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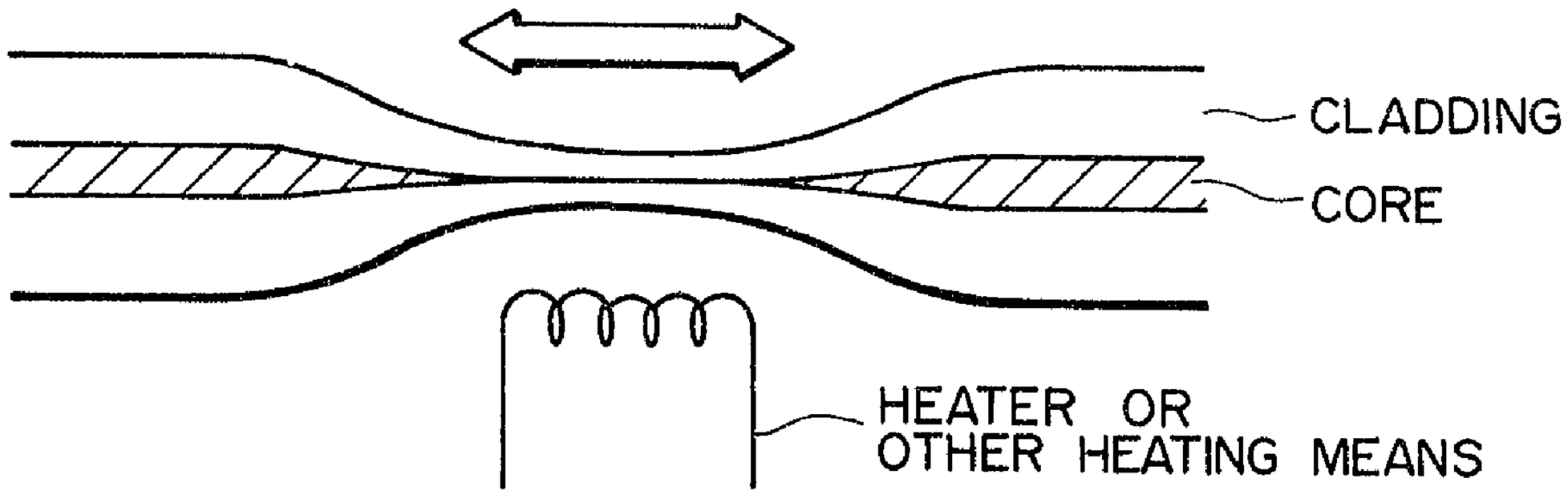
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ELONGATION METHOD

(57) Abrégé/Abstract:
An object of this invention is to provide a mode field diameter conversion optical fiber which can be processed in a short period of time to have a reduced mode field diameter at a desired portion thereof. The optical fiber according to this invention comprises a core of silica glass having a residual tensile stress, and a cladding surrounding the core and having a lower refractive index than that of the core. The desired portion is heated to relax the residual tensile stress in the core, whereby the optical fiber has a reduced mode field diameter at the desired portion.

ABSTRACT OF THE DISCLOSURE

An object of this invention is to provide a mode field diameter conversion optical fiber which can be processed in a short period of time to have a reduced mode field diameter at a desired portion thereof. The optical fiber according to this invention comprises a core of silica glass having a residual tensile stress, and a cladding surrounding the core and having a lower refractive index than that of the core. The desired portion is heated to relax the residual tensile stress in the core, whereby the optical fiber has a reduced mode field diameter at the desired portion.

Mode Field Diameter Conversion Optical Fiber

This invention relates to an optical fiber whose mode field diameter can be reduced at a desired portion, a method for fabricating the same, a mode field diameter conversion optical fiber using the optical fiber, and a method for converting a mode field diameter of the mode field diameter conversion optical fiber.

A problem involved in insertion of optical parts between optical fibers facing to each other is that a gap between the optical fibers whose amount is corresponding to a thickness of the optical parts decreases a light transmittance. A decrease of the light transmittance depends on the amount of the gap, that is, a distance between the optical fibers facing to each other, and a mode field diameter of the optical fiber. This is shown in FIGs. 1A and 1B. The relationship among a light transmittance, a destance between optical fibers facing to each other, and a mode field diameter is expressed by Formula 1.

$$T = 1/[1+a(\lambda d/w^2)^2] \quad \ldots\ldots\ldots (1)$$

where T : a light transmittance

a : a constant determined by an optical fiber

λ : a wavelength of transmission light

d : a distance between optical fibers facing to each other

w : a mode field diameter of the optical fiber

As apparent from Formula 1, in a transmission unit using light of a specific wavelength, to decrease a light transmission loss due to a distance between optical fibers facing to each other by the insertion of optical parts, it is preferable that a mode field diameter of both optical fibers at their ends facing to each other is large. In long-distance transmission using single-mode optical fibers, however, it is preferable that their mode field diameter is small in view of light losses due to their bends, twists, etc.

Then the following two methods are proposed for inserting optical parts between optical fibers suppressing the decrease of light transmittance.

a) A small-mode field diameter optical fiber is formed, and the mode field diameter is expanded at a part of the optical fiber. The optical fiber is divided at the portion of the expanded mode field diameter, and optical parts are inserted between the divided optical fibers. Optical fibers for long-distance transmission uses are connected to the divided optical fibers at the end faces other than the divided end faces.

b) An optical fiber of a large-mode field diameter is formed, and the mode field diameter is reduced at both ends

of the optical fiber. The optical fiber is divided at the part of the large mode field diameter, and optical parts are inserted between the divided optical fibers facing to each other. Optical fibers for long-distance transmission uses are connected to the divided optical fibers at the end faces of the reduced mode field diameter.

The method (a) has been conventionally used owing to its practicality. Specifically to convert a mode field diameter, the following two methods have been practiced.

1) A part of an optical fiber is heated and elongated to reduce a core diameter, whereby its mode field diameter is increased (FIG. 2).

2) A part of an optical fiber is heated to thermally diffuse a dopant added to the core for the improvement of its refractive index so as to effectively lower a refractive index difference between the core and the cladding, whereby a mode field diameter is expanded (FIG. 3).

In the method (1), since optical fibers of an outer diameter as small as 125 μm (CCITT Standards) are elongated, mode field diameters can be expanded only over regions of short lengths. The regions of short lengths can accommodate only a small number of optical parts, but cannot do a large number of optical parts. The method (2) can solve the problem of obtaining lengthy regions of expanded mode field diameters by increasing heating regions. But the method (2) takes longer heating times (some hours), which results in

not only problems of low productivity, but also problems of deformation of optical fibers due to the long-time heating.

SUMMARY OF THE INVENTION

This invention has been made to solve the above-described problems and provides a mode field diameter conversion optical fiber which can be processed in a short period of time for the reduction of mode field diameters at desired portions.

Before this invention is described, the principle this invention is based on will be explained. In drawing an optical fiber preform to an optical fiber, when the core has a higher viscosity than the cladding, a tensile stress due to a drawing tension is generated concentratively in the core, and after the drawing, the stress remains in the core. The residual tensile stress lowers a refractive index of the core. A heating treatment relaxes the residual tensile stress. A change of a refractive index of glass due to a residual tensile force is expressed by the following Formula 2

$$\Delta n = C \cdot \sigma \quad \cdots\cdots\cdots \quad (2)$$

where Δn : a change amount of a refractive index

C : photoelasticity constant determined by composition of glass

σ : residual tensile stress

It is seen from Formula 2 that σ is required that $\sigma \geq 0.12$ GPa to convert a mode field diameter effectively because in

silica glass-based optical fibers, a mode field diameter conversion is effective at a refractive index change above $0.05x10^{-2}$, and silica glass-based optical fibers has C = about $-4.2x10^{-12}Pa^{-1}$. FIG. 4 shows relationships among drawing tensions, specific refractive index differences and mode field diameters. Residual tensile stress values of an optical fiber can be measured by photoelasticity CT method described in T. Abe, Y. Mitunaga and H. Koga: "Photo-elastic computer tomography: a novel measurement method for axial residual stress profile in optical fibers", J. Opt. Soc. Am., A3, pp. 133-137 (1986).

