

United States**Carpenter**

[11] 3,830,667

[45] Aug. 20, 1974

**[54] METHOD OF MAKING FLEXIBLE
FIBEROPTIC BUNDLES****[75] Inventor:** George J. Carpenter, Southbridge,
Mass.**[73] Assignee:** American Optical Corporation,
Southbridge, Mass.**[22] Filed:** May 12, 1972**[21] Appl. No.:** 252,866**Related U.S. Application Data****[62]** Division of Ser. No. 97,719, Dec. 14, 1970,
abandoned.**[52] U.S. Cl.**..... 156/155, 65/4, 156/167,
156/168, 156/173, 156/174, 156/175,
156/180, 156/296**[51] Int. Cl.**..... B32b 31/00**[58] Field of Search** 156/180, 174, 296, 173,
156/155, 167, 168, 175; 65/4**[56] References Cited****UNITED STATES PATENTS**

3,004,368 10/1961 Hicks 350/96 B

3,033,731	5/1962	Cole.....	65/4 X
3,554,721	1/1971	Gardner.....	65/4
3,567,549	3/1971	Hoffmeister et al.....	65/4 X
3,580,775	5/1971	Siegmund.....	65/4 UX
3,615,313	10/1971	Phanenf.....	65/4
3,624,816	11/1971	Strack et al.....	65/4 X
3,669,772	6/1972	Strack.....	65/4
3,674,452	7/1972	Strack.....	65/4
3,690,853	9/1972	Law.....	65/4

Primary Examiner—Stephen J. Lechert, Jr.*Attorney, Agent, or Firm*—William C. Nealon**[57] ABSTRACT**

A flexible fiberoptic bundle of light-conducting multi-fibers wherein each multifiber comprises a plurality of fused together individually glass-clad glass monofilaments having overcladdings of glass along their respective lengths. The overcladdings are removed throughout at least intermediate portions of the lengths of each multifiber in the fused bundle to free corresponding portions of the glass-clad glass monofilaments whereby both the flexibility of the bundle and its resistance to fiber breakage are enhanced.

