(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
18 July 2019 (18.07.2019)

WIPO | PCT

(10) **International Publication Number**
WO 2019/137628 A1

(51) **International Patent Classification:**
G02B 6/44 (2006.01)

(21) **International Application Number:**
PCT/EP2018/050899

(22) **International Filing Date:**
15 January 2018 (15.01.2018)

(25) **Filing Language:** English

(26) **Publication Language:** English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title:** A METHOD FOR PRODUCING A FLEXIBLE OPTICAL FIBER RIBBON AND SAID RIBBON.

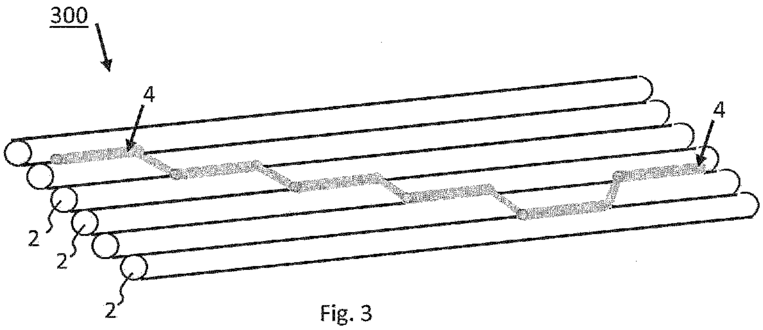

Fig. 3

(57) **Abstract:** The present invention relates to a method of producing an optical fiber ribbon, said method comprising * feeding a plurality of optical fibers to provide a longitudinal optical fiber assembly; wherein the plurality of optical fibers are in parallel and adjacent to each other; wherein each of the plurality of optical fibers comprises, from the center to the periphery thereof, a glass core, a glass cladding, a primary coating, a secondary coating and an outer layer formed of a partly cured first curable resin; * applying a curable second resin from a dispenser to a surface of said assembly wherein the second curable resin forms a plurality of successive elongated rectilinear beads being configured to form bonds between two adjacent optical fibers of the plurality of optical fibers; and * passing said assembly with the beads of the second curable resin applied thereon through a curing station for curing the second curable resin and for completing the curing of said partly cured first curable resin, of the outer layer, of each optical fiber to form the bonds. The invention also relates to the ribbon obtained.

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A method for producing a flexible optical fiber ribbon and said ribbon.

TECHNICAL FIELD

The present invention relates to a method for producing an optical fiber ribbon and to said optical fiber ribbon.

BACKGROUND

The amount of data that is transmitted over optical fiber cables is continuously increasing. This increase is specifically eminent in data centers all over the world- e.g. due to expanding of cloud computing – in which all data has to be transmitted in a limited space. This causes an increasing demand for high-fiber-count and high fiber-density optical cables. Moreover, there is always a tendency to reduce the construction cost of the access cable network, making it important to reduce the diameter and weight of the optical cable. By decreasing optical cable diameter and weight it will be possible to use existing facilities such as underground ducts, which will reduce installation cost. An additional requirement is that in order to shorten the operation time of cable connection, the optical fibers should be mass fusion spliced.

This means that there are several – possibly conflicting - demands, being on the one hand decrease in optical cable diameter and on the other hand increasing the optical fiber density. This is serious challenge for optical cable manufactures.

In order to obtain easy workability, optical fiber ribbons have been used that can be mass fusion spliced for making multiple optical fiber connections at once with improved flexibility.

Standard optical fiber ribbons however have the disadvantage of being rigid because there is a layer of resin applied around the optical fiber assembly in order to keep the optical fibers in a parallel plane. This rigidity limits the possibility to increase the fiber density in optical fiber cables.

JP2011221199 has proposed an option to provide more flexible optical fiber ribbon by applying a sine-shaped line of matrix bonding material to one side of an parallel assembly of adjacent optical fibers.

SUMMARY

It is an object of the present invention to provide an optical ribbon and method for producing the same having improved flexibility and allows for rolling or folding of the optical fibers in a ribbon width direction while having excellent ribbons strength. It is another object of the present invention to provide an optical ribbon that can be mass fusion spliced for making multiple optical fiber connections. It is a further object of the present invention to provide an optical fiber ribbon from which individual optical fibers comprising at most three optical fibers encapsulated with a matrix material, can be separated without damaging adjacent optical fibers.

One or more of these objects are achieved in a first aspect by a method for producing an optical fiber ribbon, said method comprising

* feeding a plurality of optical fibers to provide a longitudinal optical fiber assembly; wherein the plurality of optical fibers are in parallel and adjacent to each other; wherein each of the plurality of optical fibers comprises, from the center to the periphery thereof, a glass core, a glass cladding, a primary coating, a secondary coating and an outer layer formed of a partly cured first curable resin;

* applying a curable second resin from a dispenser to a surface of said assembly wherein the second curable resin forms a plurality of successive elongated rectilinear beads being configured to form bonds between two adjacent optical fibers of the plurality of optical fibers; and

* passing said assembly with the beads of the second curable resin applied thereon through a curing station for curing the second curable resin and for completing the curing of said partly cured first curable resin, of the outer layer, of each optical fiber to form the bonds. The beads bonds the outer layers of the optical fiber to each other.

One or more of these objects are achieved in a second aspect by an optical fiber ribbon, comprising:

* a plurality of adjacent optical fibers extending in a longitudinal direction and arranged in parallel forming an optical fiber assembly;

* a plurality of successive elongated rectilinear beads of a second cured resin being arranged along a length of said assembly;

- each of said plurality of beads being configured to form an elongated bond between two adjacent optical fibers of the plurality of optical fibers;

wherein each of the plurality of optical fibers comprises, from the center to the periphery thereof, a glass core, a glass cladding, a primary coating, a secondary coating and an outer layer formed of a second cured resin;

wherein the second cured resin of each elongated bond is chemically coupled to the respective second cured resin of the two adjacent optical fibers.

Corresponding embodiments of the ribbon disclosed below are also applicable for the method according to the present invention and vice versa.