The relationship between drawing tensions and refractive index decreases of a core of an optical fiber depends on viscosity ratios between the core thereof and the cladding thereof (core/cladding) when the optical fiber is drawn. FIG. 5 is a graph in which for viscosity ratios of 1.4, 4 and 5, drawing tensions are taken on the horizontal axis, and refractive index decreases are taken on the vertical axis. As in this graph, it is at a viscosity of 1.4 that a $0.05x10^{-2}$ refractive index decrease takes place at a 300 g drawing tension. But usually drawing without cutting is difficult at a drawing tension above 300g, and if it can be done, it is difficult that the fabricated optical fiber has a sufficient strength. Accordingly it is preferable that the optical fiber according to this invention has a viscosity ratio above 1.4.

The residual tensile stress of the core is relaxed by heating treatment. An example of relationships among heating temperatures, periods of heating time and relaxation amounts of silica glass-based optical fiber in the heating treatment is shown in FIG. 6. In FIG. 6, for 10 minute-heating and 30 second- heating, heating temperatures are taken on the horizontal axis, and relaxation amounts are taken on the vertical axis. As in this graph, relaxation of a residual tensile stress of a silica glass-based optical fiber starts at a heating temperature above about 600 °C. It is seen that as the heating temperature rises, the speed of relaxation of the residual tensile stress increases.

What has to be noted in converting mode field diameter is that an abrupt change of the mode field diameter results in that a larger amount of transmission light is changed into radiation, and the optical fiber has larger transmission losses. To avoid abrupt changes of a mode field diameter of the optical fiber for the decrease transmission losses, it is preferable that a heating region is not too small. It is empirically preferable that a heating region is above about 0.5 mm.

This invention is based on the above-described principle and uses the above-described method (b), and characterized in that an optical fiber of a large mode field diameter is formed, and a desired portion thereof is heated to reduce the mode field diameter at the desired portion.

This invention specifically relates to an optical fiber comprising: a core for optical transmission having a drawing induced tensile stress; and a cladding surrounding the core and having a lower refractive index than that of the core; wherein a desired portion of the optical fiber is heated for relaxing the residual tensile stress at the desired portion and for increasing a refractive index difference between the core and the cladding at the desired portion above 0.05×10^{-2}.

The core may be formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide, and the cladding may be formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide.

A viscosity ratio between the core and the cladding (core/cladding) may be above 1.4 at the time of drawing.

Another aspect of the present invention relates to a method for changing a mode field diameter of an optical fiber, the optical fiber comprising: a core for optical transmission having a drawing induced residual tensile stress; and a cladding surrounding the core and having a lower refractive index than that of the core; the method comprising the step of heating a desired portion of an optical fiber to reduce the mode field diameter at the desired portion, the heating relaxing the residual tensile

stress at the desired portion and thereby increasing a refractive index difference between the core and the cladding at the desired portion above 0.05×10^{-2}.

The desired portion of the optical fiber may be heated by a heater, a discharge electrode or a burner.

A heated region of the optical fiber may have a length above about 0.5 mm.

A residual tensile stress of a desired portion of the above-described optical fiber can be released by a short time of heating. A residual tensile stress of the core lowers a refractive index thereof. When a residual stress is above 0.12 GPa, the mode filed diameter at the desired portion is effectively reduced. Thus the heating partially or completely releases a residual stress, and a refractive index of the core is increased, resultantly with a higher refractive index difference from the cladding. Thus, a mode field diameter conversion optical fiber having a mode field diameter reduced at a desired portion can be prepared. Such mode field diameter conversion optical fiber functions not only simply as optical transmission passages, but also as optical devices for converting mode field diameters with small losses.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art form this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a graph of light transmission losses corresponding to a distance between optical fibers facing to each other.

FIG. 1B is an explanatory view of a distance between optical fibers facing to each other.

FIG. 2 is an explanatory view of an elongation method of the conventional methods for converting a mode field diameter of an optical fiber.

FIG. 3 is an explanatory view of a dopant diffusion method of the conventional methods for converting a mode field diameter of an optical fiber.

FIG. 4 is a graph of relationships among drawing tensions (residual tensile stresses of a core), mode field diameters (MFDs) and refractive index differences.

FIG. 5 is a graph of relationships between drawing tensions, and refractive index decreases of the core.

FIG. 6 is a graph of relationships between recovery of refractive index difference and heating treatment conditions.

FIG. 7 is a view of changes of a residual tensile stress distribution before and after the heating of the optical fiber according to embodiments of this invention.

FIG. 8 is a view of changes of refractive index distribution before and after the heating of the optical fiber according to the embodiments.

FIG. 9 is a view of a heating treatment for converting mode field diameter by a heater.

FIG. 10 is a view of a heating treatment for converting mode field diameter by a discharge electrode.

FIG. 11 is a view of a heating treatment for converting mode field diameter by a burner.

DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments of this invention will be explained with reference to the drawings.

First Embodiment

FIGs. 7 and 8 are schematic views of the optical fiber according to this embodiment. FIG. 7 shows a distribution change of the residual tensile stress, and FIG. 8 shows a distribution change of the refractive index before and after the heating treatment for the mode field diameter conversion.

In FIGs. 7 and 8, the optical fiber before the heating

treatment is a single mode fiber formed by the known rod in tube method. First, a columnar preform of silica glass for the core was formed. Then, a cylindrical preform of F-added silica glass for the cladding was formed. Next, the core preform was inserted into the hollow portion of the cladding preform, and heated and drawn for integration at about 1900 °C and at a drawing tension = 150 g. Thus an optical fiber (outer diameter: 125 μm) with a residual tensile stress for the mode field diameter conversion was prepared. This optical fiber had a specific refractive index difference of 0.45% between the preform core and the preform cladding. The drawing viscosity ratio was about 7. The thus-prepared optical fiber was measured on the mode field diameter, and the measured mode field diameter was 27 μm (wavelength of transmission light: 1.55 μm).

As seen on the left side of FIG. 7, the optical fiber before the heating treatment has a residual tensile stress in the core region. As seen on the left side of FIG. 8, a refractive index of the core region is lower than that of the preform core region, due to the effect of the residual tensile stress. This optical fiber was subjected to the heating treatment for 10 minutes at 1000 °C. For example, a heater (FIG. 9), a discharge electrode (FIG. 10), and a burner (FIG. 11) may be used as heating means. Then the stress is relaxed as seen on the right side of FIG. 7. As a result, as seen on the right side of FIG. 8, the core

regions has the improved refractive index. Accordingly, a refractive index difference between the core and the cladding becomes higher, and the mode field diameter becomes smaller. The mode field diameter of the heat-treated portion after the heating treatment was measured, and the measured mode field diameter was 9.5 μm (wavelength of transmission light: 1.55μm).

A long-distance transmission optical fiber (mode field diameter: 8.5 μm) was fused onto the reduced mode filed diameter portion, and a coupling loss was measured. The measured coupling loss was as good as 0.1 dB.

Second Embodiment

The second embodiment is substantially the same as the first embodiment and different from the latter only in the heating treatment conditions. That is, the same optical fiber was prepared and was subjected to the heating treatment for 30 seconds at 1850 °C. This heating treatment reduced the mode field diameter as in the first embodiment. The measured mode field diameter was reduced to 10 μm (wavelength of transmission light: 1.55 μm).

The thus-formed mode field diameter optical conversion fibers according to this invention can find various applications which require reduced mode field diameters. For example, they can be coupled, with small transmission losses, to optical parts (light waveguide devices, optical fibers, etc.) of small mode field diameters. The thus-

formed mode field diameter conversion optical fiber can have a mode field diameter reduced not only at the ends thereof, but also at desired optional portions intermediate between the ends. In the case, even when the optical fiber is largely bended at the reduced-mode field diameter portion, the advantageous effect of this invention, such as small losses, can be expected.

