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Weber

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(54) **INTRAVASCULAR TEMPERATURE MONITORING SYSTEM AND METHOD**

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See application file for complete search history.

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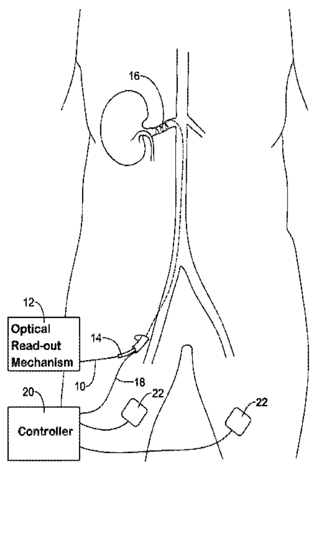
(57) **ABSTRACT**

A system for monitoring one or more temperatures at a vessel wall of a vessel of a patient includes an optical fiber, an optical read-out mechanism, and a therapeutic device. The optical fiber may be deployed along an extent of the vessel and may include one or more fiber Bragg grating (FBG) temperature sensors disposed at one or more corresponding sensor locations along a length of the optical fiber. The optical read-out mechanism may be optically coupled to the optical fiber, and it may be configured to transmit light into the optical fiber and detect light reflected from the one or more FBG temperature sensors. The detected light reflected from the one or more FBG temperature sensors may encode local temperatures at each of the one or more corresponding sensor locations. The therapeutic device may be configured for performing a therapeutic procedure to or through the vessel wall.

13 Claims, 6 Drawing Sheets



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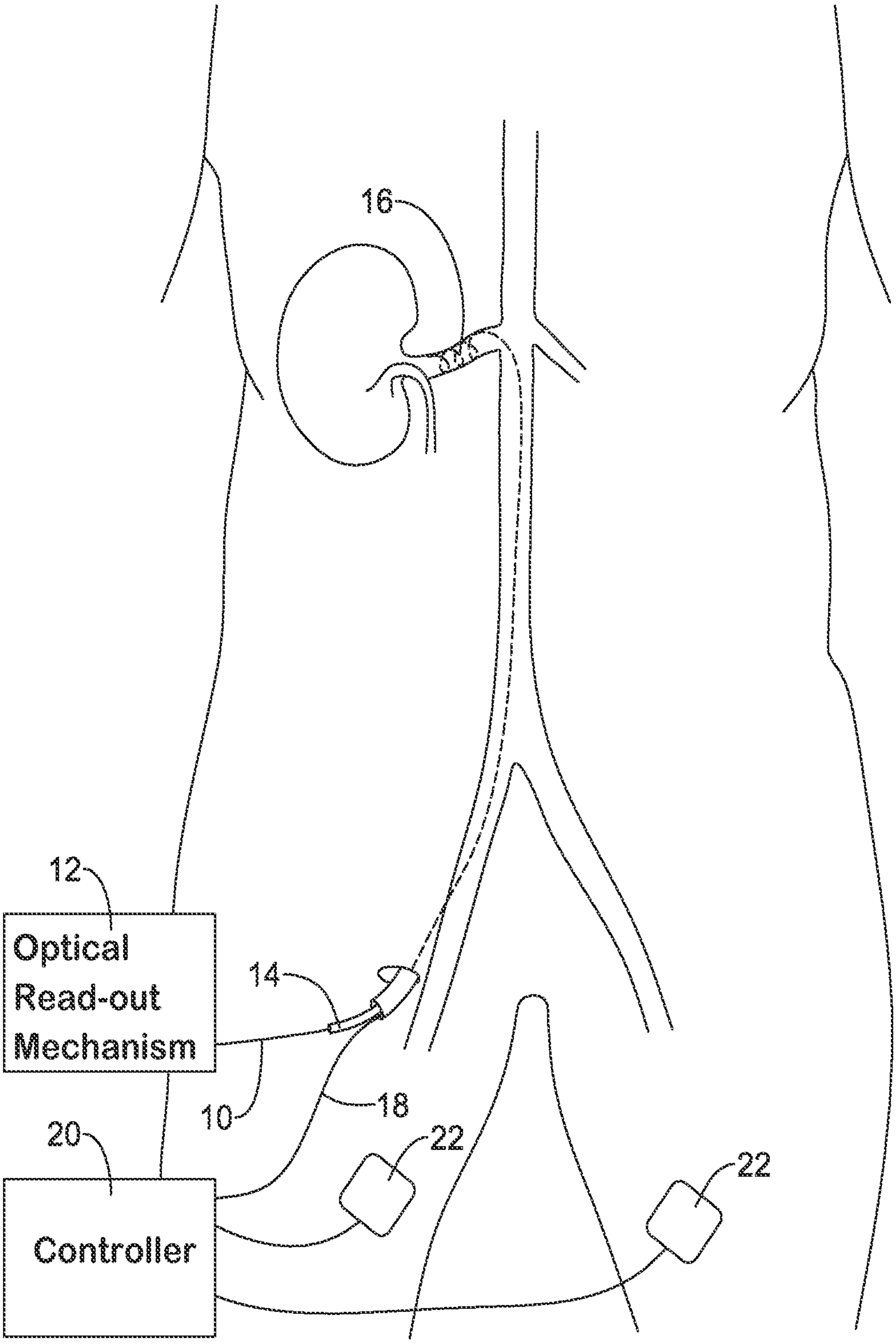
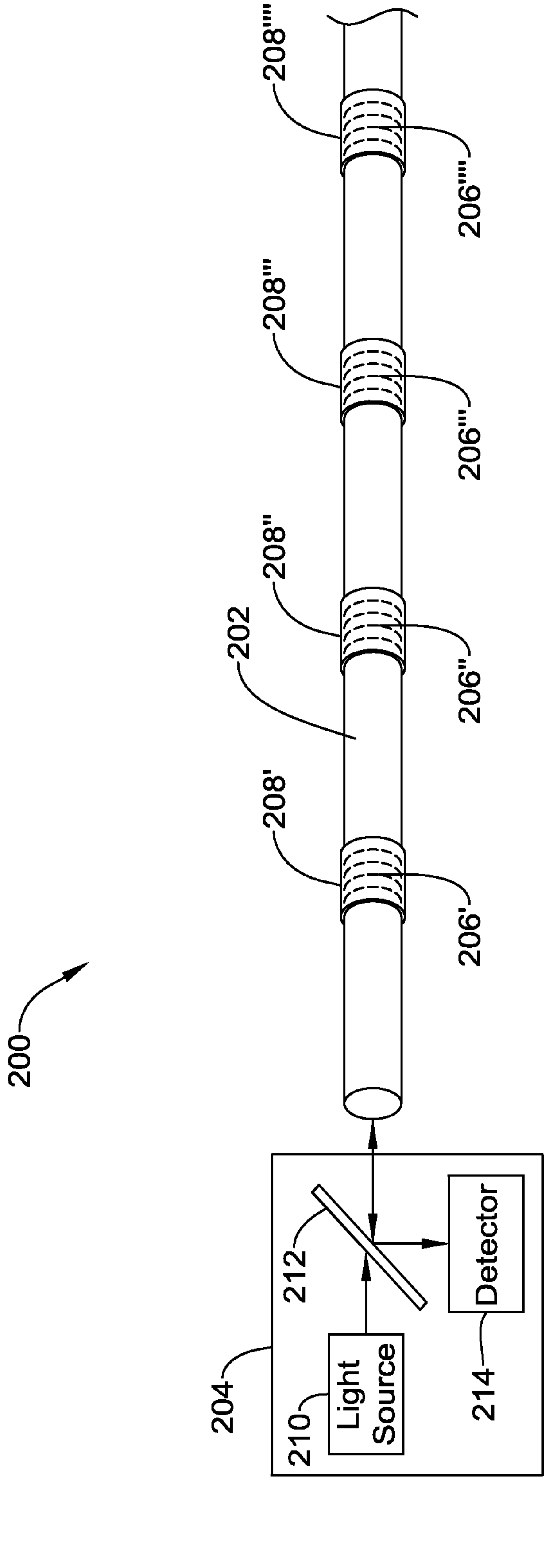


