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(54) COMPOSITE COILED TUBING WITH EMBEDDED FIBER OPTIC SENSORS

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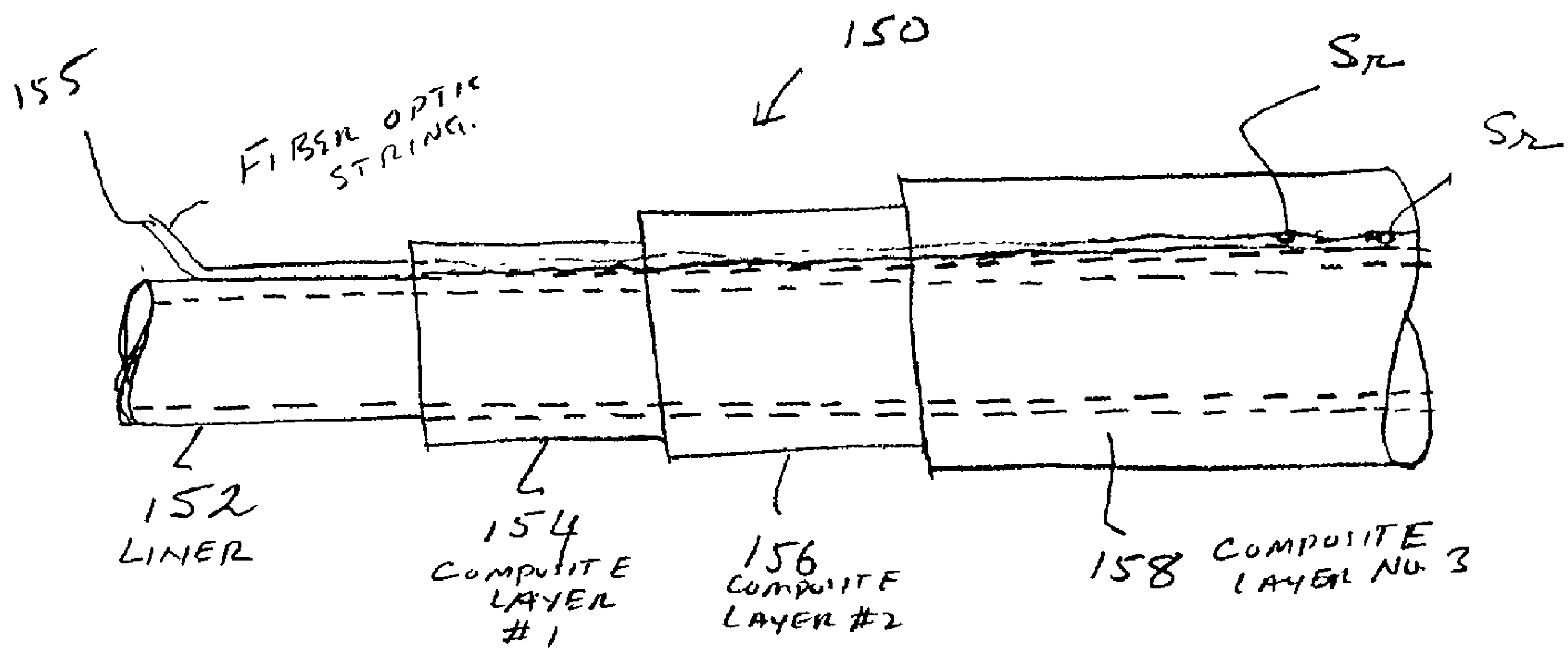
(57) **ABSTRACT**

The present invention provides spoolable continuous composite coiled tubings made from substantially nonmetallic materials for use in wellbores. The composite coiled tubing has a selected thickness and a through passage. The composite coiled tubing preferably includes a plurality of layers of composite materials. A fiber optic string is disposed in the composite coiled tubing, preferably during the manufacture of the composite tubing. A plurality of spaced apart sensor elements on the fiber optic string provide measurements of one or more downhole parameters of interest during the wellbore operations. The fiber optic string may be embedded or placed along the composite coiled tubing. A liner may be disposed inside the composite coiled tubing to isolate the inner surface of the coiled tubing and the fiber optic string from the drilling or the wellbore fluid passing through the coiled tubing.



