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ABLATION CATHETER WITH ELECTRODES

Abstract

A catheter configured to deliver therapeutic energy to a tissue is disclosed. The catheter comprises an elongate shaft extending along a shaft longitudinal axis. The catheter further comprises a flexible tip assembly coupled to a distal end of the elongate shaft, the flexible tip assembly comprising at least three mapping electrodes equally spaced about a circumference of the flexible tip, a flexible ablation electrode, and a plurality of irrigation ports. The catheter further comprises an irrigation lumen extending through the elongate shaft and into an interior of the flexible tip assembly, wherein the irrigation lumen is configured to direct irrigation fluid to the plurality of irrigation ports.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a continuation of and claims priority to U.S. patent application Ser. No. 18/331,533, filed Jun. 8, 2023, which is a continuation of and claims priority to U.S. patent application Ser. No. 16/387,487, filed Apr. 17, 2019, which is a continuation of and claims priority to U.S. patent application Ser. No. 15/542,030, filed Jul. 6, 2017, issued as U.S. Pat. No. 11,246,655, which is a National Stage Entry of and claims priority to PCT/US2016/012497, filed Jan. 7, 2016, which claims priority to U.S. Provisional Patent Application No. 62/100,843, filed Jan. 7, 2015, and to U.S. Provisional Patent Application No. 62/182,226, filed Jun. 19, 2015, all of which are hereby incorporated by reference as though fully set forth herein.

a. FIELD OF THE DISCLOSURE

[0002] This disclosure relates to an ablation catheter with electrodes.

b. BACKGROUND ART

[0003] Mapping and ablation catheters may be used for electrically mapping a body part and/or may be used to deliver therapy to a body part. In an example, the body part may include the heart and the delivery of therapy may include creating a lesion in heart tissue to treat conditions such as arrhythmia. A single point lesion, as its name implies, may be created by applying energy at a single point region of tissue. On the other hand, applying energy across an elongated region in a tissue creates a linear lesion.

BRIEF SUMMARY

[0004] In at least one embodiment, a catheter can include an elongate shaft extending along a shaft longitudinal axis. The catheter can further comprises a flexible tip assembly coupled to a distal end of the elongate shaft, the flexible tip assembly comprising at least three mapping electrodes equally spaced about a circumference of the flexible tip, a flexible ablation electrode, and a plurality of irrigation ports. The catheter can further comprises an irrigation lumen extending through the elongate shaft and into an interior of the flexible tip assembly, wherein the irrigation lumen is configured to direct irrigation fluid to the plurality of irrigation ports.

[0005] In at least one embodiment, a catheter can include an elongate shaft extending along a shaft longitudinal axis. The catheter can further comprise a flexible tip assembly coupled to a distal end of the elongate shaft, the flexible tip assembly comprising three mapping electrodes equally spaced about a circumference of the flexible tip, a flexible ablation electrode, a plurality of irrigation ports, and at least one thermocouple. The catheter can further include an irrigation lumen extending through the elongate shaft and into an interior of the flexible tip assembly, wherein the irrigation lumen is configured to direct irrigation fluid to the plurality of irrigation ports.

[0006] In at least one embodiment, a catheter can include an elongate shaft extending along a shaft longitudinal axis and comprising a shaft proximal end and a shaft distal end. In at least one

embodiment, a flexible tip assembly can comprise a tip assembly outer surface, wherein the flexible tip assembly is connected to the distal end of the elongate shaft and is configured to deliver therapeutic energy to the tissue. In at least one embodiment, an insulative layer can comprise an insulative layer outer surface, wherein the insulative layer is disposed on the tip assembly outer surface. In at least one embodiment, a mapping electrode can be disposed on the insulative layer outer surface.

[0007] In at least one embodiment, a catheter can include an elongate shaft comprising a shaft proximal end and a shaft distal end, the elongate shaft extending along a shaft longitudinal axis. In at least one embodiment, a tip assembly can comprise a tip assembly longitudinal axis and can be connected to the distal end of the elongate shaft. In at least one embodiment, the tip assembly can include a proximal electrode portion and a distal electrode portion connected to the proximal electrode portion via an intermediate portion, wherein the proximal, intermediate, and distal portions extend along the tip assembly longitudinal axis. In at least one embodiment, an insulative layer can be disposed on an outer surface of the intermediate portion. In at least one embodiment, a mapping electrode can be disposed on an outer surface of the insulative layer.

[0008] In at least one embodiment, a catheter tip assembly can include a proximal flexible electrode, wherein the proximal flexible electrode includes at least one first linear gap, configured to allow the proximal flexible electrode to flex. In at least one embodiment, an intermediate portion can be connected to a distal end of the proximal flexible electrode. In at least one embodiment, the intermediate portion can include an insulative layer circumferentially wrapped around an outer surface of the intermediate portion. In at least one embodiment, a plurality of mapping electrodes can be circumferentially disposed on an outer surface of the insulative layer. In at least one embodiment, the catheter tip assembly can include a distal flexible electrode connected to a distal end of the intermediate portion, wherein the distal flexible electrode includes at least one second linear gap, configured to allow the distal flexible electrode to flex.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is an isometric front, side, and top view of a flexible tip electrode with mapping electrodes, in accordance with embodiments of the present disclosure.

[0010] FIG. 2 is a cross-sectional front view of a flexible tip electrode with mapping electrodes, in accordance with embodiments of the present disclosure.

[0011] FIG. 3A is a side view of a second embodiment of a flexible tip electrode with mapping electrodes, in accordance with embodiments of the present disclosure.

[0012] FIG. 3B is an isometric front, side, and top view of the second embodiment of the flexible tip electrode with mapping electrodes depicted in FIG. 3A, in accordance with embodiments of the present disclosure.

[0013] FIG. 3C is a front view of the second embodiment of the flexible tip electrode with mapping electrodes depicted in FIG. 3A, in accordance with embodiments of the present disclosure.

[0014] FIG. 4A is a side view of a third embodiment of a flexible tip electrode with mapping electrodes, in accordance with embodiments of the present disclosure.

[0015] FIG. 4B is a frontal view of the third embodiment of the flexible tip electrode with mapping electrodes depicted in FIG. 4A, in accordance with embodiments of the present disclosure.

[0016] FIG. 5A is a radiused mapping electrode that includes a radiused electrode head, in accordance with embodiments of the present disclosure.

