

ACTIVE FIBER FOR OPTICAL SIGNAL TRANSMISSION**BACKGROUND OF THE INVENTION****1. Field of the Invention:**

The present invention relates to the field of optical communication systems.

2. Art Background:

Since the original invention of the laser, optical communication by laser beam has been one of the principal applications envisioned for this device. Lasers provide light beams having extreme directionality compared to beams produced by other light sources or microwave antennas. In addition, the amount of information which may be transmitted over an electromagnetic wave is proportional to the bandwidth of the wave. Since some lasers operate with very large modulation bandwidths, it is theoretically possible to transmit thousands of color television broadcasts over a single laser beam. Although bandwidth and directionality are two inherent advantages of laser communications systems. The usefulness of a laser communications system is generally limited by factors such as the necessity of electro-optic detectors, and the ease with which information can be imposed upon the beam itself. Moreover, atmospheric conditions may significantly attenuate the optical radiation of the laser, and laser light does not reflect well or penetrate through objects.

An alternative to atmospheric propagation is the use of optical fibers comprised of glass or plastic to confine and direct the laser beam. The use of optical

fibers permits efficient communication within dense population areas and eliminates the complex maze of wires and coaxial cables which have been required for electronic communication.

For long distance communication, a repeater for each channel within a fiber optic bundle is required to correct distortion of the optical signal caused by differential propagation delays, attenuation and noise. However, the use of repeaters interspersed along fiber optic cable segments in a communication system requires that the repeaters be provided with power for their circuits, significantly increases the cost of installation and decreases system reliability. Attenuation, or power loss, in an optical fiber is caused by a variety of processes, and various techniques have been attempted to reduce the attenuation, and therefore the need for repeaters, in a fiber opticcommunication system. (See: Drexhage, "Infrared Optical Fibers", Scientific American, Nov. 1988, pg. 110; and, O'Shea, "An Introduction to Lasers and Their Applications", Chapter 8, Addison-Wesley, December 1978).

As will be described, the present invention overcomes the disadvantages associated with prior art fiber optic cables, and discloses a fiber optic cable which eliminates the need for repeaters by effectively lasing the entire cable length. The cable is "pumped" to achieve lasing along its length using one of a variety of pumping mechanisms, as disclosed herein.

SUMMARY OF THE INVENTION

According to the invention there is provided an improved optical fiber for carrying an optical signal comprising:

an optically transparent core having a first index of refraction, said core being doped with a lasing material such that said core is doped having the greatest concentration of said dopant at the center of said core and said dopant is diffused outward from said center into said cladding;

an optically transparent cladding surrounding said core having a second index of refraction which is lower than said first index of refraction;

pumping means spatially disposed parallel to said cladding for providing light through said cladding and into said core, such that said lasing material lases at a desired wavelength and provides continuous gain throughout the length of the fiber for said optical signal;

whereby said optical signal is provided gain by said lasing.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatical cross section of a typical prior art fiber optic cable.

Fig. 2 illustrates a prior art three channel fiber optic communications system employing semiconductor lasers.

Fig. 3 illustrates an embodiment in which an external light source is used to pump a doped fiber cable to achieve lasing.

Fig. 4 is a cross section of a fiber optic cable in which a light emitting material is used to pump a doped fiber.

Fig. 5 is a cross section of a fiber optic cable further illustrating the use of a reflective coating to increase pumping efficiency.

Fig. 6 is a cross section of a fiber optic cable in which a doped fiber is pumped by an electroluminescent light source.

Fig. 7 is a schematic illustration of a fiber optic communications system utilizing the teachings of the present invention.

Fig. 8 is a graph illustrating the linear voltage drop along the length of the electroluminescent layer 78 which is transferred to the reflective layer 82 by shorting the two layers together at one end of each segment.

Fig. 9 is a schematic of a fiber optic communication system in which the optical fiber is broken into segments.

DETAILED DESCRIPTION OF THE INVENTION

An improved optical fiber is disclosed which has particular application for use in long distance optical communications systems. In the following description for purposes of explanation, numerous details are set forth such as specific wavelengths, angles, materials, etc., in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the invention may be practiced without these specific details. In other instances, well known components, structures and electrical processing means have not been described in detail in order not to obscure the present invention unnecessarily.

