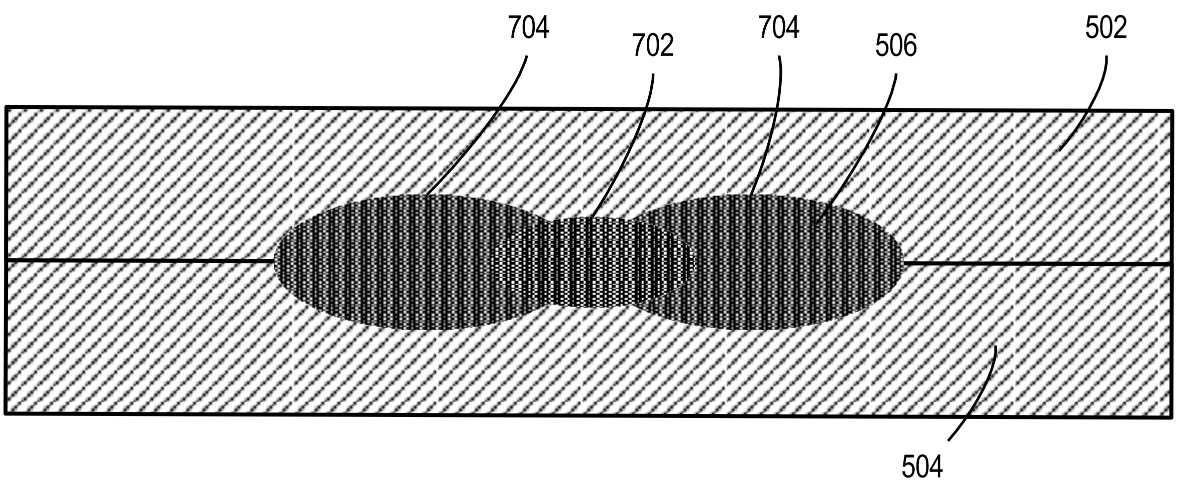

FIG. 8

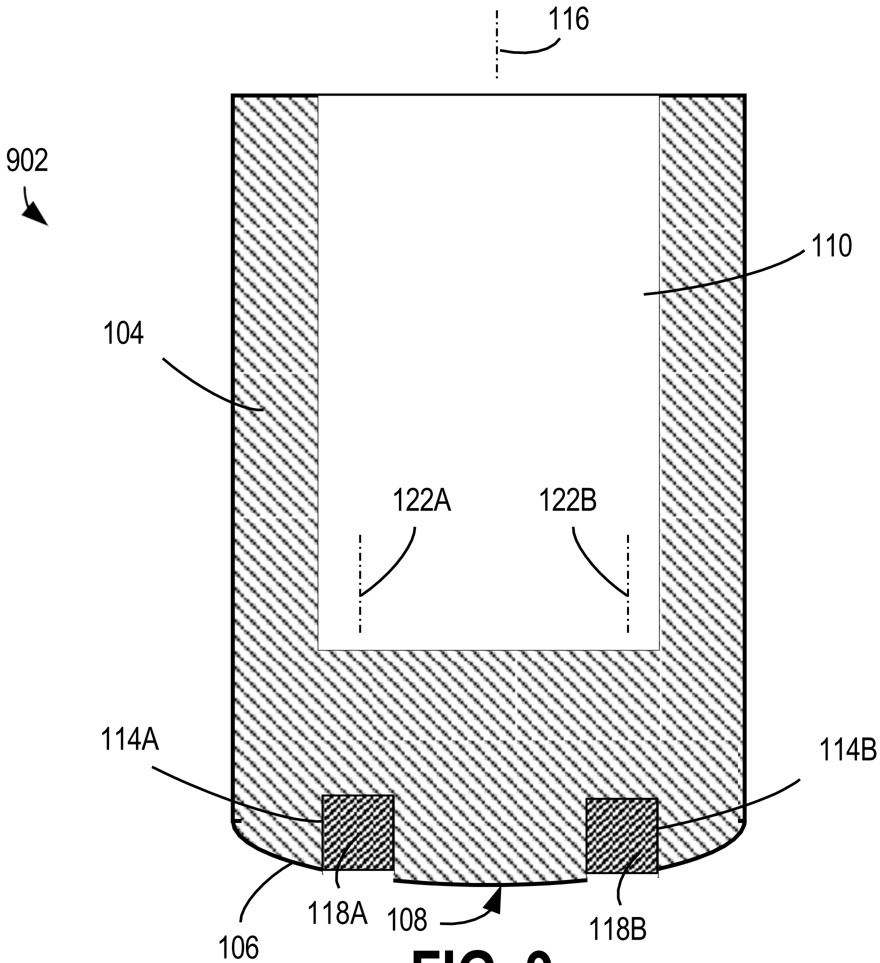
116
902
110
104
122A
122B
114A
114B
106
118A
108
118B

