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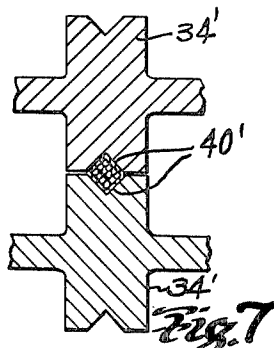
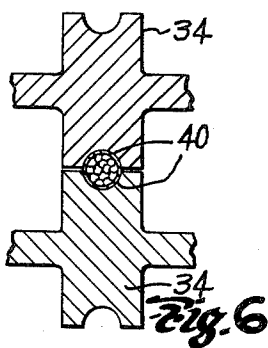
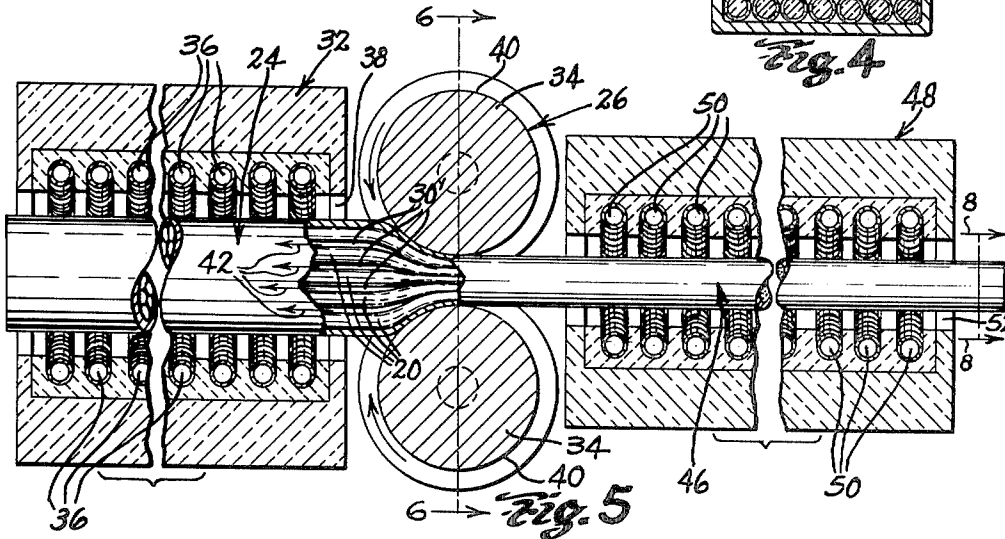
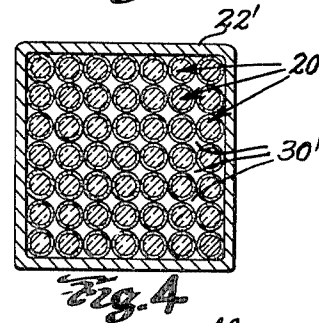
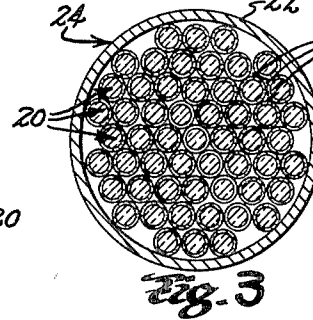
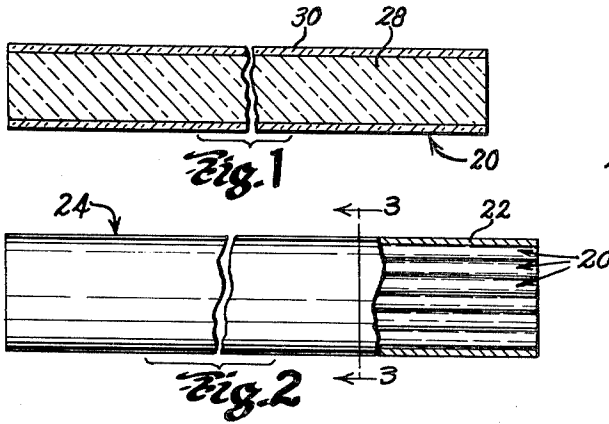
Sept. 1, 1966