6 Claims, 6 Drawing Figures

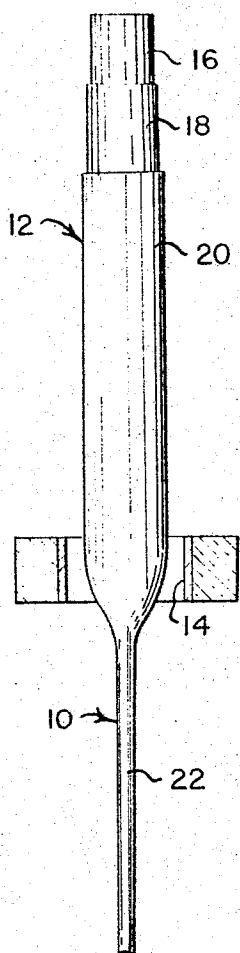


FIG. 1

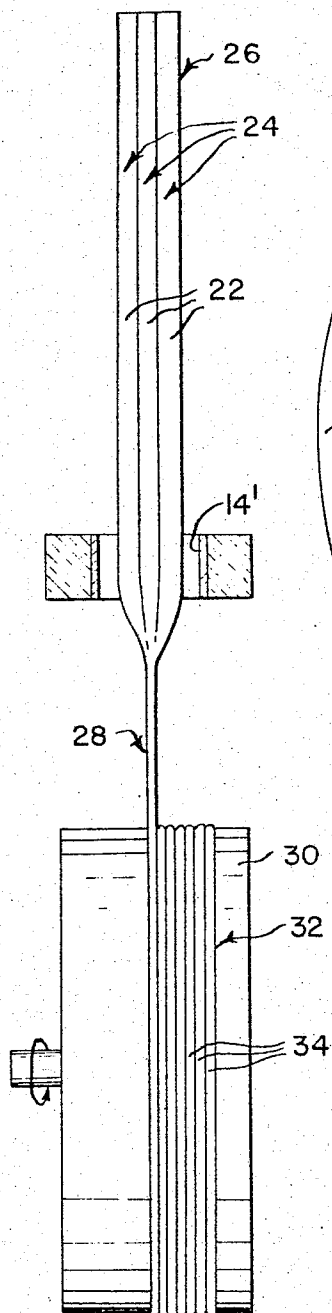


FIG. 2

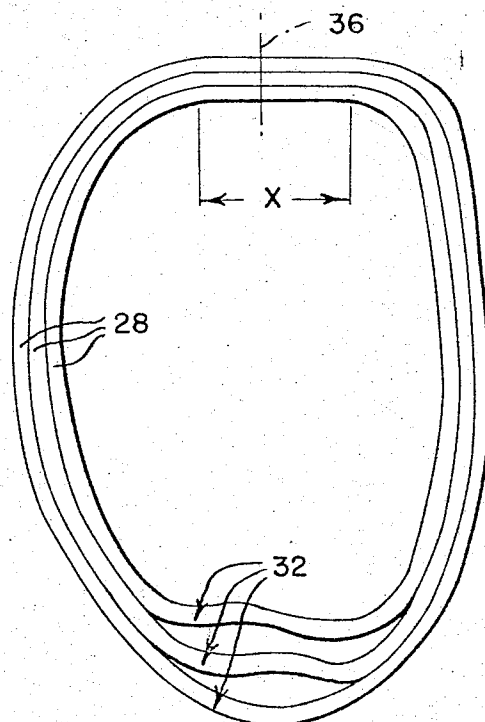


FIG. 3

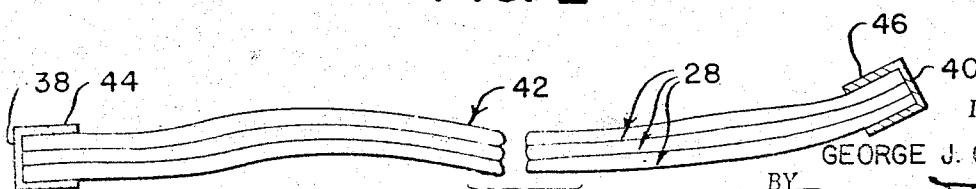


FIG. 4

INVENTOR.
GEORGE J. CARPENTER

BY *Noble J. Williams*
ATTORNEY

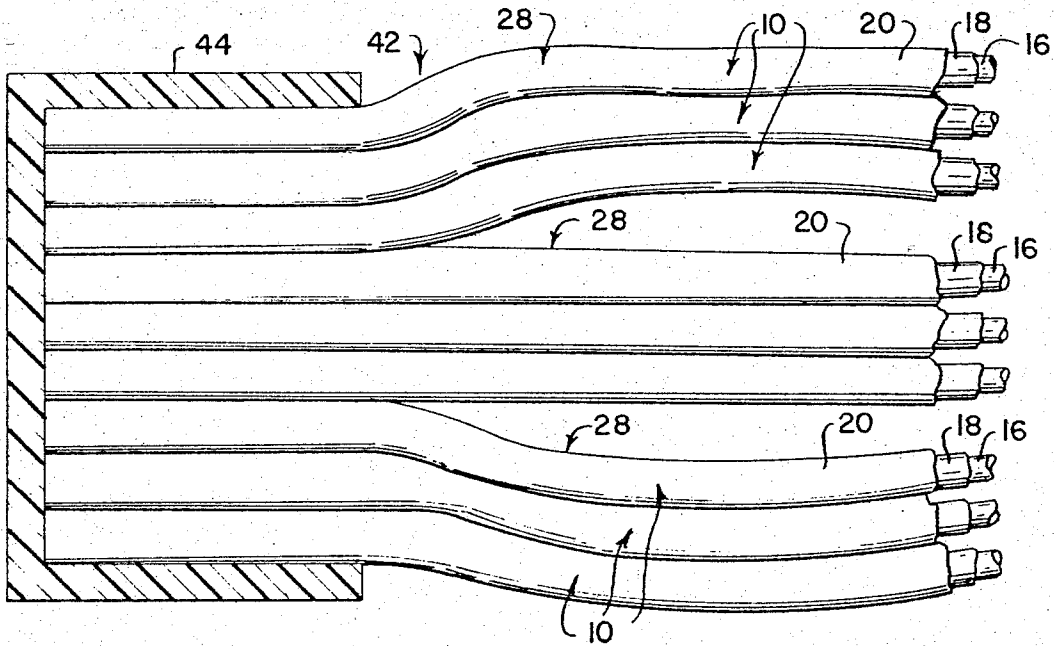


FIG. 5

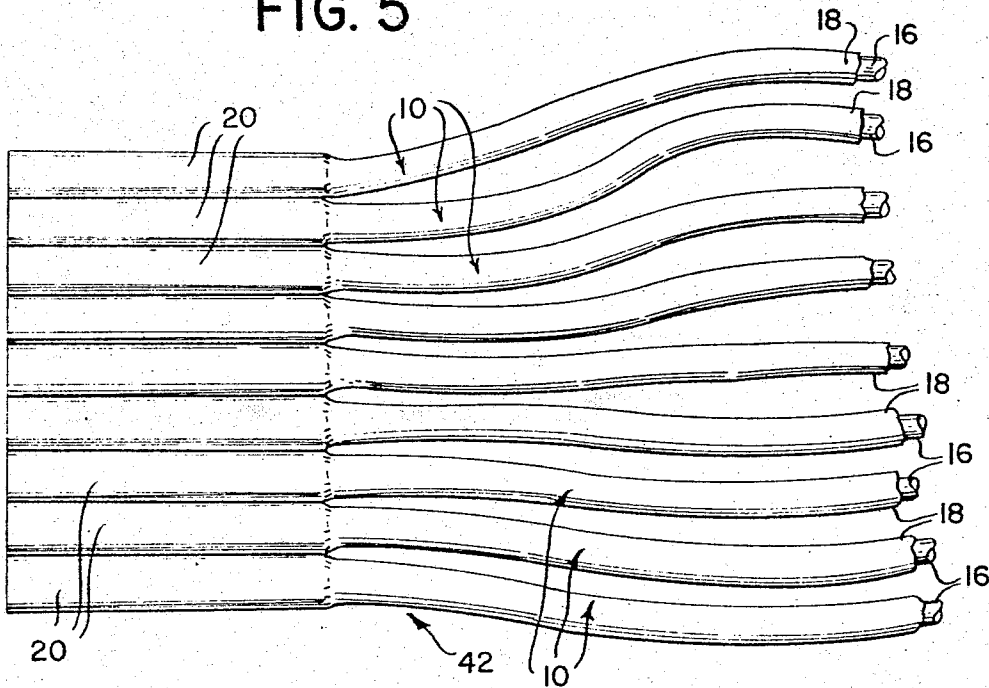


FIG. 6

INVENTOR.
GEORGE J. CARPENTER

BY *Robert J. Williams*
ATTORNEY

METHOD OF MAKING FLEXIBLE FIBEROPTIC BUNDLES

This is a division, of application Ser. No. 97,719, filed Dec. 14, 1970, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

Fiber optics with particular reference to flexible image-transmitting fiber bundles.

2. Description of the Prior Art

In dealing more particularly with the manufacture of flexible image-transmitting or coherent fiberoptic bundles, usually called "fiberscopes," there is the long-standing need for easier and more economical fabrication procedures, improvement in coherency (i.e., image resolving capabilities of the finished bundle), greater bundle strength and a reduction of the adverse effect of fiber breakage upon image definition.

The foregoing has, to some extent, been accomplished by U.S. Pat. No. 3,033,731, but not entirely without problems.

In seeking greater coherency through better fiber alignment and bundle packing fraction it is necessary to turn to the use of larger fibers which may, of course, be multifibers. The use of larger fibers, however, renders finished bundles less flexible and more susceptible to breakage. Adding to this, the breaking of a large fiber (multifiber), leaves a correspondingly large void or non-transmitting area in the bundle. Thus, as fiber size is increased, degradation of transmitted optical images resulting from fiber breakage increases by an order of magnitude corresponding to the increase in fiber size.

