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(54) **DISTRIBUTED SENSING SYSTEM EMPLOYING A FILM ADHESIVE**

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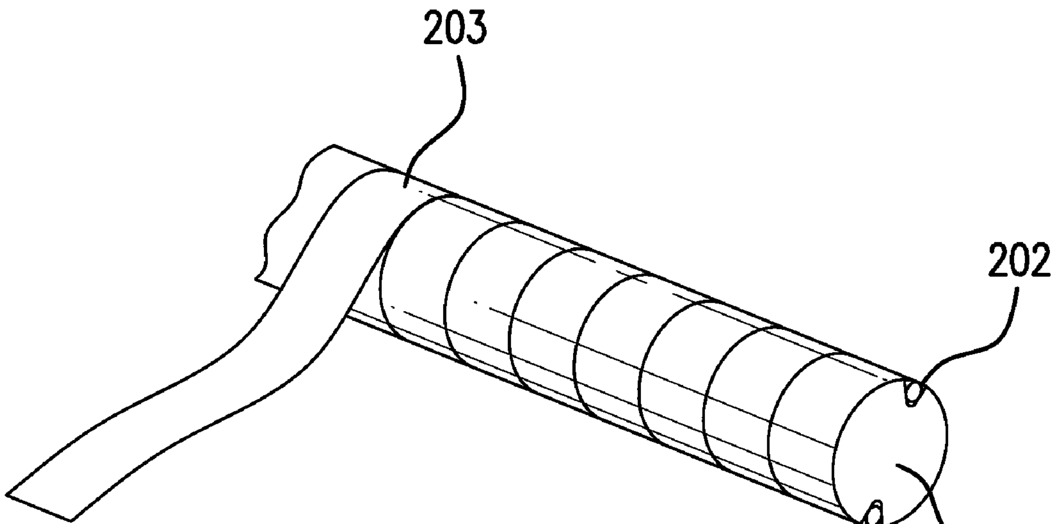
(57) **ABSTRACT**

A distributed sensing apparatus and system including one or more optical fibers disposed in a channel on the surface of a central member. A layer of film adhesive is disposed between the central member and a sheath. The film adhesive is circumferentially wrapped around the central member prior to arranging the sheath around the central member. The film adhesive is then cured and expanded to firmly attach the optical fiber to the sheath.