G. A. GRANITSAS
MULTI-ELEMENT ENERGY-CONDUCTING STRUCTURES
AND METHOD OF MAKING THE SAME

3,204,326

Filed Dec. 19, 1960

2 Sheets-Sheet 1



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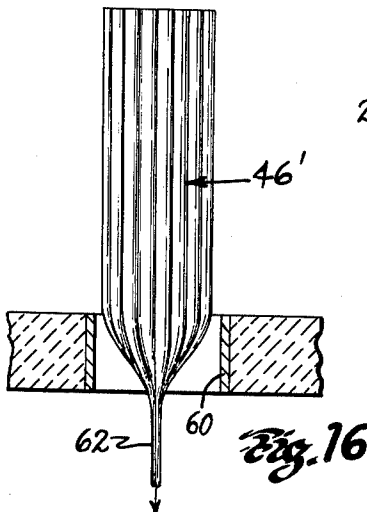
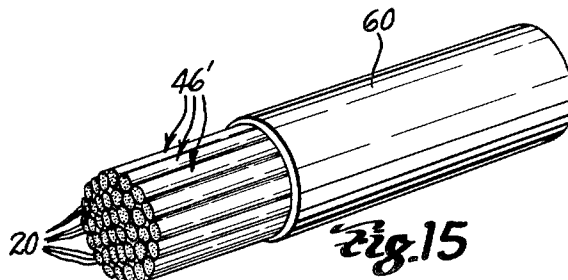
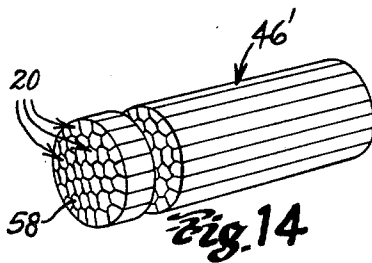
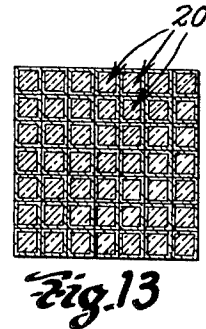
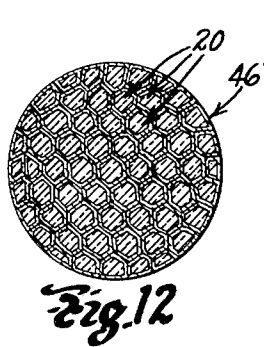
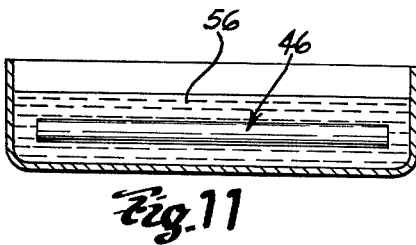
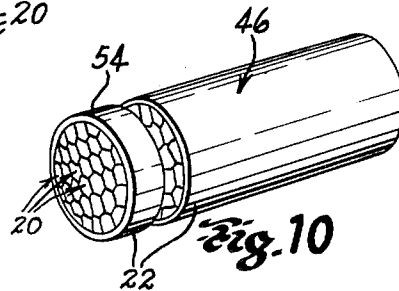
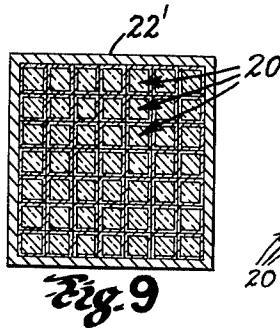
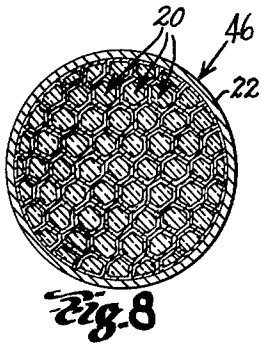
Sept. 7, 1965

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MULTI-ELEMENT ENERGY-CONDUCTING STRUCTURES
AND METHOD OF MAKING THE SAME

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2 Sheets-Sheet 2



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3,204,326

MULTI-ELEMENT ENERGY-CONDUCTING STRUCTURES AND METHOD OF MAKING THE SAME

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4 Claims. (Cl. 29—155.5)

This invention relates to devices formed of a plurality of energy-conducting elements and has particular reference to a structure wherein said elements are arranged in side-by-side fused relation with each other and method of making the same.