The present invention, in dealing with the manufacture of flexible fiberoptic bundles, particularly of large format, relates to matters of avoiding the aforementioned problems of bundle fragility and optical image degradation resulting from fiber breakage by minimizing both. Greater than usual fiber alignment and bundle packing fraction attended by improved bundle coherency and optical image resolution is achieved.

SUMMARY OF THE INVENTION

The foregoing objectives are accomplished by utilizing, as much as possible, the flexible fiberoptic bundle manufacturing technique of U.S. Pat. No. 3,033,731 which obviates some of the earlier problems of fiber hand-packing and aligning operations. In this regard, a light-conducting fiber (multifiber) is wound upon a drum to form an endless ribbon of a width approximately equal to the width or lateral dimension desired of the ultimate flexible fiber bundle. A number of ribbons, so formed, are stacked one over another throughout a relatively short section of their respective lengths and cemented, fused or otherwise connected together. The assembly is then cut to form geometrically identical opposite endfaces of the resulting flexible fiberoptic bundle.

In accordance with the present invention, however, the multifiber used to form each of the aforementioned endless fiber ribbons is comprised of a preselected number of fused together light-conducting monofilaments. Each monofilament has the usual high refractive index core, a lower refractive index first cladding and, additionally, and overcladding of readily leachable, acid soluble glass. The latter is frequently referred to in the trade as a "weathering" glass. The multifiber, being

suitably flexible for the winding of endless ribbons is of exceptionally large cross-sectional size, e.g., greater than 60 microns in thickness, so as to offer the important advantage of easy and accurate side-by-side alignment of convolutions thereof in the winding operation as well as exceptional ease in handling of the ribbons in making the fiber bundle assembly as outlined hereinabove.

The bundle, however, being relatively inflexible and fragile at this stage, is prepared for leaching. Its opposite ends are coated with an acid-resistant plastic, wax or the like and the remaining intermediate portion of the length of the bundle is exposed to a glass leaching medium, e.g., hydrochloric acid. The leaching medium, in being free to circulate in between and around the multifibers, readily effects removal of the overcladdings of the monofilaments of each multifiber. This greatly increases the flexibility of the fiberoptic bundle and correspondingly reduces image degradation resulting from accidental breakage of individual loose fibers (monofilaments) of the bundle. Thus, large losses of image definition which would ordinarily result from individual multifiber fiber breakage are avoided.

While leached fiberoptic bundles per se, are known (e.g., as shown in U.S. Pat. No. 3,004,368) the fiber aligning and packing techniques in such cases have not been entirely satisfactory, particularly when the resulting bundles are required to transport optical images. Furthermore, there has been a definite limitation as to the thickness or cross-sectional size of a bundle which can be properly and efficiently leached to free its fibers without effecting damage thereto. This has been overcome by the present invention wherein large format fiber bundles of individually flexible multifibers are leached to disconnect respective monofilament elements of each multifiber.

The invention will be more clearly understood by reference to the following detailed description when taken in conjunction with the accompanying drawing.

DESCRIPTION OF THE DRAWINGS

FIG. 1 diagrammatically illustrates a proposed technique for making overclad glass-clad fiber from which multifiber may be produced according to the present invention;

FIG. 2 diagrammatically illustrates a technique for producing an endless ribbon of a multifiber made up of a plurality of the aforementioned overclad glass-clad glass fibers;

FIG. 3 diagrammatically illustrates an assembly of the endless multifiber ribbons from which a flexible bundle may be formed;

FIG. 4 illustrates the type of flexible fiber bundle resulting from cutting transversely through the assembly of FIG. 3, opposite ends of the bundle in this case are shown as having protective coverings thereover;

FIG. 5 is a greatly enlarged fragmentary, partially cross-sectioned elevational view of one end of the fiber bundle shown in FIG. 4; and

FIG. 6 is a similarly greatly enlarged elevational view of the same bundle following treatment thereof to enhance the flexibility of the bundle and its resistance to breakage according to principles of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring more particularly to FIGS. 1-3, the opera-

tions illustrated therein represent a technique for forming a flexible bundle of optical fibers as follows:

A monofilament 10 is formed of a rod and tube assembly 12 by the well-known practice of heating and drawing the assembly through a suitable heating element 14. In the present case, assembly 12 is comprised of a rod 16 of high refractive index core glass, an inner intermediate sleeve 18 of cladding glass having a relatively low index of refraction and an outer tube 20 of acid-leachable "weathering" glass or metallic casing material having a coefficient of thermal expansion and melting temperature compatible with the core and cladding materials 16 and 18. Exemplary leachable materials are borosilicate glass or aluminum which may be leached with hydrochloric acid and sodium hydroxide respectively. Other glasses and metallic materials similar to borosilicate glass and aluminum may be used also as tube 20. A preferred material would be a silica-free acid-soluble glass having, for example, a composition of 47% (by weight) boron trioxide (B_2O_3), 45% (by weight) barium oxide (BaO) and 5% (by weight) lanthanum oxide (La_2O_3).

Monofilament 10, thus formed, has the usual light-conducting core of high refractive index glass 16, a first cladding of relatively low refractive index glass 18 and, additionally, a unique overcladding 22 of the aforementioned weathering or leachable material 20. A plurality of sections 24 of monofilament 10 are cut or broken away from the monofilament and bundled together as a boule 26 (FIG. 2) from which a multifiber 28 is drawn through heating element 14'. For purposes of illustration, boule 26 is shown as being three fiber diameters wide whereby the multifiber 28 comprises a fused together rectangular array of nine monofilaments (sections 24). Any desired greater or lesser number of monofilaments (sections 24) may be used to form boule 26 and multifiber 28.

Fabrication of the ultimate flexible bundle of optical fibers is accomplished by winding multifiber 28 on a suitable former, e.g. drum 20, to produce endless ribbon 32 having a preselected number of tightly packed convolutions 34. These convolutions may be wound vertically, one over another, or horizontally, as shown. A plurality of similar ribbons are wound, removed from the winding drum and stacked together in accurately superimposed relationship with each other throughout a short portion x (FIG. 3) of their corresponding lengths. These ribbons 32 are cemented, fused or otherwise secured together in portions x thereof and sawn or otherwise cut, e.g., along line 36, to form opposite ends 38 and 40 of flexible fiber bundle 42 (see FIG. 4) which results from opening the assembly of ribbons after cutting. The ends 38 and 40 of bundle 42 are usually subsequently optically finished as light-receiving and light-emitting opposite faces respectively of the bundle. Those interested in greater details concerning the technique of forming optical fiber image-transmitting bundles of endless fiber ribbons, as briefly described hereinabove, may refer to U.S. Pat. No. 3,033,731.

Referring now to flexible fiber bundle 42 of FIG. 4, it should be understood that the term "flexible" is used reservedly at this point in the process of the present invention. In other words, bundle 42 is free to flex intermediately of its rigid opposite ends since the lengths of multifiber 28 therebetween are not connected together. Accordingly, the bundle is flexible only to the

extent of the individual flexibility of each multifiber 28. Each length of multifiber 28, being formed of a plurality of fused together monofilaments is, by comparison to the size and flexibility of each monofilament, relatively rigid and similarly relatively fragile in bending. Thus, the present invention involves further processing of bundle 42 wherewith, as an objective, the bundle is rendered considerably more flexible and, similarly, considerably less fragile. This is achieved by leaching overcladdings 22 of materials 20 of the individual monofilaments in the bundle away from the flexible intermediate sections of their respective lengths.

Since the connected together integrity of opposite ends 38 and 40 of bundle 42 must be preserved so that these ends may ultimately become light-receiving and light-emitting opposite ends of the bundle, coverings 44 and 46 of plastic, wax or other materials which are resistant to acid are applied to bundle 42 over these ends 38 and 40 (FIGS. 4 and 5). These coverings, being of a material selected for its insolubleness in acid or other leaching solutions may be applied by painting, dipping or taping of ends 38 and 40 of the bundle.

Referring more particularly to FIG. 5 which is a greatly enlarged fragmentary elevational view of one end of bundle 42, it can be seen that, prior to leaching of the intermediate portion of the bundle, its multifibers 28 each comprise a plurality of fused together monofilaments which are all fixedly secured together beneath covering 44, and likewise beneath covering 46 (FIG. 4). Intermediately of these coverings, however, they are individually flexible but only to an extent limited by their relatively large cross-sectional size.