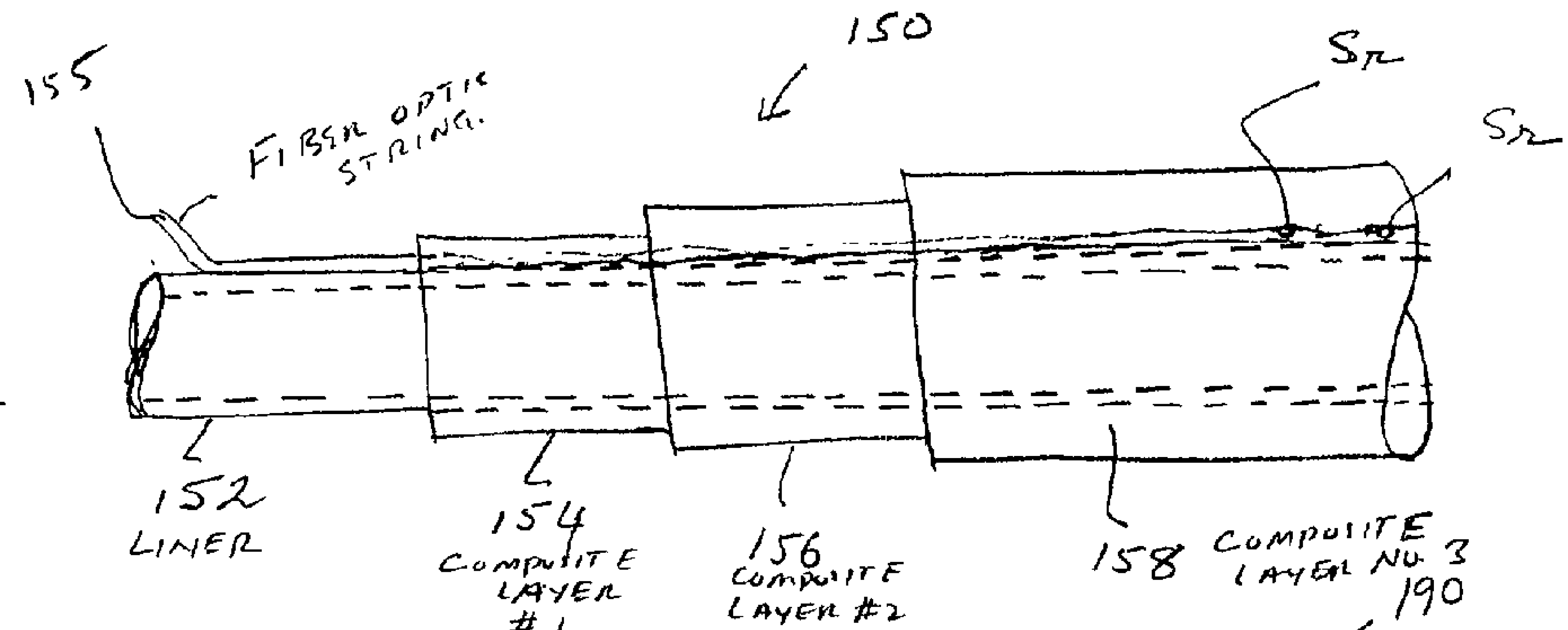


FIGURE 1

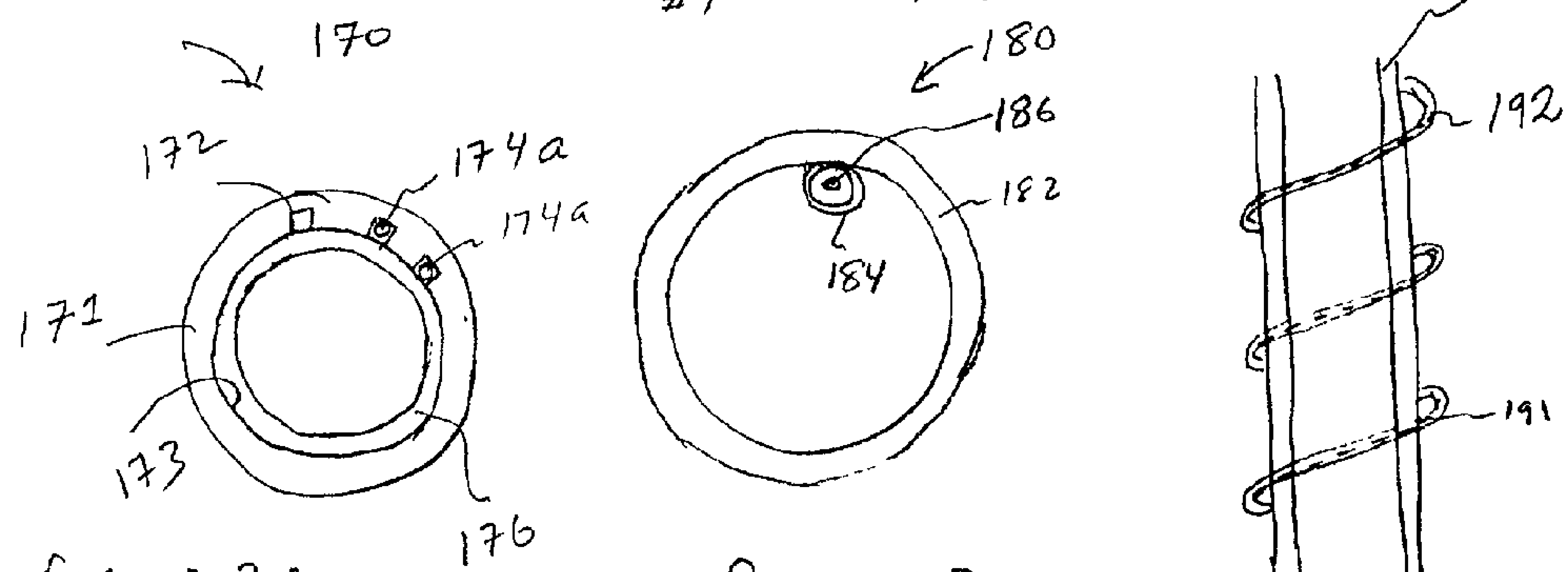


FIGURE 2A FIGURE 2B FIGURE 2C

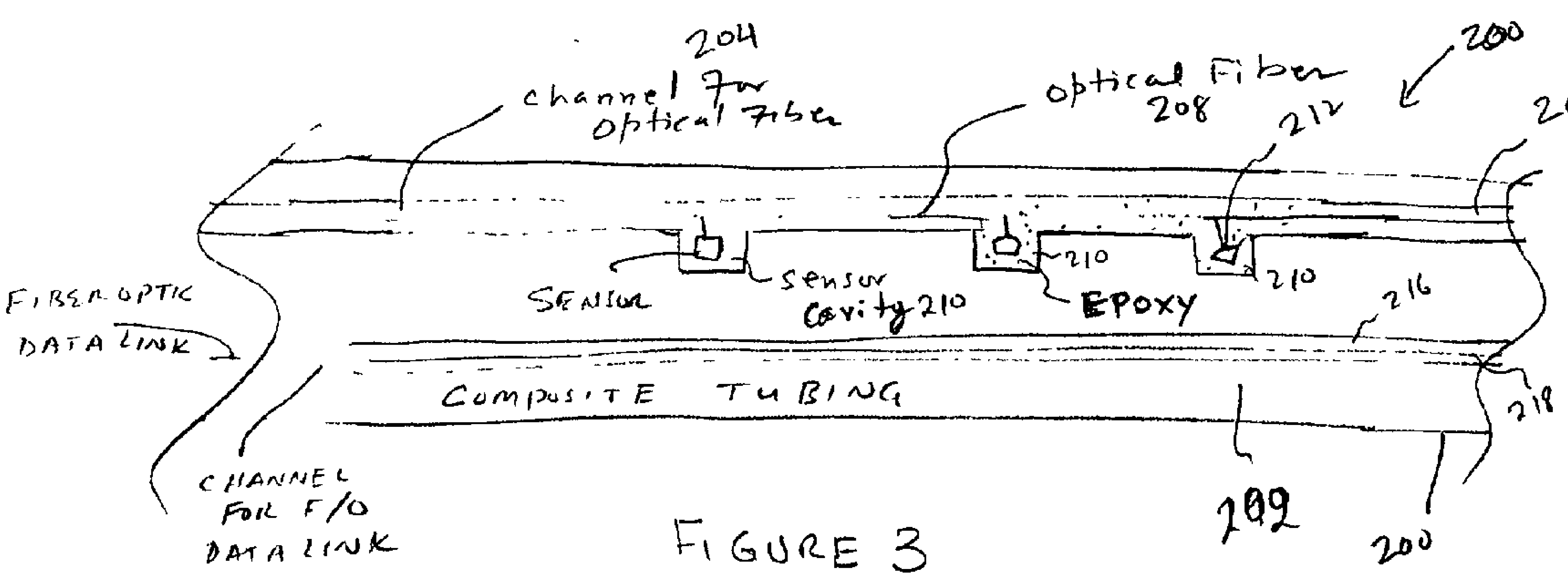


FIGURE 3

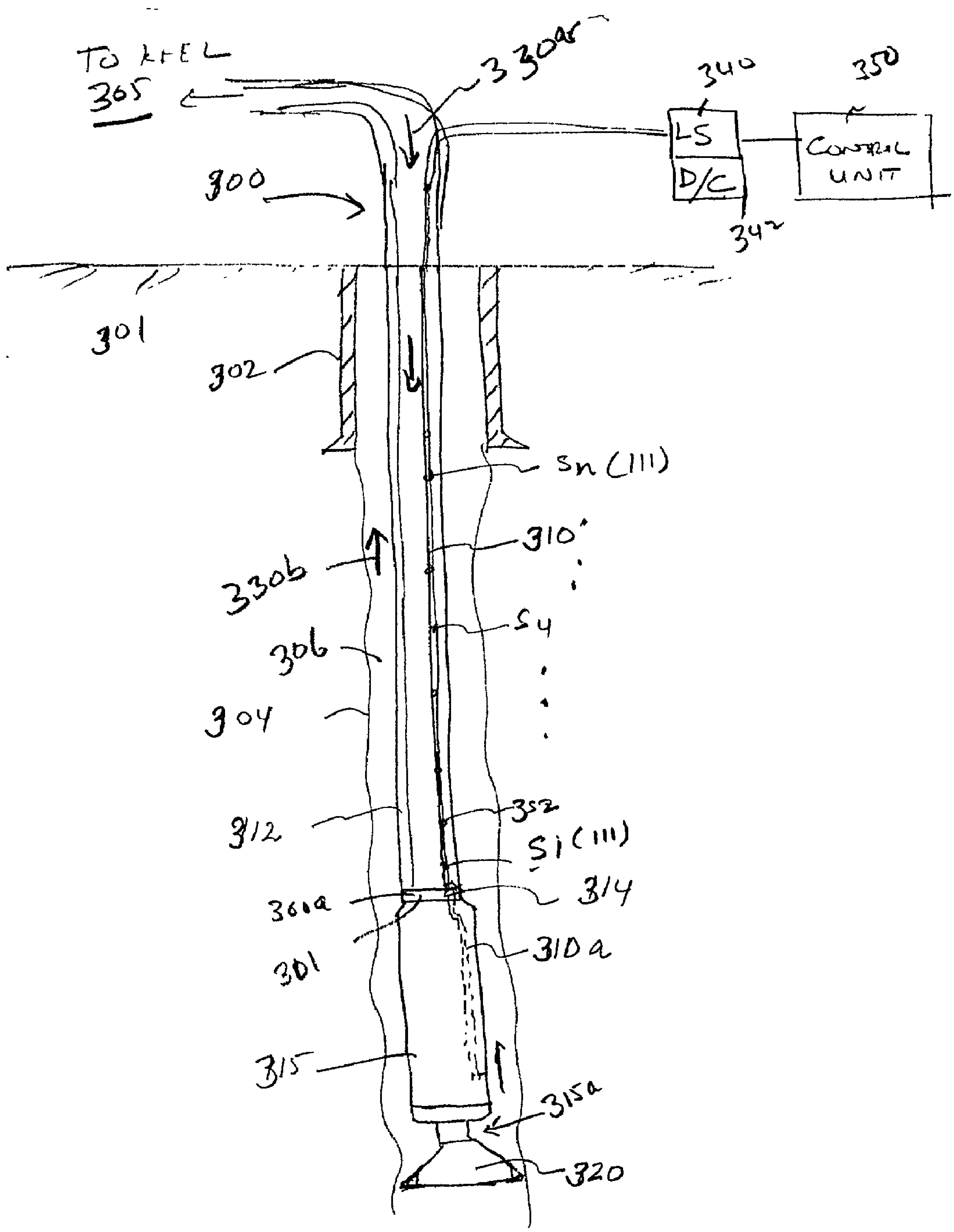

TO REEL
305
330a
340
350
LS
D/C
CONTROL UNIT
342
300
301
302
Sn (111)
310'
330b
S4
306
304
312
352
S1 (111)
314
301a
301
310a
315
315a
320

FIGURE 4

COMPOSITE COILED TUBING WITH EMBEDDED FIBER OPTIC SENSORS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Application Ser. No. 60/196,277 filed on Apr. 6, 2000.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to composite spoolable coiled tubing for use in oilwells and more particularly to composite coiled tubings including one or more fiber optic strings and fiber optic sensors.

[0004] 2. Background of the Art

[0005] Coiled or spoolable metal tubings are commonly used in various oilwell operations, which include drilling of wellbores, work over, completion and production operations. A coiled tubing is defined as a continuous tubing that is spooled on a reel and forms the conveying device for one or more downhole tools. An injector is used to run the tubing into and out of the wellbore. For drilling, a bottomhole assembly carrying a drill bit at its bottom (downhole) end is attached to the coiled tubing's bottom