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(54) PROTECTIVE CONDUIT FOR HIGH-POWER LASER APPLICATIONS IN LIGHT GUIDE CABLES

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(57) **ABSTRACT**

A protective conduit for high power laser applications in light guide cables and provides a protective conduit that surrounds a light guiding fiber for high-power laser applications in light guide cables, wherein the protective conduit includes at least one plastic laser safety layer filled with at least one allotrope of carbon or filled with cork, chipped wood, wood, or wood powder, wood particles.

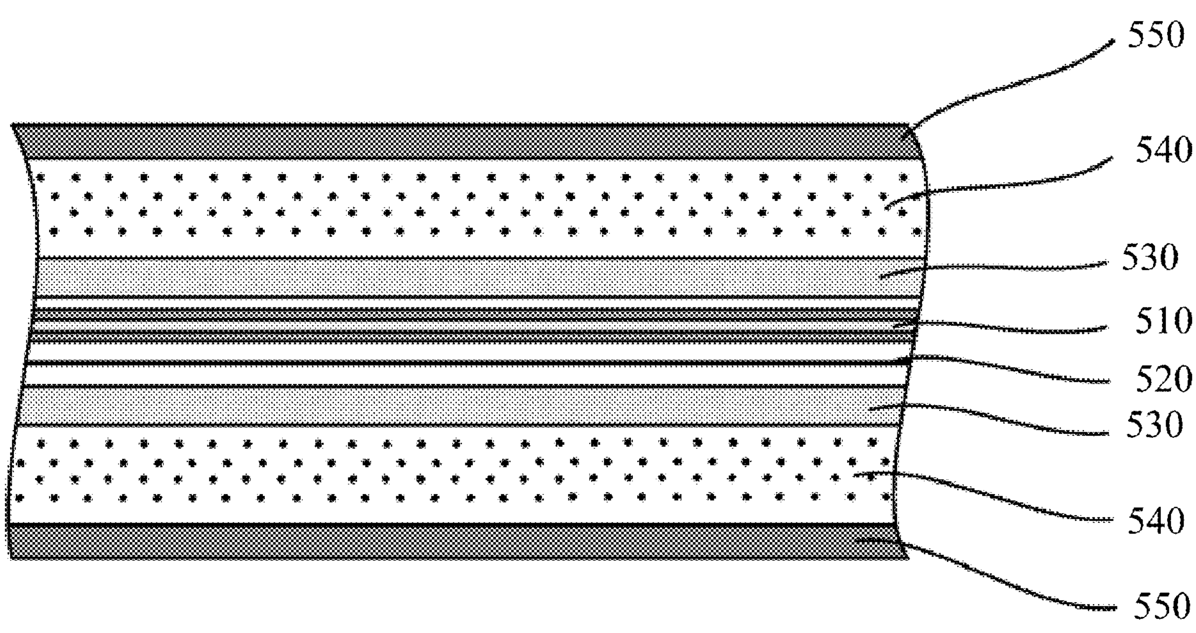


FIG. 1

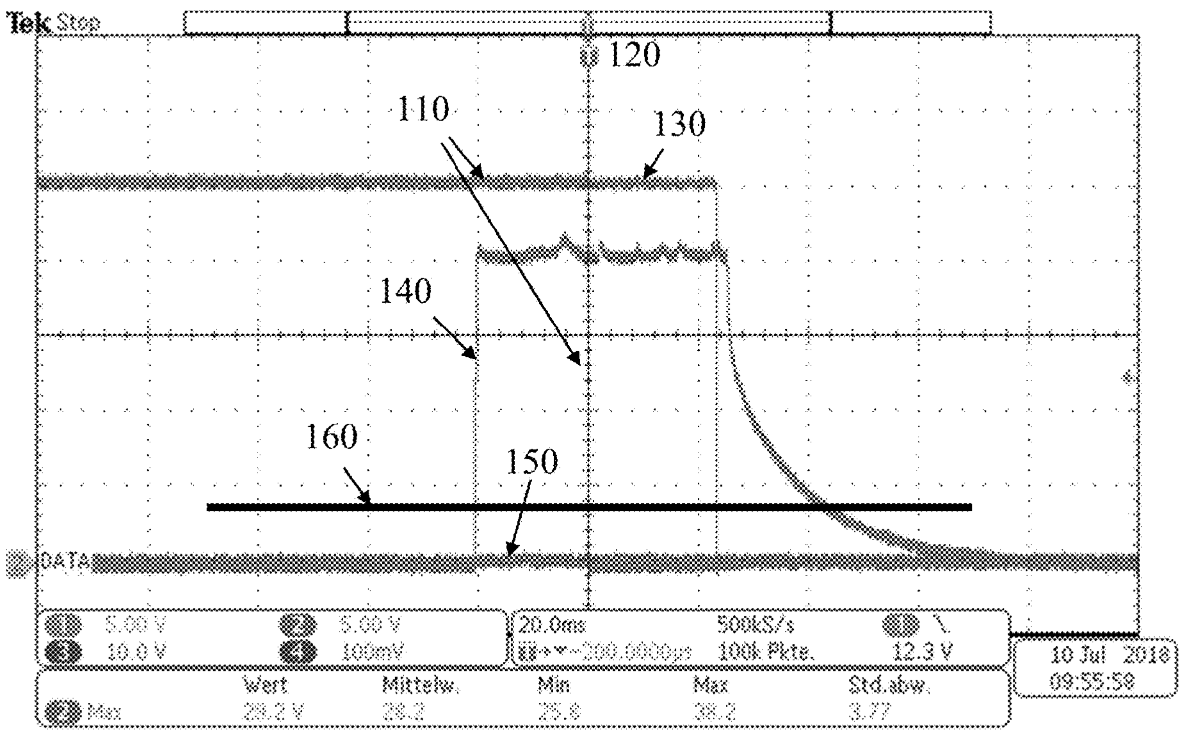
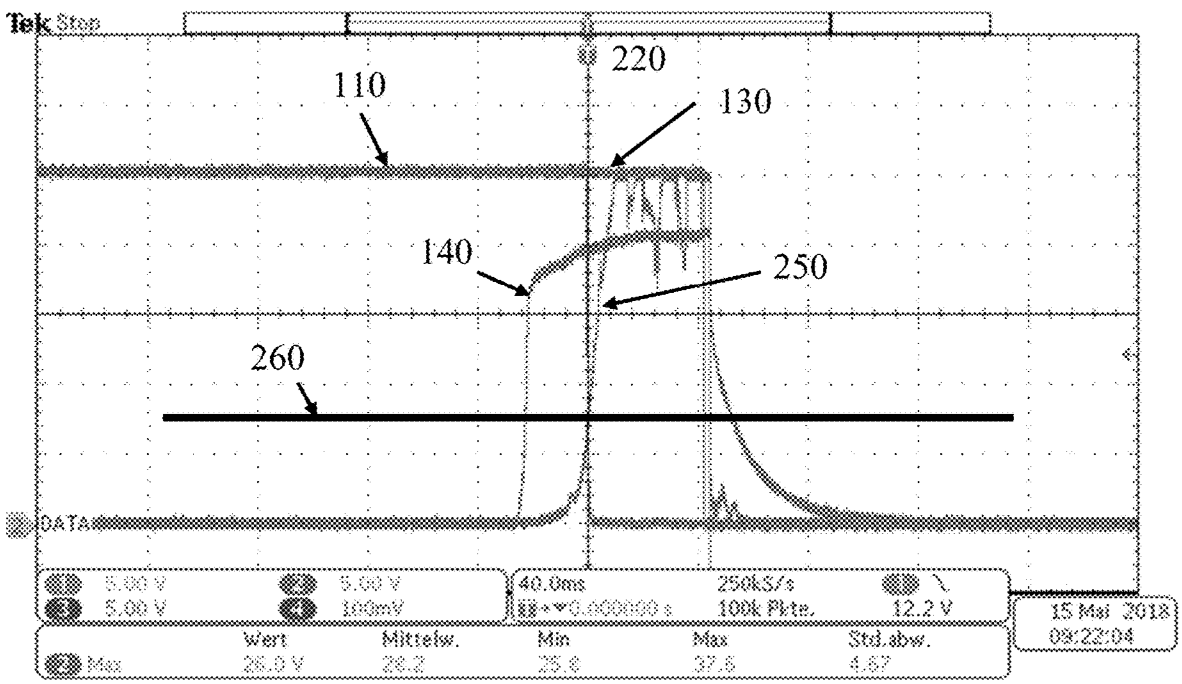