Figure 1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Light Source
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Detector
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Figure 2

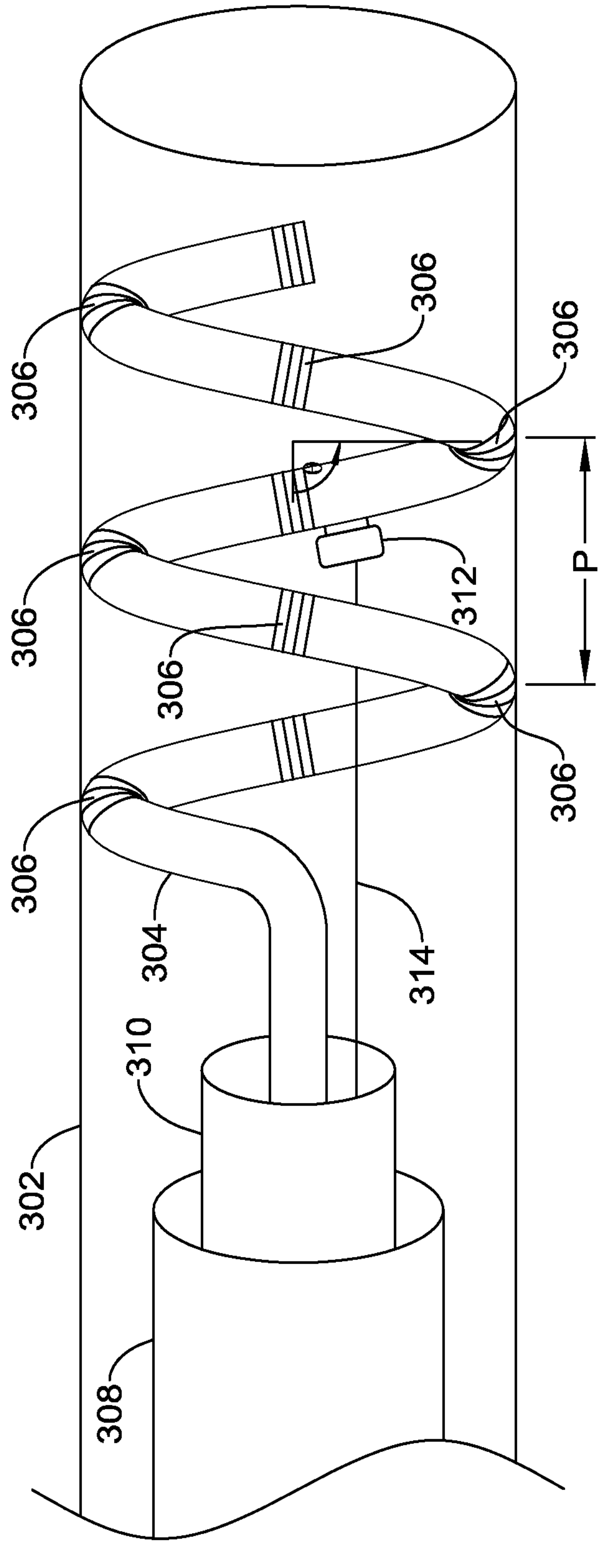

Figure 3

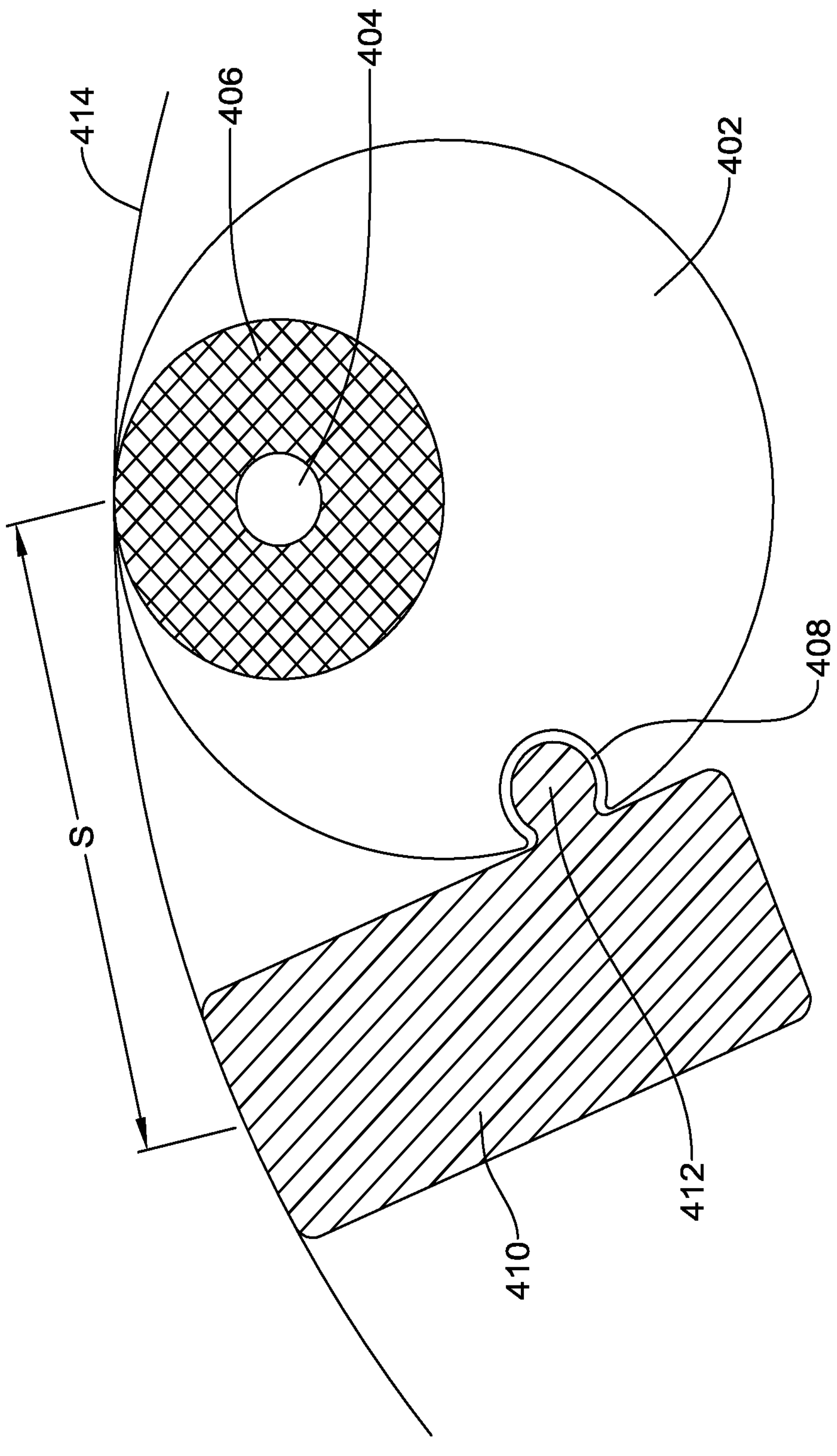

Figure 4

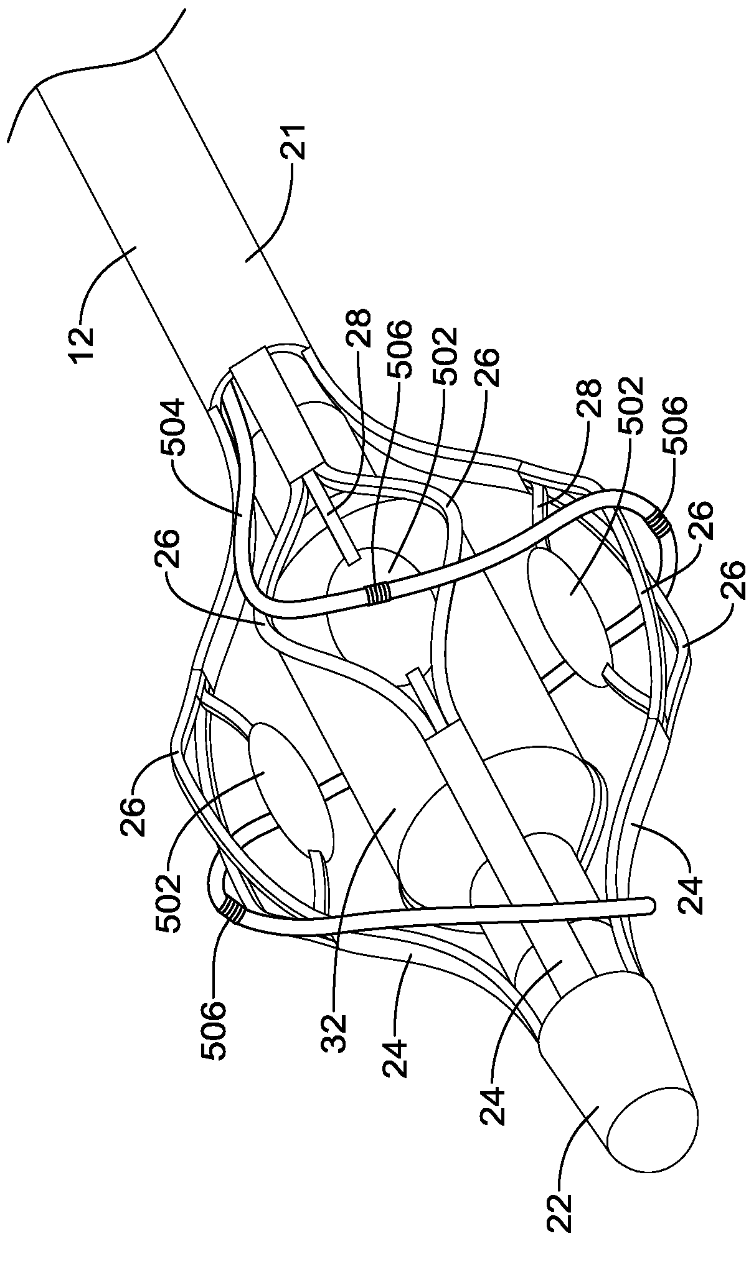
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Figure 5

