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(54) **Title:** MULTI-LAYERED COATED COLORED OPTICAL FIBERS

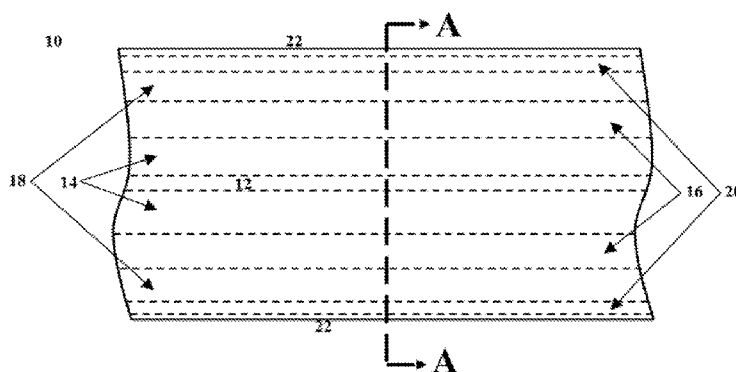


FIG. 1

(57) **Abstract:** Coated colored optical fibers and ribbons incorporating one or more coated colored optical fibers are described and claimed. Such coated colored optical fibers include an optical fiber, a primary coating layer, a secondary coating layer, an ink layer, and a clear shell layer, wherein the clear shell layer possesses a thickness of preferably about 1 micron. Also described and claimed is a method for creating a multi-layered colored coated optical fiber having a primary coating layer, a secondary coating layer, an ink layer, and a clear shell layer with a preferred thickness of about 1 micron.



MULTI-LAYERED COATED COLORED OPTICAL FIBERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of the filing date of United States Provisional Patent Application No. 62/317,131 filed April 1, 2016, the disclosure of which is hereby incorporated herein by reference

TECHNICAL FIELD

[0002] The present invention relates to radiation curable colored compositions for coating an optical fiber, processes for applying such compositions, and the multi-layered colored coated optical fibers produced therefrom.

BACKGROUND

[0003] Optical fibers are frequently coated with two or more superposed radiation-curable coatings immediately after the fiber is produced by drawing. The coating which directly contacts the optical fiber is called the “inner Primary Coating” and an overlaying coating is called the “outer Primary Coating.” In some references, the inner Primary Coating is also called simply the “Primary Coating” and the outer Primary Coating is called a “Secondary Coating.” Inner Primary Coatings are of significantly lower modulus than Secondary Coatings.

[0004] The relatively soft inner Primary Coating provides resistance to microbending which results in added attenuation of the signal transmission of the coated optical fiber and is therefore undesirable. Microbends are microscopic curvatures in the optical fiber involving local axial displacements of a few micrometers and spatial wavelengths of a few millimeters. Microbends can be induced by thermal stresses and/or mechanical lateral forces. Coatings can provide lateral force protection that protect the optical fiber from microbending, but as coating diameter decreases the amount of protection provided decreases. The relationship between coatings and protection from lateral stress that leads to microbending is discussed, for example, in D. Gloge, “Optical-fiber packaging and its influence on fiber straightness and loss”, *Bell System Technical Journal*, Vol. 54, 2, 245 (1975); W. B. Gardner, “Microbending Loss in Optical Fibers”, *Bell System Technical Journal*, Vol. 54, No. 2, p. 457 (1975); T. Yabuta, “Structural Analysis of Jacketed Optical Fibers Under Lateral Pressure”, *J. Lightwave Tech.*, Vol. LT-1, No. 4, p. 529 (1983); L. L. Blyler,

“Polymer Coatings for Optical Fibers”, Chemtech, p. 682 (1987); J. Baldauf, “Relationship of Mechanical Characteristics of Dual Coated Single Mode Optical Fibers and Microbending Loss”, *IEICE Trans. Commun.*, Vol. E76-B, No. 4, 352 (1993); and K. Kobayashi, “Study of Microbending Loss in Thin Coated Fibers and Fiber Ribbons”, IWCS, 386 (1993). The harder outer Primary Coating, that is, the Secondary Coating, provides resistance to handling forces such as those encountered when the coated fiber is ribboned and/or cabled.

[0005] Optical fiber Secondary Coating compositions generally comprise, before cure, a mixture of ethylenically-unsaturated compounds, often consisting of one or more oligomers dissolved or dispersed in liquid ethylenically-unsaturated diluents and photoinitiators. The coating composition is typically applied to the optical fiber in liquid form and then exposed to actinic radiation to effect cure.

[0006] In many of these compositions, use is made of a urethane oligomer having reactive termini and a polymer backbone. Further, the compositions generally comprise reactive diluents, photoinitiators to render the compositions UV-curable, and other suitable additives.

[0007] Reconsideration of all these components and their combination and composition, however, is required if one changes the energy emitting light source that is used to cure them. Indeed, a substantial change in the output profile (wavelength, energy, reflector configuration, etc) of the UV curing source can have a drastic impact on the final properties of the compositions applied to an optical fiber to the point where they may not cure at all.

[0008] The use of ultraviolet mercury arc lamps to emit ultraviolet light suitable to cure radiation curable coatings applied to optical fiber is well known. Ultraviolet arc lamps emit light by using an electric arc to excite mercury that resides inside an inert gas (e.g., Argon) environment to generate ultraviolet light which effectuates curing. Alternatively, microwave energy can also be used to excite mercury lamps in an inert gas medium to generate the ultraviolet light. Throughout this patent application, arc excited and microwave excited mercury lamp, plus various additives (ferrous metal, Gallium, etc.) modified forms of these mercury lamps are identified as mercury lamps.

[0009] However, the use of ultraviolet mercury lamps as a radiation source suffers from several disadvantages including environmental concerns from mercury and the generation of ozone as a by-product. Further, mercury lamps typically have lower energy conversion ratio, require warm-up time, generate heat during operation, and consume a large amount of energy when

compared with light emitting diodes (LEDs). Furthermore, in the production of coated optical fiber, the heat generated by the UV mercury lamps can negatively impact the liquid coating in that if the coating is not formulated to avoid the presence of volatiles, those volatiles may be vaporized and deposit upon the quartz tube surface, thereby blocking the UV rays from irradiating the liquid coating on the glass fiber. This inhibits the curing of the liquid coating to a solid and increases the frequency and associated cost of equipment maintenance. Accordingly, alternative radiation sources are being investigated.

[0010] Light emitting diodes (LEDs) are semiconductor devices which use the phenomenon of electroluminescence to generate light. LEDs consist of a semiconducting material doped with impurities to create a p-n junction capable of emitting light as positive holes join with negative electrons when voltage is applied. The wavelength of emitted light is determined by the materials used in the active region of the semiconductor. Typical materials used in semiconductors of LEDs include, for example, elements from Groups 13 (III) and 15 (V) of the periodic table. These semiconductors are referred to as III-V semiconductors and include, for example, GaAs, GaP, GaAsP, AlGaAs, InGaAsP, AlGaInP, and InGaN semiconductors. Other examples of semiconductors used in LEDs include compounds from Group 14 (IV-IV semiconductor) and Group 12-16 (II-VI). The choice of materials is based on multiple factors including desired wavelength of emission, performance parameters, and cost.

[0011] Early LEDs used gallium arsenide (GaAs) to emit infrared (IR) radiation and low intensity red light. Advances in materials science have led to the development of LEDs capable of emitting light with higher intensity and shorter wavelengths, including other colors of visible light, even those emitting UV light. It is possible to create LEDs that emit light anywhere from a minimum wavelength of about 100 nm to a maximum wavelength of about 900 nm. Currently, known LED UV light sources emit light at wavelengths between about 300 and about 475 nm, with 365 nm, 390 nm and 395 nm, 405nm being common peak spectral outputs. See textbook, "Light-Emitting Diodes" by E. Fred Schubert, 2nd Edition, © E. Fred Schubert 2006, published by Cambridge University Press.