[0017] FIG. 5B is a cross-sectional view of the radiused mapping electrode taken along line 5B-5B, in FIG. 5A, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0018] The contents of U.S. Pat. No. 8,480,669 B2 entitled "Ablation Catheter with Flexible Tip;" U.S. Pat. No. 8,876,817 entitled "Electrophysiology System and Methods;" U.S. application No. 61/753,429 entitled "Flexible High-Density Mapping Catheter Tips and Flexible Ablation Catheter Tips with Onboard High-Density Mapping Electrodes;" U.S. application Ser. No. 13/836,846 entitled "Deflectable Catheter Shaft Section, Catheter Incorporating Same, and Method of Manufacturing Same;" U.S. Pat. No. 8,814,825 entitled "Deflectable Catheter Shaft Section, Catheter Incorporating Same, and Method of Manufacturing Same;" U.S. application Ser. No. 14/213,289 entitled "Flex Tip Fluid Lumen Assembly with Termination Tube;" U.S. application Ser. No. 14/333,235 entitled "Deflectable Catheter Shaft Section, Catheter Shaft Incorporating Same, and Method of Manufacturing Same;" United States publication no. 2011/0313417 A1 entitled "Ablation Catheter Having Flexible Tip with Multiple Flexible Electrode Segments;" United States publication no. 2013/0085479 A1 entitled "Catheter Having Flexible Tip with Multiple Flexible Segments;" U.S. Pat. No. 8,974,454 B2 entitled "Kit for Non-Invasive Electrophysiology Procedures and Method of Its Use;" United States publication no. 2010/0286684 A1 entitled "Flexible High-Density Mapping Catheter Tips and Flexible Ablation Catheter Tips with Onboard High-Density Mapping Electrodes;" United States publication no. 2012/0010490 A1 entitled "Medical Devices Having Flexible Electrodes Mounted Thereon;" and U.S. application No. 62/100,843 entitled "Ablation Catheter with Electrodes are hereby incorporated by reference."

[0019] Cardiac radiofrequency (RF) ablation has become the first line therapy for many types of arrhythmias. In RF ablation, a first step may be to diagnose the electrical activities of the heart (mapping) to identify the origins of the arrhythmia using a diagnostic catheter. In more advanced ablation procedures, a more detailed electroanatomical mapping may be required. In most cases, mapping utilizes a separate diagnostic catheter or multiple electrodes proximal to the ablation electrode. There may be a lack of effectiveness associated with performance of atrial fibrillation (AF) ablation when using prior techniques, due to the inability to analyze electrical activity at the precise targeted ablation sites and in real time during ablation therapy.

[0020] Embodiments of the present disclosure provide for a mapping and ablation catheter. The catheter may provide for mapping functionality that possesses a higher resolution over prior mapping and ablation catheters. In an example, prior mapping catheters have used ring electrodes for obtaining electrograms and electroanatomical mapping. The ring electrodes may oftentimes be spaced several or more millimeters apart from one another along a shaft of the mapping and ablation catheter. A shaft of the catheter, as well as the ring electrodes, may be contacted with tissue (e.g., cardiac tissue) and electrical signals produced by the tissue may be picked up by the ring electrodes and/or an ablating electrode for determining conditions such as AF. Electrical signals produced by tissue (e.g., cardiac tissue) that is located between the ring electrode and the ablating electrode may travel through a material separating the ring electrode and the ablating electrode. As the signals pass through the material, the signal may experience attenuation, which may involve a gradual loss in intensity of the signal as it passes through the material separating the ring electrode and the ablating electrode.

[0021] In addition, the ring electrodes of prior mapping and ablation catheters may be located along the shaft of the catheter and thus away from a direct site where ablation is occurring. As such, determining electrical signals produced by tissue that has been ablated may be made more complex, as the ring electrodes must be moved closer to the ablation site and/or an additional diagnostic catheter is placed at the ablation site to collect electrical signals produced by the tissue. In either case, determination of electrical signals at the precise ablation site may be difficult with prior mapping and ablation catheters.

[0022] Embodiments of the present disclosure provide for a mapping and ablation catheter. The catheter may provide for mapping functionality that possesses a higher resolution over prior mapping catheters, while simultaneously allowing for ablation functionality. In addition, the catheter may provide a determination of electrical signals at the ablation site.

[0023] FIG. 1 is an isometric front, side, and top view of a flexible tip electrode **10**, also referred to herein as flexible tip assembly, with mapping electrodes **11-1**, **11-2**, **11-3**, **11-4**, hereinafter collectively referred to as electrodes **11**. The flexible tip electrode **10** may be attached to a distal end (e.g., shaft distal end) of a catheter shaft **14**, in some embodiments, and may be formed from a metallic and/or conductive material. The catheter shaft **14** can be an elongate shaft that extends along a shaft longitudinal axis and comprises a shaft proximal end and a shaft distal end and may include a number of ring electrodes **15**, as discussed herein, that may be used for mapping purposes in combination with the flexible tip electrode **10**. The flexible tip electrode **10** may include an electrode wall **12** that may be formed of a radial surface and may include at least one linear gap **13**. The at least one linear gap **13** may extend along an outer radial surface of the flexible tip electrode **10** and may form a variety of patterns on the outer radial surface of the flexible tip electrode **10**, allowing for the flexible tip electrode **10** to flex and/or deform to some degree when a force is exerted on a tip of the flexible tip electrode **10**, for example. In one embodiment, the pattern may be an interlocking dovetail pattern. The interlocking dovetail pattern may comprise a plurality of blocks wherein each of the blocks comprises a head **24** and a neck **26**. Alternatively, in some embodiments, the pattern may be any type of interlocking arrangement that provides for relative movement in the proximal and distal direction with regard to either all or part of the catheter shaft **14**. For example, alternative patterns of the interlocking arrangement may be bulbous, trapezoidal, triangular, rectangular, and/or another shape that creates an interlocking fit. In some embodiments, the at least one linear gap **13** can be configured to allow an irrigant to exit the flexible tip electrode from an inner lumen of the flexible tip electrode **10** via the at least one linear gap **13**.

[0024] The flexible tip electrode **10** may include an electrode cap **20** that may be coupled to a distal end of the electrode wall **12**. The electrode cap **20**, in some embodiments, may include a plurality of irrigation ports **19** that pass through the electrode cap **20**. The electrode cap **20** may include an electrode pocket **18**, that may be configured to receive a distal end of a thermal sensor that passes through the flexible tip electrode **10**.

[0025] In some embodiments, the flexible tip electrode **10** (e.g., flexible tip assembly) can comprise a tip electrode (e.g., tip assembly) outer surface (e.g., outer wall). In an example, the flexible tip electrode **10** may include channels **16-1**, **16-2** that run along the flexible tip electrode **10** longitudinally, which are further discussed in relation to FIG. 2. The channels **16-1**, **16-2** can be formed in the tip electrode **10** (e.g., tip assembly) outer surface. Hereinafter, channels **16-1**, **16-2** are collectively referred to as channels **16**. In an example, material may be removed from the outer wall **12** of the flexible tip electrode **10** to create the channels **16**, each of which may have axially extending longitudinal walls that are parallel to one another and/or divergent to one another. In some embodiments, a base of the channel may be flat, convex, and/or concave. Material may be removed from the outer wall **12** of the flexible tip electrode **10** to create the channels **16** which may extend into the outer wall **12** toward a central axis of the flexible tip electrode **10**.

[0026] The channels **16-1**, **16-2** may be formed in the outer wall **12** of the flexible tip electrode **10**, such that the channels **16-1**, **16-2** are located 90 degrees from one another (e.g., are formed in quadrants). In some embodiments, four channels may be formed in the outer wall **12** of the flexible tip electrode **10** and located 90 degrees from one another, such that pairs of channels are diametrically opposed from one another, which is discussed further in relation to FIG. 2. Although FIG. 1 depicts two channels **16**, the flexible tip electrode **10** may include additional channels, as depicted in FIG. 2. For instance, an additional channel may be formed in the outer wall **12** of the flexible tip electrode **10** in a position that is diametrically opposed to a first channel **16-1**. In some embodiments, an additional channel can be formed in the outer wall **12** of the flexible tip electrode **10** in a position that is diametrically opposed to a second channel **16-2**.