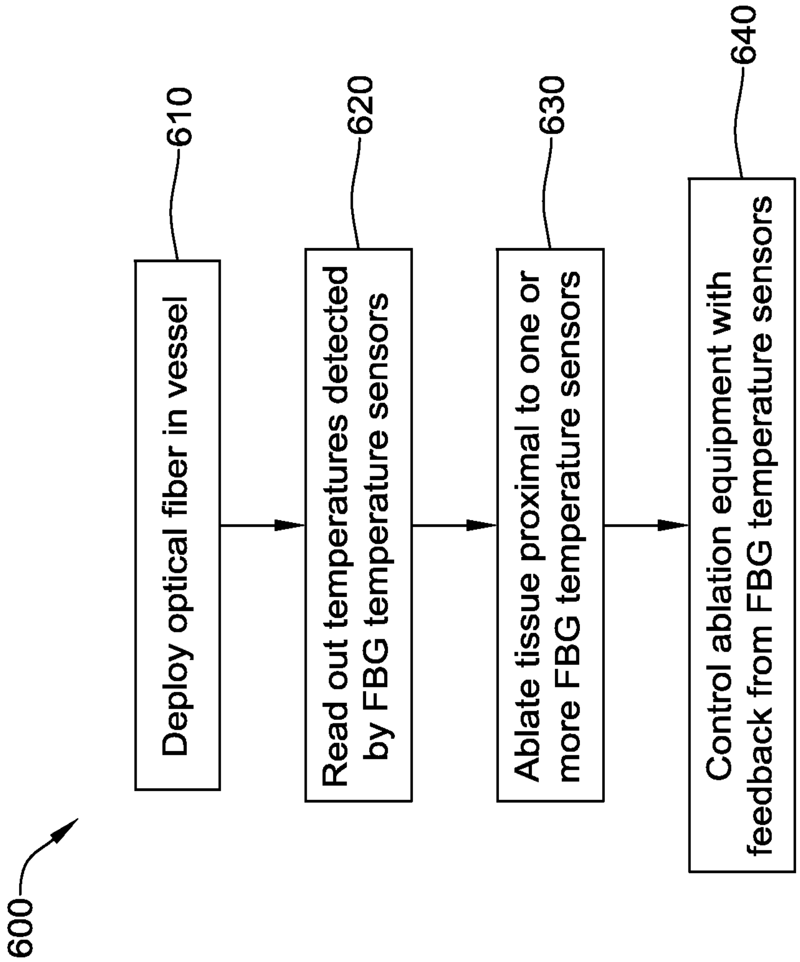
600
Deploy optical fiber in vessel
610
Read out temperatures detected by FBG temperature sensors
620
Ablate tissue proximal to one or more FBG temperature sensors
630
Control ablation equipment with feedback from FBG temperature sensors
640

Figure 6

INTRAVASCULAR TEMPERATURE MONITORING SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119 to U.S. Provisional Application Ser. No. 61/545,959, filed Oct. 11, 2011, the entirety of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to optical fiber-based sensor systems, and more particularly, optical fiber-based methods and apparatus for monitoring temperatures within vessels of a patient. Such monitoring may be performed in conjunction with ablation of nerve tissue proximal a blood vessel wall of the patient.

BACKGROUND

Certain treatments require the temporary or permanent interruption or modification of select nerve function. One example treatment is renal nerve ablation which is sometimes used to treat conditions related to congestive heart failure. The kidneys produce a sympathetic response to congestive heart failure, which, among other effects, increases the undesired retention of water and/or sodium. Ablating some of the nerves running to the kidneys reduces or eliminates this sympathetic function, which provides a corresponding reduction in the associated undesired symptoms.

Many nerves (and nervous tissue such as brain tissue), including renal nerves, run along the walls of or in close proximity to blood vessels and thus can be accessed intravascularly through the walls of the blood vessels. It is therefore desirable to provide for systems and methods for intravascular nerve modulation. It may be desirable to monitor temperatures intravascularly at vessel wall locations before, during, and/or after some such procedures. Minimally invasive in vivo temperature measurement may find uses in other medical contexts as well. Therefore, there remains room for improvement and/or alternatives in providing for systems and methods for intravascular nerve modulation.

SUMMARY

The present disclosure relates to optical fiber-based sensor systems, and more particularly, optical fiber-based methods and apparatus for monitoring temperatures within vessels of a patient. In one illustrative embodiment, a system for monitoring one or more temperatures at a vessel wall of a vessel of a patient includes an optical fiber, an optical read-out mechanism, and a therapeutic device. The optical fiber may be deployed along an extent of the vessel and may include one or more fiber Bragg grating (FBG) temperature sensors disposed at one or more corresponding sensor locations along a length of the optical fiber. The optical read-out mechanism may be optically coupled to the optical fiber, and it may be configured to transmit light into the optical fiber and detect light reflected from the one or more FBG temperature sensors. The detected light reflected from the one or more FBG temperature sensors may encode local temperatures at each of the one or more corresponding sensor locations. The therapeutic device may be configured for performing a therapeutic procedure to or through the vessel wall.

In another illustrative embodiment, an intravascular nerve ablation system includes a helical structure deployed along an extent of a vessel of a patient and an optical fiber attached to the helical structure and following a helical path of the helical structure. The optical fiber may have one or more fiber Bragg grating temperature sensors disposed at one or more corresponding sensor locations along a length of the optical fiber. The helical structure may maintain at least some of the one or more FBG temperature sensors in thermal contact with a wall of the vessel.

In yet another illustrative embodiment, a method for monitoring one or more temperatures at a vessel wall of a vessel of a patient with an optical fiber having one or more fiber Bragg grating temperature sensors is provided. The method includes the steps of deploying the optical fiber along an extent of the vessel such that the optical fiber is disposed against the vessel wall with the one or more FBG temperature sensors in thermal contact with the vessel wall, and reading-out temperatures detected by the one or more FBG temperature sensors with an optical read-out mechanism configured to transmit light into the optical fiber and detect light reflected from the one or more FBG temperature sensors. The method may further include the step of performing a therapeutic procedure with a therapeutic device disposed within the vessel proximal to at least one of the one or more FBG temperature sensors. The therapeutic procedure may include tissue ablation. In some instances, a temperature measured by the at least one of the one or more FBG temperature sensors may be used as a feedback signal for controlling the therapeutic procedure.

The above summary of some embodiments is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The Figures, and Detailed Description, which follow, more particularly exemplify these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may be more completely understood in consideration of the following detailed description of various embodiments in connection with the accompanying drawings, in which:

FIG. **1** is a schematic view of an intravascular temperature monitoring system and a renal nerve modulation system in situ.

FIG. **2** is a schematic illustration of elements of an optical fiber-based sensor system.

FIG. **3** is a schematic illustration of elements of an optical fiber-based sensor system deployed in a vessel.

FIG. **4** is a schematic cross-sectional view of a system including a support structure with an integrated optical fiber and a movable therapeutic device.