A principal object of the invention is to provide an improved structure of the above character wherein the adjoining areas of fusion between the elements thereof are formed securely and substantially free of interfacial defects by the practice of a fabrication technique which is simple to perform, highly reliable in duplication and requires a minimum of expenditure for equipment.

Another object is to integrate a bundle of individual rod-like energy-conducting elements by means of a heating and rolling operation adapted to compact and zone fuse said elements progressively along the length of said bundle.

Another object is to support said energy-conducting elements within a removable metallic sheath having a coefficient of expansion which is substantially the same or slightly higher than that of the material of said elements during said rolling operation.

Another object is to provide by the employment of said metallic sheath, means for preventing adherence of the materials of said elements to rolling equipment used to integrate and bring about fusion thereof and further providing attachment means upon the resultant rolled structure by means of which said structure or parts removed therefrom may be readily attached to articles intended to receive the same.

Another object is to provide a supporting sheath of the above character which can be readily removed, if desired, from the resultant rolled structure of the energy-conducting elements without adversely affecting the physical or energy-transmitting properties of said elements.

Another object is to provide by the technique of this invention a novel and simple method for automatically removing air and gases from interstices existing between the elements of the initial bundle thereof to render the interfacial areas of the finally integrated and fused structure bubble free.

Another object is to provide a structure of fused energy-conducting elements of the above character from which plate-like articles or articles of filament-like size and shape or other configurations can be readily formed.

Other objects and advantages of the invention will become apparent from the following description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is an enlarged longitudinal cross-sectional view of an energy-conducting element which is exemplary of the type used in the fabrication of structures relating to this invention;

FIG. 2 is a partially cross-sectional side view of an assembly embodying a plurality of elements of the above-mentioned character placed within a metallic tubular supporting member;

FIG. 3 is an enlarged cross-sectional view taken on line 3—3 of FIG. 2 looking in the direction indicated by the arrows;

FIG. 4 is a cross-sectional view generally similar to FIG. 3 which illustrates an alternate form of assembly

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adaptable to processing in accordance with the invention;

FIG. 5 is a diagrammatic illustration of means and method for performing a step in the processing of assemblies of the above-mentioned character;

FIG. 6 is a cross-sectional view taken along line 6—6 of FIG. 5 looking in the direction indicated by the arrows;

FIG. 7 is a view similar to FIG. 6 illustrating a modification of the apparatus shown in FIG. 5;

FIG. 8 is an enlarged cross-sectional view taken on line 8—8 of FIG. 5 looking in the direction indicated by the arrows;

FIG. 9 is a view similar to FIG. 8 illustrating the end result obtained by using the modified apparatus illustrated in FIG. 7;

FIG. 10 is a perspective view of the structure shown in FIG. 8 illustrated as having a portion thereof cut away;

FIG. 11 is a diagrammatic illustration of means and method for carrying out a further method step of the invention;

FIG. 12 is an enlarged cross-sectional view of a structure after having been treated in accordance with the practice of the method step of FIG. 11;

FIG. 13 is a view similar to FIG. 12 of a modified structure after having been treated in the manner illustrated in FIG. 11;

FIG. 14 is a perspective view of the structure of FIG. 12 illustrated as having a portion thereof cut away;

FIG. 15 is a perspective view of a partially assembled arrangement of parts illustrating a modification of the invention; and

FIG. 16 is a diagrammatic illustration of means and method for forming a multi-element energy-conducting filament or fiber in accordance with the invention.

Referring more particularly to the drawings wherein like characters of reference designate like parts throughout the several views, it will be seen that the invention relates to the forming of multi-element energy-conducting structures of the type embodying a plurality of fused-together energy-conducting elements each individually capable of receiving energy such as light or electricity and transferring the same from one end to the other thereof with a minimum loss in intensity and substantially without the effects of "cross-talk" (the passage of said energy from one adjacent element into another).