Tek Stop
120
110
130
140
160
150
DATA
5.00 V
5.00 V
10.0 V
100mV
20.0ms
500kS/s
100k Pkte.
12.3 V
10 Jul 2018
09:55:59
Wert
Mittelw.
Min
Max
Std.abw.
Max
28.2
25.8
38.2
3.77

FIG. 2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110
130
140
250
260
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5.00 V
100mV
40.0ms
250kS/s
100k Pkte.
12.2 V
15 Mai 2018
09:22:04
Wert
Mittelw.
Min
Max
Std.abw.
Max
26.0 V
28.2
25.6
37.5
4.67

FIG. 3

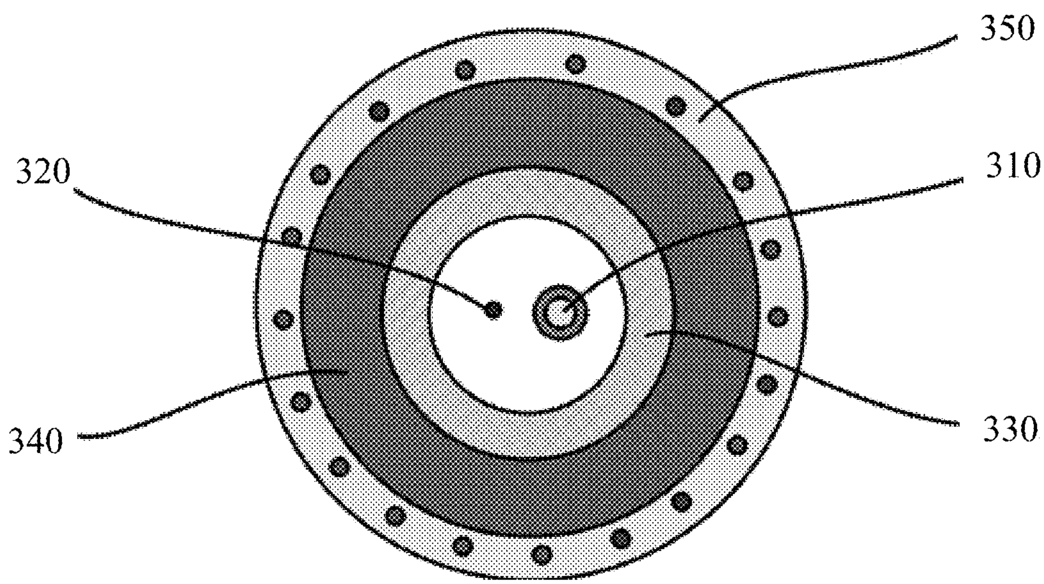


FIG. 4

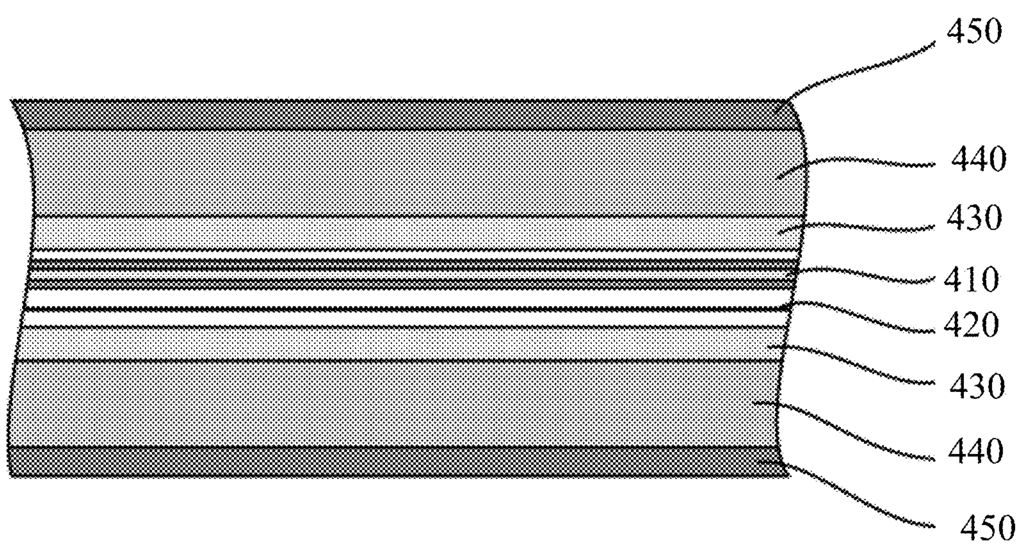
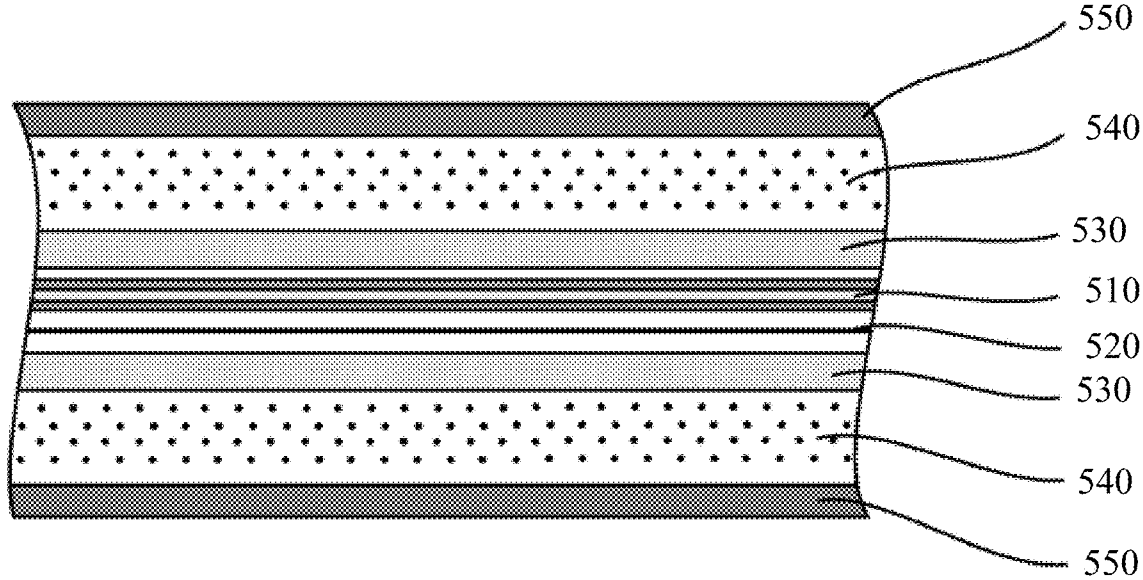


FIG. 5



PROTECTIVE CONDUIT FOR HIGH-POWER LASER APPLICATIONS IN LIGHT GUIDE CABLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] None.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention relates to a protective conduit for high power laser applications in light guide cables.

Brief Description of the Related Art

[0003] The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] Class 4 high-power laser applications use laser power which is always dangerous for health and life. Damage (such as fiber breakage) within light guiding systems such as laser light cables might release dangerous amounts of laser light causing irreversible damage to the human body. Therefore, for high-power fiber optic cables a protection against uncontrolled leaking laser radiation is prescribed for reasons of safety at work. The use of a safety system to monitor the breakage of fiber optic cables is one way of protecting against the unintended release of laser radiation. In case of fiber breakage, the laser safety system has to securely switch off the laser within a few milliseconds to avoid the leakage of laser radiation. To prevent dangerous emission of laser light at any time the fiber is enclosed said cable in a protective hose that is light proof and solid against high power laser light. The protective hose acts as a firewall and absorbs the laser light until the safety circuit has securely switched off the laser.

[0005] The prior art discloses basically two concepts for the structure of a protective conduit:

[0006] a. a sheath combining twisted or spiral metal tubing or a covering steel mesh; and

[0007] b. a sheath of a combination of a copper braiding with black, grey or transparent plastics.

[0008] The metal jacket must guarantee that the conduit is lightproof. In some embodiments several metal layers are used to increase their effect. The copper braiding combined with colored plastic is an alternative for shielding the environment against exiting laser radiation. Both approaches have in common that the laser light guiding fiber is arranged centrally in the cable, wherein a transparent polymer or plastic is surrounding the light guide fiber. The transparent polymer or plastic is surrounded by light absorbing layers.

SUMMARY OF THE INVENTION

[0009] An object of the present invention is to provide a lightproof protective conduit for a high-power laser light cable that is solid against the high-power laser light.

[0010] The present invention provides a protective conduit that surrounds a light guiding fiber for high-power laser applications in light guide cables, wherein the protective conduit includes at least one plastic laser safety layer filled with at least one allotrope of carbon.

[0011] A further aspect relates to the plastic laser safety layer that may consist of an allotrope of carbon filled thermoplastic polymer selected from the group comprising TPU, TPE and PTFE.