Enhancing the flexibility of bundle 42 and correspondingly decreasing its fragility according to principles of this invention, the bundle, with coverings 44 and 46, is immersed in a bath of a preselected leaching solution such as 5 percent (by volume) hydrochloric acid maintained at a temperature of approximately 65° C. This solution, of course, is only useful when the overcladdings 22 are formed of leachable glass. For overcladdings 22 of metal such as aluminum or its equivalent, sodium hydroxide may be used.

The leaching solution would be placed in a tank, dish or suitable receptacle, not shown, which is selected to be of a size sufficient to receive bundle 42.

It is particularly pointed out that, with multifibers 28 being disconnected throughout the intermediate portion of bundle 42 and spaced from each other or adapted to be so spaced by movement of bundle 42 in the leaching bath by vibration of the bath or bundle or both or by pumping of the leaching bath through these multifibers, relatively rapid and complete separation of all monofilaments 10 from each other by leaching of their overcladdings is effected. Thus, large format highly flexible bundles of optical fibers can be readily produced according to the present invention concept. More particularly, building of the large bundle format can be achieved with exceptional accuracy in fiber alignment and packing fraction. This being the result of the now possible use of large fiber (multifiber) in the initial fabrication (before leaching) of the bundle.

Comparing FIG. 6 with FIG. 5 wherein the same fragmentary end section of the bundle is shown in each case but with covering 44 removed and monofilament 10 released in FIG. 6, the unique results of the invention can be seen. In this respect, the initial secured together integrity of end portions of the bundle is main-

tained, i.e. with connected together materials 20 of the fiber overcladdings, while each and every monofilament 10 throughout the intermediate portion of the bundle is disconnected from all other monofilaments and free to flex individually. In this way, bundle 42 is given a substantial increase in its overall flexibility which corresponds to the decrease in cross-sectional size from multifiber 28 to monofilament 10. Also, the bundle is given a corresponding decrease in its fragility and degradation of transmitted optical images occurring from fiber breakage. In the latter respect, the breaking of one monofilament in bundle 42 (FIG. 6) will obviously affect only a relatively very small portion of an overall image transmitted through the bundle while breakage of a larger fiber (e.g., the size of multifiber 28 in the FIG. 5) would affect a considerably larger portion of such an overall image intended to be transferred through the bundle. An intent and purpose of the invention is to avoid the latter.

I claim:

1. The method of making a flexible bundle of light-conducting fibers having oppositely disposed light-receiving and light-emitting end faces comprising:
 assembling a plurality of lengths of monofilament in juxtaposed relationship with each other as a boule, said lengths of monofilament in each case comprising a core of glass having a high refractive index, said core being clad with a layer of glass of relatively low refractive index and an overcladding of fusible leachable material;
 heating and drawing the boule into the form of a multifiber wherein said monofilament overcladdings are fused together as a unit;
 winding said multifiber into the form of a plurality of

endless ribbons each comprising a multiplicity of closely packed juxtapositioned convolutions;
 securing said convolutions of each of said ribbons together throughout corresponding relatively short portions of their respective extensions;

assembling said plurality of ribbons into a bundle with said short portions thereof superposed and all secured together as a unit;

cutting transversely through said unit of secured short portions of said ribbons to form said convolutions of multifiber into a plurality of individual lengths of multifiber with corresponding opposite ends thereof constituting said end faces of said bundle; and

leaching at least the major portion of all of said overcladdings away from all monofilaments of all of said multifibers intermediately of said end faces of said bundle.

2. The method according to claim 1 wherein said ribbons are fused together throughout said corresponding relatively short portions of their respective extensions.

3. The method according to claim 1 wherein said ribbons are cemented together throughout said corresponding relatively short portions of their respective extensions.

4. The method according to claim 1 wherein said overcladding material is an acid-soluble glass.

5. The method according to claim 4 wherein said glass is a silica-free composition.

6. The method according to claim 1 wherein said overcladdings are formed of a metallic material.

* * * * *