In brief outline, the invention comprises placing a plurality of rod-like energy-conducting members 20 such as shown in FIG. 1, for example, internally of a metallic tubular supporting member or sheath 22 to form a relatively compact assembly 24 such as is shown in FIGS. 2 and 3. The assembly 24 is then heated and passed through a rolling mill 26 as shown diagrammatically in FIG. 5 to reduce its cross-sectional size and by the resultant squeezing action, cause the heated elements to assume a tightly interfitted relationship with their adjoining sides securely fused together as illustrated in FIGS. 8 and 9. In the detailed description which follows, it will also become apparent that by the rolling action which is effected progressively along the length of the assembly 24, a gradual and progressive squeezing-out or expulsion of air and gases from between the elements 20 is accomplished as the assembly 24 passes through the rollers of the mill 26. This eliminates the heretofore troublesome problems of avoiding entrapment of air and gases in structures of this general type. Energy-conducting elements of the type preferred in the forming of composite structures such as are set forth herein are provided with an outer layer of cladding which functions as light or electrical insulation means to prevent interaction or "cross-talk" of energy between the said elements when they are finally formed into an integrally

fused structure. Entrapment of air or gases between these elements during the forming of a composite fused structure thereof produces weakened areas or unfused spots along the sides of the elements which are undesirable particularly for the reason that gas and/or air bubbles tend to distort the claddings often to the degree of permitting "cross-talk" of energy to take place at these locations. An excessive amount of entrapped air or gases renders the ultimate product functionally and structurally inferior and the problems of avoiding such conditions have heretofore led to the adoption of complicated and expensive manufacturing processes requiring special equipment for effecting an evacuation of air and gases. This invention, through the use of a novel rolling technique, automatically avoids the problems of air and gas entrapment. Furthermore, it will become apparent that by using a metallic sheath 22, the process herein of forming energy-conducting structures becomes somewhat analogous to the rolling of filled metal stock and the usual difficulties of glass sticking to rolling mill equipment is avoided since the glasses of the elements 20 are confined within the sheath 22 and do not at any time engage the rolling equipment. Moreover, by containing the elements 20 (which must be rendered relatively low in viscosity by heating for proper shaping and fusing) in the sheath 22, unwanted distortion of the elements 22 or of the final overall shape and size of the resultant product is avoided.

Referring more in detail to the structure of the assembly 24 which embodies the elements 20 placed within the metallic sheath 22, it will be seen in FIG. 1 that each of the elements 20 embodies a core section 28 which is so characterized as to be conductive to energy and an outer cladding 30 which, as mentioned above, functions to individually insulate the core sections 28 of the elements 20. While the elements 20 might each embody a core section 28 of metal or other electrical-conducting materials such as a mild steel, certain stainless steels or other chrome iron alloys, the core section 28 will, for purposes of illustration, be considered to be formed of light-conducting material such as glass. The cladding 30 which, in either case, would normally be formed of glass is preferably of a minimum thickness and of such selected character as to produce the above-mentioned energy-insulating effect. A typical all-glass element 20 might embody a core section 28 formed of optical flint glass having an index of refraction of approximately 1.75, a softening temperature of approximately 500° C. and a coefficient of expansion of approximately 8.3×10^{-6} inches per each inch of length per each degree centigrade in rise of temperature between 25° C. and 125° C. A suitable cladding for such a core 28 would be crown-type or soda-lime glass having an index of refraction of approximately 1.69, a softening temperature of approximately 500° C. and a coefficient of expansion approximately the same as that of the core glass material. Soda-lime glass having a coefficient of expansion of approximately 8.9×10^{-6} inches per inch per each degree centigrade change in temperature between 25° C. and 125° C. is commercially available and suitable for such cladding purposes. A cladding thickness of approximately one-tenth the overall diameter of the element 20 will provide the necessary light-insulating function and the above given combination of glass indices will provide the resultant element with a suitable light-acceptance angle within which light entering one end of the element 20 will be substantially totally transferred therethrough by internal reflection adjacent the interface between the core and cladding parts thereof. Optical elements such as 20 may, as it is well known, be constructed of other types of glasses having different preselected indices of refraction as well as expansion characteristics for specific applications of use.

In the case of electrical conducting elements wherein the core section 28 mentioned above would consist of a suitable metal or alloy thereof preferably of the type which will be set forth hereinafter as being suitable for

use in forming the metallic sheath 22, such elements will also have expansion characteristics approximating those of the all-glass elements 20 and be similarly workable in the operation of rolling the assembly 24 to a desired fused and reduced size.

The elements 20 may be of any size which is convenient to handle in making the assembly 24 and will be considered for purposes of illustration to be initially rod-like and relatively rigid in form as opposed to being fiber-like and extremely flexible. For example, an element 12 inches long and .040 to .060 inch in diameter would be relatively rigid and rod-like whereas an element 20 of the same length and only .003 of an inch in diameter would be flexible and fiber-like. It should be understood, however, that within the scope of this invention, the element 20 sizes may range from 1/4 inch or more in diameter down to only small fractions of a thousandths of an inch.