end. The coiled tubing is hollow or has a through passage which acts as a conduit for the drilling fluid to be supplied under pressure from the surface. For completion and workover operations, the coiled tubing is used to convey one or more devices into and/or out of the wellbore. Metal tubings are usually used as coiled tubings. Such tubings tend to wear out over repeated use due to fatigue and are relatively heavy. Composite coiled tubings, which are lighter than the metal tubing, have been proposed as alternatives. Composite tubings also tend to possess high strength and have high stiffness, which are desirable properties for coiled tubings.

[0006] Composite coiled tubings are often made with layers of different types of composite materials, such as graphite fibers, aramid fibers, fiberglass, etc. Such manufacturing processes also offer opportunities to include fiber optic data links and sensors in the composite tubings during the manufacturing process. Composite tubings also are relatively easy to machine, which allows making channels and/or cavities in the finished coiled tubing to have fiber optic strings. Fiber optics can be used both as data/signal transmission links and as sensor elements for downhole parameters, such as temperature, pressure and fluid flow rates. Large amounts of data may be transmitted over the optical fibers. The optical fibers can withstand very high temperatures and are less susceptible to the corrosive effects of wellbore fluids.

[0007] The present invention provides composite coiled tubings which include fiber optic data lines and fiber optic sensors disposed, spaced apart, along the composite coiled tubing, and also provides methods for making such composite coiled tubings.

SUMMARY OF THE INVENTION

[0008] The present invention provides spoolable or coiled tubings made from substantially nonmetallic materials for use in wellbore operations. The tubing is continuous and of sufficient length to reach a desired depth in the wellbore. The composite coiled tubing has a selected thickness and a through passage. The composite coiled tubing preferably includes a plurality of layers of composite materials, which may include, among other things, graphite, aramid fiber, and fiberglass. A fiber optic string is disposed in the composite coiled tubing, preferably during the manufacture of the composite tubing. A plurality of spaced apart sensor elements on the fiber optic string provide measurements of one or more downhole parameters of interest during the wellbore operations. Such sensors may include temperature, pressure, vibration and fluid flow sensors.

[0009] The fiber optic string may be disposed inside a tubing, which may be made from a suitable metal or a composite material. This tubing may then be affixed to the inside wall of the composite coiled tubing or embedded into a channel in the composite coiled tubing. This tubing may also be helically or otherwise wrapped around the composite coiled tubing. The fiber optic string may be embedded or placed along the composite coiled tubing. The tubing may be hermetically sealed to protect the optical fibers. Any channel made to accommodate the fiber optic string may be filled with a suitable epoxy. A liner may be disposed inside the composite coiled tubing to isolate the inner surface of the coiled tubing and the fiber optic string from the drilling or the wellbore fluid passing through the coiled tubing. The liner may be made from any suitable material including a suitable metal, polyurethane, nylon or fluoropolymer. The fiber optic string may be included in the composite coiled tubing during the manufacturing process of the composite tubing or it may be pumped into the metallic tubing after the manufacture of the composite tubing. Additional fiber optic strings may be disposed in the composite coiled tubing to serve as additional data communication links and/or to provide redundancy.