The optical fiber ribbon according to the present invention thus has multiple optical fibers arranged in parallel that are connected with another optical fibers by means of cured resin beads. A connection is created by curing the curable resin of the beads on the partly cured first cured resin of the outer layer of each of the optical fibers; this creates a coupling or connection between the beads and the outer layer thereby increasing the strength of the bonding between the bead and the outer layer.

When an optical fiber is to be removed/peeled from the ribbon it is preferred that the point of failure/rupture is either in the bead itself, or in the outer layer or between the outer layer and the secondary coating. In order to keep the integrity of the optical fiber it is undesirable if the point of rupture/failure during peel off is in the secondary coating or at the interface with the primary coating, this damaging the optical fiber. This present invention – curing the outer layer to the bead, has the effect of directing the point of failure away from inside the optical fiber to either the interface between the outer layer and the secondary coating or to within the outer layer. This outer layer has the effect of acting as a release layer. The present inventors have observed that the combination of features of having an outer layer and having this coupled to the bead provides a point of failure that does not damage the optical fibers nor has an effect on its integrity. Even though the outer layer is part of the optical fiber it may be (partly) removed without damaging the structural parts of the optical fiber, being a glass core, a glass cladding, a primary coating and a secondary coating.

LIST OF DEFINITIONS

The following definitions are used in the present description and claims to define the stated subject matter. Other terms not cited below are meant to have the generally accepted meaning in the field.

optical fiber assembly as used in the present description means: a loose arrangement of the plurality of parallel adjacent optical fibers without any bonding between any of the fibers; said assembly has a width (W) and having interstices or grooves in between the adjacent optical fibers.

assembly width (W) or width (W) as used in the present description means: said assembly is formed of a number (N) of optical fibers each having a diameter (D) and a length (L); said assembly having a width (W; W = D x N).

bond as used in the present description means: a bead of a second cured resin that bonds two adjacent optical fibers over a bonding length (l). It should be noted that if two (or more) subsequent beads are applied after another within the same groove connecting the same two adjacent optical fibers these two (or more) beads are considered to form a bond together with a bonding length (l) equal to the sum of the length of such subsequent beads.

Bonding material as used in the present description means the material of with a bond is formed. This is the second cured resin – or when not yet cured- the second curable resin.

Outer layer material as used in the present description means the material of which the outer layer is formed, being a first resin that – depending on the stage of the process is either curable, partly cured or cured.

Chemically coupled as used in the present description means: the presence of chemical covalent bonds that are formed by the simultaneous curing the second curable resin and the partly cured first curable resin. These resins each comprise a plurality of chemically active groups that form crosslinks (chemical bonds) during curing; because of the simultaneous curing at the interface of the beads and the outer layer there will be chemical covalent bonds formed between the chemically active groups present in the second curable resin of the bonds/beads and the partly cured first curable resin of the outer layer.

stepwise pattern as used in the present description means a pattern constituted by a succession of beads over the plurality of optical fibers wherein the beads of said succession of beads are each time spaced apart at a distance of one optical fiber, in the width direction. That means, the step of the stepwise pattern is one optical fiber. Thus, in case that the assembly would be formed by a number of N optical fibers, an individual stepwise pattern is constituted by a succession of (N-1) beads;

zig-zag like arrangement as used in the present description means an arrangement following the trace of a triangle wave. The zig-zag like arrangement in the present application is obtained by fitting a line through mid-points of the subsequent beads of subsequent stepwise patterns;

saw-tooth like arrangement as used in the present description means an arrangement following the trace of a saw-tooth wave. The saw-tooth like arrangement in the present application is obtained by fitting a line through mid-points of the subsequent beads of subsequent stepwise patterns;

a pitch (P) as used in the present description is defined as having a length equal to the recurrence of the stepwise pattern in the same width direction.

BRIEF DESCRIPTION OF DRAWINGS

The present invention is described hereinafter with reference to the accompanying schematic drawings in which embodiments of the present invention are shown and in which like reference numbers indicate the same or similar elements.

Figure 1 shows an optical fiber assembly (not part of the invention) in 3-dimensional view.

Figure 2a shows an embodiment of an inventive optical fiber ribbon having an intermittent /discontinuous zig-zag like arrangement, in 3-dimensional view. Figure 2b shows an embodiment of an inventive optical fiber ribbon having an intermittent /discontinuous zig-zag like arrangement with a different bonding length than the embodiment of figure 2a.

Figure 3 shows an embodiment of an inventive optical fiber ribbon having an continuous zig-zag like arrangement, in 3-dimensional view.

Figure 4a shows an embodiment of an inventive optical fiber ribbon having an intermittent /discontinuous saw-tooth like arrangement, in 3-dimensional view. Figure 4b shows the embodiment of Figure 4a with a fitted saw-tooth line and pitch.

Figure 5 shows an embodiment of an inventive optical fiber ribbon having an partly continuous saw-tooth like arrangement, in 3-dimensional view.

Figure 6 shows an embodiment of an inventive optical fiber ribbon having an continuous saw-tooth like arrangement, in 3-dimensional view.

Figure 7 shows a schematic representation of a possible process line for preparing an optical fiber ribbon having six optical fibers.

Figure 8 shows a schematic representation of an optical fiber ribbon having a zig-zag like arrangement, in perspective view.

Figure 9 shows a schematic representation of an optical fiber ribbon having a saw-tooth like arrangement, in perspective view.

Figure 10 shows a picture of ribbon according to an embodiment of the present invention, in plan view.

Figure 11 shows, in cross-sectional view, a picture of an optical cable unit being prepared using 24 optical fiber ribbons each having 12 optical fibers.

DESCRIPTION OF EMBODIMENTS

As described above, in a first aspect the invention relates to a method of producing an optical fiber ribbon 100-600. Several embodiments of said method are discussed below.

In a first step, a plurality of fibers 2 are fed – preferably into a die 12 - to provide a longitudinal optical fiber assembly 3 wherein the plurality of optical fibers are in parallel and adjacent to each other. In an embodiment, shows in figure 1, the optical fibers are in a plane. This is visible from figure 7 (process from right to left) and the assembly 3 is shown in figure 1. It should be noted that the outer layer of the plurality of optical fibers is of a partly cured first curable resin. Each optical fiber has a substantially circular cross section.