[0012] It is envisaged that the allotrope of carbon can be present in form of particles or clusters in a size range from 10 nanometers up to 300 micrometers.

[0013] In a further embodiment, the allotrope of carbon can be present in form of either graphite, diamond or a member of the fullerene structural family, comprising buckyballs, buckytubes or carbon nanobuds.

[0014] It is further intended that the thermoplastic polymer laser safety layer may contain up 60% (w/w) of an allotrope of carbon.

[0015] In an embodiment of the protective conduit, the thermoplastic polymer laser safety layer may have a thickness of 0.2 to 7 mm.

[0016] A further aspect of the invention relates to the thermoplastic polymer laser safety layer that surrounds an inner low friction tube made of thermoplastic polymer comprising TPU, TPE or PTFE.

[0017] Another aspect of the invention relates to a protective conduit that surrounds a light guiding fiber for high-power laser applications in light guide cables, wherein the protective conduit includes at least one plastic laser safety layer filled with cork, chipped wood, wood, or wood powder, wood particles.

[0018] Still other aspects, features, and advantages of the present invention are readily apparent from the following detailed description, simply by illustrating a preferable embodiments and implementations. The present invention is also capable of other and different embodiments and its several details can be modified in various obvious respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Additional objects and advantages of the invention will be set forth in part in the description which follows and in part will be obvious from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE FIGURES

[0019] The invention will be described based on figures. It will be understood that the embodiments and aspects of the invention described in the figures are only examples and do not limit the protective scope of the claims in any way. The invention is defined by the claims and their equivalents. It will be understood that features of one aspect or embodiment of the invention can be combined with a feature of a different aspect or aspects of other embodiments of the invention, in which:

[0020] FIG. **1** shows measured signals at approx. 26 kW laser power using a protective conduit according to the invention.

[0021] FIG. **2** shows measured signals at approx. 24 kW laser power using a protective conduit according to previous art.

[0022] FIG. **3** shows a cross section through a protective conduit according to the invention.

[0023] FIG. **4** shows a longitudinal section through a protective conduit according to the invention with fine particles.

[0024] FIG. **5** shows a longitudinal section through a protective conduit according to the invention with coarse particles.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The object of the invention is achieved by the features of the independent claims. Further embodiments are claimed in the dependent claims.

[0026] The invention provides an inner tube made of a low-friction plastic (for instance PTFE/polytetrafluoroethylene) surrounded by at least one laser safety layer of a thermoplastic polymer such as TPU (thermoplastic polyurethane) that contains allotropes of carbon, e.g. graphite particles. The surrounding laser safety layer might also be applied without using a transparent inner tube. In normal situation these components do not significantly affect the flexibility of the conduit.

[0027] If laser light should escape from the fiber, it is effectively absorbed by the carbon-containing compounds. However, in case of fiber breakage much more power is escaping leading to much higher temperatures and a pyrolytic reaction. The carbon-containing filler material becomes heated by laser radiation, dissolves, evaporates and releases the carbon. The previously bound carbon that will be dissolved as aerosol or carbon powder will absorb the laser radiation completely. As high-purity carbon is very stable it will be heat-resistant up to at least 3000 degC and does almost not exothermically react with oxygen up to that temperature. Therefore, it does not add further heat to the protective conduit but absorbs the laser energy. Furthermore, pure carbon does not melt under atmospheric pressure but it sublimes at about 3,630 degC. Its endothermic phase-change reactions absorb the laser power safely, so that the internal safety circuit has sufficient time to switch off the laser. Experiments show that such a configuration can absorb more than 26 kW of laser light for more than one hundred milliseconds. Without these carbon-containing compounds, the escaping laser light would cut through the conduit within a few milliseconds, which is too fast to securely switch of the laser safety circuit. Therefore, a protective conduit according to the invention is able to stand by far higher temperatures than a protective conduit made or covered with steel or copper.