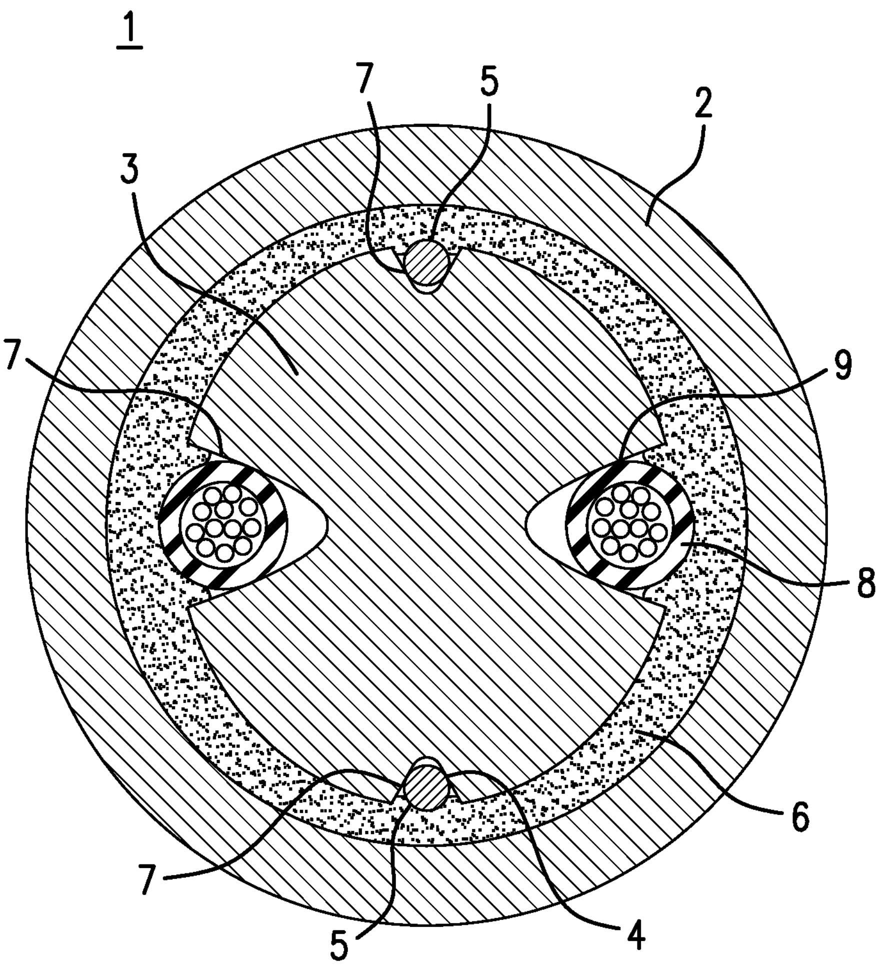


FIG. 1

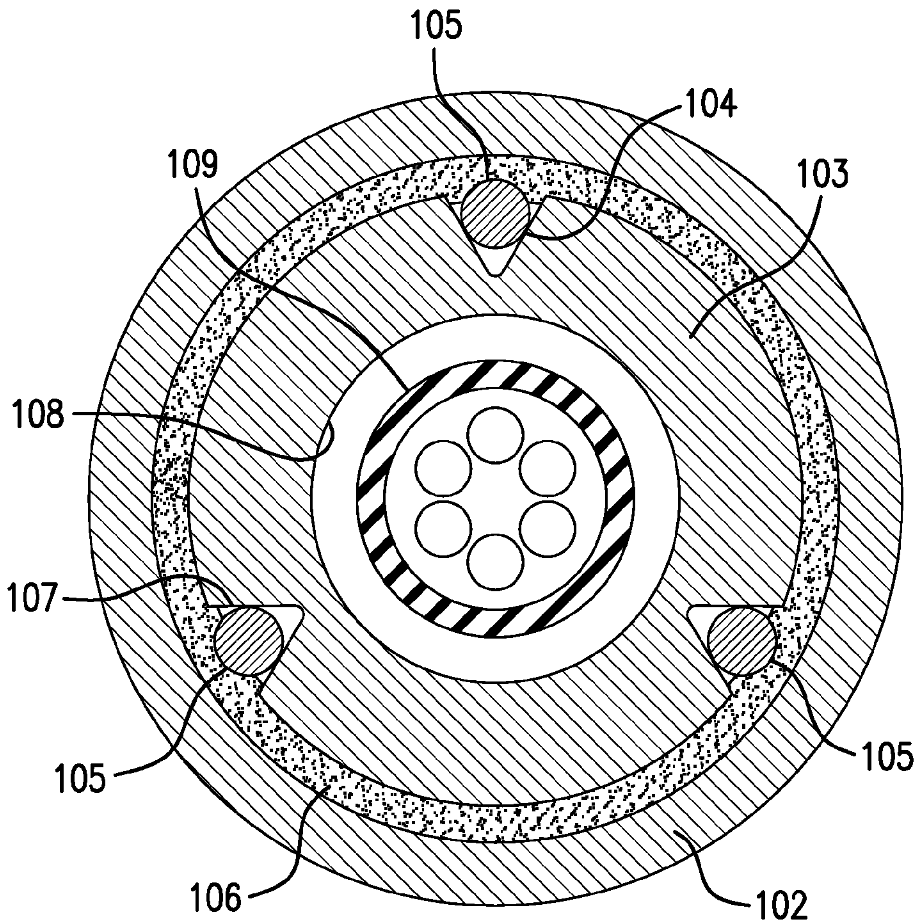


FIG. 2

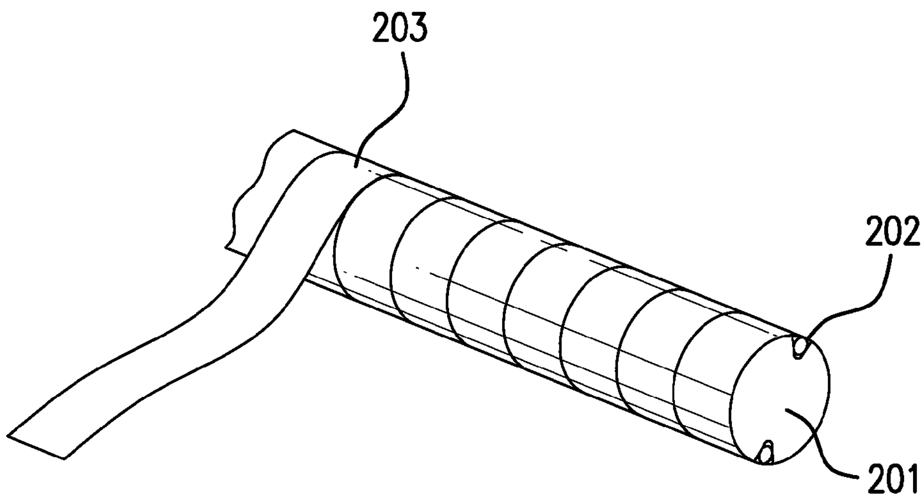


FIG.3A

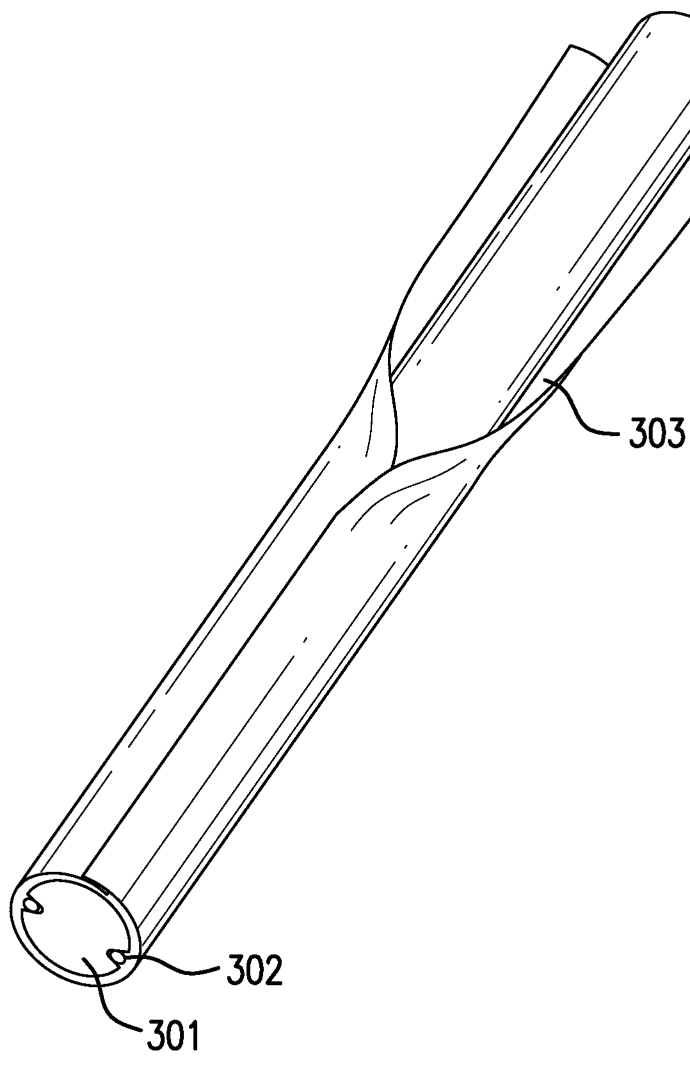


FIG.3B

DISTRIBUTED SENSING SYSTEM EMPLOYING A FILM ADHESIVE

BACKGROUND

[0001] Cables, particularly fiber optic cables, are used ubiquitously in the downhole drilling and completions industry. These cables are used for monitoring a variety of downhole conditions and parameters, such as temperature, vibration, sound, pressure, strain, etc. Due chiefly to their pervasive use, there is an ever-present desire in the industry for alternate configurations of sensing cables, particularly for enhancing the ability to more accurately sense a specific parameter.

SUMMARY

[0002] Disclosed herein is a sensing apparatus including a sheath and a central member disposed in the sheath. The central member has at least one channel formed thereon with an optical fiber disposed in the at least one channel. A film adhesive is disposed between the sheath and the central member.

[0003] Also disclosed herein is a distributed sensing system including a central member and at least one optical fiber disposed in a channel on the central member. An adhesive film is applied to the central member and is disposed between the central member and the sheath.

[0004] Also disclosed herein is a method for preparing distributed sensing system. An optical fiber is disposed in a channel on the periphery of a central member. An adhesive film is then applied onto the central member. The central member and film adhesive are then arranged in a sheath. The sheath is drawn down over the central member.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] FIG. **1** is a cross-sectional view of a sensing apparatus according to one embodiment;

[0007] FIG. **2** is a cross-sectional view of a sensing apparatus according to another embodiment; and

[0008] FIGS. **3**A and **3**B are illustrations depicting an adhesive film being applied to a central member according to additional embodiments.