FIG. 9

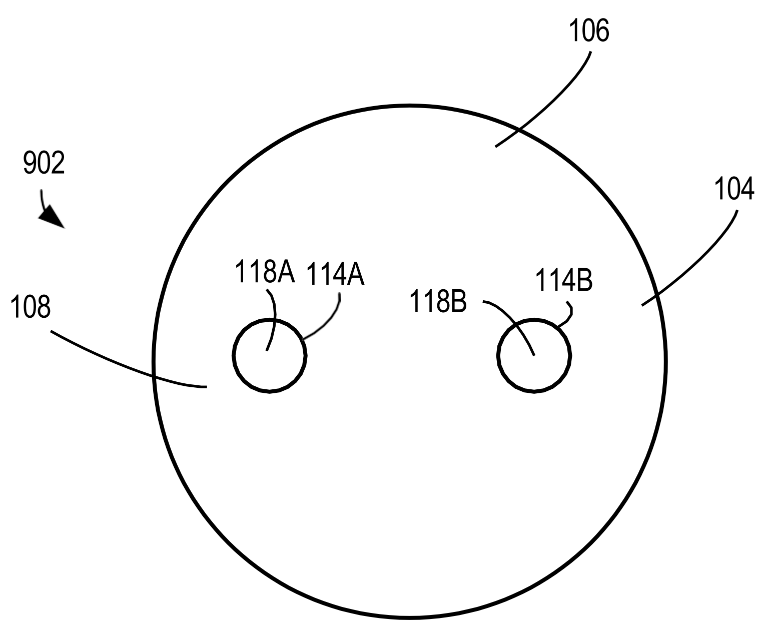
106
902
104
118A
114A
114B
108
118B

FIG. 10

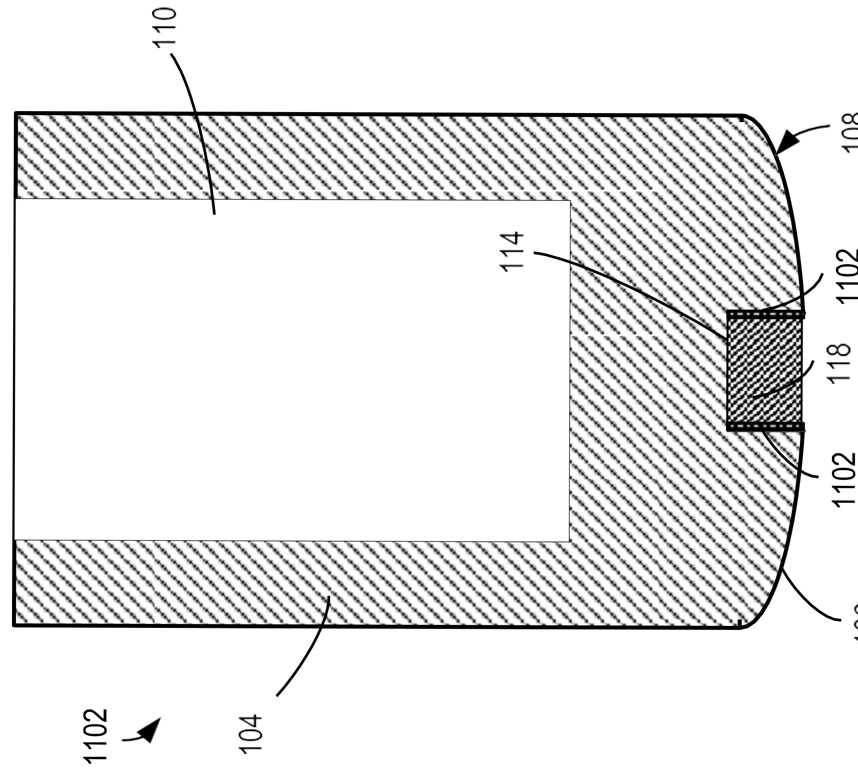
110