The elements 20 may be initially formed by placing a large rod of the selected core material within a relatively close-fitting sleeve of the cladding material and heating and drawing the assembly thereof endwise to the cross-sectional size desired of the elements 20. With the rod and sleeve parts initially having the ratios of core-to-cladding thicknesses desired of the elements 20, said ratios will remain substantially consistent regardless of the extent to which the assembly thereof is drawn. It will also become apparent hereinafter that this initial core-to-cladding thickness ratio will remain substantially consistent throughout the entire operation of the invention wherein the elements 20 within the metal sheath 22 are subsequently rolled to a reduced cross-sectional size. The rolling operation of FIG. 5 will effectively attenuate the elements 20 to reduce their cross-sectional size but, no appreciable change in the ratio of their core-to-cladding thickness will result.

Once having selected the type of elements 20 (either all-glass or metal cored) which are to be used in the fabrication of the energy-conducting structure of the invention, said elements are placed in the metal sheath 22 which may be circular as shown in FIGS. 2 and 3 or square as shown by reference numeral 22 in FIG. 4 or of any other desired cross-sectional shape. It will be noted that the elements 20 themselves are preferably selected to be circular as shown to provide interstices 30' therebetween through which air and gases can readily escape in the subsequent rolling operation of FIG. 5. The invention, however, is not limited to the use of round elements 20 as it should be clear that the same effect of providing for air or gas escapement can be accomplished with elements 20 having other cross-sectional configurations.

The material of the metallic sheaths 22 or 22' is selected to have approximately the same or a slightly higher expansion coefficient than that of the materials of the elements 20. Metals having a slightly higher expansion coefficient are preferred for the reason that, in expanding during the heating and rolling operation of FIG. 5, such a sheath 22 or 22' will tend to produce a tightening effect upon the elements 20 and assist in compacting the same to induce secure fusion of their adjoining side edges and further upon cooling after rolling the difference in expansion characteristics will cause the sheath to contract tightly upon the elements 20.

When forming the structure of this invention of glass elements 20 having expansion characteristics such as given above by way of example, it is desirable to form the sheath 22 of a metal having an expansion coefficient of from approximately 8.5×10^{-6} to 12×10^{-6} inches per inch of length per degree Centigrade between 0° C. and 300° C. In this respect, the sheaths 22 or 22' may be formed of a mild cold rolled steel such as the well known .05% carbon steel having an expansion coefficient of approximately 11.7×10^{-6} . Other metals such as the commonly known No. 430 stainless steel having an expansion coefficient of approximately 9.2×10^{-6} may be used. No. 430 stainless steel is composed of .12% maximum of carbon, 1%

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maximum of manganese, 1% maximum of silicon and from 14% to 18% chromium, with the balance of iron.

Further by way of example, an alloy of the following composition having an expansion coefficient of approximately 8.5×10^{-6} might be used:

41.5% to 42.5% -----	Nickel.
5.4% to 5.9% -----	Chromium.
.15 maximum -----	Aluminum.
.07 maximum -----	Carbon.
.15% to .25% -----	Manganese.
.025 -----	Phosphorous.
.15% to .30% -----	Silicon.
Balance -----	Iron.

Other examples of suitable metal compositions having expansion coefficients of approximately 9.8×10^{-6} are as follows:

Example 1

42% -----	Nickel.
6% -----	Chromium.
Balance -----	Iron.

Example 2

47% -----	Nickel.
5% -----	Chromium.
Balance -----	Iron.

Example 3

51% -----	Nickel.
1% -----	Chromium.
Balance -----	Iron.

It should be understood that the above metallic compositions are given by way of illustration only and that other metals having expansion coefficients ranging in and around those set forth above may be used in the construction of the sheath 22.

Having forming the assembly consisting of the elements 20 and a sheath 22 or 22' which preferably has a wall thickness of approximately from .030 inch to .060 inch, the assembly is passed through an oven 32 (see FIG. 5) and between a pair of rollers 34 of the rolling mill 24. The oven 32 may be of any suitable design preferably of the general character shown diagrammatically in FIG. 5 which embodies electrical heating elements 36 surrounding the assembly 24 and which, through conventional control devices, are operated to heat the assembly 24 to a suitable rolling temperature.