[0027] In some embodiments, an insulative strip **17-1**, **17-2** (e.g., insulative layer), hereinafter collectively referred to as insulative strips **17**, may be disposed within the channels **16** and may run longitudinally along the flexible tip electrode **10**. The insulative strip (e.g., insulative layer) can

comprise an insulative layer outer surface and can be disposed on the tip assembly (e.g., tip electrode **10**) outer surface. The insulative strips **17** may be formed from a non-metallic material, which is insulative (e.g., does not readily conduct electricity) and is flexible. In some embodiments, the insulative strips **17** may cover the base of the channels **16**, as well as the walls of the channels **16**, and may include a cutout portion between the base of the channels **16** and the walls of the channels **16**. In some embodiments, mapping electrodes **11** can be disposed on the insulative layer outer surface. In some examples, mapping electrodes **11** may be disposed within the cutout portion of the insulative strips **17**, such that the mapping electrodes are longitudinally separated from one another. In an example, each insulative strip **17** may include individual cutouts for each mapping electrode **11**. The mapping electrodes **11** may be wired through the tip, in some examples. For instance, wires may run through an inner cavity of the flexible tip electrode **10** and proximally along the catheter shaft **14**. In some embodiments, the plurality of mapping electrodes **11** may be placed over a flexible non-metallic tube in order to provide isolation and to allow the mapping electrodes to simultaneously flex with the flexible tip electrode **10**.

[0028] In some embodiments, the mapping electrodes **11** may be formed of various shapes, sizes, and materials. For example, the mapping electrodes **11** may be rectangular and/or cylindrical, among other shapes. In some embodiments, the mapping electrodes **11** may be elongated and extend longitudinally along the flexible tip electrode **10**. In some embodiments, the electrodes **11** may be formed of a material that conducts electricity. For example, the electrodes **11** may be formed from a metallic material.

[0029] Although two mapping electrodes **11** are depicted in each channel **16**, in FIG. **1**, greater or fewer than two mapping electrodes **11** may be included in each channel. In addition, while four quadrants that each contain mapping electrodes **11** are discussed, fewer or greater than four quadrants that include mapping electrodes **11** may be included in the flexible tip electrode **10**.

[0030] In some embodiments, the mapping electrodes **11** included in each channel **16** may be in longitudinal pairs. For example, as depicted in FIG. **1**, channel **16-1** includes two mapping electrodes **11** that are spaced apart longitudinally from one another in the channel **16**. In some embodiments, each channel **16** may include more than two mapping electrodes **11**. For example, each channel **16** may include three, four, etc. mapping electrodes **11**. The longitudinal pairs of mapping electrodes **11** may be disposed in different quadrants of the flexible tip electrode **10** and may be positioned radially with respect to a central longitudinal axis of the flexible tip electrode **10**.

[0031] In some embodiments, the insulative strips **17** and/or the electrodes **11** may provide mechanical support to control a degree of compression and/or flexing of the flexible tip electrode **10**. For instance, a size of the insulative strips **17** and/or the electrodes **11** may be selected to vary the degree of compression and/or flexing of the flexible tip electrode **10**. Alternatively, a type of material that the insulative strips **17** and/or the electrodes **11** are made from may be selected to vary the degree of compression and/or flexing of the flexible tip electrode **10**.

[0032] The mapping electrodes **11** included within the flexible tip electrode **10** may be used to pinpoint locations for ablation and to identify areas of interest for diagnosis and ablation and the flexible tip electrode **10** may improve contact with beating cardiac structures. This may allow the mapping electrodes **11** to remain in contact with tissue either endocardially or epicardially, improving the fidelity and resolution of the electrograms with minimal far-field signals.

[0033] Embodiments of the present disclosure may allow a physician to map the desired cardiac tissue in greater detail with higher resolution and ablate without losing the targeted sites. Unlike bipolar signals from the ablating tip and the adjacent ring electrode, the electrograms acquired from the mapping electrodes **11** may be directly from the tissue in contact with the flexible tip, which gives the user clearer electrogram attenuation in real time. The bipolar electrograms obtained from different combinations of mapping electrodes in configurations of the present disclosure may allow for directional assessment of the electrograms. In an example, electrogram recordings may be taken

from the longitudinal pairs of mapping electrodes **11**. For instance, an electrogram recording may be taken between the electrodes **11-1** and **11-2** and/or between the electrodes **11-3** and **11-4**. Alternatively, electrogram readings may be taken between circumferential pairs of electrodes **11**. For instance, an electrogram reading may be taken between electrodes **11-1** and **11-3**, electrodes **11-3** and **11-5**, electrodes **11-5** and **11-7**, electrodes **11-7** and **11-1**, electrodes **11-2** and **11-4**, electrodes **11-1** and **11-4**, electrodes **11-2** and **11-3**, or any other combination of electrodes included on the flexible tip electrode **10**. Additional electrodes **11-5**, **11-6**, **11-7**, and **11-8** are hidden from view in FIG. 1.

[0034] In addition, embodiments of the present disclosure may provide for tissue assessment at the ablation site during or after an ablation procedure, since the mapping electrodes **11** are positioned proximate to the ablation site. This may provide valuable feedback to a physician in the form of an electrogram that is taken from an area where the ablation was performed, which may be analyzed to determine whether or not additional ablation of the area should be performed. For example, if gaps in the ablation have occurred, the mapping electrodes **11** may detect the gaps and additional ablation may be performed. In addition, embodiments of the present disclosure may determine a complete conduction block, conduction velocity vectors, as well as assess adjacent tissue.

[0035] FIG. 2 is a cross-sectional front view of a flexible tip electrode **10'** with mapping electrodes **11-1'**, **11-3'**, **11-5'**, **11-7'**. In an example, the cross-sectional front view depicted in FIG. 2 may be in a direction looking proximally towards the front of the flexible tip electrode **10'**. The flexible tip electrode **10'** may include one or more irrigation ports **19**, as well as an electrode pocket **18**, as discussed herein. The flexible tip electrode **10'** can include at least one linear gap **13'** formed in the outer wall **12'**. In some embodiments, the flexible tip electrode **10'** may include a number of channels **16'** formed in the outer wall **12'** of the flexible tip electrode **10'**, as discussed herein. In an example, four channels **16-1'**, **16-2'**, **16-3'**, **16-4'**, hereinafter collectively referred to as channels **16'** may be formed in four quadrants of the outer wall of the flexible tip electrode **10'**. In an example, each of the channels **16'** may be positioned 90 degrees from one another, such that pairs of channels (e.g., **16-1'** and **16-3'**, **16-2'** and **16-4'**) are diametrically opposed from one another. Insulative strips **17-1'**, **17-2'**, **17-3'**, **17-4'**, hereinafter collectively referred to as insulative strips **17'**, may be placed within the channels **16'** and may include cutouts configured to accept mapping electrodes **11-1'**, **11-3'**, **11-5'**, **11-7'**, hereinafter collectively referred to as mapping electrodes **11'**. In some embodiments, the channels **16'** may be lined with an insulative material, that forms insulative strips **17'**. For example, the insulative material can be disposed along sidewalls (e.g., sidewall **20**) of the channels **16'** (e.g., channel **16-2'**) and a bottom channel portion **22** of the channels **16'** (e.g., channel **16-2'**). Although not shown, one or more additional mapping electrodes **11'** may be placed within the insulative strips **17'** and channels **16'**, proximally with respect to the electrodes **11'**. In an example, one additional mapping electrode may be placed behind (e.g., proximally with respect to) each of the mapping electrodes **11'**, such that each channel **16'** includes a longitudinal pair of mapping electrodes **11'** (e.g., longitudinal mapping electrode set). In some embodiments, the insulative strips **17'** can be flush with an outer surface of the flexible tip electrode **10'** and/or can extend from (e.g., radially from) an outer surface of the flexible tip electrode **10'**, as further depicted in FIG. 1.