Referring now to Fig. 1, a common prior art optical fiber is illustrated which acts as an optical

wave guide for light waves. The optical fiber, generally denoted by the numeral 10, includes a thin, cylindrical core 12 which is comprised of glass having a refractive index N_2 . Core 12 is surrounded by another layer of glass referred to as a cladding 14 having a lower refractive index N_1 than the core 12. As illustrated, rays of light incident from the core 12 onto the cladding 14 at an angle having a normal greater than $\theta_c = \sin^{-1} N_1/N_2$ are trapped within the core 12 by total internal reflection. Rays of light transmitted into the cladding are absorbed by a jacket 16 which surrounds the cladding 14, and is typically comprised of an opaque plastic. The absorption of light rays by the jacket 14 prevents cross talk with other fibers in a fiber optic bundle. In fibers constructed of a separate core and cladding, rays of light which propagate at larger angles to the optical axis of the fiber require greater propagation time than rays propagating at smaller angles. This effect results in differential delay which may be eliminated by constructing fibers which have an extremely small refractive index difference between the core 12 and cladding 14. As the ratio of N_1 over N_2 approaches 1, the critical angle (c) approaches 90° , and only a single transverse mode propagates through the cable.

It is known that by properly doping the fiber during the manufacturing process, it is possible to produce a fiber which has a refractive index which decreases parabolically as a function of distance from the optical axis of the fiber. The refractive index gradient results in the optical beam being confined to the core 12 of the fiber 10. Accordingly, despite long distances travelled, the non-paraxial rays arrive at the end of the fiber 10 at the same time as the axial rays passing through the core 12.

Referring now to Fig. 2, there is shown a common prior art fiber optic communications system. As illustrated, the fiber optic communication system accepts electrical input lines 20 carrying electrical signals, and couples these signals to electrical drivers 22 which drive diode lasers (or light emitting diodes) 24, as is well known. Each of the diodes lasers 24 are optically coupled to a fiber optic cable 28 which may run for several kilometers. Due to signal attenuation, or power loss, resulting from a loss of signal from light passing from the core 12 into the cladding 14, as well as light absorbed by atoms of the material comprising the core 12, impurities in the material, and/or density fluctuations within the fiber itself, repeaters must be coupled along lengths of the cable to recondition the signals passing along each fiber. As shown in Fig. 2, each repeater 30 includes photodiode detectors 32 coupled to the end of each optical fiber cable, appropriate electrical drivers and amplifiers 34 to recondition the (now electrical) signal and place it in appropriate digital form matching as closely as possible to the input signals 20, and diode lasers 38 to retransmit the recondition signals along another segment 40 of the fiber optic cable.

The optical receiver at the end of the fiber optic communication system comprises an output terminal 42 having photodetectors 44 for receiving the optical signals travelling along the fiber optic cables 40, along with appropriate conditioners, demultiplexors, and demodulation circuitry generally described as amplifiers 48. The electrical output signals 50 are then coupled to the appropriate digital communication link, as is well known. Each repeater 30 must be provided with some source of power (internally through a battery, or an external power source) o function. Accordingly, it is

very difficult to construct fiber optic communications systems in remote locations due to the necessity of each repeater requiring maintenance and electrical power to properly operate. Remote locations would include desolate geographies as well as undersea and space based applications. Moreover, it will be appreciated that the electrical components comprising each repeater 30 are a source of potential failure due to power failures, EMP nuclear bursts or random component failure.

Referring now to Fig. 3, an embodiment is illustrated which includes a fiber optic cable, generally referred to by the numeral 60 having a core 62 and a cladding 64. The glass fiber material comprising the optical fiber 60 is doped with a quantity of the same material used to generate laser light in the diode lasers 24 of the optical communication system of Fig. 2. It is believed that the most advantageous implementation is to dope only the inner core 62 and allow the dopant to diffuse into the cladding 64, thereby providing doping density greater in the center of the core 62 than farther out towards the peripheral edges of the optical fiber. Doping in this fashion is believed to compensate for the tendency to have a depletion of excited state material where the optical signal intensity is greatest, and avoid gain saturation in the center of the core 62.