FIG. **5** is a schematic illustration of a distal end of a renal nerve ablation system with off-wall ablation electrodes and an optical fiber-based sensor.

FIG. **6** is a flowchart of an exemplary optical fiber-based temperature measuring method.

While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

DETAILED DESCRIPTION

For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

All numeric values are herein assumed to be modified by the term "about", whether or not explicitly indicated. The term "about" generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e., having the same function or result). In many instances, the term "about" may be indicative as including numbers that are rounded to the nearest significant figure.

The recitation of numerical ranges by endpoints includes all numbers within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5).

Although some suitable dimensions, ranges and/or values pertaining to various components, features and/or specifications are disclosed, one of skill in the art, incited by the present disclosure, would understand desired dimensions, ranges and/or values may deviate from those expressly disclosed.

As used in this specification and the appended claims, the singular forms "a", "an", and "the" include plural referents unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

The following detailed description should be read with reference to the drawings in which similar elements in different drawings are numbered the same. The detailed description and the drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the disclosure. The illustrative embodiments depicted are intended only as exemplary. Selected features of any illustrative embodiment may be incorporated into an additional embodiment unless clearly stated to the contrary.

The present disclosure pertains at least in part to an optical method of temperature measurement that may be performed in vivo. Temperature measurements at point(s) of treatment may be useful in assessing, monitoring, and/or controlling a variety of medical procedures, including ablative procedures that rely on raising and/or lowering the temperature of tissue to achieve ablative effects. Systems and methods of the present disclosure may be employed in conjunction with intravascular nerve ablation procedures, but they may generally find utility in any number of other medical scenarios, as will be readily appreciated by those skilled in the art.

Nerves that lie in proximity to blood vessels often run along the length of a section of a blood vessel. Nerves are difficult to image using standard imaging techniques such as radiography. Therefore, it may be desirable to apply the ablation or other nerve modulation procedure at different radial locations on the vessel wall to achieve ablation around the complete circumference of the vessel wall. It may also be desirable to apply the procedure at different longitudinal locations so as to avoid weakening or otherwise affecting the vessel wall along a single circumferential section. Systems and methods of the present disclosure may be employed to make temperature measurements proximal to ablation treatment locations as described.

By way of a general introduction and orientation, FIG. **1** is a schematic view illustrating a system for monitoring one or more temperatures at a vessel wall of a vessel of a patient, as well as a renal nerve modulation system. In some illustrative embodiments, the temperature monitoring system and nerve modulation system may be considered parts of a single integrated system.

The temperature monitoring system includes an optical fiber **10** that includes one or more fiber Bragg grating (FBG) temperature sensors (not shown in FIG. **1**) disposed at one or more corresponding sensor locations along a length of the optical fiber. At a proximal end, the optical fiber **10** may be optically coupled to an optical read-out mechanism **12**. The optical fiber **10** may be attached to and/or integrated with a support structure **14**. Support structure **14** may be deployed within at least one vessel of a patient along an extent of the vessel, where it may substantially fix the optical fiber **10** within the vessel. As suggested schematically in FIG. **1**, at a distal region **16** the optical fiber **10** may be deployed along an extent of the vessel in a helical path, although other deployment paths are contemplated. The support structure **14** may be deployed in the same helical path as optical fiber **10**, although this is not necessary, even in cases where the optical fiber is deployed in a helical path.

FIG. **1** illustrates elements of a renal nerve modulation system which may be used in concert with the temperature monitoring system, although either system may be practiced independently of the practice or presence of the other system. The renal nerve modulation system may include an elongate conductor **18**, which may be coupled to a movable ablation tip (not shown) in the distal region **16**. Conductor **18** may be coupled to an ablation controller **20**, which may supply electrical energy to the movable ablation tip in distal region **16**. Return electrode patches **22** optionally may be supplied on the legs or at another conventional location on the patient's body to complete the circuit.

FIG. **2** is a schematic illustration of elements of an optical fiber-based sensor system **200**, which may share features with the temperature monitoring system of FIG. **1**. System **200** includes an optical fiber **202**, which may be optically coupled to an optical read-out mechanism **204**. Optical fiber includes one or more fiber Bragg gratings (FBGs) **206'-206""** (collectively, **206**). FIG. **2** is a simplified, schematic illustration and does not necessarily depict all of the technical features of an optical fiber with FBGs, as would be understood by one of ordinary skill in the art. For example, optical fiber **202** may include a core, cladding, and any other suitable layers, such as a buffer coating, protective housing, etc. Fiber Bragg gratings of the present disclosure, such as FBGs **206** of optical fiber **202**, may be formed by any suitable method, such as via two-beam interference, phase or photo masking, point-by-point writing by laser, and so on.

A FBG generally may include variations in refractive index in the core of the fiber. The refractive index variations may form a wavelength-specific grating mirror that reflects essentially all or a portion of the light at a specific reflection wavelength, while allowing the balance of light propagating in the fiber to pass. The reflection wavelength of a FBG may shift from its nominal value due to local conditions of the optical fiber at the FBG, such as (but not necessarily limited to) temperature and strain. Temperature and/or strain may each affect the refractive index and/or grating period of the FBG, resulting in a reflection wavelength shift. This effect may be exploited to form a FBG sensor. While a FBG may generally respond (in wavelength shift) to both temperature and strain, a FBG may be packaged (e.g., housed) in order to modulate the physical conditions observed at the FBG. For example, a FBG may be packaged in order to decouple the FBG from bending, tension, compression, torsion, or other forces. With a nearly negligible temperature coefficient of expansion of the fiber (for a glass fiber), changes in reflection wavelength for a FBG so-packaged may be attributed primarily to a change in refractive index of the fiber caused by temperature changes. In FIG. **2**, packaged FBG sensors are represented by **208'-208""**.

In another sensor example, a FBG may be packaged in such a way that the packaging or housing couples changes in pressure into stress in the fiber, leading to a predictable shift in reflection wavelength. Other sensors are contemplated. A

FBG chemical sensor, for example, may include a FBG housing incorporating a chemically-sensitive substrate. In general, any physical mechanism that translates a change in a physical quantity into a change in FBG reflection wavelength may potentially be used as the basis for a FBG sensor. Multiple FBG sensors (e.g., **208'-208""**) may be manufactured on a single optical fiber (e.g., **202**) such that each FBG sensor has a unique reflection wavelength. Such wavelength division multiplexing makes it possible to differentiate between reflection signals from a plurality of FBG sensors **208'-208""** on a single optical fiber **202**. To avoid ambiguity in interpreting FBG reflection signals, it may be desirable to fabricate each FBG to reflect within its own dedicated wavelength band wide enough to accommodate physically-induced reflection wavelength shifts (that encode signal information) as well as the intrinsic non-zero width of the non-shifted reflection distribution. Typically, FBG temperature sensors may be allocated an approximately 1 nm wide range, while FBG strain sensors may be allocated an approximately 5 nm wide range. Wider or narrower ranges may be employed, as appropriate.