[0036] The mapping electrodes **11'** may be formed from one or more materials. For instance, as depicted in FIG. 2, the mapping electrodes **11'** may be formed from multiple layers of different materials. In an example, and as depicted, the mapping electrodes **11'** can include an inner core circumferentially surrounded by an intermediate layer and the intermediate layer can be circumferentially surrounded by an outer layer. Alternatively, the mapping electrodes **11'** may be formed from one material. Each of the mapping electrodes **11'** may be wired to a proximal end of the catheter shaft (e.g., a proximal electrical connector). In an example, the wires associated with each of the mapping electrodes **11'** may travel through the catheter shaft. For instance, individual mapping electrodes **11'** may be discretely wired and attached to an assigned pin of a connector

located at a proximal end of a catheter handle.

[0037] FIG. 3A is a side view of a second embodiment of a flexible tip electrode **30** with mapping electrodes **44-1**, **44-2**, in accordance with embodiments of the present disclosure (an additional mapping electrode **44-3** is depicted in FIG. 3C). The flexible tip electrode **30** may be attached to a distal end of a catheter shaft **32**, in some embodiments; and portions of the flexible tip electrode **30** may be formed from a metallic and/or conductive material. The catheter shaft **32** may include a number of ring electrodes **34**, as discussed herein, that may be used for mapping purposes in combination with the flexible tip electrode **30**. The flexible tip electrode **30** may include an electrode wall **36** that may be formed of a radial surface and may include at least one linear gap.

[0038] In some embodiments, the flexible tip electrode **30** can include a proximal portion **50**, comprising at least one proximal linear gap **38-1** and a distal portion **54**, comprising at least one distal linear gap **38-2**. In an example, the proximal linear gap **38-1** can be formed in a proximal portion **50** of the electrode wall **36** defined by line C-C, as depicted, and the distal linear gap **38-2** can be formed in a distal portion **54** of the electrode wall **36** defined by line B-B, leaving an intermediate portion of the electrode wall **36** therebetween, defined by line D-D, that may not contain gaps. For example, the intermediate portion **52** (e.g., in a center of the proximal portion **50** and the distal portion **54**) may not include linear gaps such as those included in the proximal portion **50** of the electrode wall **36** and the distal portion **54** of the electrode wall **36**. The intermediate portion **52** of the electrode wall **36** located between the proximal linear gap **38-1** and the distal linear gap **38-2** may be a hollow cylindrical surface that is coaxial with a central longitudinal axis of the flexible tip electrode **30**. Thus, the intermediate portion **52** of the electrode wall **36** can be rigid, which can allow for mounting of various devices, instruments, and/or sensors to the intermediate portion **52**, as discussed herein. For example, the intermediate portion **52** of the electrode wall **36** can have a flexibility that is less than a flexibility associated with the proximal portion **50** of the electrode wall **36** (e.g., that includes the proximal linear gap **38-1**) and/or a flexibility that is less than a flexibility associated with the distal portion **54** of the electrode wall **36** (e.g., that includes the distal linear gap **38-2**).

[0039] The at least one proximal linear gap **38-1** and the at least one distal linear gap **38-2** may extend along an outer radial surface of the flexible tip electrode **30** and may form a variety of patterns on the outer radial surface of the flexible tip electrode **30**, allowing for the flexible tip electrode **30** to flex and/or deform to some degree when a force is exerted on a tip of the flexible tip electrode **30**, for example. As discussed herein, as the flexible tip electrode **30** flexes and/or deforms, the intermediate portion **52** of the flexible electrode tip defined by line DD can maintain its general shape allowing for various devices, instruments, and/or sensors to be connected to the intermediate portion **52** of the flexible tip electrode **30**.

[0040] In some embodiments, the pattern associated with the at least one proximal linear gap **38-1** and the at least one distal linear gap **38-2** may be an interlocking dovetail pattern. The interlocking dovetail pattern may comprise a plurality of blocks wherein each of the blocks comprises a head **56** and a neck **58**. Alternatively, in some embodiments, the pattern may be any type of interlocking arrangement that provides for relative movement in the proximal and distal direction with regard to either all or part of the catheter shaft **32**. For example, alternative patterns of the interlocking arrangement may be bulbous, trapezoidal, triangular, rectangular, and/or another shape that creates an interlocking fit.

[0041] In some embodiments, the proximal linear gap **38-1** can have a different pattern than the distal linear gap **38-2**. For example, the proximal linear gap **38-1** may have a dovetail, bulbous, trapezoidal, triangular, rectangular, and/or a pattern of another shape; and the distal linear gap **38-2** may have a dovetail, bulbous, trapezoidal, triangular, rectangular, and/or a pattern of another shape. In addition, the patterns between the proximal linear gap **38-1** and the distal linear gap **38-2** may be sized the same and/or differently from one another. For instance, the distal linear gap **38-2** can include a pattern (e.g., of a particular shape and/or size) that provides for an increased flexibility

over the pattern (e.g., of a particular shape and/or size) associated with the proximal linear gap **38-1**. Alternatively, the proximal linear gap **38-1** can include a pattern that provides for an increased flexibility over the pattern associated with the distal linear gap **38-2**. The patterns between the proximal linear gap **38-1** and the distal linear gap **38-2** can be varied for other reasons, as well (e.g., to provide a difference in other characteristics, such as compression, etc.).

[0042] In some embodiments, the intermediate portion **52** of the flexible tip electrode **30** can be configured (e.g., tuned) to have a flexibility that is greater than a flexibility associated with the proximal linear gap **38-1** and/or distal linear gap **38-2**. In an example, the distal linear gap **38-2** can have a flexibility that is greater than the intermediate portion **52** of the flexible tip electrode **30** and the intermediate portion **52** can have a flexibility that is greater than the proximal linear gap **38-1** of the flexible tip electrode **30**. Alternatively, the proximal linear gap **38-1** can have a flexibility that is greater than the intermediate portion **52** and the intermediate portion **52** can have a flexibility that is greater than the distal linear gap **38-2**. In some embodiments, the intermediate portion **52** can be configured to vary its flexibility by changing the axial length and/or the circumferential width of the mapping electrodes **44-1**, **44-2**, **44-3**, and/or changing the length (e.g., axial length) of the intermediate portion **52**. In some embodiments a shape of the mapping electrodes can be changed. For example, the mapping electrodes can be formed in a circular, triangular, oblong, or other type of pattern. In some embodiments, the material forming the insulative layer **42** can be changed to adjust the flexibility of the intermediate portion **52**.