[0012] Several manufacturers offer LED lamps for commercial curing applications. For example, Phoseon Technology, Summit UV, Honle UV America, Inc., 1ST Metz GmbH, Jenton International Ltd., Lumios Solutions Ltd., Solid UV Inc., Seoul Optodevice Co., Ltd, Spectronics Corporation, Luminus Devices Inc., and Clearstone Technologies, Heraeus Noblelight and

Excelitas Technologies are some of the manufacturers currently offering LED lamps most commonly for curing ink-jet printing compositions, PVC floor coating compositions, metal coating compositions, plastic coating composition, and adhesive compositions.

[0013] Over the past few years, UV LED technology has rapidly emerged as a commercial option for UV curing industry. A LED curing system offers substantial benefits over conventional mercury lamps including much lower power consumption, instant on-off capability, longer lamp life, no substrate heating, maintenance free and more environmental sustainability. However, two main drawbacks have limited it to achieve successfully curing performance, such as a typical lower power output from LED lamp than conventional mercury lamps, and the poorer surface cure from LED that traditionally requires the shorter wavelengths of the conventional mercury lamps. Recent evolutionary improvements in these areas have brought us much closer to the expectation of an all LED solution for industrial fiber optical coating curing process. However, even with these higher performance characteristics UV LED lamps do not consistently impart improved cure characteristics into photocurable compositions. UV LED curing systems encounters a primary challenge with the lack of suitable chemistry tailored for the monochromatic wavelengths produced at the longer wavelength UVA region. Existing chemistries of coating materials for optical fiber require reformulation and possibly new raw materials.

[0014] Over the past 40 years, most UV chemistry has been formulated to react with broadband mercury spectrums and relies on the shorter wavelengths for surface cure and the longer wavelengths for through cure. Along with the increased demand of optical fiber and market competition, modern optical fiber manufacturing requires the coating material able to be drawn at even higher drawing speed (up to 2500 m/min, and, in the future, maybe even higher to over 2800m/min or even over 3000m/min).

[0015] Fiber optic coatings are applied using one of two processes: wet-on-wet (WOW) and wet-on-dry (WOD). In the WOD process, the fiber passes first through a primary coating application, which is then UV or UV-LED cured, then passes through a secondary coating application, which is subsequently cured. In the WOW process, the fiber passes through both the primary and secondary coating applications, whereupon the fiber proceeds to UV or UV-LED curing. In a wet-on-wet process, the curing lamps between primary and secondary coating application are omitted.

[0016] For the purpose of multi-channel transmission, ribbon assemblies containing a plurality of coated optical fibers have been used. A typical ribbon assembly comprises a plurality of coated optical glass fibers which are bonded together in a matrix material. For example, the matrix material can encase the optical glass fibers, or the matrix material can edge-bond the optical glass fibers together. Ribbon assemblies provide a modular design which simplifies the construction, installation and maintenance of optical glass fibers by eliminating the need to handle individual optical glass fibers.

[0017] Coated optical glass fibers for use in ribbon assemblies are usually coated with an outer colored layer, called an ink coating, or alternatively a colorant is added to the outer primary coating to facilitate identification of the individual coated optical glass fibers. Thus, the matrix material which binds the coated optical glass fibers together contacts the outer ink layer if present, or the colored outer primary coating.

[0018] Ink coatings usually have a thickness of about 3 to about 10 microns and are formed from a pigment dispersed within a UV curable carrier system. The UV curable carrier system contains a UV curable oligomer or monomer that is liquid before curing to facilitate application of the ink composition to the optical glass fiber, and then a solid after being exposed to UV radiation. In this manner, the UV curable ink composition can be applied to a coated optical glass fiber in the same manner as the inner primary and outer primary coatings are applied.

[0019] As the demand for coated optical glass fibers has increased, manufacturers must respond by adding more fiber drawing production lines and by attempting to increase the linear line speeds of the existing fiber drawing production lines. In the latter case, one factor which will determine the upper limit for the line speed will be the curing rate characteristics of the radiation-curable ink composition, for a given radiation source and intensity.

BRIEF SUMMARY

[0020] A first aspect of the present invention is a coated colored optical fiber comprising: an optical fiber; a primary coating layer in contact with and surrounding said optical fiber; a secondary coating layer in contact with and surrounding said primary coating layer; an ink layer in contact with and surrounding said secondary coating layer; and a clear shell layer in contact with and surrounding said ink layer; wherein the clear shell layer has a thickness of less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.

[0021] A second aspect of the present invention is a coated colored optical fiber comprising: an optical fiber further comprising a glass core; and a cladding layer in contact with and surrounding said glass core; a primary coating layer in contact with and surrounding said optical fiber; a colored secondary coating layer in contact with and surrounding said primary coating layer; and a shell layer in contact with and surrounding said colored secondary layer; wherein the shell layer has a thickness of less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.

[0022] A third aspect of the present invention is an optical fiber ribbon comprising a first coated colored optical fiber according to the first or second aspects of the invention; a second coated colored optical fiber according to the first or second aspects of the invention; and a matrix material encapsulating the first coated colored optical fiber and the second coated colored optical fiber.

[0023] A fourth aspect of the present invention is a method for creating a multi-layered colored coated optical fiber, the method comprising: at least partially un-spooling a spool of coated optical fiber; directing the coated optical fiber through an inking machine; applying an ink composition to the surface of the coated optical fiber; optionally exposing the ink composition to a first radiation source capable of emitting ultraviolet radiation to affect curing of said ink composition and form an ink layer; applying a shell coating composition to the ink composition or ink layer, thereby forming a multi-layered colored coated optical fiber; exposing the multi-layered colored coated optical to a second radiation source capable of emitting ultraviolet radiation to affect curing of at least said shell coating composition and form a shell layer, and optionally also to affect curing of said ink coating composition to form an ink layer; thereby forming a cured multi-layered colored coated optical fiber; wherein the average thickness of the shell coating is less 5 microns, preferably

less than 3 microns thick, most preferably about 1 micron thick; and wherein the shell coating composition is substantially free of an ink.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. 1 schematically depicts a cross section of an optical fiber according to one configuration of a first aspect of the invention as described herein;

[0025] FIG. 2 is a cross-sectional view taken along the line A-A of the optical fiber of FIG. 1;

[0026] FIG. 3 schematically depicts a cross section of an optical fiber according to one configuration of a second aspect of the invention as described herein;

[0027] FIG. 4 is a cross-sectional view taken along the line B-B of the optical fiber of FIG. 3.

DETAILED DESCRIPTION

[0028] A first embodiment of the present invention is a coated colored optical fiber comprising: an optical fiber; a primary coating layer in contact with and surrounding said optical fiber; a secondary coating layer in contact with and surrounding said primary coating layer; an ink layer in contact with and surrounding said secondary coating layer; and a clear shell layer in contact with and surrounding said ink layer; wherein the clear shell layer has a thickness of less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.

[0029] One exemplary configuration according to the first embodiment is depicted in Figures 1 and 2. This configuration is an optical fiber with a four-layered coating. Turning to Figs. 1 and 2, two orthographically-projected views a section of a multi-layered colored coated optical fiber **10** are shown. The coated optical fiber **10** possesses, at its center, an optical fiber consisting of core layer **12** and cladding layer **14**, a primary coating layer **16**, a secondary coating layer **18**, an ink layer **20**, and a clear shell layer **22**.

[0030] In exemplary embodiments shown and described herein, core **12** comprises pure silica glass (SiO₂) or silica glass with one or more dopants that increase the index of refraction of the glass core relative to pure, undoped silica glass. Suitable dopants for increasing the index of refraction of the core include, without limitation, GeO₂, Al₂O₃, P₂O₅, TiO₂, ZrO₂, Nb₂O₅, Ta₂O₅, and/or combinations thereof.