[0010] Examples of the more important features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For detailed understanding of the present invention, reference should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, and wherein:

[0012] **FIG. 1** is a schematic illustration of a composite coiled tubing with inner liner and a fiber optic string according to one embodiment of the present invention.

[0013] **FIGS.** 2*a*-2*c* show various embodiments of deploying fiber optic strings in a composite coiled tubing.

[0014] **FIG. 3** is a schematic illustration of a composite coiled tubing with fiber optic strings disposed on channels along the outside of the composite coiled tubing according to one embodiment of the present invention.

[0015] **FIG. 4** is a schematic illustration of a bottomhole assembly conveyed into a wellbore by a coiled tubing made according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] **FIG. 1** shows a schematic of an embodiment of a composite coiled tubing **150** made according to the present invention. The composite coiled tubing **150** preferably includes an inner liner **152** which is a hollow continuous tubular member. In the finished coiled tubing, as described below, the drilling fluid will flow through the liner **152** under pressure and the liner **152** will come in contact with the wellbore fluid that contains corrosive materials. Accordingly, the liner **152** is made from a material that can withstand the harsh environment in the wellbore and the various chemicals in the wellbore fluid. The liner **152** may be made from a suitable plastic material, such as polyurethane, nylon, or fluoropolymer. The liner **152** may also be made from a suitable metal, such as stainless steel.

[0017] In one embodiment, one or more optical fiber strings, such as string **155**, may be axially disposed along the outer surface of the liner **152**. A first layer **154** of a first composite material is then suitably placed around the liner **152**. The composite material utilized may include graphite, aramid fibers, fiberglass, or any other suitable material. Such materials are known and are commercially available from a variety of sources. A second layer **156** and a third layer **158** may be successively placed over the first layer **154**. A number of methods have been proposed for orientation and thickness of different types of composite materials. Suitable resins are used within and between the layers. For example, U.S. Pat. No. 5,419,916 describes one method of constructing a layered composite coiled tubing. U.S. patent application Ser. No. 09/080,413 assigned to the assignee of this application, describes another method of constructing a layered composite tubular. U.S. patent application Ser. No. 09/080,413 is incorporated herein by reference. For the purpose of this invention, any composite coiled tubing may be utilized, whether or not layered.

[0018] Still referring to **FIG. 1**, the fiber optic string or line **155** preferably includes optical fibers **157** extending the length of the string **155** and a plurality of sensor elements **159**, spaced apart along at least a selected section or segment of the composite coiled tubing **150**. The optical fiber **157** itself may be utilized as the sensor element. Such optical fiber sensors can be used to measure temperature, pressure, vibration and fluid flow.

[0019] In an alternative embodiment, as shown in **FIG.** 2A, the composite coiled tubing **170** may be made as desired with one or more channels **172** axially along the inside wall **173** of the coiled tubing. The channels **172** are made of sufficient size to accommodate the optical fibers **174***a,* which may include spaced apart or distributed sensors along its length. The channels **172** may be formed during the manufacturing process of the coiled tubing **170**. The channels **172** may be filled with a suitable epoxy. A liner **176** may be disposed in the coiled tubing **170** to isolate the optical fibers **174***a* from the borehole fluid.

[0020] In an alternative method as shown in **FIG.** 2B, the optical fiber string **186** may be disposed in a tubing **184**, which is placed inside the composite coiled tubing **182**. The tubing **184** may be integrated to the coiled tubing **182** during the manufacturing process. The optical fibers **186** can be pressure inserted, or pumped, into the tubing **184** after the assembly of the coiled tubing **182**. The tubing **184** may have a corrugated outer surface. The tubing **184** may be hermetically sealed to provide protection to the optical fiber from the downhole environment.