In a second step of the present method, a second curable resin is applied from a dispenser (or dispensing device) 14 to a surface, such as an upper surface of said assembly. The application of said second curable resin leads to said second resin forming a – preferably stepwise - pattern of a plurality of intermittently arranged beads 4 along the upper surface of said assembly 3.

In a third step of the present method, as shown in figure 7, said assembly with beads applied thereon is passed through a curing station 16 for curing both the second resin of said beads as well as the partly cured first resin of the respective outer layers of the optical fiber thereby forming bonds between them.

In this method, each of said beads being arranged to form a bond between two adjacent optical fibers over a bonding length (l). Preferably a bond connects two adjacent optical fibers and a successive bond connects two adjacent optical fibers at least one of which differs from the optical fibers bonded by the preceding bond. Preferably, each of said bonds being distanced in longitudinal direction from a successive bond by a bonding distance (d). In an embodiment, the bonding length is larger than the bonding distance (l > d).

Figure 8 shows a schematic drawing of an optical fiber ribbon having six optical fibers and a zig-zag stepwise arrangement of second resin. Figure 9 shows a schematic drawing of an optical fiber ribbon having six optical fibers and a saw-tooth stepwise arrangement of second resin.

In an embodiment, prior to feeding the plurality of optical fibers to provide a longitudinal optical fiber assembly, a second curable resin of the outer layer of each of said plurality of optical fibers is partly cured to a curing degree of between 85% and 95%, such as between 88 % and 92%, for example 90 %, to provide optical fibers having an outer layer of a partly cured second curable resin. In an embodiment, with a degree of curing of between 85 and 95% is meant a degree of surface curing, meaning the amount of curing of the outermost layer (surface) of the outer layer.

In an embodiment, said optical fibers are formed by providing an optical fiber comprised from the center to the periphery of a glass core, a glass cladding, a primary coating, and a secondary coating and applying a first curable resin to form an outer layer, this curable first resin is then party cured to form an optical fiber having a partly cured outer layer.

The percentage or degree of surface curing may be determined by measuring the peak area using FTIR of the peak of the chemically active group of the resin, e.g. the peak at 1410 cm^{-1} of an acrylate group in case of an UV curable acrylate resin. This peak area is then compared to a reference peak of a fully cured sample (e.g. no peak of chemically active group, such as 1410 cm^{-1} present) and to a reference peak of a fully uncured sample. The ratio of the relative peaks provide the amount of surface cure degree.

In an embodiment, the outer layer of second curable resin of each of said plurality of optical fibers is partly cured in an environment comprising oxygen. If oxygen is present during curing the outer surface of the outer layer does not fully cure. Preferably the amount of oxygen surrounding the outer layer during curing is between 500 and 3500 ppm, preferably between 1000 and 2000 ppm.

In an embodiment, the second curable resin – forming the beads - is applied with a viscosity of between 100 and 1000 cPS, preferably between 100 and 400 cPs. This allows a sufficient viscous mass to fill the grooves in between two adjacent optical fibers and will provide after curing an optical fiber ribbon having a flush ribbon bead thereby reducing possible stresses in the ribbon when rolled or folded. If the viscosity is too low, the material is too thin and runny and the adhesive will excessively flow between the fibers, not forming a consisting bond. The viscosity is measured using a Brookfield digital rotational viscometer Model DV-II with RV1 spindle at 10rpm. The viscosity may be measured at several different temperatures, such as at 23 °C and/or at 30 °C and/or at 40 °C and/or at 50 °C and/or at 60 °C to determine for a specific second resin material the optimal temperature for the application of said second resin material.

In an embodiment the second curable resin is heated and applied at a temperature of up to 60 °C. In case a higher temperature is used during the preparation of the optical ribbons this might lead to thermal stress in the optical fiber leading to attenuation, for example at 1310 nm, 1550 nm and/or 1625 nm wavelenghts.

In an embodiment, the dispenser (dispensing device) is oscillating in a direction transverse to the longitudinal direction of the optical fiber assembly. Said oscillating device creates the stepwise pattern on one side of the optical fiber assembly; the tip of said dispenser may oscillate (vibrate) at a high frequency, such as in the order of between 100 and 200 Hz in a transverse direction. In an embodiment, the dispenser is oscillating in a direction transverse to the longitudinal direction (i.e. in the width direction) of the optical fiber assembly. The optical fiber assembly is moved in longitudinal direction, preferably by reels.

In an embodiment the dispenser may deliver the liquid resin in fine droplets to the moving optical fiber assembly. Due to the surface tension of liquid resin it will flow together to form elongated beads.

In an embodiment, the curing station emits UV radiation for curing said beads of second curable resin and for completing the curing of the partly cured second curable resin for the outer layer of the optical fibers.

In an embodiment, the first cured resin and/or the second cured resin that is/are used during the method is/are a curable Ultra Violet (UV) resin. In an embodiment, the resins used are the same for the beads and the outer layer. In an embodiment the first curable resin is a UV curable ink comprising a pigment or dye for coloring. In an embodiment, a difference between the first resin and the second resin is that in the first resin > 0.5 wt.% release agent or slip agent is present and in the second resin no, or substantially no release or slip agent (<0.5wt%) is present.

Several embodiments of the second aspect of the invention, the ribbon are disclosed below.

Figure 1 discloses a plurality of adjacent optical fibers 2 having a diameter D and arranged in parallel forming a longitudinal optical fiber assembly 3 said assembly 3 having a width W and a length L. This assembly forms the basis for the optical fiber ribbon according to the present invention.

In an embodiment, a bond has a bonding length (l) and bonds are spaced apart in longitudinal direction by a distance (d). In this embodiment, the bonding length is larger than the distance (l > d). The effect thereof is that the mechanical properties in terms of robustness are increased; a larger mechanical bond between the fibers is achieved.

In an embodiment, the bonding length is between 2 and 20 times the distance (($2d \leq l \leq 20d$ or l/d = 2 to 20). The values of 2 and 20 are included. In an embodiment, the bonding length is between 4 and 15 times the distance ($4d \leq l \leq 15d$ or l/d = 4 to 15). The values of 4 and 15 are included. The bead as applied has an elongated form. It will flow into the groove between two adjacent optical fibers. The elongated beads forming a bond may have a width seen in plan view of between 75 and 350 micrometer, e.g. between 200 and 275 micrometer (viz. of similar dimension as the optical fiber).