[0028] FIG. **1** shows exemplified experimental results achieved with a protective conduit according to the invention. It shows an oscilloscope screen shot of the measured signals during a simulated fiber break at 26 kW laser power. The signal (**110**) represents the safety sensor cable with its laser-caused interruption at time (**120**) minus 12 milliseconds. The minus 12 milliseconds time delay is caused by the switching time of the laser safety switch used in this setup. Thereupon the laser switch-off signal is further delayed by 21 milliseconds (**130**). Its drop triggers the laser to switch off after a total delay time of 33 milliseconds. The difference between 12 minus milliseconds and the starting point of the laser radiation-on signal is given by the time need to interrupt the laser safety sensor cable. After a short time delay of approximately 3 milliseconds (caused by the laser safety control system), the falling laser radiation signal indicates the laser has been switched off (**140**). At any time, the TROS-sensor signal (**150**) stays far below the allowed maximum value (**160**) specified by the rules of hazardous radiation (according to TROS) applicable to safety at work. As the protective conduit according to the invention is completely light-tight the signal does not show any deviations from its noise level.

[0029] FIG. **2** shows exemplified experimental results achieved with a protective conduit according to previous art. The signal numbers **110**, **130**, **140** used are the same as in FIG. **1**. The TROS-sensor signal (**250**) exceeds the maximum value (**260**) specified by the rules of hazardous radiation (according to TROS) applicable to safety at work at time (**220**).

[0030] FIG. **3** shows a cross section through a possible variation of a protective conduit according to the invention with the light guiding fiber (**310**), monitored by a Laser safety sensor cable (**320**), concentrically surrounded by an inner tube (**330**), concentrically surrounded by a laser safety layer (**340**) and covered by a Mechanical function layer with strain relief and to avoid abrasion (**350**).

[0031] FIG. **4** shows a longitudinal section through a possible variation of a protective conduit according to the invention with the light guiding fiber (**410**), monitored by a Laser safety sensor cable (**420**), concentrically surrounded by an inner tube (**430**), concentrically surrounded by a laser safety layer filled with fine particles of allotrope of carbon such as graphite (**440**) and covered by a mechanical function layer with strain relief and to avoid abrasion (**450**).

[0032] FIG. **5** shows a longitudinal section through a possible variation of a protective conduit according to the invention with the light guiding fiber (**510**), monitored by a Laser safety sensor cable (**520**), concentrically surrounded by an inner tube (**530**), concentrically surrounded by a laser safety layer filled with coarse particles of allotrope of carbon that form discrete clusters homogeneous embedded into a transparent polymer matrix (**540**) and covered by a mechanical function layer with strain relief and to avoid abrasion (**550**). This setup is particularly advantageous as it allows the laser radiation to penetrate deeper into the laser safety layer and release more carbon at the same time.

[0033] The present invention provides a protective conduit that solid for lasers with an output of at least 20 kW for a beam duration of at least 30 milliseconds after detecting fiber breakage. At the same time, the protective hose according to the invention is far more light weight and flexible than conventional metal based conduits—especially in application where torsion needs to be applied to the protective conduit, such as 6 axis robot applications.

[0034] The foregoing description of the preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The embodiment was chosen and described in order to explain the principles of the invention and its practical application to enable one skilled in the art to utilize the invention in various embodiments as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents. The entirety of each of the aforementioned documents is incorporated by reference herein.

1. A protective conduit that surrounds a light guiding fiber for high-power laser applications in light guide cables, wherein the protective conduit includes at least one plastic laser safety layer filled with at least one allotrope of carbon in an amount and a configuration sufficient to absorb substantially all of a laser power contained with the light guiding fiber for a predetermined amount of time.

2. The protective conduit of claim **1**, wherein the plastic laser safety layer consists of an allotrope of carbon filled thermoplastic polymer selected from the group comprising TPU, TPE and PTFE.

3. The protective conduit of claim **1**, wherein the allotrope of carbon is present in form of particles or clusters in a size range from 10 nanometers up to 300 micrometers.

4. The protective conduit of claim **1**, wherein the allotrope of carbon is present in form of either graphite, diamond or a member of the fullerene structural family, comprising buckyballs, buckytubes or carbon nanobuds.

5. The protective conduit of claim **1**, wherein the thermoplastic polymer laser safety layer contains up 60% (w/w) of an allotrope of carbon.

6. The protective conduit of claim **1**, wherein the thermoplastic polymer laser safety layer has a thickness of 0.2 to 7 mm.

7. The protective conduit of claim **1**, wherein the thermoplastic polymer laser safety layer surrounds an inner low friction tube made of thermoplastic polymer comprising TPU, TPE or PTFE.

8. A protective conduit that surrounds a light guiding fiber for high-power laser applications in light guide cables, wherein the protective conduit includes at least one plastic laser safety layer filled with cork, chipped wood, wood, or wood powder, wood particles.

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