[0043] As discussed herein, the flexible tip electrode **30** may include an electrode cap **40** that may be coupled to a distal end of the electrode wall **36**. The electrode cap **40**, in some embodiments, may include a plurality of irrigation ports **46-1**, **46-2**, **46-3**, **46-4** that pass through the electrode cap **40**, as depicted in FIGS. **3B** and **3C**. The electrode cap **40** may include an electrode pocket **48**, as depicted in FIGS. **3B** and **3C**, that may be configured to receive a distal end of a thermal sensor that passes through the flexible tip electrode **30**. In some embodiments, an axial length of the flexible tip electrode **30**, defined by line A-A can be approximately 5 millimeters, although the axial length of the flexible tip electrode **30** can be greater than or less than 5 millimeters.

[0044] In some embodiments, the proximal portion **50** of the electrode wall **36**, defined by line C-C, can have an axial length of approximately 2 millimeters; the distal portion **54** of the electrode wall **36** defined by line B-B can have an axial length of approximately 2 millimeters; and the intermediate portion **52** of the electrode wall **36**, defined by line D-D, can have an axial length of approximately 1 millimeter, although these dimensions are exemplary only and can be greater than or less than the lengths provided herein. However, in some embodiments, the proximal portion **50** can have a longer axial length than the distal portion **54**. Alternatively, the distal portion **54** can have a longer axial length than the proximal portion **50**. Thus, the intermediate portion **52** (and the mapping electrodes **44-1**, **44-2**, **44-3**) can be moved proximally or distally along the flexible tip electrode **30**. In some embodiments, an axial length of the mapping electrodes **44-1**, **44-2**, **44-3** can be approximately 0.5 millimeters, although the dimensions of the mapping electrodes can be greater than or less than 0.5 millimeters. The axial length of the mapping electrodes **44-1**, **44-2**, **44-3** be in a range of 0.5 to 2.0 millimeters. In some embodiments, the axial length of the mapping electrodes **44-1**, **44-2**, **44-3** can be in a range of 0.5 to 1.0 millimeters.

[0045] In some embodiments, one or more insulative strips **42** may be disposed around the intermediate portion **52** of the flexible tip electrode **30**. The insulative strips **42** may be formed from a non-metallic material, which is insulative (e.g., does not readily conduct electricity) and is flexible, as discussed herein. In an example, the insulative strip **42** can extend axially between the proximal portion **50** of the flexible tip electrode **30** and the distal portion **54** of the flexible tip electrode **30** and can be circumferentially wrapped around the intermediate portion **52**, such that it is concentric with the central longitudinal axis of the flexible tip electrode **30**. In some embodiments, the insulative strip **42** can be a planar piece of material (e.g., in the shape of a rectangle), which can be wrapped around and connected to the intermediate portion **52** of the

flexible tip electrode **30** to form a hollow cylinder that is concentric with the intermediate portion **52**. Alternatively, the insulative strip **42** can be a hollow cylinder that is slid over and connected with the intermediate portion **52**. In some embodiments, the intermediate portion **52** of the flexible tip electrode **30** where the insulative strip **42** is disposed can be recessed such that the outer radial surface of the electrode wall **36** is flush with an outer radial surface of the insulative strip **42**.

[0046] In some embodiments, one or more mapping electrodes **44-1**, **44-2**, **44-3** can be disposed on the insulative strip **42** (e.g., around the outer radial surface of the intermediate portion **52** of the electrode wall **36**). As depicted in FIGS. **3A-3C**, three mapping electrodes **44-1**, **44-2**, **44-3** can be disposed on the insulative strip **42** (mapping electrode **44-3** is depicted in FIG. **3C**). In some embodiments, the mapping electrodes **44-1**, **44-2**, **44-3** can be circumferentially disposed in tri-sectors around the flexible tip electrode **30**, as depicted in FIGS. **3A** to **3C**. In some embodiments, the intermediate portion **52** of the flexible tip electrode **30** where the insulative strip **42** and mapping electrodes **44-1**, **44-2**, **44-3** are disposed can be recessed, such that the outer radial surface of the electrode wall **36** is flush with the outer radial surface of the insulative strip **42** and/or outer radial surface of the mapping electrodes **44-1**, **44-2**, **44-3**.

[0047] As depicted, the mapping electrodes **44-1**, **44-2**, **44-3** can be planar strips (e.g., rectangles) that have a circumferential width that is greater than an axial length. The planar strips can be formed around the outer radial surface of the intermediate portion **52** of the electrode wall **36**, such that a segmented ring electrode is formed (e.g., spaces exist between the mapping electrodes **44-1**, **44-2**, **44-3**), in some embodiments. Although three mapping electrodes **44-1**, **44-2**, **44-3** are depicted, greater than or fewer than three mapping electrodes can be disposed around the outer radial surface of the intermediate portion **52** of the electrode wall **36**. In some embodiments, the mapping electrodes **44-1**, **44-2**, **44-3** can be planar surfaces that have been formed as arcs, such that they wrap around the outer radial surface of the intermediate portion **52** of the electrode wall **36**. However, the mapping electrodes **44-1**, **44-2**, **44-3** can be formed of various shapes, sizes, and materials. For example, the mapping electrodes **44-1**, **44-2**, **44-3** can be rectangular and/or cylindrical, among other shapes.

[0048] In some embodiments, the mapping electrodes **44-1**, **44-2**, **44-3** can be circumferentially spaced apart from one another such that the mapping electrodes **44-1**, **44-2**, **44-3** do not touch one another (e.g., a space exists between each of the mapping electrodes **44-1**, **44-2**, **44-3**). In some embodiments, a ring electrode can be disposed around the intermediate portion **52** of the electrode wall **36**. In an example, the ring electrode can circumferentially extend around the intermediate portion **52** of the electrode wall **36** such that it is coaxial with the central longitudinal axis of the flexible tip electrode **30**. In some embodiments, the mapping electrodes **44-1**, **44-2**, **44-3** can be wired through the flexible tip electrode **30**. For example, holes can be formed through a wall of the intermediate portion **52** of the electrode wall **36** and wires can extend from the mapping electrodes **44-1**, **44-2**, **44-3** through the wall of the intermediate portion **52**, through the flexible tip electrode **30**, and proximally through the catheter shaft **32**.

[0049] FIG. **3B** is an isometric front, side, and top view of the second embodiment of the flexible tip electrode **30** with mapping electrodes **44-1**, **44-2**, **44-3** depicted in FIG. **3A**, in accordance with embodiments of the present disclosure. As depicted, the irrigation ports **46** can extend through the electrode cap **40**. In addition, the electrode cap **40** can include an electrode pocket **48** that may be configured to receive the distal end of a thermal sensor (e.g., thermocouple) that passes through the flexible tip electrode **30**.