This invention has been explained by means of the embodiments but covers other variations. For example, the mode field diameter conversion optical fiber according to this invention can be formed by various forming methods, such as MCVD, OVD, double crucible method, etc. Formation of the core and the cladding of the optical fiber is not restricted to the formation of the embodiment, and the core may be formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide; the cladding may be formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide. Whether the mode field diameter conversion optical fiber according to this invention is a single mode fiber or a multi-mode fiber, the same effects can be attained in some cases.

From the invention thus described, it will be obvious

that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An optical fiber comprising:
a core for optical transmission having a drawing induced tensile stress; and
a cladding surrounding the core and having a lower refractive index than that of the core;
wherein a desired portion of the optical fiber is heated for relaxing the residual tensile stress at the desired portion and for increasing a refractive index difference between the core and the cladding at the desired portion above 0.05×10^{-2}.

2. An optical fiber according to claim 1, wherein the core is formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide; and wherein the cladding is formed of highly pure silica glass substantially containing no impurities, or silica glass containing at least one of fluorine, chlorine, boron oxide, phosphorus pentaoxide and germanium oxide.

3. An optical fiber according to claim 1, wherein the core is formed of silica glass substantially containing no impurities.

4. An optical fiber according to claim 1, wherein the cladding is formed of fluorine-containing silica glass.

5. An optical fiber according to claim 1, wherein the core is formed of highly pure silica glass

substantially containing no impurities, and the cladding is formed of fluorine-containing silica glass.

6. An optical fiber according to any one of claims 1 to 5, wherein at the time of drawing, a viscosity of the core is higher than that of the cladding.

7. An optical fiber according to any one of claims 1 to 6, wherein at the time of drawing, a viscosity ratio between the core and the cladding is above 1.4.

8. A method for changing a mode field diameter of an optical fiber, the optical fiber comprising:

a core for optical transmission having a drawing induced residual tensile stress; and

a cladding surrounding the core and having a lower refractive index than that of the core;

the method comprising the step of heating a desired portion of an optical fiber to reduce the mode field diameter at the desired portion, the heating relaxing the residual tensile stress at the desired portion and thereby increasing a refractive index difference between the core and the cladding at the desired portion above 0.05×10^{-2}.

9. A method for converting a mode field diameter of an optical fiber according to claim 8, wherein the desired portion of the optical fiber is heated at a temperature above about 600°C.

10. A method for converting a mode field diameter of an optical fiber according to claim 8 or 9, wherein a heated region of the optical fiber has a length above about 0.5 mm.

Fig. 1A

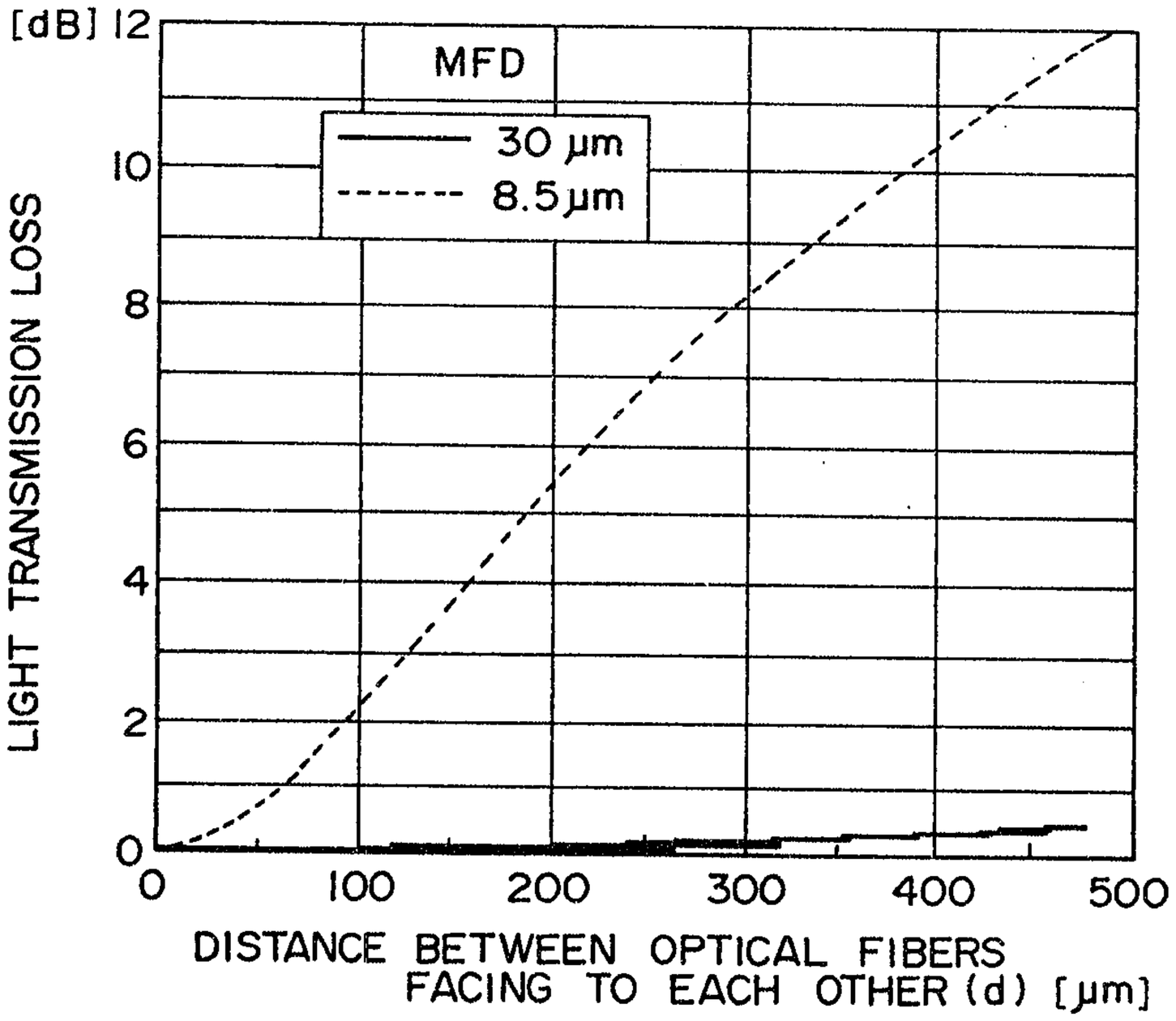
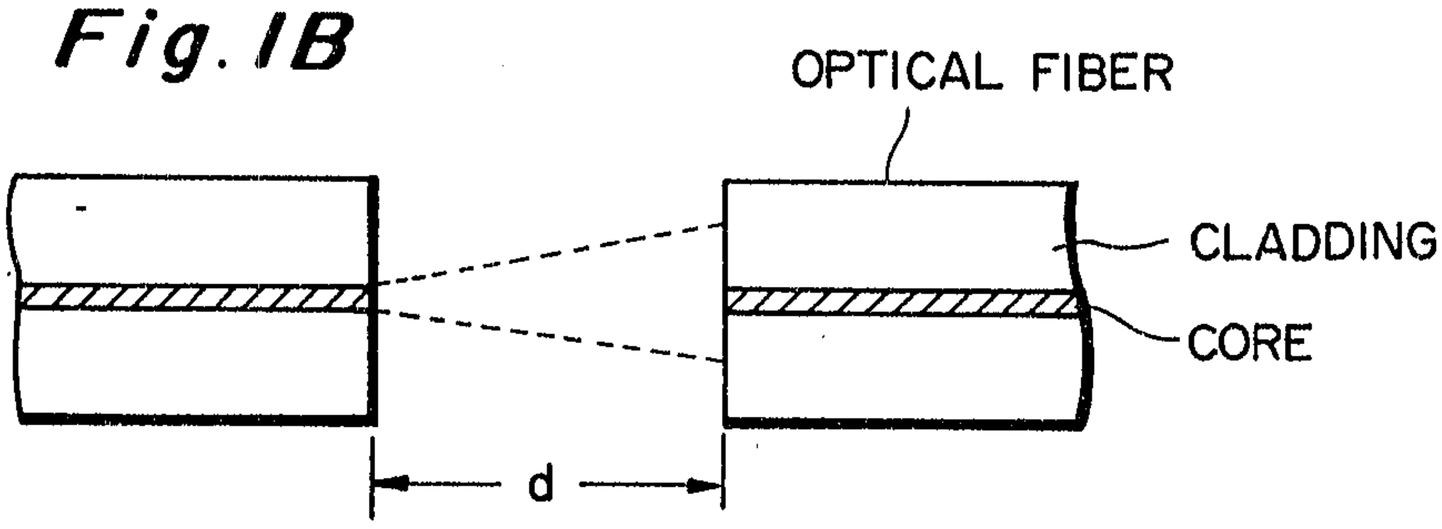
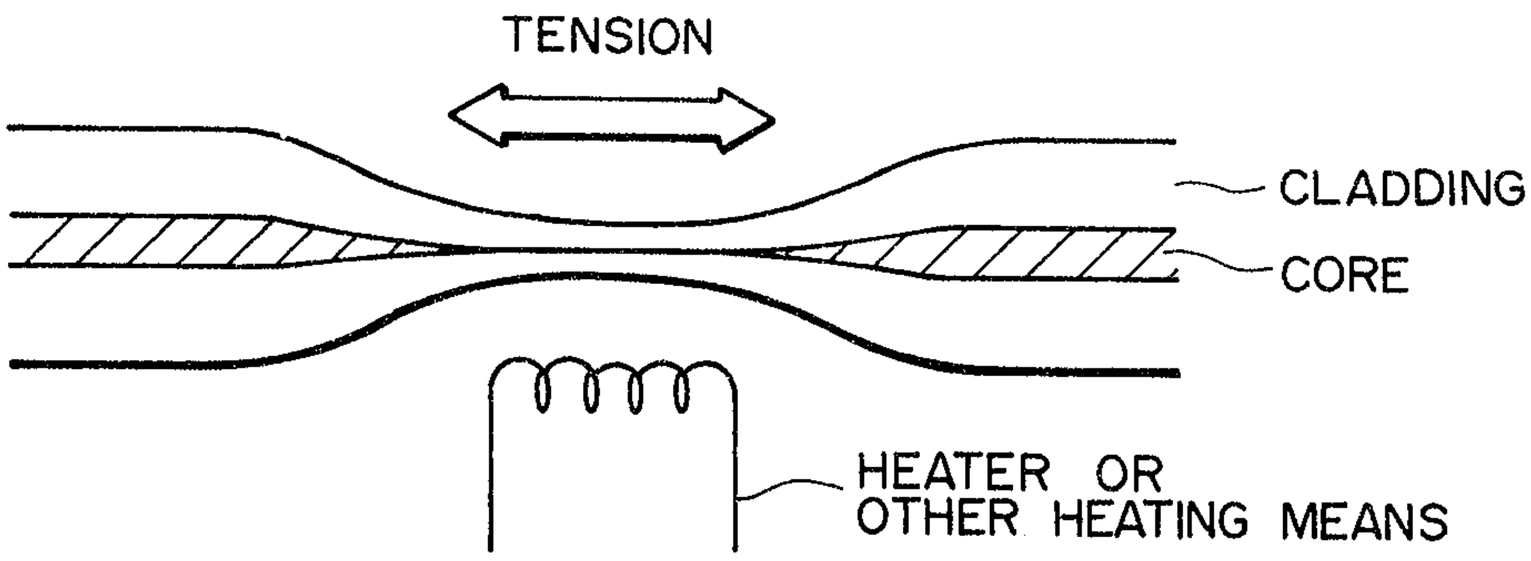