In an embodiment, the bonding length (l) of a bead is between 1.5 and 20 mm. the bonding length of the bead is effectively defined by the ratio of bonding length of bonding distance (l/d) and by the ratio of pitch of the stepwise pattern over width of the optical fiber assembly (P/W).

In an embodiment, each of the plurality of optical fibers has substantially the same diameter. In an embodiment, the optical fiber has a diameter of between 240 and 260 micrometer, more preferably 250 micrometer. Alternatively the optical fibers may have a reduced diameter such as between 180 and 230 micrometer. In an embodiment, the optical fiber assembly comprises between 6 and 36 optical fibers (including 6 and 36), such as between 12 and 24 optical fibers (including 12 and 24), for example 12 optical fibers.

In an embodiment, the point of failure when removing an optical fiber from the ribbon is in the bead. In an embodiment, the point of failure when removing an optical fiber from the ribbon is at the interface between the bead and the outer layer. In an embodiment, the point of failure when removing an optical fiber from the ribbon is in the outer layer. In an embodiment, the point of failure when removing an optical fiber from the ribbon is between the outer layer and the secondary coating layer or an ink layer whichever is the layer contactly surrounded by the outer layer.

In an embodiment, the optical fibers are optical fibers comprising - in addition to the first and second coating - an ink layer and an outer layer. In another embodiment, the outer layer may be the ink layer. In such an embodiment it is preferred that the point of failure is either in the bead or at the interface of the bead and the outer layer. A person skilled in the art is aware of the different types of primary coatings, secondary coatings and ink layers and the structure and thickness thereof.

In an embodiment, the beads have been arranged on only one side of said assembly. For example, the beads have been arranged only on the upper surface of said assembly (seen in plan view when the optical fibers of the assembly are arranged in a ribbon like manner and not in a rolled up manner). The assembly could be seen as a ribbon-like assembly defining two side edges, an upper surface and a lower surface. Said upper and lower surfaces are not fully flat, since they are formed of a parallel arrangement of optical fibers. The upper and lower surfaces comprises parallel longitudinal grooves between adjacent optical fibers. The beads are arranged to lie in the grooves formed between the optical fibers.

In an embodiment, two successive beads of said plurality of beads have been connected by a transition part of said second cured resin. In an embodiment, in plan view said transition part is S-shaped. In an embodiment, each two successive beads of said plurality of beads have been connected by a transition part of said second cured resin.

In an embodiment, a succession of alternating beads and transition parts forms a thread, wherein at each longitudinal position of the optical fiber assembly there is at most one thread. In an embodiment, the thread has a mass (in grams) per 10000 meter of between 60 and 120 dtex, preferably between 75 and 110 dtex.

In an embodiment, each two successive beads of said plurality of beads are free from each other in that no second cured resin connecting said two beads is present. In other words, there is no thread of resin but merely individual beads.

In an embodiment, a number of successive beads form a stepwise pattern over the plurality of optical fibers, the step each time being one optical fiber.

In an embodiment, the first cured resin and/or the second cured resin is/are a cured Ultra Violet (UV) curable resin. In an embodiment, the first and/or said second cured resin is an acrylate resin. The first and second cured resins may be different or the same. In an embodiment the first curable resin is a UV curable ink comprising a pigment or dye for coloring. In an embodiment, a difference between the first resin and the second resin is that in the first resin > 0.5 wt.% release agent or slip agent is present and in the second resin no, or substantially no release or slip agent (<0.5 wt.%) is present.

In an embodiment, the second cured resin has a elongation at break of at least 150 %, preferably between 200 % and 300 %, such as between 200 and 250 %. In an embodiment, the second cured resin has a modulus of elasticity (or Young's modulus) of between 1 and 50 MPa, such as between 10 and 20 MPa. In the present invention elongation at break and modulus of elasticity was measured using the following method: ASTM D683-14 "*Standard Test Method for Tensile Properties of Plastics*". The outer layer (first curable resin) may comprise a release agent to facilitate release of an optical fiber from the ribbon Convention ribbon matrix materials that are used to completely surround and encapsulate an optical fiber assembly comprise a certain amount of release agent to facilitate breakout of individual fibers or splitting of a fiber ribbon. For the present invention it is preferred to reduce the amount of release agent, It has been found surprisingly that by reducing the amount of release agent, the point of failure (point of break) upon removing an optical fiber shifts to the interface between the bead and the outer layer or to the outer layer itself, which is desirable since there is less chance of damage to the optical fiber.

In an embodiment, the thickness of the outer layer of first cured resin is between 2 and 10 micrometer, such as between 3 and 5 micrometer.

The ribbon robustness can be tested using a mechanical tester such as a tensile tester (e.g. Instron 5567). In a T-peel test a single fiber, or a group of fibers from an end of the ribbon is clamped in a grip of the tensile tester, while the remaining fibers from the same end of the ribbon are clamped in the opposite grip of the tensile tester and the force to separate both is measured. In such T-peel test the force to break a single bond is measured. In an embodiment, the required force to separate the optical ribbon in the T-peel test is between 0.01 N and 0.1 N, preferably between 0.01 N and 0.05 N.

In an embodiment, a first bead forming a first bond connects a first pair of adjacent optical fibers while the successive bond formed by the successive bead connects a further pair of adjacent optical fibers, wherein at least one optical fiber of the further pair differs from the optical fibers of the first pair. In an embodiment, at each longitudinal position of the optical fiber assembly there is at most one bond.

In a first example of this embodiment the beads will have a stepwise pattern. In an embodiment, at an end of said stepwise pattern of beads, the bead that follows the last bead of said pattern starts a subsequent stepwise pattern in the same width direction, preferably wherein the successive stepwise patterns are free from each other in that no second cured resin connecting said two stepwise patterns is present. This succession of stepwise patterns may be repeated, preferably over the length of the fibers, thereby forming a saw-tooth-like arrangement over the plurality of fibers, seen in plan view. In an embodiment of this saw-tooth like arrangement, a pitch (P) is defined having a length equal to the recurrence of the stepwise pattern in the same width direction and wherein the pitch (P) has a length that is between 10 times W and 100 times W, preferably between 15 times W and 80 times W.