[0050] FIG. **3B** further depicts the mapping electrodes **44-1**, **44-2** (mapping electrode **44-3** is hidden from view) circumferentially disposed in tri-sectors around the flexible tip electrode **30**. As depicted, from the front, side, and top view of the flexible tip electrode **30**, the mapping electrodes **44-1**, **44-2** can be seen as conforming to a contour of the outer radial surface of the insulative strip and/or the outer radial surface of the intermediate portion **52** of the flexible tip electrode **30**. For example, the mapping electrodes **44-1**, **44-2**, **44-3** can be arced, such that they are contoured to the

outer radial surface of the insulative strip **42** and/or the outer radial surface of the intermediate portion **52** of the flexible tip electrode **30**.

[0051] FIG. **3C** is a front view of the second embodiment of the flexible tip electrode **30** with mapping electrodes **44-1**, **44-2**, **44-3**, in accordance with embodiments of the present disclosure. As depicted, the mapping electrodes **44-1**, **44-2**, **44-3** are arced and thus conform to a contour of the outer radial surface of the insulative strip and/or outer radial surface of the intermediate portion **52** of the flexible tip electrode **30**. In some embodiments, the mapping electrodes **44-1**, **44-2**, **44-3** can be high resolution electrodes. The mapping electrodes **44-1**, **44-2**, **44-3** can be circumferentially disposed in tri-sectors around the flexible tip electrode **30**. In some embodiments, fewer than or greater than three mapping electrodes can be included on the flexible tip electrode **30**, as discussed herein. The flexible tip electrode **30** can include an electrode cap **40**, as depicted. The electrode cap **40** can include irrigation ports **46** and an electrode pocket **48**, as discussed herein.

[0052] In some embodiments, as depicted in FIGS. **3A** to **3C**, the mapping electrodes **44-1**, **44-2**, **44-3** can be raised from an outer surface of the electrode wall **36**. In some embodiments, the raised mapping electrodes **44-1** can help to ensure that when the flexible electrode tip **30** is in contact with tissue, the mapping electrodes **44-1**, **44-2**, **44-3** make sufficient contact with the tissue in order to perform diagnostic procedures (e.g., collect electrical signals from the tissue).

[0053] FIG. **4A** is a side view of a third embodiment of a flexible tip electrode **60** with radiused mapping electrodes **68-1**, **68-2**, **68-3** (mapping electrode **68-3** is depicted in FIG. **4B**), in accordance with embodiments of the present disclosure. The one or more embodiments included in FIG. **4** can include the same features as those previously discussed in relation to FIGS. **3A** to **3C**, with the addition of radiused mapping electrodes **68-1**, **68-2**, **68-3**. The flexible tip electrode **60** may be attached to a distal end of a catheter shaft **70**, in some embodiments; and portions of the flexible tip electrode **60** may be formed from a metallic and/or conductive material. The catheter shaft **70** may include a number of ring electrodes **72-1**, **72-2**, **72-3**, as discussed herein, that may be used for mapping purposes in combination with the flexible tip electrode **60**. The flexible tip electrode **60** may include an electrode wall **74** that may be formed of a radial surface and may include at least one linear gap.

[0054] In some embodiments, the flexible tip electrode **60** can include a proximal portion **62**, comprising at least one proximal linear gap **76-1** and a distal portion **66**, comprising at least one distal linear gap **76-2**, as well as an electrode cap **82**. An intermediate portion **64** can be disposed between the proximal portion **62** and the distal portion **66**. The intermediate portion **64** may not include linear gaps, such as those included in the proximal portion **62** of the electrode wall **74** and the distal portion **66** of the electrode wall **74**.

[0055] The intermediate portion **64** of the electrode wall **74** located between the proximal linear gap **76-1** and the distal linear gap **76-2** may be a hollow cylindrical surface that is coaxial with a central longitudinal axis of the flexible tip electrode **60**. Thus, the intermediate portion **64** of the electrode wall **74** can be rigid, which can allow for mounting of various devices, instruments, and/or sensors to the intermediate portion **64**, as discussed herein. For example, the intermediate portion **64** of the electrode wall **74** can have a flexibility that is less than a flexibility associated with the proximal portion **62** of the electrode wall **74** (e.g., that includes the proximal linear gap **76-1**) and/or a flexibility that is less than a flexibility associated with the distal portion **66** of the electrode wall **74** (e.g., that includes the distal linear gap **76-2**).

[0056] The at least one proximal linear gap **76-1** and the at least one distal linear gap **76-2** may extend along an outer radial surface of the flexible tip electrode **60** and may form a variety of patterns on the outer radial surface of the flexible tip electrode **60**, allowing for the flexible tip electrode **60** to flex and/or deform to some degree when a force is exerted on a tip of the flexible tip electrode **60**, for example. As discussed herein, as the flexible tip electrode **60** flexes and/or deforms, the intermediate portion **64** of the flexible tip electrode **60** can maintain its general shape allowing for various devices, instruments, and/or sensors to be connected to the intermediate

portion **64** of the flexible tip electrode **60**.

[0057] In some embodiments, the pattern associated with the at least one proximal linear gap **76-1** and the at least one distal linear gap **76-2** may be an interlocking dovetail pattern. The interlocking dovetail pattern may comprise a plurality of blocks wherein each of the blocks comprises a head **78** and a neck **80**. Alternatively, in some embodiments, the pattern may be any type of interlocking arrangement that provides for relative movement in the proximal and distal direction with regard to either all or part of the catheter shaft **70**. For example, alternative patterns of the interlocking arrangement may be bulbous, trapezoidal, triangular, rectangular, and/or another shape that creates an interlocking fit.

[0058] In some embodiments, the proximal linear gap **76-1** can have a different pattern than the distal linear gap **76-2**, as discussed in relation to FIGS. **3A** to **3C**. In some embodiments, the intermediate portion **64** of the flexible tip electrode **60** can be configured (e.g., tuned) to have a flexibility that is greater than a flexibility associated with the proximal linear gap **76-1** and/or distal linear gap **76-2**. In an example, the distal linear gap **76-2** can have a flexibility that is greater than the intermediate portion **64** of the flexible tip electrode **60** and the intermediate portion **64** can have a flexibility that is greater than the proximal linear gap **76-1** of the flexible tip electrode **60**. Alternatively, the proximal linear gap **76-1** can have a flexibility that is greater than the intermediate portion **64** and the intermediate portion **64** can have a flexibility that is greater than the distal linear gap **76-2**.

[0059] In some embodiments, one or more insulative strips **84** may be disposed around the intermediate portion **64** of the flexible tip electrode **60** and can include the same or similar properties with respect to the one or more insulative strips **42** discussed in relation to FIGS. **3A** to **3C**. In an example, the insulative strip **84** can extend axially between the proximal portion **62** of the flexible tip electrode **60** and the distal portion **66** of the flexible tip electrode **60** and can be circumferentially wrapped around the intermediate portion **64**, such that it is concentric with the central longitudinal axis of the flexible tip electrode **60**. In some embodiments, the insulative strip **84** can be a planar piece of material (e.g., in the shape of a rectangle), which can be wrapped around and connected to the intermediate portion **64** of the flexible tip electrode **60** to form a hollow cylinder that is concentric with the intermediate portion **64**. Alternatively, the insulative strip **84** can be a hollow cylinder that is slid over and connected with the intermediate portion **64**. In some embodiments, the intermediate portion **64** of the flexible tip electrode **60** where the insulative strip **84** is disposed can be recessed such that the outer radial surface of the electrode wall **74** is flush with an outer radial surface of the insulative strip **84**.