Fig. 1B



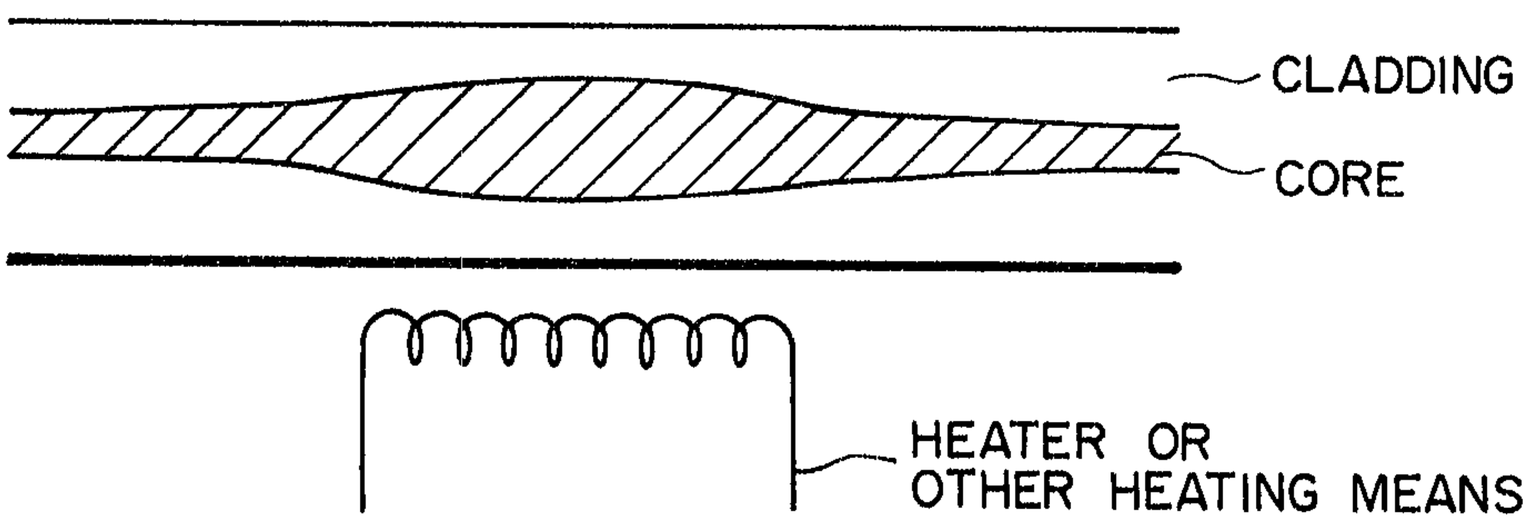
Hasko & Clark

Fig. 2



ELONGATION METHOD

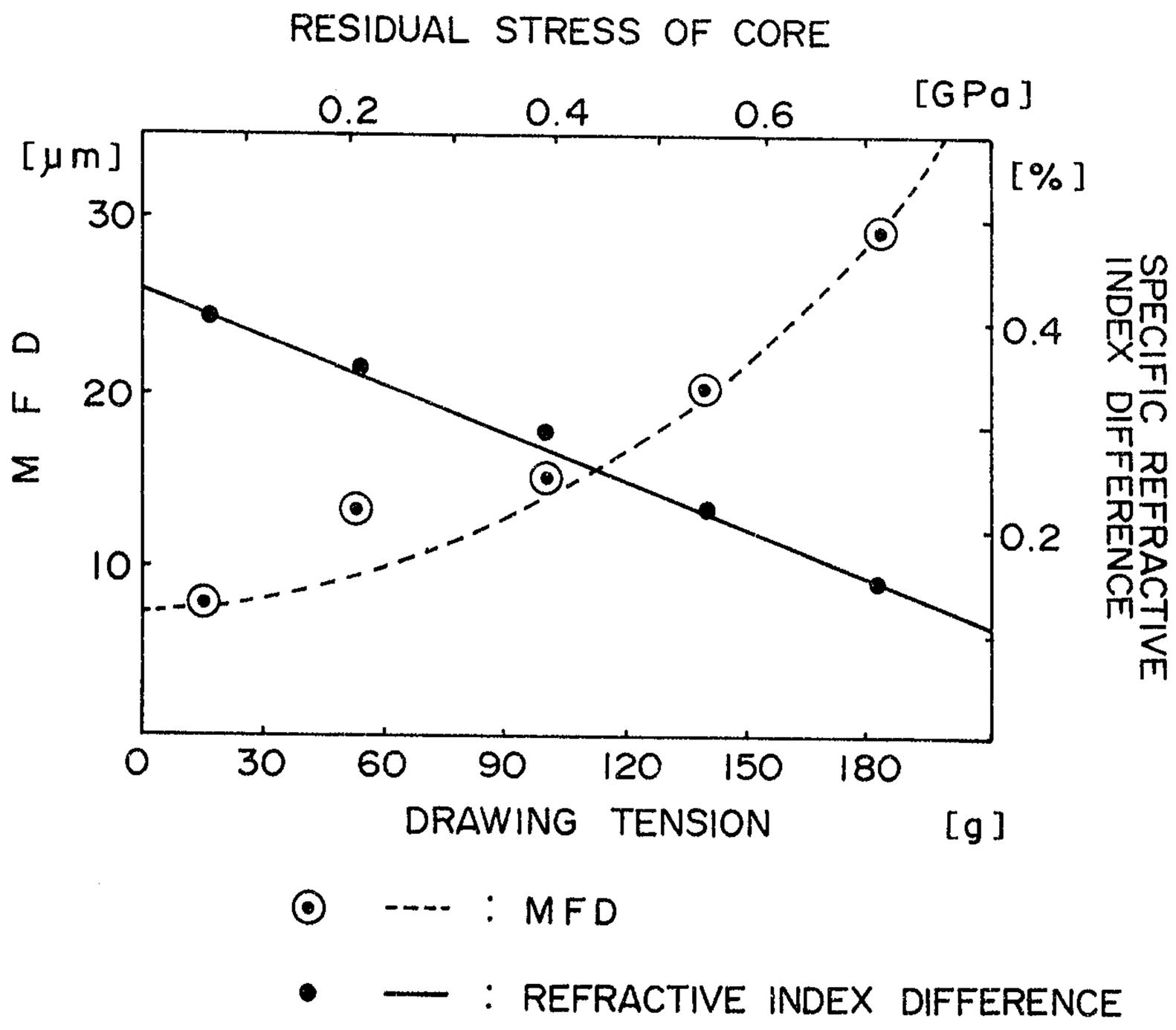
Fig. 3



DOPANT DIFFUSING METHOD

Agent's Stamp

Fig. 4



OPTICAL FIBER CONDITIONS	