Figure 4 (a&b) discloses an embodiment of an optical fiber ribbon 400 having a saw-tooth like arrangement. In this arrangement of Figure 4 none of the beads 4 are connected and the plurality of beads is arranged as a discontinuous line. The saw-tooth like arrangement has a constant repetition that follows the trace of a saw tooth wave with a pitch (P) (see Figure 4b).

Figure 5 discloses an embodiment of an optical fiber ribbon 500 having a saw-tooth like arrangement. The plurality of beads are arranged as a partly continuous line of said second cured resin. The continuous line starts with a first bead 4 being applied between the first and second optical fibers 2 seen from the most distant edge. This continuous line continues over the top of said second optical fiber, with a transition part 9, to the groove between the second and third optical fiber, and further on over the top of said third optical fiber, with a transition part 9, to the groove between the third and fourth optical fiber and so on and so on. The continuous line ends in the groove between the fifth and sixth (last) optical fiber. A new continuous lines starts again in the groove between the first and second optical fiber at a distance P of the pitch (shown in fig. 4) from the first continuous line.

Figure 6 discloses an embodiment of an optical fiber ribbon 600 having a saw-tooth like arrangement. The plurality of beads are arranged as a continuous line of said second cured resin. The difference with the embodiment shown in Figure 5 is that there is also a resin line 9' between the bead 4 between the fifth and sixth optical fiber 2 of the first saw-tooth like arrangement and the bead 4 between the first and the second optical fiber 2 of the second saw-tooth like arrangement.

In another example of the embodiment with a stepwise pattern, a first stepwise pattern has been formed in a first width direction and wherein at the end of said stepwise pattern a further stepwise pattern in the opposite direction has been formed. This succession of stepwise patterns may be repeated, preferably over the length of the fibers, thereby forming a zigzag-like arrangement over the plurality of fibers, seen in plan view. The plurality of beads have been provided in such a manner that the plurality of adjacent optical fibers of the fiber assembly, when the fiber assembly would be brought into a folded-out condition, extend in the same virtual flat plan. In an embodiment of this zig-zag like arrangement, a pitch (P) is defined having a length equal to the recurrence of the stepwise pattern in the same width direction and wherein the pitch (P) has a length that is between 14 times W and 140 times W, preferably between 18 times W and 100 times W.

Figure 2a discloses a first embodiment of an optical fiber ribbon 100 having a zig-zag like arrangement. In this arrangement none of the beads 4 are connected and the plurality of beads is arranged as a discontinuous line. Figure 2b discloses a second embodiment of an optical fiber ribbon 200 having a zig-zag like arrangement (which arrangement is shown by the black striped line connecting the middle points of the beads). The difference with figure 2a being that the bonding length l is shorter. In this arrangement none of the beads 4 are connected and the plurality of beads is arranged as a discontinuous line.

Figure 3 discloses a third embodiment of an optical fiber ribbon 300 having a zig-zag like arrangement. The plurality of beads 4 are arranged as a continuous line of said second cured resin, in the same manner as is the case in figure 6, so having the transition parts 9, 9'. The zig-zag like arrangement of the embodiments according Figures 2a, 2b and 3 has a constant repeated arrangement that follows the trace of a triangle wave with a pitch (P) as shown in Figure 2b.

In an embodiment, W is between 2 and 10 mm, preferably between 2 and 4 mm. The width W is effectively formed by the number (N) of optical fibers each having a diameter (D) so that W = D x N.

In an embodiment, at a certain longitudinal position over the width (W) of the optical fiber assembly there is one bond. In an embodiment, at each longitudinal position over the width (W) of the optical fiber assembly there is one bond. In other words, at one certain longitudinal position there is only a bond between two optical fibers, there is no bond present between another set of two adjacent optical fibers. This structure minimizes the amount of bonds required and allows maximum flexibility.

Figure 10 shows a picture of a ribbon according to the present invention having a zig-zag like arrangement with a continuous line of a cured resin.

The optical fiber ribbon of the present invention may be used to form optical fiber cable units and optical fiber cables. An example of such an optical fiber cable unit is shown in Figure 11, this unit has 24 ribbons of 12 optical fibers. This cable unit packs 288 optical fibers in a very high fiber density.

In an aspect, the present invention relates to an optical fiber cable unit comprising one or more optical fiber ribbons according to the present invention surrounded by a polymeric sheath. In another aspect, the present invention also relates to an optical fiber cable comprising one or more of the optical fiber ribbons or optical fiber cable units according to the present invention.

As stated above the present invention aims at making a flexible optical fiber ribbon that allows mass fusion splicing and that allow optical fibers to be removed/peeled from said ribbon without damaging said fibers. According to the embodiments as discussed above this is done by chemical coupling of the beads to the outer layer of the optical fibers thereby directing the point of failure during fiber peel off away from the optical fiber. There are other solutions that are able to provide similar results that are also part of the present invention. A first solution is the decrease of amount of release agent that is present in the outer layer even when the outer layer is fully cured prior to the application of the beads. The present inventors have observed that this also shifts the point of failure to either between the beads and the outer layer, to the outer layer itself or to the interface between the outer layer and the second coating layer (or ink layer). Another solution is to increase the modulus of the material of the beads, thereby making the beads (after curing) more brittle and thereby shifting the point of failure to the bead itself. The beads will break while keeping the integrity of the optical fiber.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The scope of the present invention is defined by the appended claims. One or more of the objects of the invention are achieved by the appended claims.

CLAIMS

1. A method of producing an optical fiber ribbon, said method comprising

* feeding a plurality of optical fibers to provide a longitudinal optical fiber assembly; wherein the plurality of optical fibers are in parallel and adjacent to each other; wherein each of the plurality of optical fibers comprises, from the center to the periphery thereof, a glass core, a glass cladding, a primary coating, a secondary coating and an outer layer formed of a partly cured first curable resin;

* applying a second curable resin from a dispenser to a surface of said assembly wherein the second curable resin forms a plurality of successive elongated rectilinear beads being configured to form bonds between two adjacent optical fibers of the plurality of optical fibers; and

* passing said assembly with the beads of the second curable resin applied thereon through a curing station for curing the second curable resin and for completing the curing of said partly cured first curable resin, of the outer layer, of each optical fiber to form the bonds.