DETAILED DESCRIPTION

[0009] A detailed description of one or more embodiments of the disclosed apparatus, system and associated method are presented herein by way of exemplification and not limitation with reference to the Figures. It is to be understood that other embodiments may be utilized and changes may be made without departing from the scope of the present disclosure. In particular, the disclosure provides various examples related to a strain-locked sensing system for use in downhole operations, whereas the advantages of the present disclosure as applied in a related field would be apparent to one having ordinary skill in the art and are considered to be within the scope of the present invention.

[0010] Many downhole operations benefit from the use of distributed sensing systems to sense underground parameters such as movement and temperature. These measurements are, in some instances, achieved using optical fibers, typically carried in a metallic sheath. Measuring strain from within the sheath can be challenging, however, because accurate measurements require that any given length of optical fiber is unable to shift or slip relative to the sheath. The attachment of the fiber to the sheath in this manner is sometimes called "strain-locking." In some cases, such as in bend/shape sensing, the fiber must also be located off the central axis of the sheath, which increases the challenge of strain-locking. Furthermore, downhole conditions can reach or exceed 300° C. (572° F.), requiring that the materials selected can withstand such heat and remain . strain-locked.

[0011] The present disclosure provides a sensing apparatus and system that includes at least one optical fiber strain-locked to the sheath. FIG. **1** illustrates a cross-sectional view of a sensing apparatus **1** according to one embodiment of the disclosure. A sheath **2** contains a central member **3**. The central member **3** comprises at least one channel **4**, in which at least one corresponding optical fiber **5** is placed. An adhesive layer **6** is disposed between the sheath **2** and the central member **3**. In the illustrated embodiment, the adhesive layer **6** swells to substantially fill void spaces **7**. The central member **3** may be configured to contain additional elements such as one or more Fiber in Metal Tube (FIMT) cables **8**, as shown in FIG. **1**. This is done, for example, by providing one or more additional channels **9** on the surface of the central member **3**. These elements, such as FIMT cable **8**, can also be strain-locked to the sheath **2** if necessary.

[0012] The sheath **2** of the sensing apparatus **1** is provided to protect the cable from the elements and maintain the assembled arrangement of the components. The sheath **2** may be constructed of any material that is suitable for a particular application, such as a metal, polymer or other material. In the example of a distributed sensing system for use in downhole environments, the sheath **2** comprises a metal, such as steel or aluminum. The metal sheath **2** can be made by rolling a long thin sheet of metal and welding it into a tube about the central member that contains the fiber. The thickness of the sheath **2** will to vary by +/−10%.

[0013] The one or more optical fibers **5** of the present disclosure are strain-locked with the sheath **2**. A radial component of external forces is directly transferred from the sheath **2** to the optical fiber **5**, allowing the radial component of the force to be measured using techniques that are commonly known. This arrangement ensures that the one or more optical fibers **5** will be responsive to forces that act on the sheath **2** and which may not otherwise be transferred to the central member **3**. The one or more optical fibers **5** may comprise one or more fiber bundles, one or more FIMT cables having one or more optical fibers disposed therein, or another arrangement known in the art. For example, one or more optical fibers **5** are presented in a tube that is disposed on the central member **3**. Alternatively, the one or more optical fibers may be embedded inside a hole or groove one or in the central member **3**, such as a small hole drilled in a generally axial direction. In any case, a film adhesive may still be used to bind or couple the tube and/or central member **3**, as the case may be, to the sheath **2**. Where the one or more optical fibers **5** are bound to the tube and/or the central member **3**, the one or more optical fibers **5** may still be strain-locked to the sheath.

[0014] The central member **3** is a structure that provides support to the optical fiber **5** in a chosen configuration, the shape of which may vary. The central member **3** can be formed of a polymer, ceramic, metal or other material and may be matched to the sheath material in terms of thermal expansion. Also, the central member **3** may comprise a plurality of elements that are assembled together to form a structure. The plurality of elements comprising the central member **3** could be bound prior to introduction into the sheath or may be held together using the film adhesive layer **40** or another adhesive layer. In the illustrated example, the central member **3** is a generally cylindrical member that includes one or more channels **4** on the surface of the central member **3** for receiving one or more optical fibers **5** each. In some embodiments, the channels **4** are arranged in a helical shape or are arranged in parallel with an axis of the central member. Alternatively, the one or more optical fibers **5** are disposed on the surface of the central member **3** rather than in a channel **4**. In some embodiments, the channels **4** are sized to support one or more optical fibers **5** such that the one or more optical fibers **5** reside approximately at the radial extent of the central member **3**. As used in this disclosure, the term channel is construed to encompass grooves, flutes, trenches, depressions, indentations, or the like formed in the surface of the central member **3** for receiving one or more optical fibers **5**.