CORE MATERIAL	SiO_2
CLADDING MATERIAL	F-SiO_2
SPECIFIC REFRACTIVE INDEX DIFFERENCE OF PREFORM	0.45%

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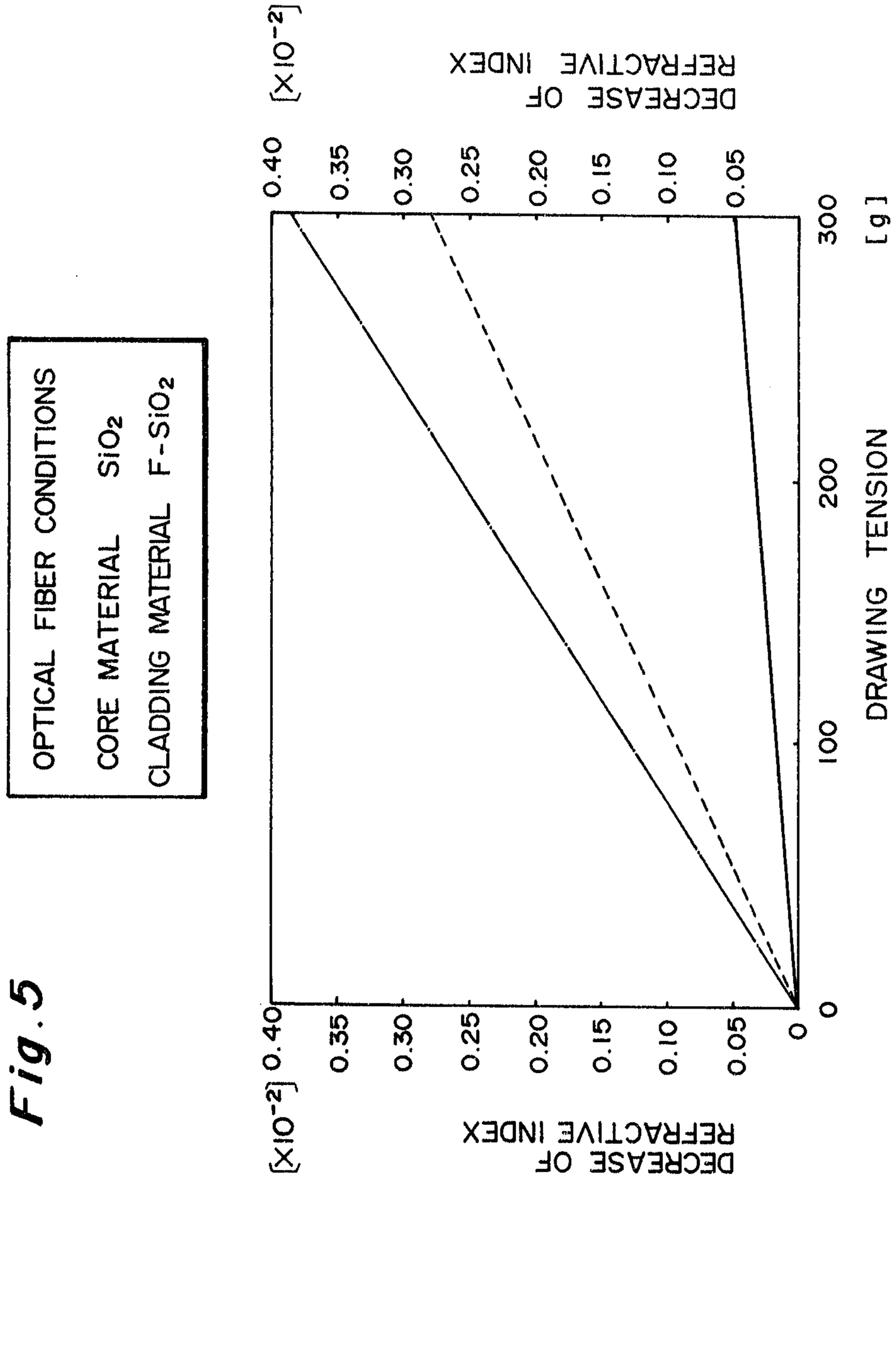
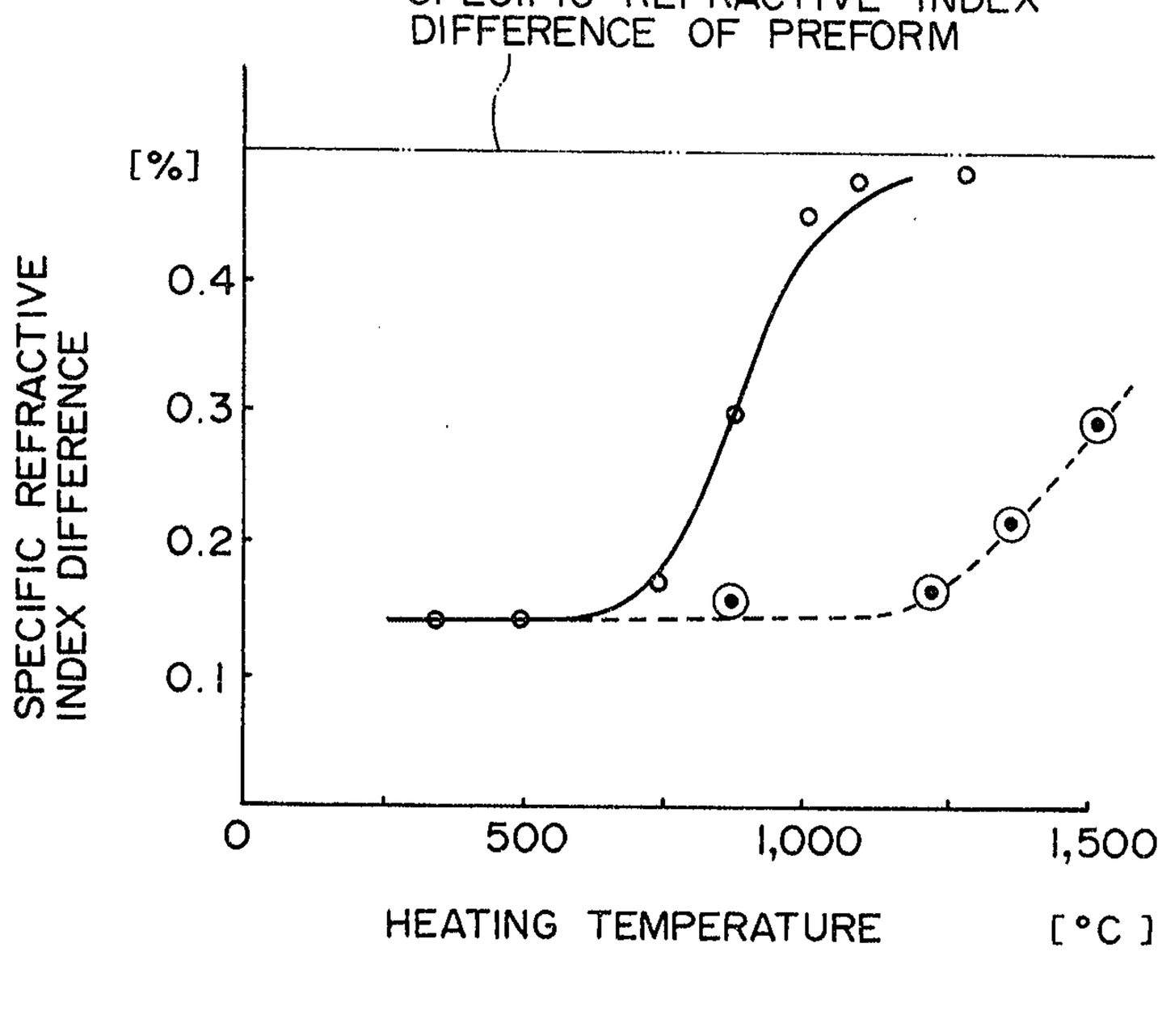