[0021] In yet another method, the optical fiber **191** disposed inside along the length of a tubing **192** may be helically wrapped around the composite coiled tubing **190**, as shown in **FIG. 2C** or it may be strapped axially (not shown) on the coiled tubing **190** outside. The optical fiber **191** may be loosely disposed in the tubing **192** so that stretching of the tubing **192** or the coiled tubing **190** will not cause the optical fiber to break or deteriorate its performance. The tubing **192** may have a corrugated outer surface. The tubing **192** may be hermetically sealed to provide protection to the optical fiber from the downhole environment.

[0022] **FIG. 3** shows an embodiment of a composite coiled tubing **200** wherein fiber optical strings are disposed in channels made axially along the outside **202** of the coiled tubing. A channel **204** of sufficient dimensions is made axially on the outside wall **202** of the composite tubing **200**. One or more fiber optical strings **208** are disposed in the channel **204**. Cavities **210** may be formed in the composite tubing **200** to house various types of sensors. Channel **204** and the cavities **210** may be filled with a suitable epoxy to protect the fiber optic string and the sensors **212** from the outside environment. Additional channels, such as channel **216**, may be formed to house optical fibers, such as **218**, which may be used as redundant sensor strings or as data links.

[0023] Thus, the composite coiled tubing made according to the present invention includes a suitable composite tubing that is made for use in wellbores and to withstand the downhole environment. One or more fiber optic strings are included in the composite coiled tubing. The sensors may include temperature sensors, pressure sensors, vibration sensors, etc. Same or separate optical fibers may be used as data links to transmit data to the uphole end of the composite coiled tubing.

[0024] **FIG. 4** depicts the use of the composite coiled tubing **300** made according to the present invention in drilling of a wellbore **304**. A bottomhole assembly (BHA) **315** carrying a drill bit **320** at its bottom end **315***a* is attached to the bottom end **300***a* of the composite coiled tubing **300** by a suitable coupling device **301**. The fiber optic string **310***a* may be connected to optical fibers **310** in the bottomhole assembly **315** by an optical coupler **314**. The BHA usually includes a variety of measurement-while-drilling ("MWD") sensors, which typically include electromagnetic sensors for determining resistivity of the formation, acoustic sensors for determining borehole condition and formation acoustic velocity, and nuclear devices for determining the formation porosity. The BHA also includes sensors for determining the BHA direction and orientation. If an MWD sensor is a fiber optic sensor, then the fiber optic string **310** may be couple to such devices to provide light energy and to transmit signals from such sensors to the surface. Alternatively, the MWD sensors may include devices which convert the MWD sensor signals to optical signals, which are then passed on to the optical fiber **310** via a suitable coupler for transmission to the surface. In this case, the optical fibers **310** act as a data link.

[0025] The optical fiber string **310** includes spaced apart sensors S1-Sn **111** which may provide measurements for temperature, pressure, flow and vibration during drilling of the wellbore **304**. A light source **340** provides light energy to the string, and a detector/converter (D/C) **342** converts light signals to electrical signals and vice versa. A control unit **350**, which is preferably a computer, controls the operation of the light source **340** and D/C **342** and processes data received from the sensors **111** and the MWD sensors in the BHA **315**.

[**0026**] During drilling, the composite coiled tubing **300** is conveyed into the wellbore **304** from a reel **305** by a suitable injector (not shown). Drilling fluid **330***a* is supplied under pressure into the tubing **300** which discharges at the drill bit **320** bottom. The fluid **330***b*, carrying drill cuttings, returns to the surface via the annulus **306**. The sensors Si-Sn **111** provide measurements along the wellbore, while data from the MWD sensors in the BHA are transmitted uphole by the fiber optic string **310**.

[**0027**] It should be noted that **FIG. 4** is an example of the manner the composite coiled tubing made according to the present invention may be utilized. The composite coiled tubing **300** may also be utilized as part of a completion string, workover string or a production string.

[**0028**] While the foregoing disclosure is directed to the preferred embodiments of the invention, various modifications will be apparent to those skilled in the art. It is intended that all variations within the scope and spirit of the appended claims be embraced by the foregoing disclosure.