[0015] As stated above, the thickness of the sheath may vary +/−10% based on common manufacturing tolerances. As a result, the sheath **2** may be irregular in shape or have cavities or depressions therein. When assembled with a central member **3**, subject to its own tolerances, the irregularities of the annular space formed there between are compounded. As used herein, the term "void" is intended to encompass all such cavities, depressions, gaps, irregularities, and the like.

[0016] Other embodiments may comprise any number of central member geometries or number of optical fibers. FIG. **2** illustrates one embodiment having a sheath **102** containing a central member **103**. Three channels **104** are formed on an outer surface of the central member **103** with corresponding optical fibers **105** disposed therein. The adhesive layer **106** is disposed between the central member **103** and the sheath **102** and may substantially fill one or more voids **107**. Multiple optical fibers **105** may be provided at equal distances along a circumference of the central member **103**. The central member **103** is hollow, having a bore **108** formed therein. A bundle **109** is contained in the bore **108**, which bundle **109** may comprise a sensing bundle, a FIMT cable, or other device.

[0017] Referring again to FIG. **1**, the adhesive layer **6** attaches the optical fiber **5** and the underlying central member **3** with the sheath **2**. The bond between the adhesive layer **6** and the sheath **2** is required to be very strong in order to withstand variances in strain over short distances. Further, the adhesive must be resilient at high temperatures. In order to fill the annular space between the central member **3** and the sheath **2**, it is possible to use a liquid or gel adhesive during the construction of the cable, then curing the adhesive to form a solid structure. Such techniques are known in the art. However, practical issues arise when using liquid adhesives, including difficulty controlling the liquid to not contaminate the weld, containing the adhesive inside a long length of cable, and challenges metering the right amount of adhesive to fill the necessary voids.

[0018] The adhesive layer **6** of the present disclosure is formed using a film adhesive. Some examples of such film adhesives comprise partially cured films of epoxy or other material. The film adhesive are provided in sheets or in a strip, such as on a roll of tape, or other available forms. The film adhesive may be provided at a selected thickness for an application. Alternatively, or in combination, a thin film adhesive may be provided and disposed between the central member **3** and the sheath **2** in any number of layers to achieve a desired thickness. The film adhesive is provided, for example, with a thickness of about 0.01 inches or less prior to curing. In one example, the film adhesive is provided with a thickness of about 0.006 inches, for use in a sheath having an outer diameter of about 0.25 inches, the sheath having a radial thickness of about 0.035 inches. Thus, the sheath effectively has a chosen internal diameter of about 0.18 inches.

[0019] FIGS. **3**A and **3**B illustrate additional embodiments of a method for forming a sensing apparatus. Referring to FIG. **3**A, a central member **201** is provided with a pair of optical fibers **202** disposed thereon. A film adhesive **203** is wrapped circumferentially around the central member **201**. The film adhesive **203** may be wrapped in such a manner as to provide a selected thickness of an adhesive layer. The selected thickness may be measured in terms of a radial distance from the center of the central member **201**. Alternatively, the film adhesive **203** may be disposed on the sheath material, prior to being rolled and welded to form a tubular structure.

[0020] In FIG. **3**A, the film adhesive is depicted as being applied circumferentially in a helical pattern. In some embodiments, the film adhesive **203** can be wrapped circumferentially in segments, applied longitudinally along the length of the central member **201**. For example, FIG. **3**B illustrates a central member **301** and optical fibers **302** that are wrapped longitudinally by a film adhesive **303**. A longitudinally applied film adhesive **303** may be applied in a sheet, (as shown), or in individual strips. In other embodiments, the film adhesive **203**, **303** may be applied in alternating layers of longitudinally and circumferentially applied films. As may be appreciated, the film adhesive may be disposed in any other arrangement of directions, layers, etc. that results in a consistent and predictable film thickness and such configurations are all within the scope of the present disclosure.