Fig. 5

Fig. 6



OPTICAL FIBER CONDITIONS	
CORE MATERIAL	SiO_2
CLADDING MATERIAL	F-SiO_2
SPECIFIC REFRACTIVE INDEX DIFFERENCE OF PREFORM	0.45%

Hiroko Ohmi

Fig. 7

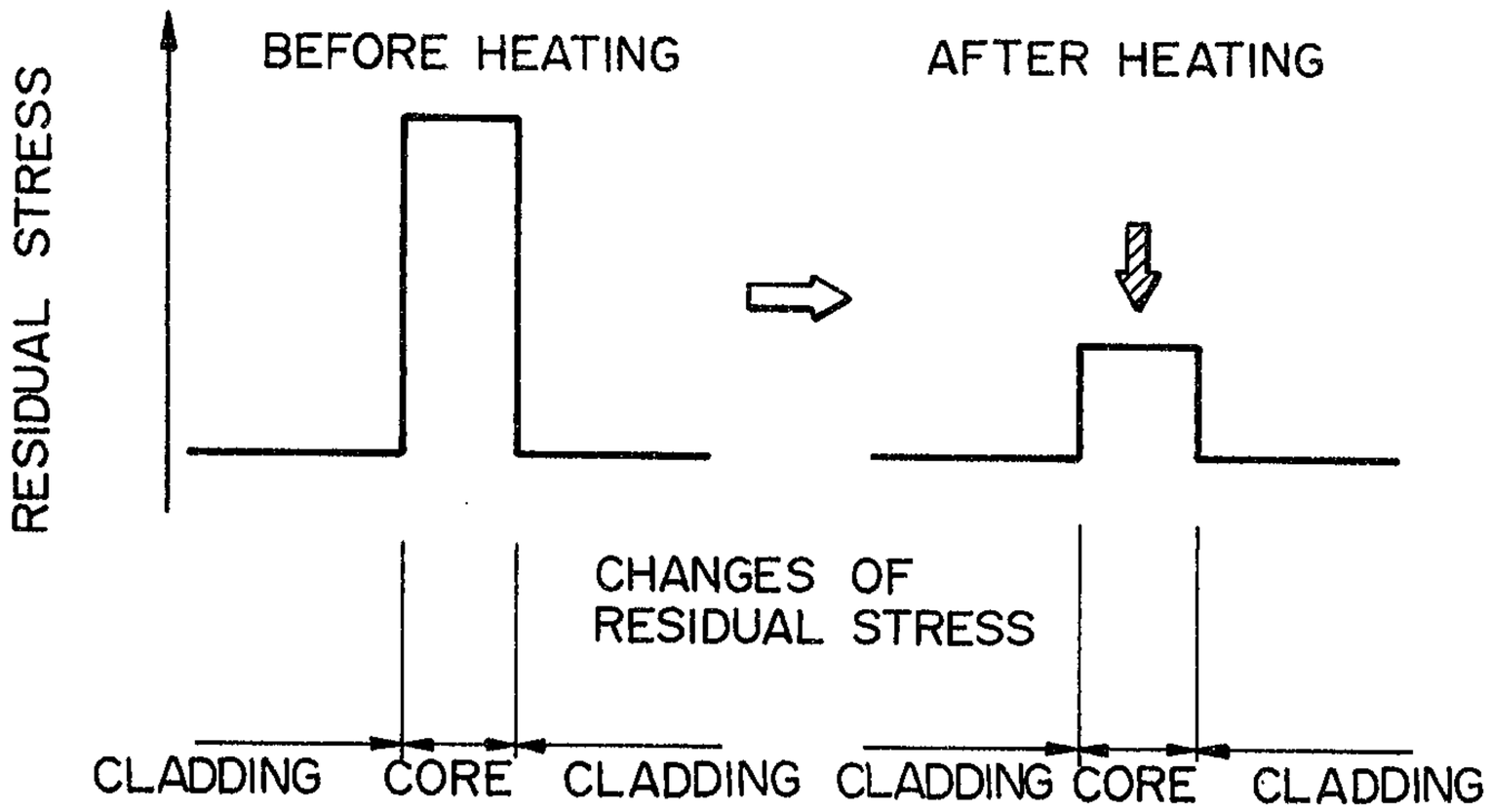
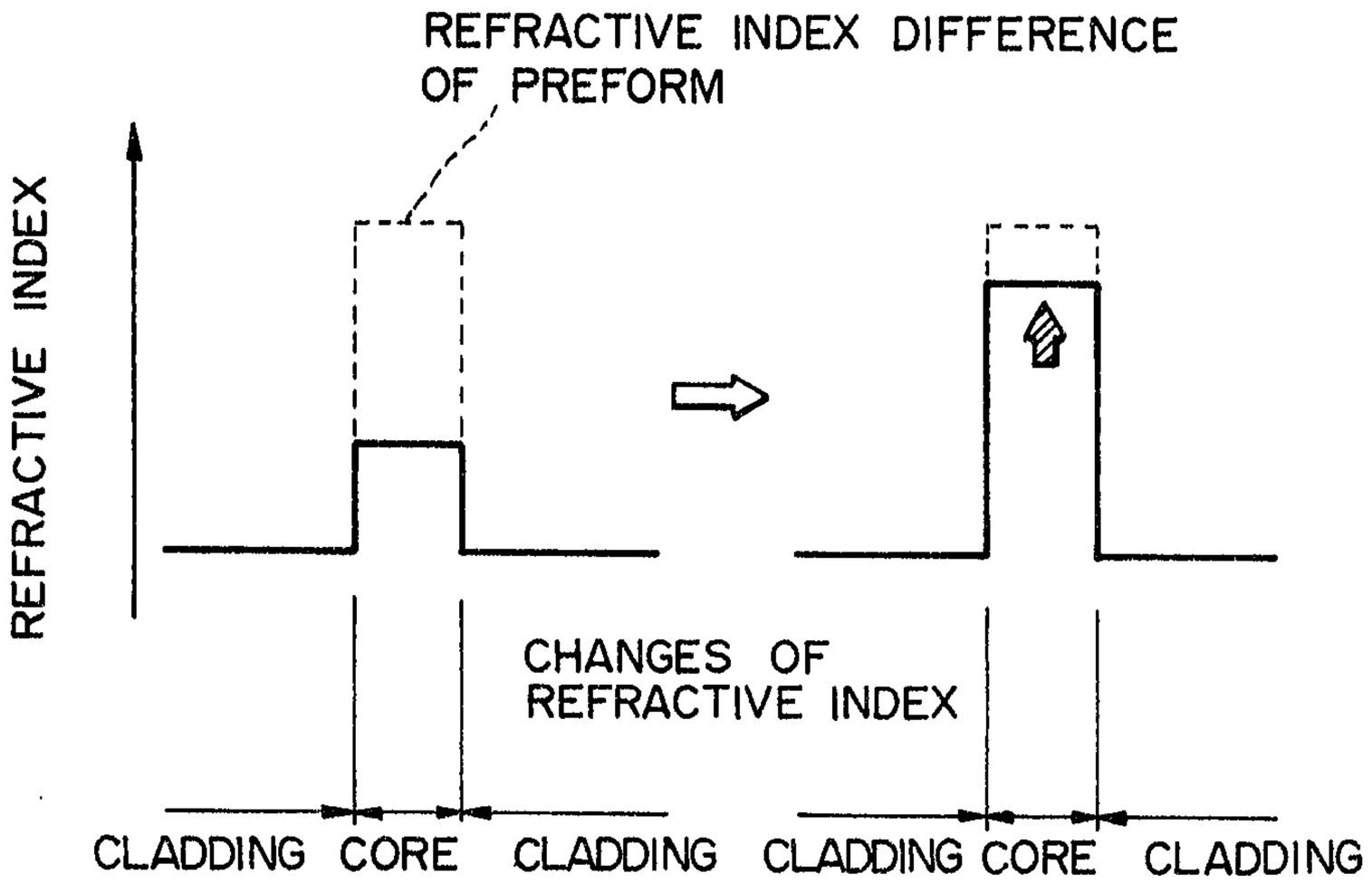