FBG sensors **208'-208""** having unique reflection wavelengths may be formed at distinct locations along optical fiber **202**, such that each particular reflected wavelength may then correspond to a specific sensor location along the optical fiber.

In some cases, shifts in reflection wavelength from multiple FBG sensors may be interpreted in combination to arrive at a physical measurement. For example, a temperature reading from a FBG temperature sensor may be used to calibrate a pressure reading from a FBG pressure sensor, which by itself may be sensitive to both temperature and pressure changes. In the present disclosure, a FBG sensor may incorporate one or more fiber Bragg gratings to achieve measurement of a physical quantity.

A device such as optical read-out mechanism **204** (and **12** of FIG. **1**) may be employed to measure the wavelength reflected by a FBG sensor **208** of optical fiber **202**. Optical read-out mechanism **204** may include any suitable light source **210** which may transmit light into the optical fiber **202** via an optical coupler **212**. While optical coupler **212** is illustrated schematically to suggest a partially-reflective mirror or beam-splitter, any suitable optical coupler may be used. Light propagates down the optical fiber **202** and is selectively reflected by one or more fiber Bragg gratings at their specific reflection wavelengths. The specific reflection wavelengths may encode information about conditions at the FBG sensor **208**, such as temperature, pressure, etc. Reflected light returns up the optical fiber **202** back to the optical read-out mechanism **204**, where optical coupler **212** may direct the reflected light to detector **214**. Detection of light reflected by FBG sensors **208**, including determination of reflection wavelengths, may then be interpreted by other components (not shown) of the optical read-out mechanism **204** (or external to the optical read-out mechanism) in order to arrive at the desired quantities measured by the FBG sensors **208**.

A number of different light source **210**/detector **214** combinations may be employed in an optical read-out mechanism **204**. In one illustrative embodiment, a broadband continuous light source may be used in conjunction with a dispersive element that distributes various wavelength components of the reflected light to different locations on a detector array. In another illustrative embodiment, a tunable laser is swept over a range of wavelengths, and a photodetector measures the intensities of reflected light corresponding to the wavelengths provided by the laser at given sweep times. Other light source and detector combinations are contemplated, and any suitable combination of light source **210** and detector **214** may be employed in optical read-out mechanism **204**. Some current technologies may be able to resolve reflected wavelength shifts on the order of a single picometer, which may translate to temperature measurement resolution on the order of 0.1 degree Celsius. In some cases, temperature measurement resolutions on the order of 0.03 degree Celsius may be achievable.

Optical fiber-based sensor systems of the present disclosure may be deployed in vivo in any suitable manner, and may be highly compatible with minimally-invasive techniques. FIG. **3** is a schematic illustration of elements of an optical fiber-based sensor system deployed in a vessel **302**. Elements of the system of FIG. **3** may be similar to or the same as corresponding elements of FIGS. **1** and **2**. In the illustrative embodiment of FIG. **3**, component **304** is an optical fiber integrated with a support structure. In some other illustrative embodiments, an optical fiber may be attached to, but not necessarily be integrated with, a support structure.

Support structure with integrated optical fiber **304** may be configured to compact for delivery into the vessel **302**, and expand for deployment in the vessel. The system may include any suitable components to facilitate delivery of optical fiber/support structure **304** to a target location in vessel **302** and deployment at the target location. Such delivery/deployment components may include (but are not necessarily limited to) a delivery catheter **308**, which may be advanced from an entry site to the target location, and a sheath **310**, which may surround structure **304** and maintain it in a compact configuration during delivery, then be withdrawn to allow expansion and fixation of the support structure and optical fiber. Structure **304** may be self-expanding or may be expanded through the use of a balloon, pull wire or the like.

Any suitable material may be used for the support structure. In some illustrative embodiments, the support structure may be fabricated from non-conducting polymers.

Optical fiber/support structure **304** may be deployed along an extent of vessel **302** in a helical path. In the illustrative embodiment of FIG. **3**, the support structure has a helical shape, and the optical fiber is attached to the support structure and follows the helical shape of the support structure. In some other illustrative embodiments, the support structure may not have a helical shape, but the optical fiber may be attached to the support structure and itself follow a helical path. The support structure may substantially fix the optical fiber within vessel **302**. FBG sensors **306** may be distributed along a length of the optical fiber of component **304**. The support structure may fix the one or more FBG sensors **306** against the wall of vessel **302** such that at least one, some, or all of the one or more FBG sensors is in effective contact with the vessel wall at its corresponding sensor location. In the context of a FBG temperature sensor, for example, "effective contact" may mean thermal contact. In the context of a FBG pressure sensor, "effective contact" may mean mechanical contact.

At least some of the FBG sensors **306** may be substantially equally-spaced-apart along the optical fiber such that, in combination with the helical path along which the optical fiber is deployed, the plurality of FBG sensors are disposed around the vessel with substantially equal angular displacements between adjacent FBG sensors. The angular displacement between adjacent FBG sensors is schematically illustrated in FIG. **3** as the angle θ. The FBG sensors **306** may be spaced such that θ has a value of about 90, 60, 45, 30, or 120 degrees, or any other suitable value. The helical path followed by the optical fiber/support structure **304** may have any suitable pitch (indicated in FIG. **3** by "p"). In some illustrative embodiments, the pitch may be between about 5 mm to about 15 mm.

The system of FIG. **3** may also include a therapeutic device **312** for performing a therapeutic procedure to or through the wall of vessel **302**. Therapeutic device **312** may be any suitable device. In some illustrative embodiments, therapeutic device **312** is a movable ablation tip, which may be an RF ablation tip. Therapeutic device **312** may be attached to a cable **314**, which may be a conductor like elongate conductor **18** of FIG. **1**. Cable **314** may also serve as a pull wire for applying mechanical force to therapeutic device **312**, by which means the device may be repositioned. Support structure **304** may be configured to guide motion of the therapeutic device **312** on a path adjacent the wall of the vessel **302** along at least part of an extent of the vessel. For example, the support structure **304** of the present disclosure may take the form of a helical "rail" support system for guiding an optical fiber-based sensor system.