[0031] The cladding layer **14** may comprise pure silica glass (SiO_2), silica glass with one or more dopants which increase the index of refraction (e.g., GeO_2 , Al_2O_3 , P_2O_5 , TiO_2 , ZrO_2 , Nb_2O_5 , Ta_2O_5 and/or combinations thereof), such as when the cladding is “up-doped,” or silica glass with a dopant which decreases the index of refraction, such as fluorine, such as when the inner cladding is “down-doped”, so long as the maximum relative refractive index $[\Delta_{1\text{MAX}}]$ of the core **12** is greater than the maximum relative refractive index $[\Delta_{4\text{MAX}}]$ of the cladding **14**. According to one embodiment, cladding **14** is pure silica glass.

[0032] In direct contact with and surrounding the optical fiber is primary coating layer **16**. The primary coating layer **16** preferably has a higher refractive index than the cladding **14** of the optical fiber, in order to allow it to strip errant optical signals away from the core of optical fiber. For example, an exemplary transmission optical fiber may have refractive index values at a wavelength of 1550 nm for the core and cladding of 1.447 and 1.436, respectively; as such, it is desirable that the refractive index of primary coating layer **16** be greater than 1.44 at 1550 nm. The primary coating layer **16** maintains adequate adhesion to the glass fiber during thermal and hydrolytic aging, yet (if needed) is capable of being strippable therefrom for splicing purposes.

[0033] The primary coating layer **16** is preferably formed from a soft crosslinked polymer material having a low in situ modulus (e.g., less than about 0.35 MPa at 25° C) and a low in situ T_g (e.g., less than about -35° C). The in situ modulus is preferably less than about 0.3 MPa, more preferably less than 0.2 MPa. The in situ T_g is preferably between about -100° C and about -35° C, more preferably between about -100° C and about -40° C, most preferably between about -100° C and about -50° C.

[0034] The primary coating layer **16** preferably has a thickness that is less than about 40 μm , more preferably between about 20 to about 40 μm , most preferably between about 20 to about 30 μm . In another embodiment, the primary coating layer **16** typically has a thickness in the range of 20-50 μm (e.g., about 25 or 32.5 μm), thinner thickness in the range of 15-25 μm for 200 μm fibers. Primary coating layer **16** is typically applied to the glass fiber and subsequently cured, as will be described in more detail herein below. Various additives that enhance one or more properties of the primary coating can also be present, including antioxidants, adhesion promoters, PAG compounds, photosensitizers, carrier surfactants, tackifiers, catalysts, stabilizers, surface agents, and optical brighteners of the types described below.

[0035] The primary coating layer **16** is the cured product of a radiation curable composition containing one or more compositional elements. In a preferred embodiment, the primary coating layer **16** is the cured product of a composition containing, without limitation, (a) a radiation curable oligomer; (b) a reactive diluent monomer; and (c) a primary photoinitiator. In preferred embodiments, the primary coating layer **16** is the cured product of a composition containing, without limitation, about 10 to 90 weight percent, more preferably from about 25 to about 75 weight percent of one or more urethane acrylate oligomers; about 10 to about 65 weight percent, more preferably from about 25 to about 65 weight percent of one or more monofunctional ethylenically unsaturated monomers; about 0 to about 10 weight percent of one or more multifunctional ethylenically unsaturated monomers; and about 1 to about 5 weight percent of one or more photoinitiators. The primary coating layer **16** may optionally be the cured product of a composition additionally containing 0.5 to about 1.5 pph of one or more antioxidants; optionally about 0.5 to about 1.5 pph of one or more adhesion promoters; optionally about 0.1 to about 10 pph PAG compound; and about 0.01 to about 0.5 pph of one or more stabilizers.

[0036] In direct contact with and surrounding the primary coating layer **16** is the secondary coating layer **18**. Secondary coating layer **18** serves at least some of the traditional purposes of an outer primary coating. According to preferred embodiments, the secondary coating layer **18** is, for example, the polymerization product of a radiation curable composition whose molecules become highly crosslinked when polymerized. According to several embodiments described herein secondary coating layer **18** has a high in situ modulus (e.g., greater than about 800 MPa at 25° C) and a high T_g (e.g., greater than about 50° C). The in situ secondary modulus is preferably greater than about 1000 MPa, more preferably greater than about 1100 MPa and most preferably greater than about 1200 MPa. According to some preferred embodiments, the in situ secondary modulus is greater than 1200 MPa. In other preferred embodiments, the in situ secondary modulus is between about 1000 MPa and about 8000 MPa, more preferably between about 1200 MPa and about 5000 MPa, and most preferably between about 1500 MPa and about 3000 MPa. The in situ T_g of the secondary coating is preferably between about 50° C and about 120° C, more preferably between about 50° C and about 100° C. In an embodiment, the secondary coating layer **18** has a thickness that is less than about 40 μm , more preferably between about 20 to about 40 μm , most preferably between about 20 to about 30 μm .

[0037] Other suitable materials for use in forming secondary coating layers, as well as considerations related to selection of these materials, are well known in the art and are described in, for example, U.S. Pat. Nos. 4,962,992 and 5,104,433 to Chapin. As an alternative to these, high modulus coatings have also been obtained using low oligomer content coating systems, as described in U.S. Pat. No. 6,775,451 to Botelho et al., and U.S. Pat. No. 6,689,463 to Chou et al. In addition, non-reactive oligomer components have been used to achieve high modulus coatings, as described in U.S. Application Publ. No. 20070100039 to Schissel et al. Secondary coating layers are typically applied to the previously coated fiber (either with or without prior curing) and subsequently cured. Various additives that enhance one or more properties of the coating can also be present, including antioxidants, PAG compounds, photosensitizers, catalysts, lubricants, low molecular weight non-crosslinking resins, stabilizers, surfactants, surface agents, slip additives, waxes, micronized-polytetrafluoroethylene, etc.

[0038] Like the primary coating layer **16**, the secondary coating layer **18** is the cured product of a radiation curable composition containing one or more compositional elements. In an embodiment, the primary coating layer **18** is the cured product of a composition containing, without limitation, (a) a radiation curable oligomer; (b) a reactive diluent monomer; and (c) a secondary photoinitiator. The photoinitiator (c) may be the same or different as that used in the primary coating layer. In certain embodiments, the secondary coating layer **18** is the cured product of a composition containing, without limitation, about 10 to 90 weight percent, more preferably from about 25 to about 75 weight percent of one or more urethane acrylate oligomers; about 10 to about 65 weight percent, more preferably from about 25 to about 65 weight percent of one or more monofunctional ethylenically unsaturated monomers; about 0 to about 10 weight percent of one or more multifunctional ethylenically unsaturated monomers; and about 1 to about 5 weight percent of one or more photoinitiators.

[0039] Other suitable compositions for forming a secondary coating layer **18** include, without limitation, about 0 to 20 weight percent of one or more urethane acrylate oligomers; about 75 to about 95 weight percent of one or more multifunctional ethylenically unsaturated monomers; about 0 to about 10 weight percent of one or more monofunctional ethylenically unsaturated monomers; about 1 to about 5 weight percent of one or more photoinitiators; about 0 to about 5 pph of one or more slip additives; and about 0.5 to about 1.5 pph of one or more antioxidants. Other customary additives may further be utilized as is known in the art.

[0040] In direct contact with and surrounding the secondary coating layer **18** is the ink layer **20**. The ink layer is the cured product of radiation curable compositions which are primarily designed to impart color into the multi-layered colored cured optical fiber into which they are incorporated, although other ancillary uses for such layers also exist.

[0041] The ink layer **20** is the cured product of any known colored coating compositions for coating and identifying coated optical glass fibers. In general, such radiation-curable ink compositions contain at least one colorant, such as a pigment, dispersed within a radiation-curable carrier system. The radiation-curable carrier system contains monomers, oligomers and an ink layer photoinitiator. Preferably, the ink layer is the cured product of a colored coating composition containing at least the following: a radiation curable monomer or oligomer, a reactive diluent monomer, an ink layer photoinitiator, and a colorant.