By passing the assembly 24 through the oven 32 at a precontrolled rate determined in accordance with the heat applied thereto, the portion of its structure emerging from the opening 38 enters the rollers 34 at a proper temperature for re-shaping and fusing. The temperature in the oven 32 and rate of rolling in the mill 26 must be cooperatively controlled in accordance with the volume and heat-softening characteristics of the material of the elements 20 in the assembly 24. The heat-softening characteristics of the metallic sheaths 22 or 22' are relatively immaterial to the rolling process since metals, in general, lend themselves readily to rolling at most any temperature and, in fact, can usually be cold rolled if necessary. The softening temperature of the metal sheath 22, however, should be well above that of the glass or materials of the elements 20 as is the case where metals of the above given compositions are used. With the combination of glasses and metals given above as examples, the metal sheaths 22 or 22' will be relatively highly viscous or non-flowable at temperatures of from 1100° F. to 1400° F. which temperatures normally render the glasses of the elements 20 easily reformable in shape and readily fusible to each other. The relatively rigid heated sheath 22 or 22' will then support the more viscous elements 22 at all times during the rolling operation and prevent overall distortion of the assembly 24 and the resultant rolled part 46 thereof. Furthermore,

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the metal sheath, in surrounding the elements 20 prevents direct contact between the rollers 34 and the glass materials of the elements 20 and thereby avoids any problems of glass sticking to the rollers which, as it is known, would occur if glasses heated to fusible temperatures were to be passed through rolling mills of most all general types.

The rolling operation is accomplished with conventional rolling mill equipment employing the usual steel rollers 34 or 34' having preformed peripheral recessed areas 40 (FIG. 6) or 40' (FIG. 7) shaped to receive and reform the assembly 24 to a desired reduced cross-sectional configuration and size. A circular assembly such as shown in FIGS. 2 and 3 would preferably be passed through rollers 34 having a circular shaping area 40 as shown in FIG. 6 and a square assembly such as shown in FIG. 4 would normally be passed through rollers 34' having the square area 40' as shown in FIG. 7. It should be understood, however, that in the rolling operation an assembly having an initial circular shape may be rolled to a square shape, for example, or vice-versa simply by the proper selection of rollers used to receive the particular assembly. The assembly 24 may be rolled to shapes other than those mentioned and illustrated and the invention is not limited to the cross-sectional configurations which have been shown only for purposes of illustration.

Referring more particularly to the squeezing effect produced upon the assembly 22 by rolling as shown in FIG. 5, it is pointed out that with the elements formed of glasses of the above-mentioned character which are preferably heated to approximately 1200° F. upon entering the rollers 34, the complete assembly 22 will be compressed and effectively attenuated as illustrated. This compression, being gradually and progressively applied at the receiving end of the rolling mill 26, causes a squeezing or forcing-out of air and gases from between the elements 20 through the interstices 30' rearwardly in the direction indicated by the arrows 42. By so expelling air and gases, a perfect bubble-free fused joinder is provided between each and every element 20 which elements are compressed and fused together by the rollers 34 as shown diagrammatically in FIGS. 5, 8 and 9.

In FIG. 8, it will be noted that the elements 20, after rolling, inherently take on a generally hexagonal interfitting shape as a result of their being initially circular and placed in the sheath 22 as shown in FIG. 3. However, the same elements when placed in a square or rectangular sheath 22' (FIG. 4) will, when rolled as shown in FIG. 7, inherently assume a square or rectangular interfitted fused relationship such as shown diagrammatically in FIG. 9. In all cases, the rolling operation will cause the heat-softened elements 20 to assume a compact side-by-side interfitting relationship and become securely fused to each other. The portions of the elements 20 adjacent the metallic sheath will inherently adhere thereto and form with the sheath a secure integral unit.

After having passed through the rolling mill 26, the resultant rolled and fused part 46 of the assembly 24 is directed through an annealing oven 48 which is similar in most respects to the oven 32, but which is operated through control of its heating elements 50 to reduce the temperature of the rolled fused part 46 to a suitable annealing temperature of approximately within the range of from 750° F. to 900° F. The annealing oven 48 is of such a length in accordance with the rate of progression of the part 46 therethrough as to render the glasses of said part 46 fully annealed before exiting from the annealing oven 48 through the opening 52. It should be understood that, in place of the oven 48, a more conventional annealing oven or furnace may be used. In such a case, after the entire assembly 24 is rolled, the resultant part 46, in rod-like form as shown in FIG. 5, is placed therein and allowed to remain for the proper annealing period.