2. A method according to claim 1, wherein prior to feeding the plurality of optical fibers to provide a longitudinal optical fiber assembly, a first curable resin of the outer layer of each of said plurality of optical fibers is partly cured to a curing degree of between 85% and 95% to provide optical fibers having an outer layer of a partly cured first curable resin.

3. A method according to claim 2, wherein the outer layer of second curable resin of each of said plurality of optical fibers is partly cured in an environment comprising oxygen, preferably between 500 ppm and 3500 ppm.

4. A method according to any one of the preceding claims, wherein said second curable resin is applied with a viscosity of between 100 and 1000 cPS, preferably between 100 and 400 cPs.

5. The method according to any one of the preceding claims, wherein the second curable resin is heated and applied at a temperature of maximum 60 °C.

6. The method according to any one of the preceding claims, wherein the dispenser is oscillating in a direction transverse to the longitudinal direction of the optical fiber assembly.

7. The method according to any one of the preceding claims, wherein the curing station emits Ultra Violet (UV) radiation for curing said beads of second curable resin and for completing the curing of the partly cured second curable resin for the outer layer of the optical fibers.

8. An optical fiber ribbon, comprising:

* a plurality of adjacent optical fibers extending in a longitudinal direction and arranged in parallel forming an optical fiber assembly;

* a plurality of successive elongated rectilinear beads of a second cured resin being arranged along a length of said assembly;

- each of said plurality of beads being configured to form an elongated bond between two adjacent optical fibers of the plurality of optical fibers;

wherein each of the plurality of optical fibers comprises, from the center to the periphery thereof, a glass core, a glass cladding, a primary coating, a secondary coating and an outer layer formed of a first cured resin;

wherein the second cured resin of each elongated bond is chemically coupled to the respective first cured resin of the two adjacent optical fibers.

9. The ribbon according to claim 8, wherein the first cured resin and/or the second cured resin is/are a cured Ultra Violet (UV) curable resin.

10. The ribbon according to claim 8 or 9, wherein a first bead forming a first bond connects a first pair of adjacent optical fibers while the successive bond formed by the successive bead connects a further pair of adjacent optical fibers, wherein at least one optical fiber of the further pair differs from the optical fibers of the first pair.

11. The ribbon according to any one of the claims 8-10, wherein at each longitudinal position of the optical fiber assembly there is at most one bond.

12. The ribbon according to any one of the claims 8-11, wherein the bonding material has an elongation at break of at least 150 %, preferably between 200 and 300 %.

13. The ribbon according to any one of the claims 8-12, wherein the bonding material has a modulus of elasticity of between 1 and 50 MPa.

14. The ribbon according to any one of claims 8-13, wherein said beads have been arranged on only one side of said assembly.

15. The ribbon according to any one of claims 8-14, wherein two, preferably each two, successive beads of said plurality of beads have been connected by a transition part of said second cured material, preferably wherein in plan view said transition part is S-shaped.