It will be appreciated by one skilled in the art, that by doping optical fiber 60 with the same material used to generate laser light in diode lasers 24, that the effect of pumping the length of fiber 60, and thereby raise the fiber material to an excited energy state, is to lase the dopant material and provide optical gain throughout the length of the fiber. Since the dopant within the fiber 60 is the same dopant as utilized in diode lasers 24, the effect of lasing the

dopant within the fiber 60 is to create a laser amplifier for the optical signal while preserving collimation and phase coherence.

The mechanism for pumping the fiber 60 to create the lasing effect may take a variety of forms. As shown in Fig. 3, the pumping may be accomplished by providing a light source 68 within an elliptical reflector 69 surrounding the fiber 60, with the fiber at one locus of the elliptical reflector. This pumping apparatus is similar in construction to that used in the original ruby rod laser wherein the light source 68 provides the optical energy to pump the lasing material doped into the optical fiber 60, to achieve the desired optical gain for the optical wave length used by the diode lasers 24. Although the embodiment illustrated in Fig. 3 would accomplish the desired results, it will be appreciated that the necessity of surrounding the optical fiber 60 and an external light source 68 within the electrical reflector 69 would be quite bulky and unsuited for underground and other limited space applications.

Referring now to Fig. 4, another embodiment is illustrated in which the optical fiber 60 is coated with a light emitting material 72 to provide the energy source required to pump the dopant within the core 62 and cladding 64. An example of a light emitting material which may be utilized is radium fluorescent paint in which the half life of the radium provides a corresponding half life for the achievement of gain through lasing of the dopant within the fiber 60. In order to improve pumping efficiency, a reflective layer 74 may be provided to surround the light emitting material 72 and reflect light back through the cladding 64 and into the core 62 to improve lasting efficiency

(see Figure 5). It will be appreciated, that by coating the fiber 60 with the light emitting material 72, no additional light source is necessary to pump the fiber to achieve the requisite optical gain, and that the fiber may be utilized over in long segments without the need for repeaters, since the optical signal originally applied by the diode lasers 24 will be provided with a constant gain along the length of the entire cable 60.

Referring now to Fig. 6, a further embodiment is illustrated wherein an electroluminescent material 78 surrounds the cladding 64. As shown, an insulating layer 80 surrounds the electroluminescent layer 78 and a reflective layer 82 surrounds the insulating layer 80. The insulating layer 80 may comprise another layer of glass which is optically clear to avoid loss of pumping efficiency, and the reflector may comprise some form of metal (for example, aluminum). The application of a voltage across the length of the fiber 60 results in the electroluminescent layer 78 generating photon energy which is used to pump the dopant within core 62 to achieve the desired lasing. As best illustrated in Fig. 7, the fiber optic communications system utilizing the teaching disclosed in Fig. 6, includes electrical input signals 90 which are coupled to drivers 92 and diode lasers 94, in a similar fashion as the system disclosed in Fig. 2. Each optical fiber 98 coupled to its respective diode laser has the structure illustrated in Fig. 6. As in the case of the prior art systems, the detector generally denoted by the numeral 100 includes photodetectors 104 and appropriate circuitry 106 to convert incident optical signals travelling along the fibers 98 into appropriate data output signals 110, as is known in the art.

As shown in Fig. 7, applying a voltage V across the length of each optical fiber 98 on the electroluminescent layer 78, results in the generation of photon energy by the electroluminescent layer 78 and the lasing of the core dopant. However, as will be appreciated, there will be a voltage drop along the length of each fiber 98 in the electroluminescent layer 78, and this voltage drop from current flowing along the length of the fiber 98 must be sufficiently low to avoid breakdown of the insulator layer 80 separating the electroluminescent layer 78 from the reflective layer 82. To avoid the breakdown of the insulating layer 80, for long sections of the fiber the reflective layer 82 is shorted to the electroluminescent layer 78 to equalize the voltage drop on both surfaces. Accordingly, fiber 98 must be segmented such that at one end of each segment the reflective layer 82 is shorted to the electroluminescent layer 78. As best shown in Fig. 8, the linear voltage drop along the length of the electroluminescent layer 78 is transferred to the reflective layer 82 by shorting the two layers together at one end of each segment. As shown in Fig. 8, the stepped function indicates the stepped voltage drop for the reflecting reflective layer 82 at each segment.