[0042] Any radiation curable monomer or oligomer used and described elsewhere herein for use in the primary coating layer **16** or secondary coating layer **18** similarly can be suitable for use in forming the ink layer **20** as well. In a preferred embodiment, the ink layer **20** is cured from a radiation curable composition comprising greater than 20 wt%, relative to the entire weight of the ink layer **20**, of one or more urethane acrylate oligomers. Preferred amounts of the radiation-curable oligomer include from about 10 to about 70% by weight, more preferably, about 20 to about 60% by weight, based on the total weight of the ink layer.

[0043] Similarly, any reactive diluent monomer used and described elsewhere herein for use in the primary coating layer **16** or secondary coating layer **18** similarly can be suitable for use in forming the ink layer **20** as well. In preferred embodiments, amounts of the radiation-curable diluent monomer include from about 10 to about 70% by weight, more preferably, about 20 to about 60% by weight, based on the total weight of the ink layer.

[0044] In likewise fashion, any photoinitiator used and described elsewhere herein for use in the primary coating layer **16** or secondary coating layer **18** similarly can be suitable for use as the ink layer photoinitiator in forming the ink layer **20** as well. In an embodiment, the ink layer photoinitiator is the same as the primary photoinitiator and secondary photoinitiator. In another embodiment, the ink layer photoinitiator is different than one of the primary photoinitiator and secondary photoinitiator. In yet another embodiment, the ink layer photoinitiator is different from both of the primary photoinitiator and secondary photoinitiator.

[0045] Preferred amounts of the ink photoinitiator are from about 1.5 to about 20 weight %, more preferably from about 4 to about 15 weight%, relative to the total weight of the ink layer. In other embodiments, the ink layer contains additional photoinitiators in an amount of about 1 to about 20% by weight, more preferably about 1 to about 10% by weight, based on the total weight of the ink composition.

[0046] The colorants used in forming the ink layer **20** may include dyes or pigments (or both) of varying colors. Examples of ink compositions suitable for forming an ink layer **20** according to the present invention are described in, *inter alia*, U.S. 6,130,980, assigned to DSM N.V.

[0047] A specific example of a suitable colorant which is a black pigment includes carbon black. A specific example of a suitable colorant which is a white pigment includes titanium dioxide. Specific examples of suitable colorants which are yellow pigments include diarylide yellow and diazo based pigments. Specific examples of suitable colorants which are blue pigments include phthalocyanine blue, basic dye pigments, and phthalocyanines. Specific examples of suitable colorants which are red pigments include anthraquinone (red), naphthole red, monoazo based pigments, quinacridone pigments, anthraquinone, and perylenes. Specific examples of suitable colorants which are green pigments include phthalocyanine green and nitroso based pigments. Specific examples of suitable colorants which are orange pigments include monoazo and diazo based pigments, quinacridone pigments, anthraquinones and perylenes. Specific examples of suitable colorants which are violet pigments include quinacridone violet, basic dye pigments and carbazole dioxazine based pigments. Colorants including suitable aqua, brown, gray, and pink pigments can easily be formulated by combining other colors. One skilled in the art is able to form any color as desired by combining different pigments as described herein, along with any other pigment or dye which is known in the art to which this invention applies.

[0048] The colorant can be present in the ink composition in an amount that provides coloration that is visible without magnification to facilitate identification of the individual colored optical glass fiber. The amount of the colorant should not be so great as to significantly reduce the cure speed of the ink composition or result in other undesirable affects. Examples of suitable amounts of colorants have been found to be from about 1 to about 50 weight %, preferably about 1 to about 25 weight %, more preferably about 1 to about 20 weight %, more preferably from about 1 to about 10 weight%, based on the total weight of the ink layer **20**.

[0049] Based on the above, according to an embodiment, a suitable colored coating composition for forming the ink layer **20** can be formulated thusly: from about 1 to about 20 weight % of at least one pigment that absorbs light of a visible wavelength; from about 1 to about 25 weight % of an ink cure speed enhancing photoinitiator; and from about 55 to about 98% of a radiation-curable carrier system containing at least radiation-curable monomer or oligomer, based on the total weight of the ink layer **20**.

[0050] According to one embodiment, a preferred colored coating composition for forming the ink layer **20** can be formulated thusly: from about 1 to about 20 weight % of at least one pigment which absorbs light of a visible wavelength; from about 1 to about 80 weight % of at least one radiation-curable oligomer; from about 1 to about 80 weight % of at least one radiation-curable diluent monomer; and from about 1 to about 20 weight % of at least one ink cure speed photoinitiator, based on the total weight % of the ink composition.

[0051] Colored coating compositions suitable for forming an ink layer **20** may be constructed according to methods known by those having ordinary skill in the art of formulating radiation curable compositions for coating an optical fiber to adjust the Young's Modulus and glass transition temperature (T_g) to within certain desired ranges. According to an embodiment, the ink layer **20** is formulated so as to possess a Young's Modulus and glass transition temperature (T_g) that is less than the Young's Modulus and T_g of the primary coating layer. In yet other embodiments, the ink layer **20** is formulated such that its Young's Modulus and T_g are greater than the primary coating layer.

[0052] In an embodiment, ink coatings are from about 3 to about 10 microns thick, and should be concentric to prevent attenuation of the signal transmission. The ink coating also generally has a T_g of at least about 30° C., more preferably at least about 50° C. One of ordinary skill in the art of formulating radiation-curable ink compositions knows how to adjust the radiation-curable composition to provide the desired properties of the cured coating. Thus, radiation-curable compositions which are usually used for forming outer primary coating compositions can be reformulated and utilized as the radiation-curable carrier system in the ink composition according to the present invention. Examples of suitable radiation-curable compositions which may be reformulated variously include those which are disclosed in U.S. Pat. Nos. 4,624,994; 4,682,851; 4,782,129; 4,794,133; 4,806,574; 4,849,462; 5,219,896; and 5,336,563.

[0053] The thickness of the ink layer **20** according to at least the exemplary configuration of the first embodiment as depicted in Figs. 1 and 2 can be controlled according to well-known methods, with the understanding that at least one primary purpose of such layer is to impart sufficient color intensity to the coated colored optical fiber for purposes of ready identification. In embodiments where it is desired to minimize the cost of materials used per unit length of colored optical fiber, or where it is desired to minimize the diameter of each colored optical fiber, for example, the ink layer **20** may possess a thickness of less than 20 microns, less than 10 microns, or less than 5 microns. In an embodiment, the thickness of the ink layer **20** is about 4 microns. Thicknesses of less than 5 microns are possible if the ink layer **20** is cured from a composition possessing sufficiently intense and numerous colorant levels, such that color identification is readily performed despite the presence of an additional clear shell layer **22** applied thereon.

[0054] In yet further embodiments, it may be desirable to utilize the ink layer **20** further as a mechanically functional layer; i.e., in addition to enabling colored fiber identification, one which also contributes meaningfully to the protection of the optical fiber itself as measured by reduced attenuation and signal loss of the optical signal passing therethrough. In such embodiments, the ink layer **20** possesses a thickness of from 20-30 microns, and in another embodiment greater than 25 microns, and in yet another embodiment greater than 40 microns.

[0055] The final, outermost layer in the exemplary configuration of the first embodiment as depicted in Figs. 1 and 2 is the clear shell layer **22**. The clear shell layer **22** lies in direct contact with and surrounds the ink layer **20**. The clear shell layer **22** serves several functions which enable the creation of improved colored coated optical fibers. First, it serves as an outermost protective layer which can promote uniform geometry and curing of a potentially undercured ink layer. Next, it enables the production of a colored coated optical fiber wherein materials only needed on or near the outermost surface are efficiently concentrated in appropriate locations. Also, it allows for the inclusion of enhanced functionality and versatility to the entire colored coated optical fiber. It can even serve to enhance or protect the vibrancy of the colors in the adjoining ink layer **20**, particularly in long-term ageing conditions, or after exposure to harsh ambient conditions. To enable the fulfillment of these advantages and functions, the clear shell layer **22** possesses a thickness of less than 5 microns, and is substantially free of an ink.