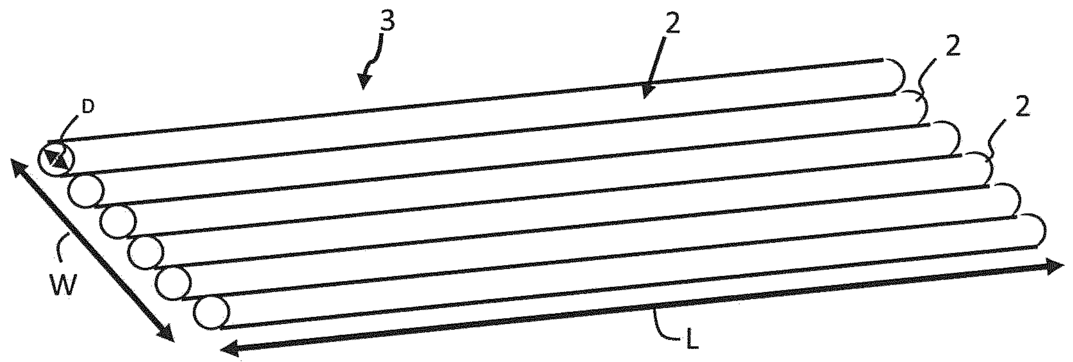

Fig. 1

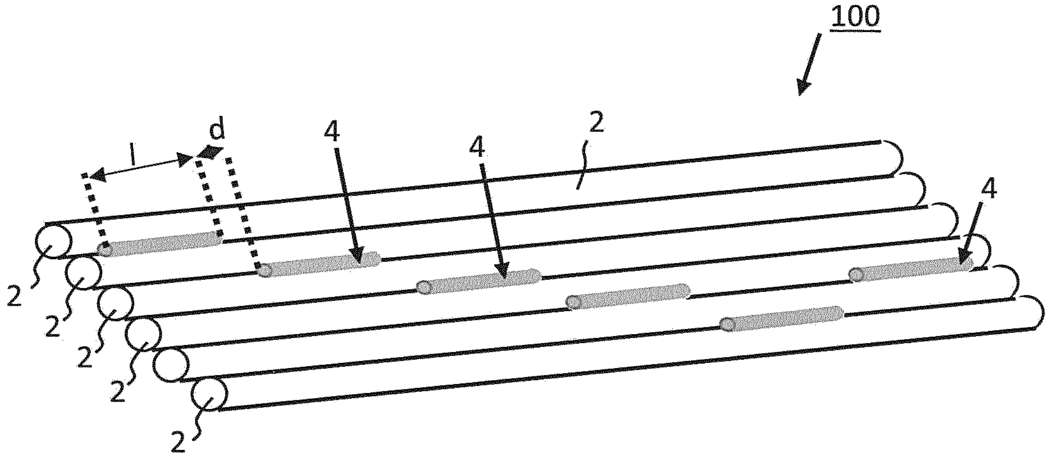

Fig. 2a

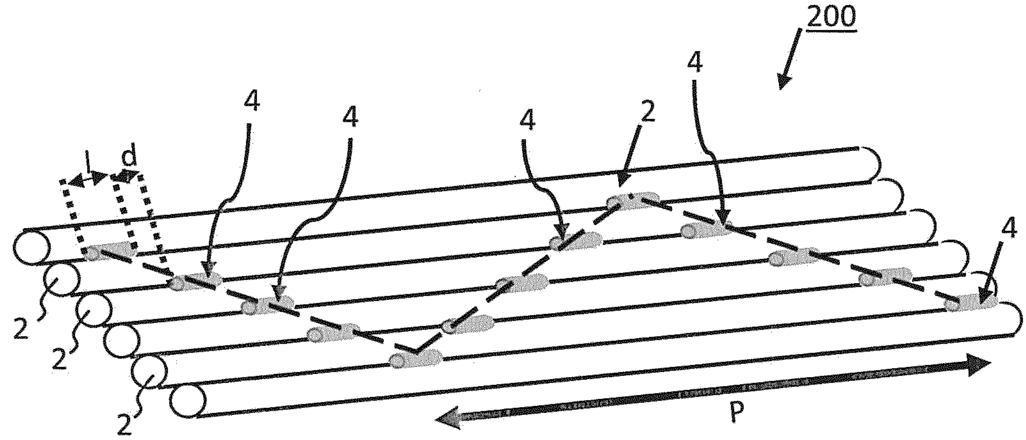

Fig. 2b

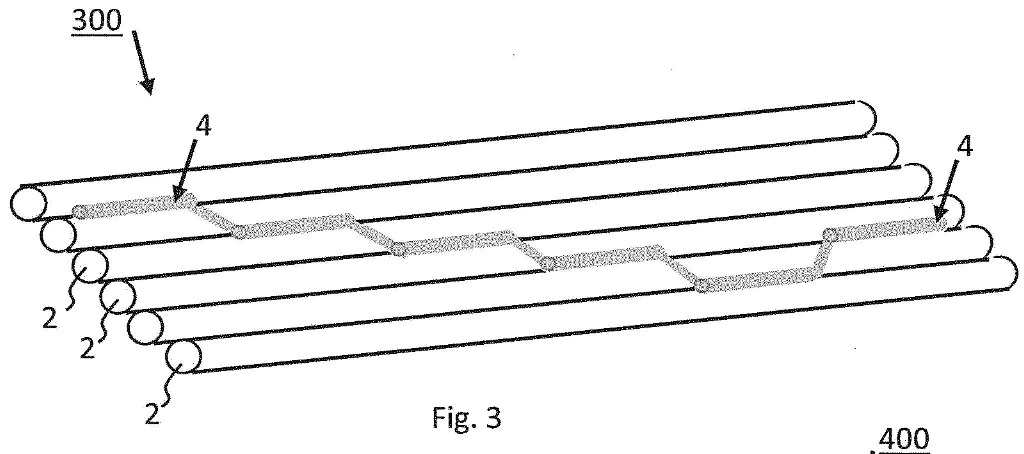

Fig. 3

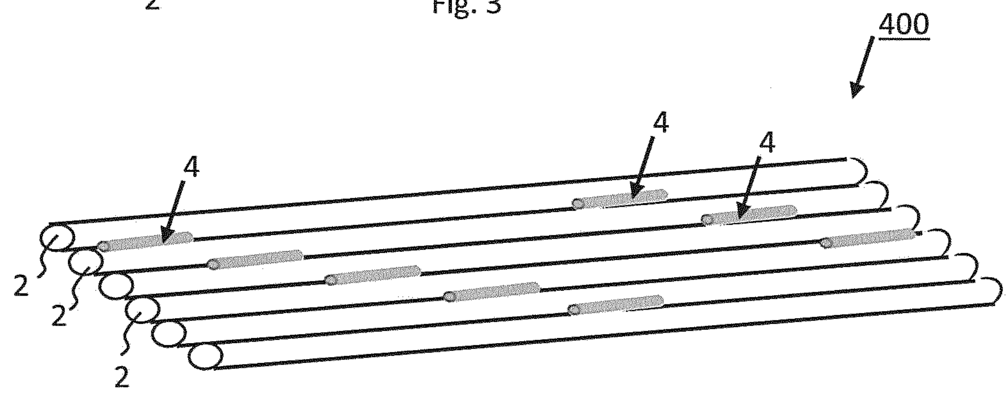

Fig. 4a

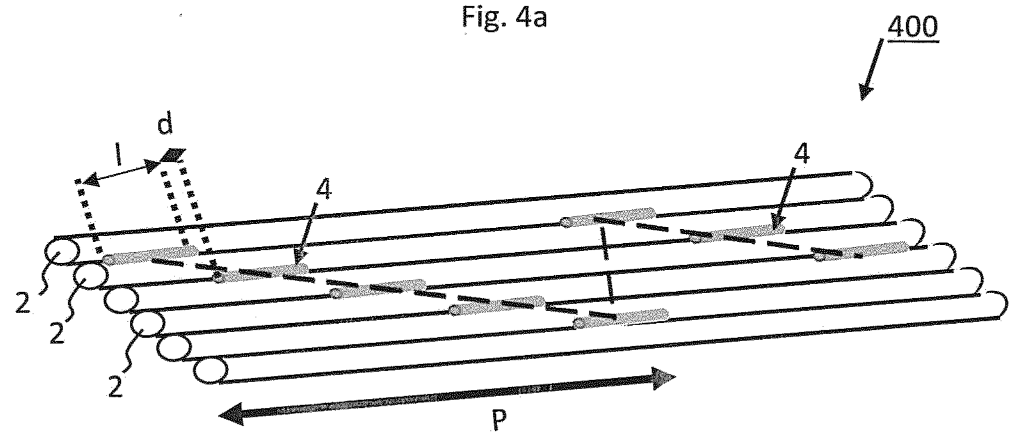

Fig. 4b

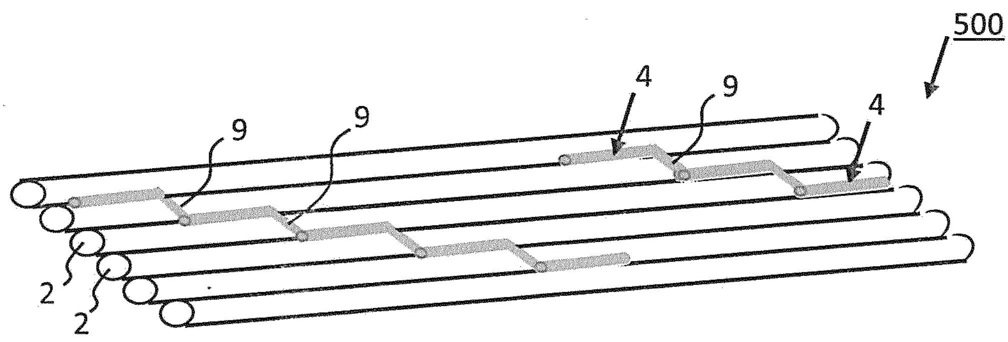

Fig. 5

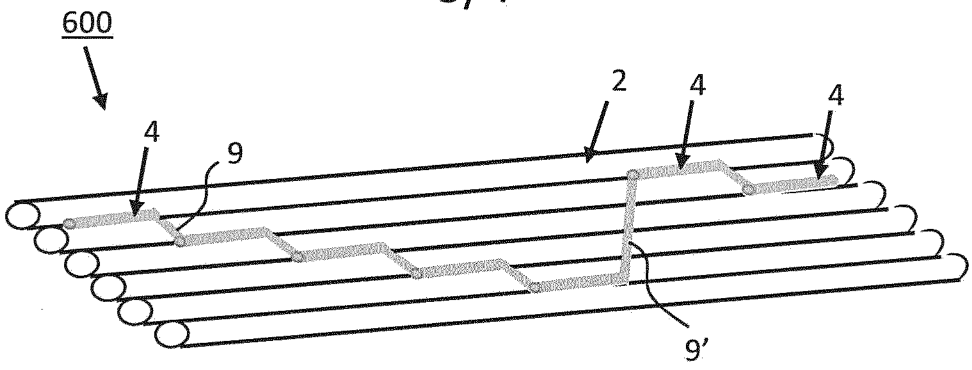

Fig. 6

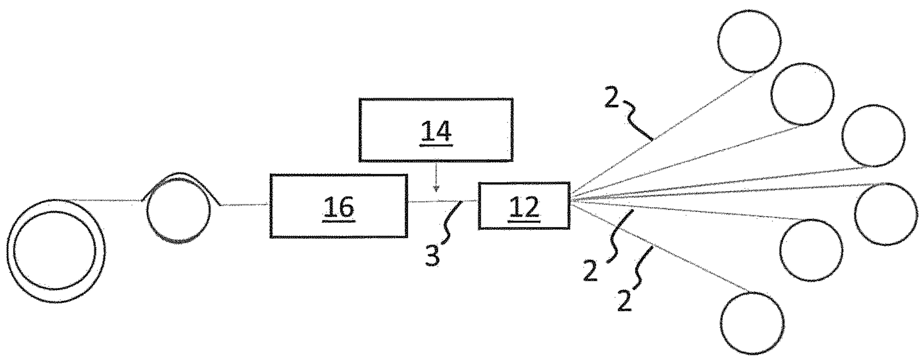

Fig. 7

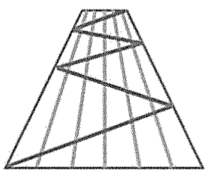

Fig. 8

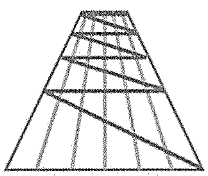

Fig. 9

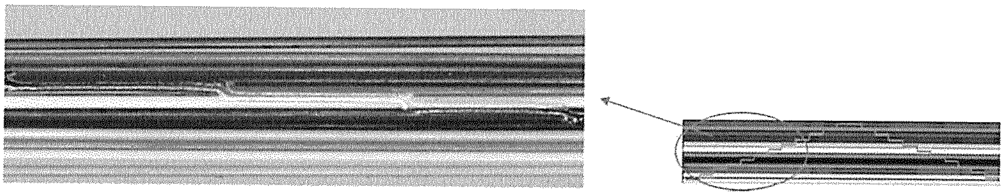

Fig. 10

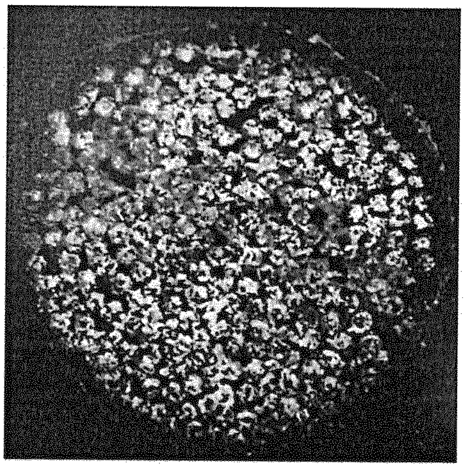

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/050899

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/44
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)
G02B

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2016/356976 A1 (SAJIMA YOSHIE [JP] ET AL) 8 December 2016 (2016-12-08) paragraphs [0042] - [0045]; figures 1-3b -----	8-14 1-7
X A	JP 2015 021734 A (SWCC SHOWA CABLE SYS CO LTD) 2 February 2015 (2015-02-02) paragraph [0020]; figures 1-3 -----	8-14 1-7
X A	US 2017/219792 A1 (DEBBAN HAROLD P [US] ET AL) 3 August 2017 (2017-08-03) paragraphs [0028] - [0031], [0039]; figures 2,3 -----	8-14 1-7

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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	Date of mailing of the international search report
28 September 2018	11/10/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ciarrocca, Marco

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/050899

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016356976 A1	08-12-2016	AU 2015347944 A1	11-08-2016
		CN 106030364 A	12-10-2016
		EP 3252511 A1	06-12-2017
		JP 2016138937 A	04-08-2016
		US 2016356976 A1	08-12-2016
		WO 2016121178 A1	04-08-2016
JP 2015021734 A	02-02-2015	JP 5695138 B2	01-04-2015
		JP 2015021734 A	02-02-2015
US 2017219792 A1	03-08-2017	JP 2017138594 A	10-08-2017
		US 2017219792 A1	03-08-2017