[0060] In some embodiments, one or more radiused mapping electrodes **68-1**, **68-2**, **68-3** can be disposed on the insulative strip **84** (e.g., around the outer radial surface of the intermediate portion **64** of the electrode wall **74**). As depicted in FIGS. **4A** and **4B**, three radiused mapping electrodes **68-1**, **68-2**, **68-3** can be disposed on the insulative strip **84** (mapping electrode **68-3** is depicted in FIG. **4B**). FIG. **4B** is a frontal view of the third embodiment of the flexible tip electrode with mapping electrodes depicted in FIG. **4A**, in accordance with embodiments of the present disclosure.

[0061] In some embodiments, the mapping electrodes **68-1**, **68-2**, **68-3** can be circumferentially disposed in tri-sectors around the flexible tip electrode **60**, as depicted in FIGS. **4A** to **4B**. Also depicted in FIG. **4B** are irrigation ports **86-1**, **86-2**, **86-3**, **86-4** that pass through the electrode cap **82** and an electrode pocket **88**. In some embodiments, the intermediate portion **64** of the flexible tip electrode **60** where the insulative strip **84** and mapping electrodes **68-1**, **68-2**, **68-3** are disposed can be recessed, such that the outer radial surface of the electrode wall **74** is flush with the outer radial surface of the insulative strip **84**.

[0062] As further depicted in FIGS. **4A** and **4B**, an outer face (e.g., exposed face) of the mapping electrodes **68-1**, **68-2**, **68-3** can be button shaped (e.g., dome shaped, having rounded circumferential edges, having radiused circumferential edges). In some embodiments, mapping

electrodes can be cylindrical and can have 90 degree circumferential edges. The mapping electrodes **68-1**, **68-2**, **68-3** can be positioned around the outer radial surface of the intermediate portion **84** of the electrode wall **74**, such that a segmented electrode is formed (e.g., spaces exist between the mapping electrodes **68-1**, **68-2**, **68-3**), in some embodiments. Although three mapping electrodes **68-1**, **68-2**, **68-3** are depicted, greater than or fewer than three mapping electrodes can be disposed around the outer radial surface of the intermediate portion **84** of the electrode wall **74**. [0063] In some embodiments, the mapping electrodes **68-1**, **68-2**, **68-3** can be circumferentially spaced apart from one another such that the mapping electrodes **68-1**, **68-2**, **68-3** do not touch one another (e.g., a space exists between each of the mapping electrodes **68-1**, **68-2**, **68-3**). For example, as depicted in FIG. 4B, the mapping electrodes **68-1**, **68-2**, **68-3** can be disposed in tri-sectors of the flexible tip electrode **60** (e.g., positioned approximately 120 degrees apart from one another). Although three mapping electrodes **68-1**, **68-2**, **68-3** are depicted, less than or greater than three mapping electrodes **68-1**, **68-2**, **68-3** can be disposed (e.g., circumferentially disposed) on the flexible tip electrode **60**. In some embodiments, the mapping electrodes **68-1**, **68-2**, **68-3** can be wired through the flexible tip electrode **60**. For example, holes can be formed through a wall of the intermediate portion **64** of the electrode wall **74** and wires can extend from each of the mapping electrodes **68-1**, **68-2**, **68-3** through the wall of the intermediate portion **64**, through the flexible tip electrode **60**, and proximally through the catheter shaft **70**.

[0064] In some embodiments, one or more circumferential rows of mapping electrodes **68-1**, **68-2**, **68-3** can be disposed on the intermediate portion **84** of the flexible tip electrode **60**. For example, while one circumferential row of mapping electrodes **68-1**, **68-2**, **68-3** is depicted in FIGS. 4A and 4B, one or more additional circumferential rows of mapping electrodes **68-1**, **68-2**, **68-3** can be positioned proximally or distally with respect to the circumferential row of electrodes **68-1**, **68-2**, **68-3**. In some embodiments, an additional circumferential row of mapping electrodes can be radially offset from the circumferential row of mapping electrodes **68-1**, **68-2**, **68-3**. For instance, with respect to FIG. 4B, each mapping electrode **68-1**, **68-2**, **68-3** is radially disposed from an adjacent mapping electrode by 120 degrees. In some embodiments, a second row of mapping electrodes can be disposed proximally and/or distally with respect to the set mapping electrodes **68-1**, **68-2**, **68-3** and radially disposed from the set by a particular amount (e.g., 60 degrees), which can provide a greater circumferential density of mapping electrodes.

[0065] FIG. 5A depicts a radiused mapping electrode **100** that includes a radiused electrode head **102** (e.g., head portion), in accordance with embodiments of the present disclosure. The radiused mapping electrode **100** can include a distal end **108** and a proximal end **110**. In an example, a distal end of radiused mapping electrodes **68-1**, **68-2**, **68-3** is depicted as protruding from (e.g., extending radially outward from) the insulative strip **84** in FIG. 4A. The radiused electrode head **102** can have a proximal circumferential lip **104** that extends around a proximal portion of the radiused electrode head **102**. In some embodiments, distal circumferential edges of the radiused electrode head **102** can be radiused, as depicted in FIG. 5A.

[0066] In some embodiments, the radiused mapping electrode **100** can include a cylindrical intermediate portion **106** that extends proximally from the radiused electrode head **102** (e.g., radially inward from the radiused electrode head **102**). The cylindrical intermediate portion **106** can have a diameter that is less than the radiused electrode head **102**, in some embodiments. A proximal retainer base **112** can be disposed at a distal end of the cylindrical intermediate portion **106**. The proximal retainer base **112** can include a distal circumferential lip **114** that is opposed to the proximal circumferential lip **104** of the radiused electrode head **102**, which in some embodiments can include 90 degree circumferential edges for reasons further discussed herein. In some embodiments, the cylindrical intermediate portion **106** and the proximal retainer base **112** can form a body portion of the radiused mapping electrode **100**.

[0067] The proximal retainer base **112** can include a radiused proximal circumferential lip **116**, in some embodiments. In an example, the proximal circumferential lip **116** can be radiused at a 45

degree angle, although the proximal circumferential lip **116** can be radiused at other angles. In some embodiments, a diameter of the retainer base portion **112** can be greater than the diameter of the intermediate portion **106** and less than a diameter of the radiused electrode head **102**. FIG. 5B depicts a cross-sectional view of the radiused mapping electrode **100** taken along line 5B-5B, in FIG. 5A, in accordance with embodiments of the present disclosure. As depicted, the radiused mapping electrode **100** can define a lumen extending distally into the radiused mapping electrode **100** along a longitudinal axis of the radiused mapping electrode **100** and from a proximal end of the radiused mapping electrode **100**. In some embodiments, a lead (e.g., wire) can be inserted into the lumen and connected (e.g., soldered) to the radiused mapping electrode **100**.