108
114
1102
118
1102
106
1102
104

FIG. 12

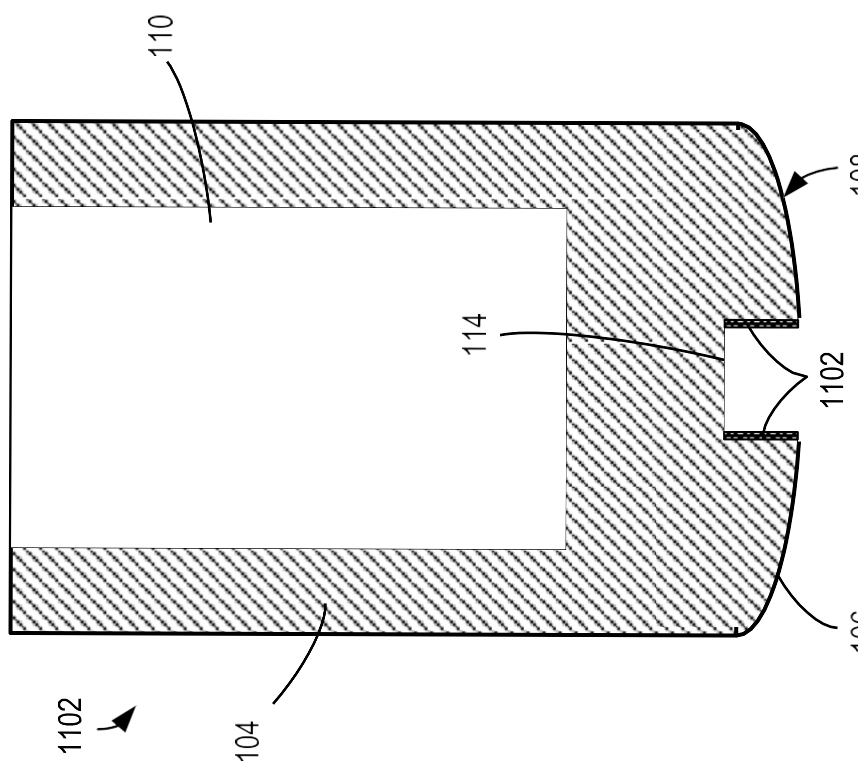
110
108
114
1102
106
1102
104

FIG. 11