Fig. 8



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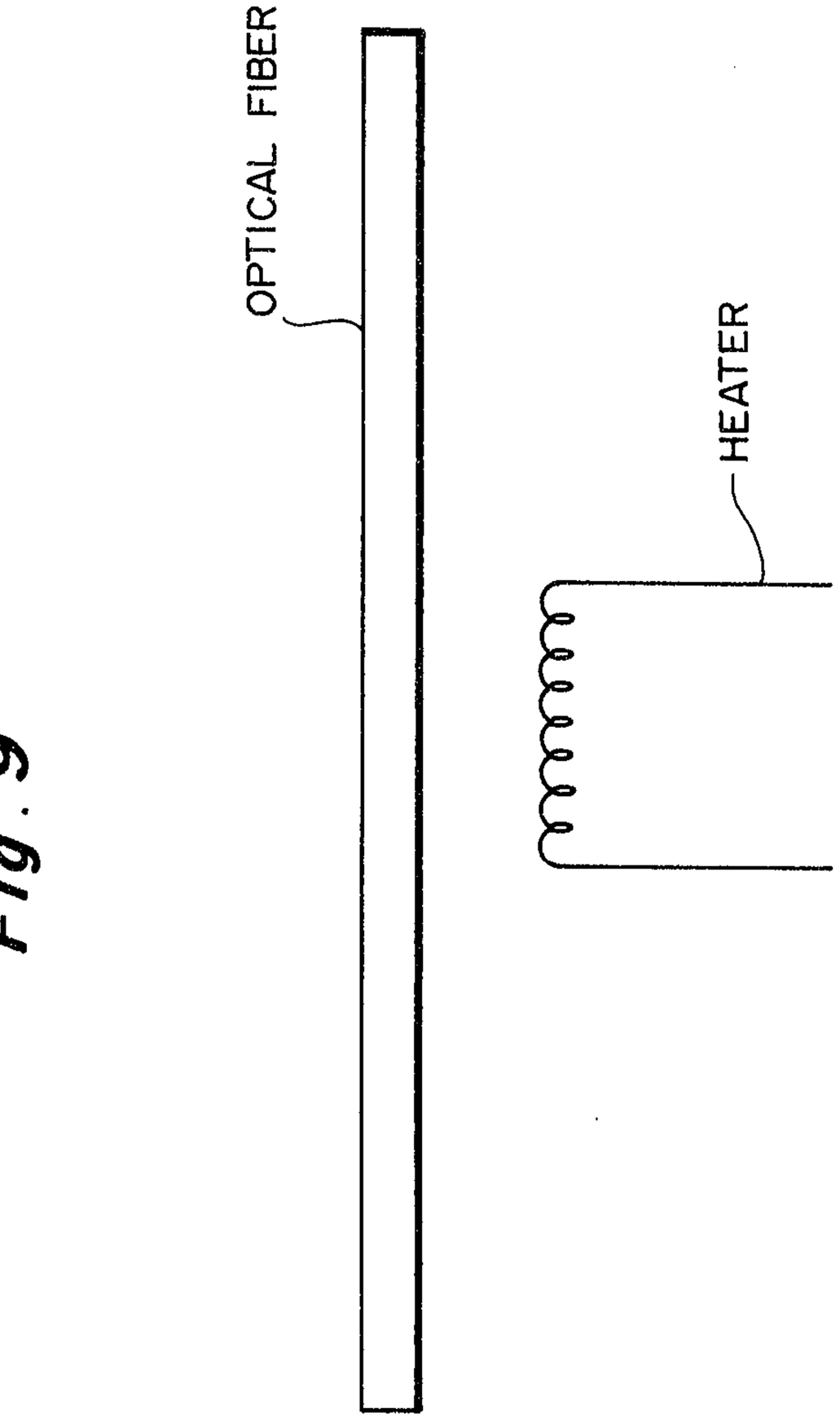