[0021] With the film adhesive **203** in place, the sheath is arranged over the central member **201**. This is done by placing the central member **201** within the tubular sheath. Alternatively, the sheath is formed and welded around the central member **201**.

[0022] In some embodiments, the sheath is formed and welded having a first selected internal diameter. The first selected internal diameter is larger than a second selected internal diameter associated with a finished product. The sheath is then extruded, drawn, or otherwise worked to reduce the sheath from the first selected internal diameter to the second selected internal diameter. This process stretches the sheath by a percentage of its overall length, depending on how the sheath is worked. For example, some processes may stretch the sheath by about 30% or more. Unlike the sheath material discussed above, optical fibers **202** do not stretch. In order to avoid damaging the optical fibers **202**, an appropriate thickness of the adhesive layer can be selected. As discussed above, where a sheath is drawn down to a selected outer diameter and having an expected radial thickness, the sheath is effectively drawn down to a selected internal diameter.

[0023] In one embodiment, the adhesive layer is formed such that the overall thickness of the adhesive layer on top of the central member results in a diameter that is less than the second selected internal diameter of the sheath. In theory, this ensures that the optical fibers **202** will not come into interference with the sheath as it is being stretched. One advantageous feature of some film adhesives **203** is that the film adhesives tend to expand with heat and humidity. As the film adhesive **303** expands during the curing process, it fills any remaining space between the central member **201** and the sheath, and places the optical fiber **202** and central member **201** in a state of compression. This process substantially fills any remaining voids between the sheath and the central member, enhancing the bond between the sheath and the one or more optical fibers **302**.

[0024] The present disclosure provides examples of a system and apparatus, and a method for making such, having many advantages over current technologies in distributed sensing applications. When used in a downhole environment of high temperature and pressure, the film adhesives discussed above are resilient and provide a strong attachment between the optical fiber and the sheath. The present disclosure may also be useful in other related industries where distributed sensing is used.

[0025] While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc., do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

1. A sensing apparatus, comprising:
a sheath;
a central member disposed in the sheath;
at least one optical fiber disposed with the central member; and
a film adhesive disposed between the sheath and the central member.

2. The apparatus of claim **1**, the central member having at least one channel formed thereon, the at least one optical fiber disposed in the at least one channel.

3. The apparatus of claim **2**, comprising a plurality of channels in the central member and a plurality of optical fibers, each of the plurality of optical fibers being arranged in one or more of the plurality of channels.

4. The apparatus of claim **2**, the at least one channel and the at least one optical fiber being arranged in a helical shape.

5. The apparatus of claim **1**, wherein the film adhesive is circumferentially wrapped around the central member.

6. The apparatus of claim **1**, wherein the film adhesive substantially fills a void between the at least one optical fiber and the sheath.

7. The apparatus of claim **6**, wherein the film adhesive expands to fill the void when cured.

8. The apparatus of claim **7**, wherein the expanded film adhesive results in a compressive force on the optical fiber and the central member.

9. A distributed sensing system, comprising:
a central member disposed in a sheath;
at least one optical fiber disposed with the central member; and
an adhesive film disposed between the central member and the sheath, the adhesive film being circumferentially wrapped around the central member.

10. The system of claim **9** deployed in a well.

11. The system of claim **10**, wherein the sheath is coupled to a production tubing or casing.

12. The system of claim **9**, wherein the at least one optical fiber is disposed in a channel on the periphery of the central member.

13. The system of claim **9**, wherein the at least one optical fiber is disposed in a hole through the central member.

14. A method for preparing distributed sensing system, comprising:
disposing at least one optical fiber in or on a central member;
applying a film adhesive onto the central member;
arranging a sheath over the film adhesive and central member; and
drawing down the sheath.

15. The method of claim **14** wherein the at least one optical fiber is disposed in a channel on the periphery of the central member.

16. The method of claim **14** wherein applying the film adhesive onto the central member is performed by circumferentially wrapping the film adhesive around the central member or by applying the film adhesive longitudinally along the central member.

17. The method of claim **14** wherein the sheath is drawn down to a selected internal diameter.

18. The method of claim **16**, wherein a radius of the applied adhesive film is less than the selected internal diameter.

19. The method of claim **14**, further comprising curing the adhesive film.

20. The method of claim **18**, wherein curing the adhesive film causes the adhesive film to expand and substantially fill a plurality of voids between the central member and the sheath.

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