What is claimed is:

1. A spoolable coiled tubing conveyable into and out of a wellbore, comprising:

a substantially nonmetallic continuous tubular member of sufficient length to reach a desired depth in the wellbore, said tubular member having a wall of a selected thickness and a through passage; and

a fiber optic string in the nonmetallic tubular member, said fiber optic string having a plurality of spaced apart sensor elements for providing measurements of one or more downhole parameters of interest.

2. The spoolable coiled tubing of claim 1, wherein the fiber optic string is disposed inside a tubing.

3. The spoolable coiled tubing of claim 2, wherein said tubing is affixed to an inside wall of the nonmetallic tubular member.

4. The spoolable coiled tubing of claim 2, wherein said tubing is disposed around the outside of the nonmetallic tubular member.

5. The spoolable coiled tubing of claim 1, wherein the fiber optic string is disposed in a channel formed along the inside wall of the nonmetallic tubular member.

6. The spoolable coiled tubing of claim 1 further including an inner liner disposed along the inside of the nonmetallic tubular member to isolate the fiber optic sensors from the passage through the nonmetallic tubular member.

7. The spoolable coiled tubing of claim 1, wherein the sensor elements provide measurements selected from a group consisting of (i) temperature, (ii) pressure (iii) vibration, and (iv) fluid flow.

8. The spoolable coiled tubing of claim 2, wherein said tubing has an outside corrugated surface.

9. The spoolable coiled tubing of claim 2, wherein the tubing is hermetically sealed to provide protection to the fiber optic string from the downhole environment.

10. The spoolable coiled tubing of claim 2, wherein the tubing is U-shaped enabling said fiber optic string to return to a common end of said nonmetallic tubular member.

11. The spoolable coiled tubing of claim 2, wherein the fiber optic string is pumped into said tubing after placing the tubing in the nonmetallic tubular member.

12. The spoolable coiled tubing of claim 2, wherein the fiber optic string is embedded into the nonmetallic tubular member during the manufacture of the nonmetallic tubular member.

13. The spoolable coiled tubing of claim 1 further comprising a second fiber optic string in the nonmetallic tubular member for communicating data signals.

14. The spooled coiled tubing of claim 1, wherein the fiber optic string has an end accessible for connection with a source of optical energy.

15. The spoolable coiled tubing of claim 1, wherein the nonmetallic tubular member is made from a composite material.

16. The spoolable coiled tubing of claim 15, wherein the composite material is selected from a group consisting of (i) graphite, (ii) aramid fiber, and (iii) fiberglass.

17. The spoolable coiled tubing of claim 6, wherein the liner is made from a material selected from a group consisting of a (i) metal, (ii) polyurethane, (iii) nylon and (iv) fluoropolymer.

18. The spoolable coiled tubing of claim 1, wherein the nonmetallic tubular member includes a plurality of layers of composite materials.

19. The spoolable coiled tubing of claim 18, wherein the substantially nonmetallic tubing includes a layer of metallic material.

20. A spoolable coiled tubing conveyable into and out of a wellbore, comprising: a substantially nonmetallic continuous tubular member of sufficient length to reach a desired depth of the wellbore, said tubular member having a wall of a certain thickness and a through axial bore; and a fiber optic string disposed in the nonmetallic tubular member in a manner that is one of (i) at least partially inside the wall of the nonmetallic tubular member (ii) inside a tubing that is further disposed at least partially inside the wall of the nonmetallic tubular member (iii) at least partially inside a channel made along the inside wall of the nonmetallic tubular member (iv) helically placed along the outside wall of the nonmetallic tubular member, and (v) disposed in a channel made along the outside of the nonmetallic tubular member.

21. The spoolable coiled tubing of claim 20, wherein the nonmetallic tubular member further comprises: a plurality of overlapping layers of substantially nonmetallic materials bonded together by a suitable resin.

22. The spoolable coiled tubing of claim 21 further comprising a metallic material disposed in the nonmetallic material to provide durability to the nonmetallic material.

23. The spoolable coiled tubing of claim 20, wherein the nonmetallic tubular member includes a plurality of notches, for accommodating sensors for providing selected downhole measurements.

24. The spoolable coiled tubing of claim 23, wherein said sensors are selected from a group consisting of (i) electromagnetic radiation sensor, (ii) an acoustic sensor, and (iii) a nuclear magnetic resonance sensor.

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