[0056] It has been traditionally known in the art of creating colored coated optical fibers that creation of layers below about 10 microns, especially 5 microns, and most especially about 3

microns is undesirable because of a difficulty in controlling the application of such a thin layer consistently without incurring the known phenomenon of fiber break. This is because of the inherent manufacturing tolerances which are built into coating and inking processes of multiple layers at line speeds of greater than 1800 m/min, in some cases greater than 2300 m/min, and even in other instances as high as 3000 m/min or greater. These speeds and processes induce variances in coating thickness, fiber concentricity/run-out, and are amplified as additional coating layers are applied. This error build-up would be expected to be particularly pronounced in the coated optical fiber **10** with four coating layers (primary coating layer **16**, secondary coating layer **18**, ink layer **20**, and clear shell layer **22**) as depicted in Figures 1 and 2.

[0057] In contravention of the expectation that fiber systems of the current type described would suffer a high probability of fiber break during processing, inventors have surprisingly discovered that it is possible to control the application and curing of the clear shell layer **22** to such granularity such that fourth-layer coatings of less than 10 microns, more preferably less than 5 microns, more preferably about 1 micron are possible, particularly if the inking process is carefully controlled and special die designs are created to accommodate such purpose.

[0058] The clear shell layer **22** is the cured product of a composition which minimally contains a curable monomer or oligomer and a shell photoinitiator. Preferably clear shell layer **22** additionally comprises one or more reactive diluent monomers and at least one additive.

[0059] Any radiation curable monomer or oligomer used and described elsewhere herein for use in the primary coating layer **16**, the secondary coating layer **18**, or the ink layer **20** similarly can be employed in forming the clear shell layer **22** as well. In an embodiment, the clear shell layer **22** is cured from a radiation curable composition comprising greater than 20 wt%, relative to the entire weight of the clear shell layer **22**, of one or more urethane acrylate oligomers. Preferred amounts of the radiation-curable oligomer include from about 10 to about 70% by weight, more preferably, about 20 to about 60% by weight, based on the total weight of the clear shell layer **22**.

[0060] In likewise fashion, any photoinitiator used and described elsewhere herein for use in the primary coating layer **16**, the secondary coating layer **18**, or ink layer **20** similarly can be employed in the clear shell layer **22** as well. In an embodiment, the photoinitiator used in the clear shell layer **22** (shell photoinitiator) is the same as the primary photoinitiator, the secondary photoinitiator, and the ink photoinitiator. In other embodiments, the shell photoinitiator is different than one or more of the primary photoinitiator, the secondary photoinitiator, and the ink

photoinitiator. In yet another embodiment, the shell photoinitiator is different from each of the primary photoinitiator, the secondary photoinitiator, and the ink photoinitiator.

[0061] Preferred amounts of the shell photoinitiator are from about 1.5 to about 20 weight %, more preferably from about 4 to about 15 weight%, relative to the total weight of the clear shell layer **22**. In other embodiments, the clear shell layer **22** contains additional shell photoinitiators in an amount of about 1 to about 20% by weight, more preferably about 1 to about 10% by weight, based on the total weight of the ink composition. Special considerations surrounding the thin (i.e. less than 5 micron) layer may dictate, according to the knowledge of those of ordinary skill the art, to employ different shell photoinitiator(s) to adjust absorption and cure performance.

[0062] The clear shell layer **22** advantageously also includes one or more additives. Additives are typically added to optical fiber coatings to achieve certain desirable characteristics such as improved shelf life, improved coating oxidative and hydrolytic stability, and the like. There are many different types of desirable additives, and the disclosure herein is not intended to be limited by those specifically mentioned. Additives to radiation curable compositions for optical fibers are well-known. Various additives that enhance one or more properties of such a coating include, without limitation, antioxidants, adhesion promoters, PAG compounds, photosensitizers, carrier surfactants, tackifiers, catalysts, stabilizers, optical brighteners, lubricants, low molecular weight non-crosslinking resins, surfactants, surface agents, slip additives, waxes, and micronized-polytetrafluoroethylene, fillers, wetting agents, and levelling assistants.

[0063] Several types of coating additives are useful and needed only in the outermost-facing surfaces of a cured colored optical fiber. Furthermore, despite their benefits, many such additives inevitably impart tradeoffs to the composition into which they are included, such as by inducing detrimental effects upon the physical properties of the cured coating. Examples of such detrimental effects include a reduction in cure performance, viscosity, modulus, or T_g , just to name a few. Still other additives may be necessary to incorporate into a colored coated optical fiber, but are expensive or have less than ideal environmental impacts. Yet others are vital to the successful function of a colored coated optical fiber, but contain ingredients which have a tendency to migrate inward and cause damage to the glass optical fiber optical, thereby reducing signal carrying performance. In light of the foregoing, it would therefore be highly desirable to minimize the reliance on such additives to the extent possible by directing them onto an outermost thin coating layer.

[0064] Accordingly, a set of additives particularly suitable for use in the clear shell layer **22** are slip additives or release agents. Therefore, in an embodiment, the clear shell layer **22** incorporates a slip additive or release agent. Slip additives or release agents are particularly desirable in a matrix fiber configuration, as they reduce the level of adhesion between the colored coated optical fiber and the encapsulating matrix material, thereby enabling easier ribbon break-out. Suitable release agents include silicones, silicone acrylates, fluorocarbon oils or resins and the like. In a preferred embodiment, the slip additive or release agent is silicone-based. In a preferred embodiment, the silicone-based slip additive or release agent is a silicone diacrylate. Commercial examples of silicone-based slip additives include DC-190 and DC-57, available from Down Corning, along with Ebecryl® 350, available from Allnex. The slip additive or release agent can be present in an amount of about 0.1 to about 20 wt. %, more preferably about 0.1 to about 10 wt. %, based on the total weight of the clear shell layer **22**.

[0065] Another additive ideally suited for inclusion in the clear shell layer **22** is a source-identifying or finger printing additive. Such additives are useful for identifying whether a particular coating was made by a particular manufacturer, by a particular manufacturing process, or with the inclusion of certain “signature” raw materials. They may also identify different optical fibers in a bundle, matrix, or loose tube configuration via methods other than visual identification in the visible portion of the electromagnetic spectrum. In an embodiment, the finger printing additive is selected from the group consisting of a fluorescent dye or a yellow phosphor, such as Ce-YAG.

[0066] Other additives ideally suited for inclusion in the clear shell layer **22** are functionalized additives. Such additives functionalize the coating in various ways for improved compatibility with, or resistance to, the environment surrounding the colored coated optical fiber. In an embodiment, therefore, the clear shell layer is functionalized to impart greater heat resistance to the coated optical fiber. In another embodiment, the clear shell layer is functionalized to impart greater water resistance to the coated optical fiber.

[0067] One or more of the aforementioned additives can be employed in compositions according to the present invention in any suitable amount, and may be chosen singly or in combination of one or more of the types enumerated herein. In a preferred embodiment, the additive component is present in an amount, relative to the entire weight of the clear shell layer **22**, of from about 0.01 wt.% to about 5 wt.%, more preferably from about 0.1 wt.% to about 2 wt.%.

According to another embodiment, the one or more of the aforementioned additives are included in an amount from about 1 wt.% to about 5 wt.%, relative to the entire weight of the clear shell layer **22**.