FIG. **4** is a schematic cross-sectional view of a system including a support structure **402** with an integrated optical fiber **404**, the features of which may be the same or similar in part or in whole with those of the systems of FIGS. **1** and **3**. Optical fiber **404** includes at least one FBG sensor **406**. FBG sensor **406** generally may displace a larger cross-sectional area than the optical fiber **404** alone. Support structure **402** may integrally house the optical fiber **404** and one or more FBG sensors **406** such that the support structure, optical fiber, and FBG sensors present a substantially constant cross-section along a length of the support structure. A substantially constant cross-section may assist in deploying or otherwise positioning the integrated support structure **402** and optical fiber **404**. The support structure **402** with integrated optical fiber **404** and FBG sensor(s) **406** may have a substantially constant catheter size of about 0.5 mm, 0.8 mm, 1.0 mm, or about 1, 1.5, 2, 2.5, 3, or 4 Fr. FBG sensors maybe about 1, 2, 3, or 4 mm in length along the fiber. Radiopaque markers may be incorporated into the support structure to aid localization of the FBG sensors.

Support structure **402** may include a groove **408**, protrusion, or other structure(s) to facilitate slidable attachment of a therapeutic device **410**, which may have a mating element **412** corresponding to groove **408**. With such features, therapeutic device **410** may be made to slide longitudinally along the support structure, following its path (helical or otherwise). In such a way, the therapeutic device **410** may be positioned in one or more treatment locations. The support structure **402** may be configured such that the position of the therapeutic device **410** is maintained relative to the vessel wall **414** such that the therapeutic device may function effectively, at least at the one or more treatment locations. This may include maintaining mechanical, thermal, or any other type of contact between the therapeutic device **410** and the wall **414**. In some illustrative embodiments, the support structure **402** may be configured such that the therapeutic device **410** is moved out of contact with the wall **414** between treatment locations, and in contact only at treatment locations. In some illustrative embodiments, FBG sensors may be provided proximal (with a specified positional relationship) to some or all treatment locations such that the FBG sensor may provide measurements related to the therapy. In some illustrative embodiments, at least one FBG sensor is provided proximal to each treatment location. In some illustrative embodiments, the therapeutic device **410** is an ablation tip, and the support structure **402** may be configured such that the ablation tip ablates tissue within a specified distance of a FBG temperature sensor. The specified distance may be about 1, 2, or 3 mm. The specified distance may be within an effective ablation radius of the ablation tip, which may be about 3 mm.

Systems and methods for optical fiber-based sensing can provide robust real-time in vivo measurement capabilities for medical procedures. For example, in a system like that of FIGS. **3** and **4**, therapeutic device **312**, **410** may be an RF ablation tip and the FBG sensors **306**/**406** may be temperature sensors. Having a real-time temperature sensor proximal to a treatment location may allow a clinician to verify that ablation energy is being delivered to tissue as intended, for example, by observing that an expected temperature rise is observed. (Similarly, a temperature drop due to cryo-ablation could be observed.) The combination of temperature measurement capability along with knowledge of the locations of the FBG temperature sensors may provide the ability to confirm the position of the ablation tip. In some illustrative embodiments, a system and/or method may use information provided by a FBG sensor for real-time feedback control of a therapeutic procedure. For example, in an RF ablation procedure performed with the apparatus of FIG. **1**, a temperature measurement from a FBG temperature sensor may be used as a feedback signal for ablation controller **20**, which may modulate the electrical energy delivered to the ablation tip via conductor **18**. The energy could, for example, be increased such that it is sufficient to heat tissue to at least a minimum effective temperature for ablation, but also limited such that it does not overheat tissue. A typical ablation temperature may be, for example, about 60 degrees Celsius. Temperature resolutions achievable by FBG temperature sensor system may depend on various factors, such as the type of optical read-out mechanism used. In some instances, resolutions of 0.1 degrees Celsius may be measured. Lower resolutions, such as 0.5 or 1 degree Celsius, may be obtainable with less costly equipment, and may be sufficient for therapeutic monitoring.

In some illustrative embodiments, an optical fiber-based sensing system may include more than one type of FBG sensor on a single optical fiber. For example, a single optical fiber may include both FBG temperature sensors and FBG pressure sensors. In a renal nerve ablation procedure or another procedure in which lowering blood pressure is a desired outcome, a FBG pressure sensor could allow a real-time, local blood pressure measurement to be made immediately before, during, and after a procedure. The typical responsiveness of blood pressure to the nerve ablation therapy may not be known, but such a pressure sensor could permit the response to be characterized in the actual patient undergoing treatment. In some illustrative embodiments, leaving an optical fiber with FBG sensors in situ following an ablation procedure is contemplated (perhaps particularly feasible in cases where the fiber and support structure are independent of ablation hardware), making longer term monitoring of blood pressure at a particular vascular location practicable. With an optical fiber left in situ, it is contemplated that ablation hardware may be reintroduced into the vessel at a later time for a follow-up procedure. If the optical fiber is fixed in the original position, then it may be possible to obtain precise knowledge various old and new therapy locations via the fixed FBG sensors.

Fiber optic-based sensor systems may be fabricated without the use of metals or other conductors. Accordingly, they may be compatible with magnetic resonance imaging and other medical procedures for which the presence of conductors may present issues. Their dependence on optics for their operation can eliminate electromagnetic interference (at non-optical frequencies) as a potential problem.

Other configurations for optical fiber-based sensor systems are contemplated. FIG. **5** is a schematic illustration of a distal end of a renal nerve ablation system with ablation electrodes **502** that, when deployed, are maintained in positions spaced-apart from the vessel wall (not shown). In the embodiment of FIG. **5**, an optical fiber **504** is attached to and wraps around the device such that FBG temperature sensors **506** are placed where, upon deployment, they may be disposed in thermal contact with a vessel wall between the wall and each ablation electrode **502** so that they may be used to monitor temperatures during an ablation procedure.