It is pointed out that the temperatures used for rolling

the assembly 24, the rate at which it is rolled and the time cycle of subsequent annealing are all determined in accordance with the nature of the glasses used to form the initial elements 20 thereof. Also, the initial cross-sectional size of the assembly 24 and the extent of its reduction in size during rolling are other determinative factors in selecting proper rolling temperatures and rates. In view of this, the following example of a typical rolling temperature, rate and time cycle for annealing is given for an assembly of elements 20 formed of the above-mentioned flint and soda-lime glasses placed in a mild .05% carbon cold rolled steel sheath 22 having a wall thickness of approximately .030 inch and an outer diameter of approximately $\frac{3}{8}$ inch wherein the elements 20 are each approximately .040 inch in diameter and the assembly 24 is to be reduced by approximately an 8% area reduction during rolling.

Temperature of assembly 24 at	
point of rolling -----	1200° F.
Rate of rolling-----	20 ft./min.
Temperature for annealing ----	800° F.
Time required for annealing the	
rolled structure -----	45 minutes to one hour
	and thereafter slow-cooled.

Referring now to FIG. 10 wherein the rolled and annealed part 46 of FIG. 5 is shown in perspective, it can be seen that disc-like energy-conducting articles 54 can be formed therefrom by cutting transversely through the part 46 as shown. Such articles are usually optically finished by grinding and polishing one or both of their sides and have useful application as cathode ray tube face plates or energy-conducting windows for optical or electrical coupling devices or the like. The metallic outer sheath 22 in this case provides convenient means for attaching the articles 54 to devices with which they are to be used. For certain applications of use, however, it is desirable to have the metallic sheath removed so as to render the articles glass fusible to the receiving parts of devices with which they are to be incorporated. This can be accomplished by grinding or other mechanical operations but is more easily performed chemically by placing the rolled structure or part 46 in an acid bath 56 as illustrated in FIG. 11 for a period of time sufficient to chemically remove the sheath 22 therefrom by etching with the result of producing an article 46' such as shown in FIGS. 12 and 14. Acid solutions consisting of HCl, HNO₃ or combinations thereof would be suitable for this purpose. In FIG. 12, there is shown an enlarged cross-sectional view of the part 46 following removal of its metallic sheath 22 and in FIG. 13, a rectangularly shaped part, identical to the part 46 in all respects other than its shape, is shown after being similarly acid-treated to remove its outer metallic sheath 22' which is shown in FIG. 9. Again, as in the case of FIG. 10, window-like or plate-like energy-conducting devices 58 can be formed from the resultant acid-treated article 46' by cutting the same transversely to desired thicknesses.

Alternatively, if it is desired to produce a multi-element filament, such as the type commonly referred to as a multifiber, the article 46' of FIG. 14 can be heated adjacent one of its ends as shown in FIG. 16 by a suitable ring-like heating element 60 and drawn as a unit into a multifiber 62. The term "multifiber" is intended to mean an element of fiber size which may be as small as a few microns in diameter and which embodies a plurality of individually insulated energy conducting channels.

Furthermore, as shown in FIG. 15, a plurality of the elements 46' may be formed and assembled together in another metallic sheath 60 whereupon the resultant assembly may be heated and rolled as a unit to form another integrally fused unit of the element 46' which, in themselves, each embody a fused-together plurality of the initial individually insulated elements 20. The re-

assembling and re-rolling operations may be repeated any desired number of times either with or without removing the metallic sheaths therefrom.

From the foregoing, it can be seen that improved, simple and economical means and method have been provided for accomplishing all of the objects and advantages of the invention. However, it should be apparent that many changes in the details set forth herein may be made without departing from the spirit of the invention as expressed in the accompanying claims and the invention is not limited to the exact matters shown and described as only preferred matters have been given by way of illustration.