[0068] In order to ensure its maximum effectiveness in furtherance of the functions as described herein, the clear shell layer **22** possesses an average thickness of less than about 10 microns. In a preferred embodiment, the clear shell layer **22** possesses an average thickness of less than about 5 microns, more preferably less than 3 microns, most preferably about 1 micron. In a preferred embodiment, the combined average thickness of the ink layer **20** and the clear shell layer **22** is not more than about 10 microns, more preferably not more than about 6 microns, even more preferably not more than 5 microns. It is not thought to be practically attainable to achieve a thickness substantially less than 1 micron and still carry out the effects of the present invention. However, it is desirable to apply the clear shell layer **22** as thinly as possible to the ink layer **20**, in order to maximize the ability to discern and identify the color vibrancy of the ink layer **20**, the efficiency of the placement of certain additives which are only needed on an outward layer, and also in order to minimize the cost per unit length of any expensive additives employed.

[0069] A second embodiment of the present invention is a coated colored optical fiber comprising: an optical fiber further comprising a glass core; and a cladding layer in contact with and surrounding said glass core; a primary coating layer in contact with and surrounding said optical fiber; a colored secondary coating layer in contact with and surrounding said primary coating layer; and a shell layer in contact with and surrounding said colored secondary layer; wherein the shell layer has a thickness of less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.

[0070] One exemplary configuration according to the second embodiment is depicted in Figures 3 and 4. This configuration is an optical fiber with a three-layered coating. Turning to Figs. 3 and 4, two orthographically-projected views a section of a multi-layered colored coated optical fiber **110** are shown. The coated optical fiber **110** possesses, at its center, an optical fiber consisting of core layer **112** and cladding layer **114**, a primary coating layer **116**, a colored secondary coating layer **118**, and a clear shell layer **122**.

[0071] The optical fiber of Figs. 3 and 4 consisting of core layer **112** and cladding layer **114** is not functionally different from the optical fiber of Figs. 1 and 2 consisting of core layer **12** and

cladding layer **14**. Therefore, the disclosure above pertaining to those layers applies equally to elements **112** and **114**, respectively, as well.

[0072] In direct contact with and surrounding the optical fiber is primary coating layer **116**. The primary coating layer **116** is not functionally different from the primary coating layer **16** depicted in Figs. 1 and 2. Therefore, the disclosure above pertaining to this layer applies equally to element **116** as well.

[0073] The configuration of the second aspect of the invention depicted in Figs. 3 and 4 notably does not include an ink layer. Rather, in direct contact with and surrounding the primary coating layer **116** is the colored secondary coating layer **118**. The colored secondary coating layer **118** contains functional elements derived from secondary coating layer **18** and ink layer **20** into a single, unitary (rather than bifurcated) coating layer, as is well-known in the art. The colored secondary coating layer **118** may therefore be cured from a single composition containing one or more elements from the disclosure pertaining to secondary coating layer **18** and ink layer **20**, provided that at least the following are included: (a) a radiation curable monomer or oligomer, (b) a reactive diluent monomer, (c) a photoinitiator, and (d) a colorant. The colored secondary coating layer **118** may possess any suitable thickness as would be derived by the combination of the secondary coating layer **18** and ink layer **20** described elsewhere herein.

[0074] The final, outermost layer in the exemplary configuration of the second embodiment as depicted in Figs. 3 and 4 is the clear shell layer **122**. The clear shell layer **122** lies in direct contact with and surrounds the colored secondary layer **118**. The clear shell layer **122** is not functionally different from the clear shell layer **22** depicted in Figs. 1 and 2. Therefore, the disclosure above pertaining to this layer applies equally to element **122** as well.

[0075] A third embodiment of the present invention is an optical fiber ribbon comprising a first coated colored optical fiber according to the first or second aspects of the invention; a second coated colored optical fiber according to the first or second aspects of the invention; and a matrix material encapsulating the first coated colored optical fiber and the second coated colored optical fiber. Optical fiber ribbon assemblies may require 2 or more optical fibers. Often, optical fiber ribbon assemblies utilize 12 or less coated optical glass fibers, and therefore require only at most 12 different colors to adequately distinguish each of the coated optical fibers from one another. Examples of twelve colors normally used for making ribbon assemblies include: black, white, yellow, blue, red, green, orange, brown, pink, aqua, violet, and gray. In accordance with the third

embodiment of the invention, the colors would be imparted into the ink layer or colored secondary layer as appropriate, and not into the clear shell layer.

[0076] The novel ribbon assembly made according to this invention can be used in telecommunication systems. Such telecommunication systems typically include ribbon assemblies containing optical glass fibers, transmitters, receivers, and switches. The ribbon assembly containing the coated optical glass fibers are the fundamental connecting units of telecommunication systems. The ribbon assembly can be buried under ground or water for long distance connections, such as between cities. The ribbon assembly can also be used to connect directly to residential homes.

[0077] The novel ribbon assembly made according to this invention can also be used in cable television systems. Such cable television systems typically include ribbon assemblies containing optical glass fibers, transmitters, receivers, and switches. The ribbon assembly containing the coated optical glass fibers are the fundamental connecting units of such cable television systems. The ribbon assembly can be buried under ground or water for long distance connections, such as between cities. The ribbon assembly can also be used to connect directly to residential homes.

[0078] A fourth embodiment of the present invention is a method for creating a multi-layered colored coated optical fiber, the method comprising: at least partially un-spooling a spool of coated optical fiber; directing the coated optical fiber through an inking machine; applying an ink composition to the surface of the coated optical fiber; optionally exposing the ink composition to a first radiation source capable of emitting ultraviolet radiation to affect curing of said ink composition and form an ink layer; applying a shell coating composition to the ink composition or ink layer, thereby forming a multi-layered colored coated optical fiber; exposing the multi-layered colored coated optical to a second radiation source capable of emitting ultraviolet radiation to affect curing of at least said shell coating composition and form a shell layer, and optionally also to affect curing of said ink coating composition to form an ink layer; thereby forming a cured multi-layered colored coated optical fiber; wherein the average thickness of the shell coating is less 5 microns, preferably less than 3 microns thick, most preferably about 1 micron thick; and wherein the shell coating composition is substantially free of an ink.

[0079] In an embodiment, the ink composition comprises greater than 20 wt%, relative to the entire weight of the ink layer, of one or more urethane acrylate oligomers, and the combined average thickness of the ink layer and the shell layer is less than about 10 microns, preferably less

than about 5 microns. In an embodiment, at least one of the first radiation source and second radiation source contains one or more light emitting diodes (LED's).

[0080] The ink composition can be applied to the coated optical fiber and cured using any suitable method. An example of a suitable method is disclosed in U.S. Pat. No. 4,629,285. The ink composition can also be applied in a manner similar to the application of the primary coating layer or secondary coating layers on an optical glass fiber drawing and coating tower, as is well-known in the art.

[0081] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLES

[0082] These examples illustrate embodiments of the instant invention. Table 1 describes the various components of the compositions used in the present examples.