FIG. **6** is a flowchart of an exemplary optical fiber-based temperature measuring method **600**, such as may be performed with devices of the present disclosure. At **610**, an optical fiber with FBG temperature sensors is deployed in a vessel. At **620**, temperatures detected by FBG temperature sensors are read out over the optical fiber. Optionally, at **630**, tissue is ablated proximal to one or more FBG temperature sensors. In some other illustrative embodiments, other therapeutic actions may be performed. Optionally at **640**, the ablation equipment is controlled with feedback (e.g, measured temperatures) from the FBG temperature sensors. In some other illustrative embodiments, other therapeutic actions may be controlled with feedback from FBG sensors, which may be sensors other than temperature sensors.

Those skilled in the art will recognize that the present disclosure may be manifested in a variety of forms other than the specific embodiments described and contemplated herein. Accordingly, departure in form and detail may be made without departing from the scope and spirit of the present disclosure as described in the appended claims.

What is claimed is:

1. A system for providing therapy at and for monitoring a plurality of temperatures at a vessel wall of a vessel of a patient, the system comprising:

an optical fiber designed to be deployed along an extent of the vessel, the fiber including a plurality of fiber Bragg grating (FBG) temperature sensors disposed at a plurality of corresponding sensor locations along a length of the optical fiber;

an optical read-out mechanism optically coupled to the optical fiber, the optical readout mechanism configured to transmit light into the optical fiber and detect light reflected from the plurality of FBG temperature sensors, the detected light reflected from the plurality of FBG temperature sensors encoding local temperatures at each of the plurality of corresponding sensor locations;

a therapeutic device capable of performing a therapeutic procedure to or through the vessel wall, the therapeutic device including a plurality of electrodes, wherein each electrode is positioned at a sensor location adjacent an FBG temperature sensor;

a support designed to be deployed within the vessel that is capable of substantially fixing the optical fiber within the vessel; and

wherein the optical fiber is attached to the support such that each of the plurality of FBG temperature sensors is positioned radially over one of the plurality of electrodes.

2. The system of claim **1**, wherein the support is configured to compact for delivery into the vessel, and expand for deployment in the vessel.

3. The system of claim **1**, wherein the support is capable of fixing the plurality of FBG temperature sensors against the vessel wall such that each of the plurality of FBG temperature sensors is in thermal contact with the vessel wall at its corresponding sensor location.

4. The system of claim **1**, wherein the support has a helical shape, and the optical fiber follows the helical shape of the support.

5. The system of claim **4**, wherein the optical fiber and plurality of FBG temperature sensors are integrally housed by the support such that the support, optical fiber, and plurality of FBG temperature sensors present a substantially constant cross-section along a length of the support.

6. The system of claim **1**, wherein the optical fiber has a helical region and is designed to be deployed along the extent of the vessel in a helical path.

7. The system of claim **6**, wherein the plurality of FBG temperature sensors are substantially equally-spaced-apart along the optical fiber such that, in combination with the helical path along which the optical fiber is deployed, the plurality of FBG temperature sensors are capable of being disposed around the vessel with substantially equal angular displacements between adjacent FBG temperature sensors.

8. The system of claim **7**, wherein the substantially equal angular displacements between adjacent FBG temperature sensors are about 90 degrees.

9. The system of claim **7**, wherein the substantially equal angular displacements between adjacent FBG temperature sensors are about 60 degrees.

10. The system of claim **6**, wherein the pitch of the helical region is between about 5 mm to about 15 mm.

11. The system of claim **1**, wherein the optical fiber includes at least one FBG sensor other than the plurality of FBG temperature sensors.

12. The system of claim **1**, wherein the electrodes are spaced apart circumferentially around the therapeutic device and wherein the optical fiber is a single element with a helical shape extending around the therapeutic device.

13. A method for monitoring a plurality of temperatures at a vessel wall of a vessel of a patient with an optical fiber having a plurality of fiber Bragg grating (FBG) temperature sensors, the method comprising:

deploying the optical fiber along an extent of the vessel such that the optical fiber is disposed against the vessel wall with the plurality of FBG temperature sensors in thermal contact with the vessel wall;

wherein a helical support is attached to the optical fiber that maintains the position of the optical fiber in the vessel and positions the FBG temperature sensors against the vessel wall and wherein deploying the optical fiber along an extent of the vessel such that the optical fiber is disposed against the vessel wall with the plurality of FBG temperature sensors in thermal contact with the vessel wall includes deploying the optical fiber along with the integrated helical support;

reading-out temperatures detected by the plurality of FBG temperature sensors with an optical read-out mechanism configured to transmit light into the optical fiber and detect light reflected from the plurality of FBG temperature sensors; and

performing a therapeutic procedure with a therapeutic device disposed within the vessel proximal to at least one of the plurality of FBG temperature sensors, wherein performing the therapeutic procedure includes ablating tissue with a plurality of electrodes, wherein each of the plurality of FBG temperature sensors is positioned directly between one of the plurality of electrodes and the vessel wall.

* * * * *

专利名称(译)	血管内温度监测系统和方法		
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[标]申请(专利权)人(译)	波士顿科学西美德公司		
申请(专利权)人(译)	BOSTON SCIENTIFIC SCIMED，INC.		
当前申请(专利权)人(译)	BOSTON SCIENTIFIC SCIMED，INC.		
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IPC分类号	A61B5/01 A61B5/02 A61B18/14 A61B18/00 A61B5/00		
CPC分类号	A61B5/01 A61B5/02007 A61B18/1492 A61B5/6857 A61B5/4836 A61B2018/00434 A61B2018/00196 A61B2018/00214 A61B2018/00404 A61B2018/00511 A61B2018/00577 A61B2018/00642 A61B2018/00702 A61B2018/00797 A61B5/0036		
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摘要(译)

一种用于监测患者血管壁处的一个或多个温度的系统包括光纤，光学读出机构和治疗装置。光纤可以沿着容器的范围展开，并且可以包括沿着光纤的长度设置在一个或多个相应的传感器位置处的一个或多个光纤布拉格光栅（FBG）温度传感器。光学读出机构可以光学耦合到光纤，并且它可以配置成将光传输到光纤中并检测从一个或多个FBG温度传感器反射的光。从一个或多个FBG温度传感器反射的检测到的光可以编码一个或多个相应传感器位置中的每一个处的局部温度。治疗装置可以配置用于对血管壁执行治疗程序或通过血管壁执行治疗程序。