

Description**Background of the Invention**5 **[Field of the Invention]**

The present invention concerns optical fiber couplers employed in communication systems.

10 **[Prior Art]**

In one type of optical fiber coupler known in the art, two or more fibers are aligned side by side in a plane and thermally fused and elongated, thereby forming a fused-elongated region.

15 In the fused-elongated region thus formed, the diameter of each component optical fiber is reduced, as is the diameter of the core of each fiber. To the extent that diameter of the cores of the optical fibers are reduced, a proportionately larger fraction of the light propagated therein leaks through the clad which surrounds the core of each fiber. Also, to the extent that the component optical fibers are drawn out and thereby elongated, the distance between the cores of adjacent optical fibers is reduced, and due to this fact, the coupling between the propagated modes of the individual fibers becomes extremely great. In this way, the light signal carried by one fiber branches and is thus caused to be multiplexed over two or more optical fibers.

20 However, the above described optical fiber coupling technique has the following shortcoming:

When conventional quartz glass single mode optical fiber is used to form the optical fiber coupler, because the properties of the material are such that very little light energy is lost through the lateral surface of the fiber, the fused-elongated region must be quite long in order to sufficiently achieve optical coupling. 25 Further, in order to form a fused-elongated region of sufficient length, the resulting diameters of the component optical fibers in the fused-elongated region end up being considerably reduced. For example, starting with quartz optical fibers having an outer diameter of 125 μm , it is possible that in the fused-elongated region of the resulting coupler, the fibers have a final outer diameter in the order of 20 μm . Because of this effect, even a relatively small curvature in the optical fiber results in light leaking through the side of the fiber to the exterior with loss in light energy. With a larger amount of bending in the optical fiber, the bending losses become significant.

30 **Summary of the Invention**

35 In answer to the above described difficulties, it is an object of the present invention to provide an optical fiber coupler that can be fabricated with ease and from which losses are minimal.

As the result of various experiments, it has been found that by employing a single mode optical fiber within a parameter range in which the mode field diameter increases monotonically with decrease in the diameter of the optical fiber core, that even when the amount of optical fiber elongation is limited, adequate optical coupling can be achieved.

40 Accordingly, the present invention provides an optical fiber coupler formed by fusing a section of each of two or more component optical fibers, and then elongating the fused section thereby forming a fused-elongated region which constitutes the optical fiber coupler, in which at least one of the component fibers is a single mode optical fiber having a parameter range in which the mode field diameter increases monotonically with decrease in the diameter of the optical fiber core. By virtue of this feature, the amount of elongation or drawing of each component fiber which is carried out after fusing the fibers can be limited while still achieving adequate optical coupling.

45 The invention is therefore to be distinguished from that described in US-A-4755037 which is generally concerned with the geometry of the intermediate tapering regions and the existence of a central fused region with parallel side walls.

50 **Brief Explanation of the Drawings**

Fig. 1 is a sideview of the optical fiber coupler of a first embodiment of the present invention.

55 Fig. 2 is a graph illustrating the relationship between core diameter and diameter of the mode field for a single mode optical fiber.

Fig. 3 is a side view of the optical fiber coupler of a second embodiment of the present invention.

Figs. 4 and 5 are graphs illustrating the relationship between wavelength and dispersion for the optical fibers.

Fig. 6 is a sideview of the optical fiber coupler of a third embodiment of the present invention.

Fig. 7 is a graph illustrating one example of the relationship between wavelength and coupling ratio for the optical fiber coupler shown in Fig. 6.

Detailed Description of the Preferred Embodiments

[First Embodiment]

In the following section, the first embodiment of the present invention will be described with reference to Figs. 1 and 2.

The optical fiber coupler 11 of the present embodiment as shown in Fig. 1 consists of a fused-elongated region 14 formed by thermally fusing and then drawing out a section of each of two component optical fibers 12 and 13, one of which is a conventional quartz single mode optical fiber 12 (hereafter referred to as conventional fiber), and one of which is a single mode optical fiber 13 characterized by having a parameter range in which the mode field diameter increases monotonically with decrease in the diameter of the optical fiber core. For the single mode optical fiber 13, it is preferable to use quartz single mode optical fiber of which the extent of its mode (mode field diameter) rapidly increases with decrease in the diameter of its core, and hence, with drawing out of the fiber.