TABLE 1

Component	Function in Formula	Chemical Descriptor	Supplier/Manufacturer
	Coated Optical Fiber	Glass optical fiber coated with primary layer and secondary layer	Corning Incorporated
751 Blue	Ink layer	See table 2	DSM Desotech
DS-2042	Clear shell layer	Clear secondary	DSM Desotech
DS-2088	Clear shell layer	Clear secondary	DSM Desotech
Coat-o-sil 1770	Additive	Silane-based additive	Momentive
Ebecryl 350	Slip agent	Silicone-diacrylate	Allnex

Claims

What is claimed is:

1. A coated colored optical fiber comprising:
 - an optical fiber;
 - a primary coating layer in contact with and surrounding said optical fiber;
 - a secondary coating layer in contact with and surrounding said primary coating layer;
 - an ink layer in contact with and surrounding said secondary coating layer; and
 - a clear shell layer in contact with and surrounding said ink layer;wherein the clear shell layer has a thickness of less than 10 microns, more preferable less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.
2. The coated colored optical fiber according to claim 1, wherein the ink layer is cured from a radiation curable composition comprising greater than 20 wt%, relative to the entire weight of the ink layer, of one or more urethane acrylate oligomers.
3. The coated colored optical fiber according to claim 1, wherein the ink layer possesses a Young's Modulus and glass transition temperature (T_g) that is less than the Young's Modulus and T_g of the primary coating layer.
4. The coated colored optical fiber according to claim 1, wherein the primary coating layer is cured from a radiation curable composition comprising:
 - (a) a radiation curable oligomer;
 - (b) a reactive diluent monomer; and
 - (c) a primary photoinitiator.
5. The coated colored optical fiber according to claim 1, wherein the secondary coating layer is cured from a radiation curable composition comprising:
 - (a) a radiation curable oligomer;
 - (b) a reactive diluent monomer; and

- (c) a secondary photoinitiator.
6. The coated colored optical fiber according to claim 1, wherein the ink layer is cured from a radiation curable composition comprising:
 - (a) a radiation curable monomer or oligomer;
 - (b) a reactive diluent monomer;
 - (c) an ink layer photoinitiator; and
 - (d) a colorant;wherein the combined thickness of the ink layer and the clear shell layer is less than 10 microns, preferably less than 5 microns.
 7. The coated colored optical fiber according to claim 1, wherein the ink layer possesses a thickness of less than 10 microns, preferably less than 5 microns, and in another embodiment greater than 25 microns, in another embodiment greater than 40 microns.
 8. The coated colored optical fiber according to claim 6, wherein colorant includes a dye or a pigment.
 9. The coated colored optical fiber according to claim 1, wherein the clear shell layer is cured from a composition comprising:
 - (a) a curable monomer or oligomer; and
 - (b) a shell photoinitiator.
 10. The coated colored optical fiber according to claim 9, wherein the wherein the shell photoinitiator is different than the primary, secondary, and ink-layer photoinitiators.
 11. The coated colored optical fiber according to claim 10, further comprising a slip additive or release agent.
 12. The coated colored optical fiber according to claim 11, wherein the slip additive or release agent is silicone-based.

13. The coated colored optical fiber according to claim 12, wherein the silicone-based slip additive or release agent is a silicone diacrylate.
14. The coated colored optical fiber according to claim 9, further comprising a finger printing additive.
15. The coated colored optical fiber according to claim 14, wherein the finger printing additive is selected from the group consisting of a fluorescent dye or a yellow phosphor, such as Ce-YAG.
16. The coated colored optical fiber according to claim 8, wherein the clear shell layer is functionalized to impart greater heat resistance to the coated optical fiber.
17. The coated colored optical fiber according to claim 15, wherein the clear shell layer is functionalized to impart greater water resistance to the coated optical fiber.
18. A coated colored optical fiber comprising:
 - (a) an optical fiber further comprising
 - a glass core; and
 - a cladding layer in contact with and surrounding said glass core;
 - (b) a primary coating layer in contact with and surrounding said optical fiber;
 - (c) a colored secondary coating layer in contact with and surrounding said primary coating layer; and
 - (d) a shell layer in contact with and surrounding said colored secondary layer;

wherein the shell layer has a thickness of less than 5 microns, preferably less than 3 microns, more preferably about 1 micron, and is substantially free of an ink.
19. A optical fiber ribbon comprising:
 - (a) a first coated colored optical fiber according to any one of claims 1-17;
 - (b) a second coated colored optical fiber according to any one of claims 1-17;

- (c) a matrix material encapsulating the first coated colored optical fiber and the second coated colored optical fiber.

20. A method for creating a multi-layered colored coated optical fiber, the method comprising:

- (a) at least partially un-spooling a spool of coated optical fiber;
- (b) directing the coated optical fiber through an inking machine;
- (c) applying an ink composition to the surface of the coated optical fiber;
- (d) optionally exposing the ink composition to a first radiation source capable of emitting ultraviolet radiation to affect curing of said ink composition and form an ink layer;
- (e) applying a shell coating composition to the ink composition or ink layer, thereby forming a multi-layered colored coated optical fiber;
- (f) exposing the multi-layered colored coated optical to a second radiation source capable of emitting ultraviolet radiation to affect curing of at least said shell coating composition and form a shell layer, and optionally also to affect curing of said ink coating composition to form an ink layer; thereby forming a cured multi-layered colored coated optical fiber;

wherein the average thickness of the shell coating is less 5 microns, preferably less than 3 microns thick, most preferably about 1 micron thick; and

wherein the shell coating composition is substantially free of an ink.

21. The method of claim 20, wherein the ink composition comprises greater than 20 wt%, relative to the entire weight of the ink layer, of one or more urethane acrylate oligomers, and the combined average thickness of the ink layer and the shell layer is less than about 10 microns, preferably less than about 5 microns.

22. The method of claim 20, wherein at least one of the first radiation source and second radiation source contains one or more light emitting diodes (LED's).

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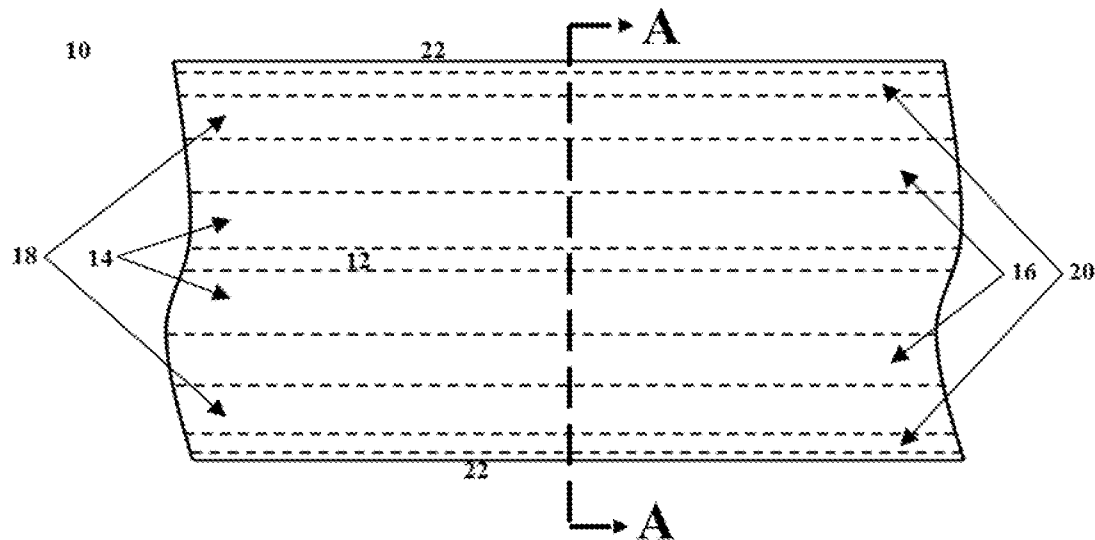