Fig. 9

Fig. 10

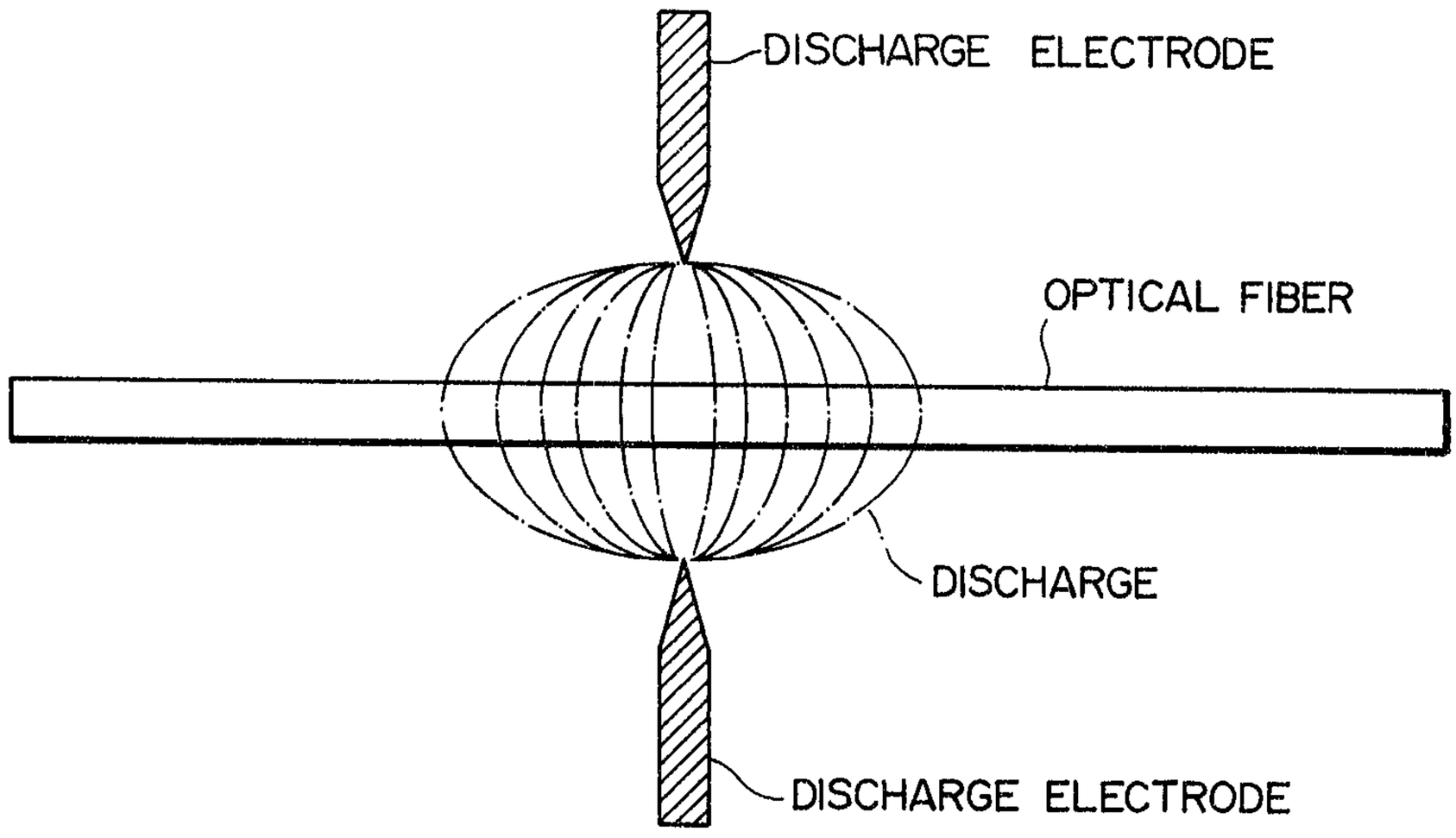
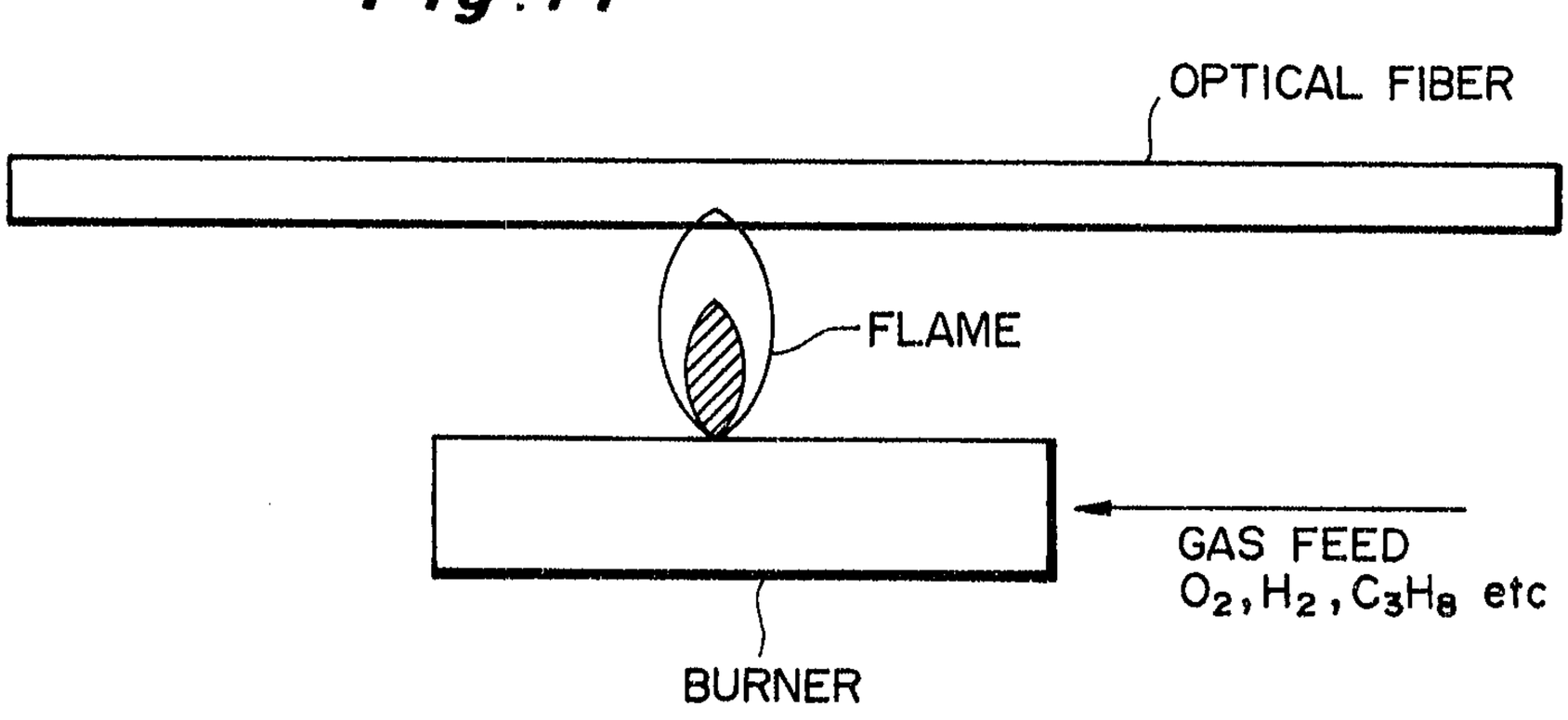
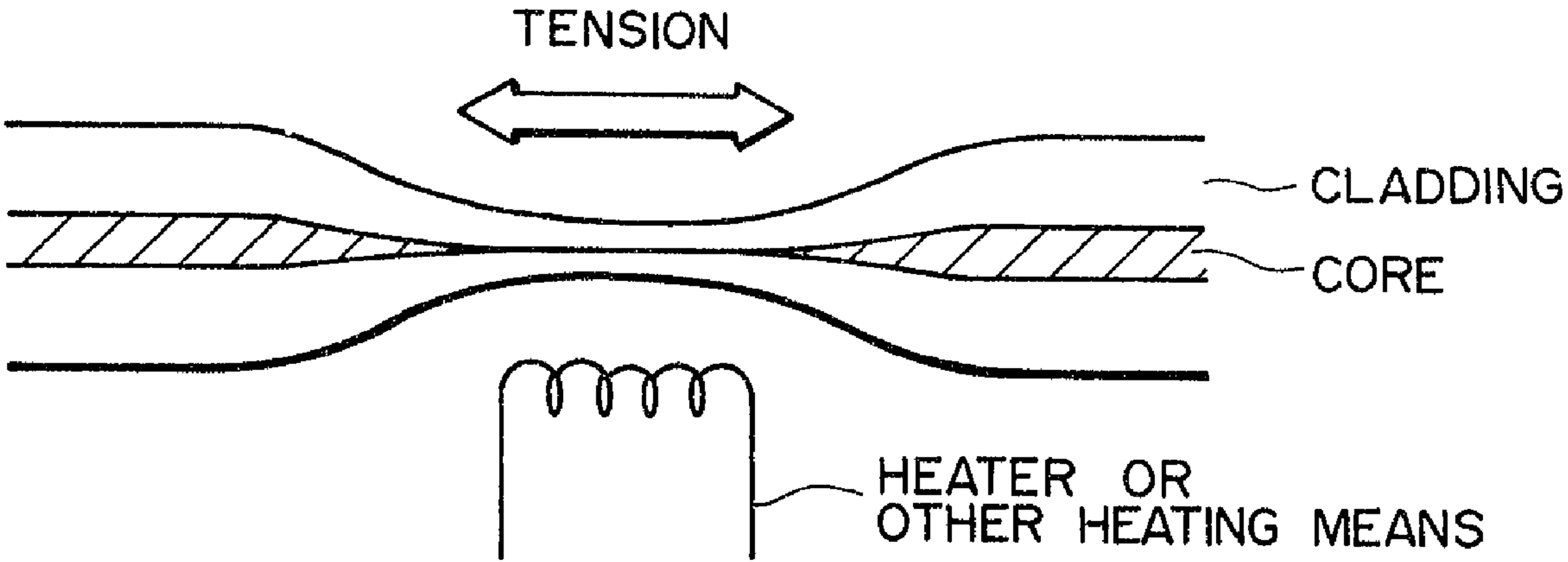


Fig. 11



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ELONGATION METHOD