In Fig. 2, the relationship between core diameter and mode field diameter for conventional quartz single mode optical fiber suitable for transmitting optical signals at a wavelength of 1.3 μm is graphically illustrated. In the graph, a series of approximately parallel curves are shown, each of which represents a fiber having a different value for the refractive index difference between the clad and the core. As can be seen in the graph, a curve has a respective minimum value for the mode field diameter corresponding with a particular value for the diameter of the fiber core. The line 1B in the drawing interconnects the minimum values of the respective curves. The above mentioned refractive index difference (RRID) is calculated by Equ. 1 below in which m_1 represents the refractive index for the core material and m_2 represents the refractive index for the cladding material.

$$\text{RRID} = \frac{m_1 - m_2}{m_1} \quad \text{Equ. 1}$$

In Fig. 2, the region 1A relates to a range for the structural parameters characteristic of the conventional quartz single mode optical fiber, the structural parameters being as follows: core diameter 9 - 10 μm , refractive index difference 0.28 - 0.35 %, external diameter of clad 125 μm . As shown in the graph, the region 1A corresponds to a relatively low mode field diameter, and thus indicates a parameter range not very suitable for the fully formed optical fiber coupler. Further, this region 1A is significantly to the right of the above mentioned line 1B which coincides with minimum values of mode field diameter for various examples of the optical fiber. Thus, if starting material corresponding with the region 1A were to be used for the single mode optical fiber 13 used to form the optical fiber coupler of the present invention, a considerable amount of drawing of the fused fibers would be required to obtain a coupler in which the single mode optical fiber 13 possesses a suitably large mode field diameter, which would accordingly result in an excessively long optical fiber coupler. Thus it can be seen that for the single mode optical fiber 13, it is preferable to use quartz single mode optical fiber of which the structural parameters correspond with a point somewhere to the left of the line 1B in Fig. 2.

Because in the optical fiber coupler 11 of the present embodiment, one of the two fibers which are fused together to form the coupler is a single mode optical fiber 13 characterized by having a parameter range in which the mode field diameter increases monotonically with decrease in the diameter of the optical fiber core, the amount of drawing out of the fused component fibers can be limited to a relatively small amount while still achieving adequate optical coupling. For this reason, it is possible to fabricate a small sized optical fiber coupler 11.

In the optical fiber coupler 11 of this first preferred embodiment as described, only one conventional fiber 12 and one single mode optical fiber 13 each were employed. However, it is also possible to

incorporate a plurality of the conventional fibers 12 and/or a plurality of the single mode optical fibers 13 in the manufacture of such an optical fiber coupler 11. The coupler may also be manufactured using only two or more of the single mode optical fibers 13.

5 [First Experimental Example]

Using a quartz optical fiber suitable for transmitting light signals at a wavelength of $1.3\ \mu\text{m}$ having a core diameter of $5\ \mu\text{m}$, an external clad diameter of $125\ \mu\text{m}$, and a refractive index difference of 0.3 % for the single mode optical fiber 13, and a single mode quartz optical fiber having a core diameter of $9\ \mu\text{m}$, an external clad diameter of $125\ \mu\text{m}$, and a refractive index difference of 0.3 %, for the conventional fiber 12, a portion of each were aligned side by side and thermally fused. The fused portion was then draw out to produce an optical fiber coupler 11 of the same type as that of the first embodiment as shown in Fig. 1. The fused-elongated region 14 thus manufactured had a minimum outer diameter of $45\ \mu\text{m}$, and a length of 7 mm. The measured value for loss from the thus produced optical fiber coupler 11 was 0.1 dB which is extremely low.

[Second Embodiment]

In the following section, the second embodiment of the present invention will be described with reference to Fig. 3.

The optical fiber coupler 15 of the present embodiment as shown in Fig. 3 consists of a fused-elongated region 17 formed by thermally fusing and then drawing out a section of each of two component optical fibers 12 and 16, one of which is the previously described conventional fiber 12, and one of which is a single mode optical fiber 16 characterized by having negligible wavelength dispersion and being a dispersion shifted optical fiber at wavelengths of $1.4\ \mu\text{m}$ and greater (hereafter referred to as dispersion shifted fiber 16).

For the above mentioned dispersion shifted fiber 16, the bending loss characteristics are extremely good, and the refractive index difference (Δ %) is comparatively high. Additionally, the core diameter is such that the structural parameters lie in the region to the left of the line 1B in Fig. 2.