FIG. 1

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Section A-A

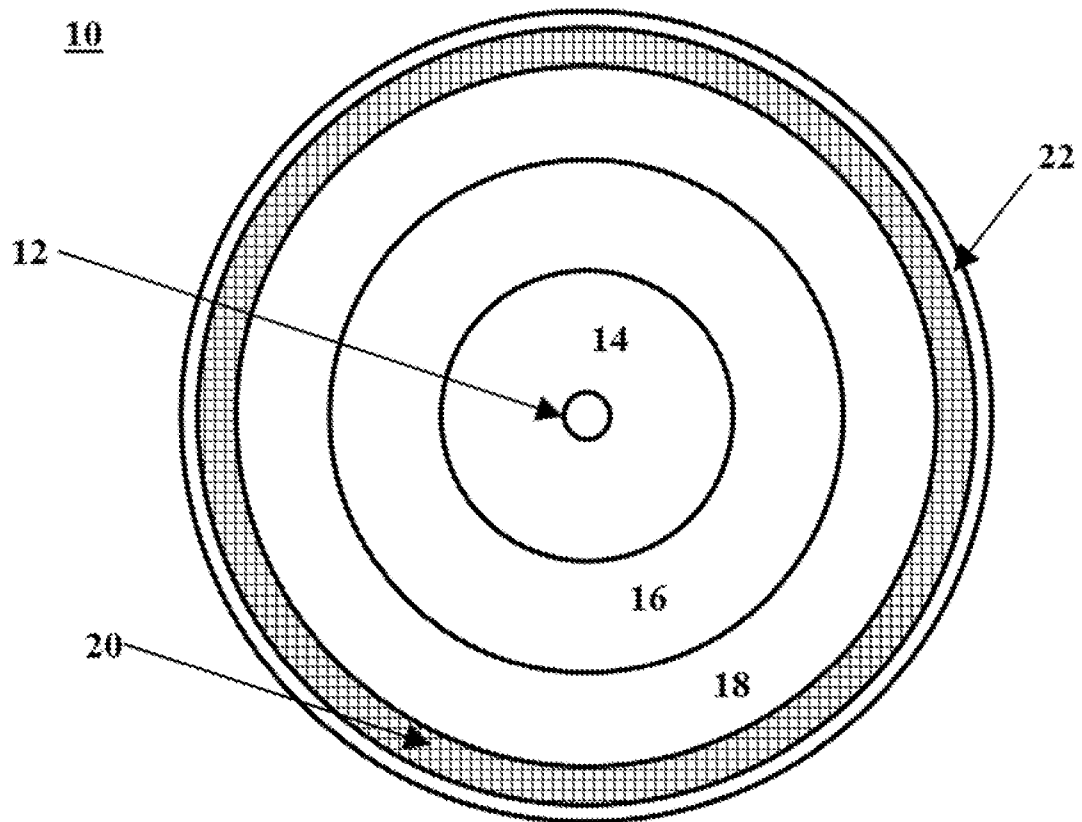


FIG. 2

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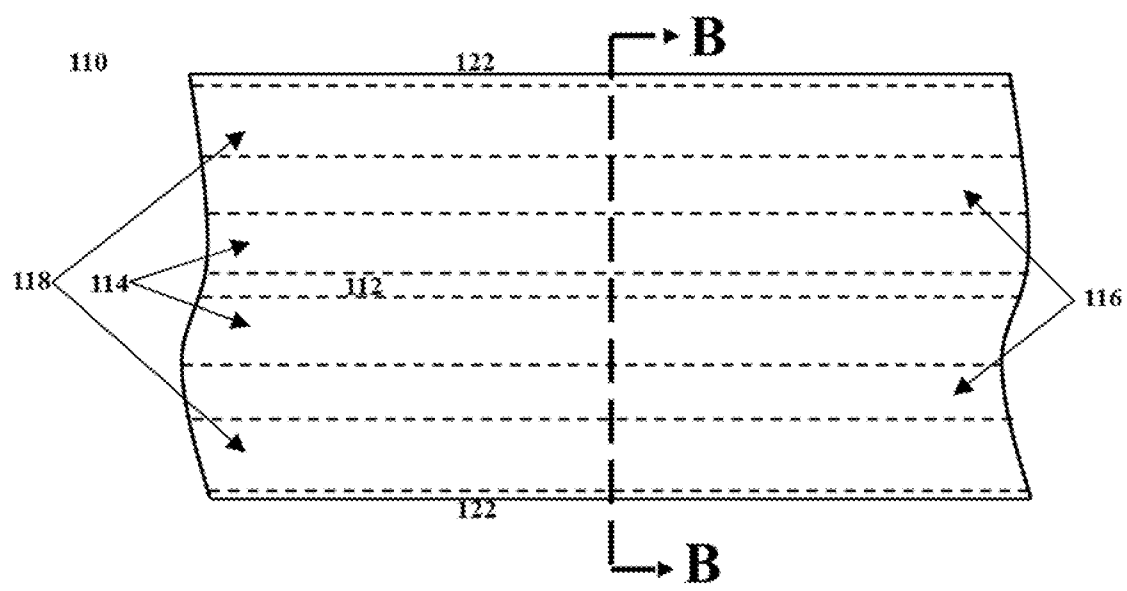


FIG. 3

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Section B-B

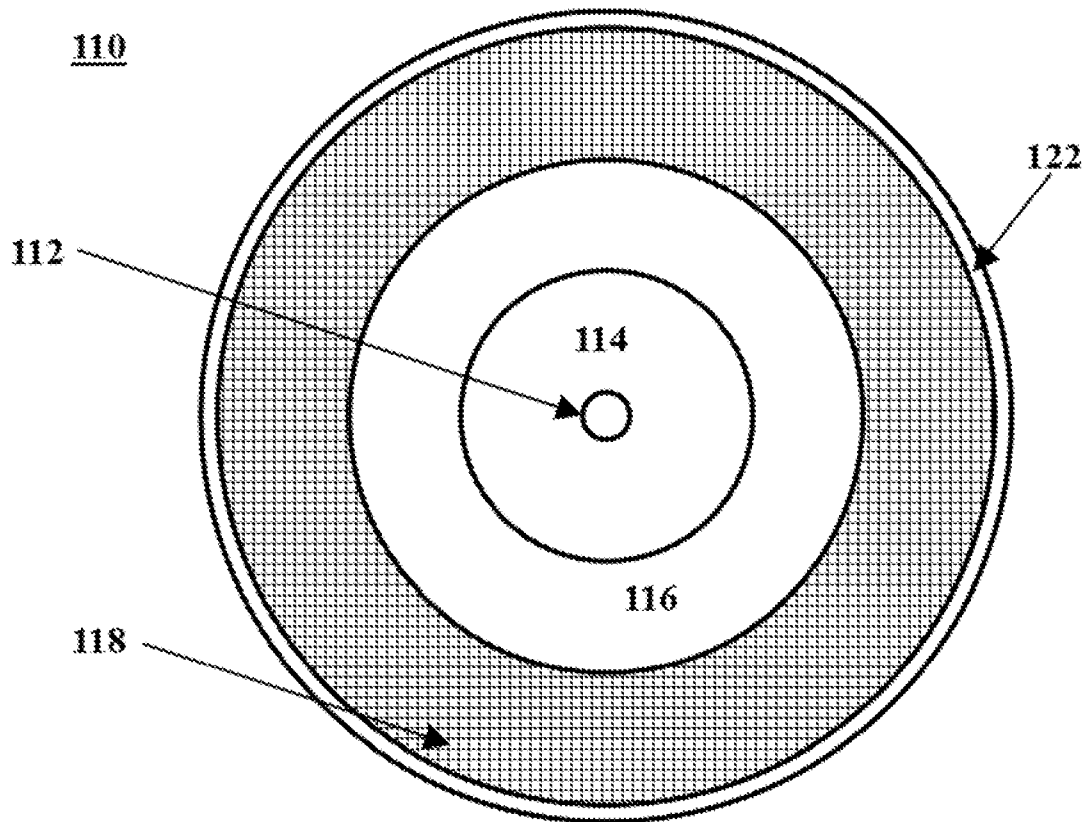


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/025419

A. CLASSIFICATION OF SUBJECT MATTER

INV. C03C25/10 C03C25/50
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/038593 A1 (CHIEN CHING-KEE [US] ET AL) 17 February 2011 (2011-02-17)	1-5,7, 9-11,18, 19
Y	paragraph [0119] - paragraph [0120]; claim 9 paragraph [0121] paragraph [0078] paragraph [0015]	6,8
X	US 4 629 285 A (CARTER R SYKES [US] ET AL) 16 December 1986 (1986-12-16)	20,21
Y	column 8, line 24 - line 50; claims 1, 9	6,8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 August 2017

Date of mailing of the international search report

18/08/2017

Name and mailing address of the ISA/

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Authorized officer

Friederich, Pierre

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/025419

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