Having described my invention I claim:

1. The method of making a fused energy-conducting structure having a multiplicity of juxtaposed long and thin energy-conducting guides extending from one end toward the other end thereof utilizing a rolling mill, said method comprising the steps of placing a multiplicity of energy-conducting fibers each clad with a glass having a relatively low softening temperature and coefficient of expansion in side-by-side bundled relationship longitudinally within a tubular supporting member formed of a metal having a substantially higher softening temperature and coefficient of expansion than said glass, said fibers being in such number and of such diameter as to substantially fill said supporting member, there being undesired interstices containing air and gases extending longitudinally between said fibers, heating the assembly of said supporting member and fibers to a temperature sufficient to soften and fuse claddings together and rolling said heated assembly under compression progressively from one end toward the other end thereof to a reduced cross-sectional size, the reduction in size being of an amount at least sufficient to effect substantially complete closure of said interstices progressively along the length of the assembly and simultaneous longitudinal extrusion of air and gases therein immediately prior to adjoinment and fusion of portions of said claddings along said interstices as said assembly is rolled.

2. The method of making a fused light-conducting structure having a multiplicity of juxtaposed long and thin light-conducting guides extending from one end toward the other end thereof utilizing a rolling mill, said method comprising the steps of placing a multiplicity of light conducting fibers in bundled side-by-side relation longitudinally within a tubular supporting member formed of a metal having a relatively high softening temperature and coefficient of expansion, said fibers having glass core parts of relatively high index of refraction each clad with a relatively thin coating of glass of relatively low index of refraction, said glasses each having a substantially lower softening temperature and coefficient of expansion than that of said metal supporting member, the quantity and respective diameters of said fibers being such as to substantially fill said supporting member, there being undesired interstices containing air and gases extending longitudinally between said fibers, heating the assembly of said supporting member and fibers to a temperature sufficient to soften and fuse said claddings together and rolling said heated assembly under compression progressively from one end toward the other end thereof to a relatively sharply transitioned materially reduced cross-sectional size, the reduction in size being of an amount at least sufficient to effect substantially complete closure of said interstices progressively along the length of the assembly and simultaneous longitudinal extrusion of air and gases therein immediately prior to fusion of portions of said claddings along said interstices as said assembly is rolled.

3. The method of making a fused electrical energy-conducting structure having a multiplicity of juxtaposed long and thin individually insulated electrically conductive guides extending from one end toward the other end thereof utilizing a rolling mill, said method comprising

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the steps of placing a multiplicity of electrically conductive fibers in bundled side-by-side relation longitudinally within a tubular supporting member formed of a metal having a relatively high softening temperature and coefficient of expansion, said fibers having electrically conductive core parts each clad with a coating of glass having a substantially lower softening temperature and coefficient of expansion than that of said metal supporting member and being in such quantity and size as to substantially fill said supporting member, there being undesired interstices containing air and gases extending longitudinally between said fibers, heating the assembly of said supporting member and fibers to a temperature sufficient to soften and fuse adjoining claddings of respective fibers and rolling said heated assembly under compression progressively from one end toward the other end thereof to a relatively sharply transitioned materially reduced cross-sectional size, the reduction in size being of an amount at least sufficient to effect substantially complete closure of said interstices progressively along the length of the assembly and simultaneous longitudinal extrusion of air and gases therein immediately prior to fusion of portions of said claddings along said interstices.

4. The method of making a fused energy-conducting structure having a multiplicity of juxtaposed long and thin energy-conducting guides extending from one end toward the other end thereof utilizing a rolling mill, said method comprising the steps of placing a multiplicity of energy-conducting fibers each clad with a glass having a relatively low softening temperature and coefficient of expansion in side-by-side bundled relationship longitudinally within a tubular supporting member formed of a metal having a substantially higher softening temperature and coefficient of expansion than said glass and adapted to rigidly support the fibers when heated to the effective fusing temperature of respective glass claddings thereof, there being undesired interstices containing air and gases

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between the fibers in said supporting member, heating the assembly of said supporting member and fibers to a temperature below the softening temperature of said supporting member yet sufficient to soften and fuse respective claddings of said fibers together and pressure rolling said heated assembly progressively from one end toward the other end thereof to a relatively sharply transitioned materially reduced cross-sectional size, the reduction in size being of an amount at least sufficient to effect closure of said interstices progressively along the length of said assembly during rolling thereof and simultaneous longitudinal extrusion of air and gases therein adjacent the interfacial fusing area of portions of said claddings along said interstices.

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