A fiber optic communication system in accordance with the teachings as illustrated in Fig. 6 is shown in Fig. 9. As illustrated, the transmitter including the appropriate drivers and diode lasers as in Fig. 2 and 7 is identified generally by the numeral 120. The optical fiber 125 having the structure of the fiber illustrated in Fig. 6 is broken into segments S1, S2, S3 and S4, as shown. At one end of each segment is a connector 135. Each of the connectors 135 physically short the electroluminescent layer 78 to the reflective layer 82 of the upstream segment, thereby insuring that the

voltage across the insulating layer 80 is identical at that point. As previously described, the application of a voltage over the length of fiber 125 results in the lasing of the dopant within the core 62 and the requisite optical gain to avoid the need for repeaters spaced along the length of the cable. Detector electronics 145 are provided to receive the transmitted signal along the cable 125 and coupled the electrical signal to appropriate digital electronics. It will be appreciated, that the connectors 135 are simple mechanical connectors which are not prone to failure and require no external power for operation. Alternatively, the electroluminescent layer 75 may be shorted to the reflective layer 82 by etching a portion of the reflective layer 82 and insulating layer 80 to expose the electroluminescent layer 75 and plating the etched surface to form the connection between the electroluminescent layer 75 and reflective layer 82.

Thus, an improved optical fiber has been disclosed which obviates the need for repeaters to be spaced along the length of the fiber to correct for signal attenuation. The use of a doped core 62 and fused dopant in the cladding 64, in conjunction with one of the variety of pumping configurations, results in optical gain along the length of the fiber. Since the technology of the present invention is not dependent upon electrical repeaters, it is highly immune to EMP factors resulting from, for example, nuclear blasts. In addition, since the fiber provides inherent gain through lasing of the dopant in the core, the diode laser may be of lower power.

The present application has been divided out of our co-pending UK patent application No. 8924819.9 (2228362) in which there is described and claimed a data

transmission system for transmitting an optical signal, comprising:

laser light generation means for generating laser light having a predetermined wavelength, and comprising said optical signal;

an optical fiber having a first and second end, said first end coupled to said laser light generation means, said optical fiber comprising;

an optically transparent core having a first index of refraction, said core being doped with a lasing material;

an optically transparent cladding surrounding said core having a second index of refraction which is lower than said first index of refraction;

pumping means spatially disposed parallel to said cladding and extending from said first end to said second end, said pumping means for providing light through said cladding and into said core such that said lasing material lases at the same wavelength as said laser light generated by said laser light generation means and provides gain for said optical signal continuously over a great distance along said optical fibre;

receiving means coupled to said second end of said fiber for receiving said optical signal.

whereby said optical signal is provided gain by the lasing of said lasing material.

In co-pending UK Patent Application No. 9325719.4, divided out of the present application, there is described and claimed an improved optical fibre for carrying an optical signal comprising:

an optically transparent core having a first index of refraction, said core being doped with a lasing material;

an optically transparent cladding surround said core having a second index of refraction which is lower than said first index of refraction;

pumping means spatially disposed parallel to said cladding, comprising a light emitting material surrounding said cladding, for providing light through

said cladding and into said core such that said lasing material lases at a desired wavelength and provides continuous gain for said optical signal;

whereby said optical signal is provided gain by said lasing.



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CLAIM

1. An improved optical fiber for carrying an optical signal comprising:

an optically transparent core having a first index of refraction, said core being doped with a lasing material such that said core is doped having the greatest concentration of said dopant at the center of said core and said dopant is diffused outward from said center into said cladding;

an optically transparent cladding surrounding said core having a second index of refraction which is lower than said first index of refraction;

pumping means spatially disposed parallel to said cladding for providing light through said cladding and into said core, such that said lasing material lases at a desired wavelength and provides continuous gain throughout the length of the fiber for said optical signal;

whereby said optical signal is provided gain by said lasing.