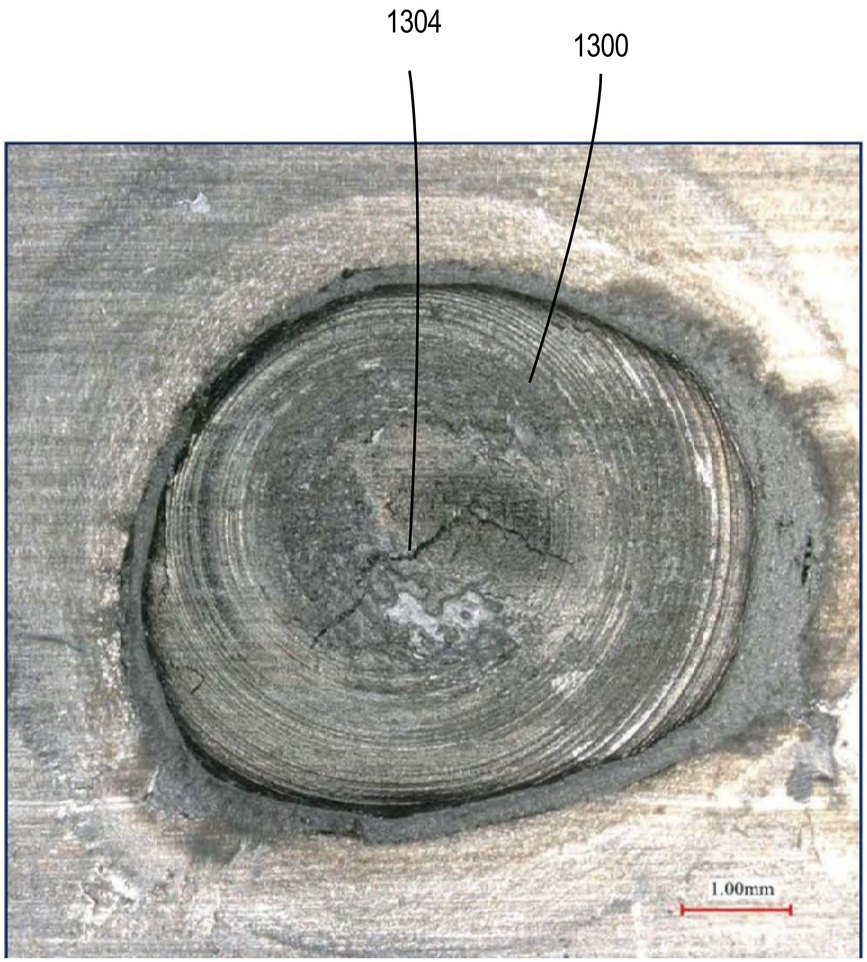

FIG. 13A

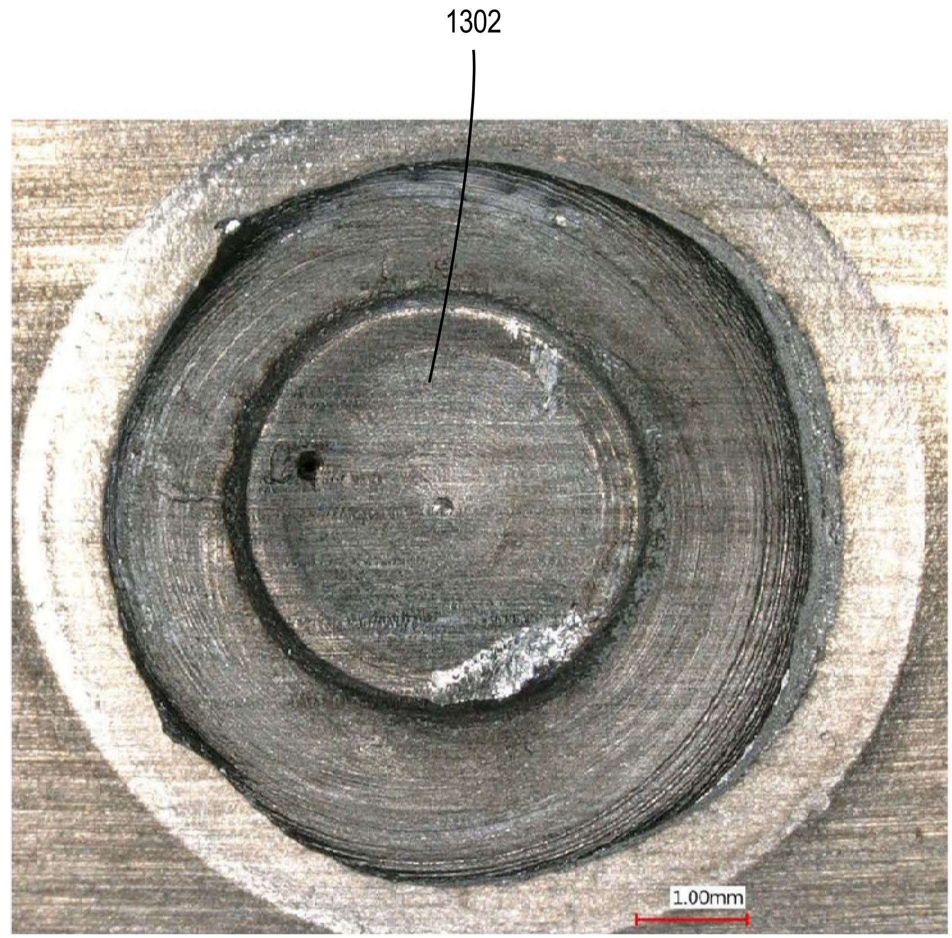

FIG. 13B

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