[0068] In some embodiments, the radiused mapping electrode **100** can be disposed in (e.g., inserted into) the insulative strip **84**. For example, the insulative strip **84** can be disposed around the intermediate portion **106**. In some embodiments, the retainer base portion **112** can have a diameter that is greater than the intermediate portion **106**, but less than the radiused electrode head **102**. In an example, the retainer base portion **112** and the radiused electrode head **102** can retain the radiused mapping electrode **100** in the insulative strip **84**. In some embodiments, the insulative strip **84** can include a hole (e.g., circular hole) in which the radiused mapping electrode **100** can be disposed. In an example, a diameter of the hole can have a dimension that is less than the diameter of the retainer base portion **112**. In some embodiments, the diameter of the hole in the insulative strip **84** can be sized and configured to engage an outer surface of the intermediate portion **106**.

[0069] In some embodiments, the radiused mapping electrode **100** can be inserted into the hole formed in the insulative strip **84**. For example, the proximal end **110** can be inserted into the hole formed in the insulative strip **84**. In some embodiments, the insulative strip **84** can be formed of a deformable, flexible, semi-rigid, and/or rigid material. The radiused circumferential lip **116** can aid with insertion into the insulative strip **84**. For example, the radiused circumferential lip **116** can reduce a resistance associated with inserting the radiused mapping electrode **100** into the insulative strip **84**.

[0070] Embodiments are described herein of various apparatuses, systems, and/or methods. Numerous specific details are set forth to provide a thorough understanding of the overall structure, function, manufacture, and use of the embodiments as described in the specification and illustrated in the accompanying drawings. It will be understood by those skilled in the art, however, that the embodiments may be practiced without such specific details. In other instances, well-known operations, components, and elements have not been described in detail so as not to obscure the embodiments described in the specification. Those of ordinary skill in the art will understand that the embodiments described and illustrated herein are non-limiting examples, and thus it may be appreciated that the specific structural and functional details disclosed herein may be representative and do not necessarily limit the scope of the embodiments, the scope of which is defined solely by the appended claims.

[0071] Reference throughout the specification to “various embodiments,” “some embodiments,” “one embodiment,” or “an embodiment”, or the like, means that a particular feature, structure, or characteristic described in connection with the embodiment(s) is included in at least one embodiment. Thus, appearances of the phrases “in various embodiments,” “in some embodiments,” “in one embodiment,” or “in an embodiment,” or the like, in places throughout the specification, are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. Thus, the particular features, structures, or characteristics illustrated or described in connection with one embodiment may be combined, in whole or in part, with the features, structures, or characteristics of one or more other embodiments without limitation given that such combination is not illogical or non-functional.

[0072] It will be appreciated that the terms “proximal” and “distal” may be used throughout the specification with reference to a clinician manipulating one end of an instrument used to treat a

patient. The term “proximal” refers to the portion of the instrument closest to the clinician and the term “distal” refers to the portion located furthest from the clinician. It will be further appreciated that for conciseness and clarity, spatial terms such as “vertical,” “horizontal,” “up,” and “down” may be used herein with respect to the illustrated embodiments. However, surgical instruments may be used in many orientations and positions, and these terms are not intended to be limiting and absolute.

[0073] Although at least one embodiment for an ablation catheter with electrodes has been described above with a certain degree of particularity, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this disclosure. All directional references (e.g., upper, lower, upward, downward, left, right, leftward, rightward, top, bottom, above, below, vertical, horizontal, 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 the devices. Joinder references (e.g., affixed, attached, coupled, connected, and the like) are to be construed broadly and may include intermediate members between a connection of elements and relative movement between elements. As such, joinder references do not necessarily infer that two elements are directly connected and in fixed relationship to each other. It is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative only and not limiting. Changes in detail or structure may be made without departing from the spirit of the disclosure as defined in the appended claims.

[0074] Any patent, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated materials does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

Claims

1. A catheter comprising: an elongate shaft extending along a shaft longitudinal axis; a flexible tip assembly coupled to a distal end of the elongate shaft, the flexible tip assembly comprising: at least three mapping electrodes equally spaced about a circumference of the flexible tip, each of the at least three mapping electrodes comprising an elongated shape having a length that is longer than a width, the length extending parallel to the shaft longitudinal axis; an ablation electrode, wherein each of the at least three mapping electrodes are disposed within a respective elongated groove such that the at least three mapping electrodes are flush with an outer surface of the ablation electrode; and a plurality of irrigation ports; and an irrigation lumen configured to direct irrigation fluid to the plurality of irrigation ports.
2. The catheter of claim 1, wherein the at least three mapping electrodes are configured to receive signals from tissue of a patient.
3. The catheter of claim 1, wherein at least one pair of mapping electrodes of the at least three mapping electrodes are configured to receive bipolar signals from tissue of a patient.
4. The catheter of claim 1, wherein the flexible tip assembly is adapted to conform to tissue.
5. The catheter of claim 1, wherein the flexible tip assembly is formed from an expandable material.
6. The catheter of claim 1, further comprising a ring electrode disposed on the elongate shaft, proximally with respect to the flexible tip assembly.

7. The catheter of claim 1, wherein at least one portion of each of the at least three mapping electrodes are connected to the ablation electrode.
 8. The catheter of claim 7, wherein the at least one portion of each of the at least three mapping electrodes are connected to the ablation electrode via an insulative layer.
 9. The catheter of claim 8, wherein each insulative layer is disposed in a channel formed in an outer surface of the flexible tip assembly.
 10. The catheter of claim 9, wherein the insulative layer is configured to enable compression and flexing of portions of the ablation electrode.
 11. The catheter of claim 1, wherein the ablation electrode forms an underlying structure of the flexible tip assembly.
 12. The catheter of claim 1, wherein the ablation electrode extends radially about the shaft longitudinal axis from beneath the exterior surface of the at least three mapping electrodes.
 13. The catheter of claim 1, wherein the at least three mapping electrodes comprise three mapping electrodes spaced 120 degrees apart.
 14. The catheter of claim 1, further comprising at least one thermal sensor.
 15. A catheter comprising: an elongate shaft extending along a shaft longitudinal axis; a flexible tip assembly coupled to a distal end of the elongate shaft, the flexible tip assembly comprising an ablation electrode, the ablation electrode including a cylindrical body and a distal end, the distal end of the ablation electrode including a flat surface, wherein at least one linear gap extends along an outer radial surface of the ablation electrode to promote flexibility of the ablation electrode; at least one mapping electrode; and a plurality of irrigation ports, at least one irrigation port of the plurality of irrigation ports extending through the flat surface of the distal end of the ablation electrode; an irrigation lumen extending through the elongate shaft and into an interior of the flexible tip assembly, wherein the irrigation lumen is configured to direct irrigation fluid to the plurality of irrigation ports.
 16. The catheter of claim 15, wherein the ablation electrode is configured for bipolar ablation.
 17. The catheter of claim 15, wherein the at least one mapping electrode comprises a ring electrode.
 18. The catheter of claim 15, wherein the at least one linear gap forms an interlocking dovetail pattern.
 19. The catheter of claim 15, further comprising at least one thermal sensor.
 20. The catheter of claim 15, wherein the flexible tip assembly is adapted to conform to tissue.
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