In general, it cannot be said that bending loss characteristics are always good with optical fiber having a comparatively low refractive index difference. In order to improve the bending loss characteristics, it is desirable to use optical fiber material for which the refractive index difference is high, and for which the core diameter is such that the structural parameters lie in the region to the left of the line 1B in Fig. 2. With such optical fiber material, because change in the mode field diameter is sensitive to variation in the core diameter or regulated variation of the light frequency, the so called wave guide dispersion is high.

In Figs. 4 and 5, examples of the wavelength dispersion characteristics can be seen for conventional optical fiber suitable for transmitting light signals at a wavelength of $1.3\ \mu\text{m}$ of which the refractive index difference is high and of which the core diameter is small. For the optical fiber material represented in Fig. 4, the waveguide dispersion is low, and in the vicinity of $1.3\ \mu\text{m}$, the wavelength dispersion representing the sum of the wave guide dispersion and materials dispersion is zero. Concerning the above mentioned waveguide dispersion, because the measured value varies with respect to the wavelength of the propagated light, the mode propagation state also varies. Similarly, concerning the above mentioned materials dispersion, because the refractive index difference for the optical fiber material varies with the wavelength of the propagated light, the mode propagation velocity also varies.

In the case of Fig. 5, the optical fiber material again has a refractive index difference which is high and a small core diameter. However, for the material represented by Fig. 5, the waveguide dispersion is high. Due to the high wave guide dispersion, the wavelength dispersion is shifted towards longer wavelengths. The above mentioned dispersion shifted fiber 16 is an example of an optical fiber material for which the wave guide dispersion has been intentionally shifted to a higher value in this way. For this kind of dispersion shifted fiber 16, the wavelength at which the wavelength dispersion value becomes zero is shifted to a wavelength longer than $1.3\ \mu\text{m}$, and is generally in the range of $1.4 - 1.6\ \mu\text{m}$. When the wavelength at which the wavelength dispersion value becomes zero is shorter than $1.4\ \mu\text{m}$, an optical fiber having sufficiently stable characteristics in response to bending is not obtainable. Thus when used to form an optical fiber coupler, there is increased chance for optical losses in the portions of the optical fiber leading up to the optical fiber coupler.

With the optical fiber coupler 15 of the present preferred embodiment, by choosing optical fiber materials having selected values for the refractive index difference for the two component optical fibers, conventional fiber 12, and dispersion shifted fiber 16, the propagation constant of the respective component

optical fibers 12, 16 can be varied to match desired values. By selecting desired propagation constant for the two component fibers 12, 16 which are different and then thermally fusing together a portion of each component optical fiber 12, 16 and drawing out the fused portion as described above to form the fused-elongated region 17, the wavelength dependance characteristics of the resulting optical fiber coupler 15 can be controlled. By this means, an optical fiber coupler which is largely wavelength independent (or wide band-pass type optical fiber coupler) can be fabricated.

Further, by using a dispersion shifted fiber 16 having superior stability characteristics in response to fiber bending, the resulting optical fiber coupler 15 includes lead fibers 18 leading up to the fused-elongated region 17 for which the stability characteristics in response to fiber bending are supported.

[Second Experimental Example]

Using a quartz optical fiber suitable for transmitting light signals at a wavelength of $1.3\ \mu\text{m}$ having a core diameter of $9\ \mu\text{m}$, an external clad diameter of $125\ \mu\text{m}$, and a refractive index difference of 0.3 % for the conventional fiber 12, and an optical fiber having a core diameter of $4\ \mu\text{m}$, an external clad diameter of $125\ \mu\text{m}$, a refractive index difference of 0.7 %, and a zero wavelength dispersion value at $1.55\ \mu\text{m}$ for the dispersion shifted fiber 16, a portion of each were aligned side by side and thermally fused. The fused portion was then drawn out to produce an optical fiber coupler 15 of the same type as that of the second embodiment as shown in Fig. 3. The fused-elongated region 17 thus manufactured had a minimum outer diameter of $55\ \mu\text{m}$, and a length of 6 mm. The measured value for loss from the thus produced optical fiber coupler 15 was 0.05 dB which is extremely low. Further, when the lead fiber 18 of the optical fiber coupler 15 manufactured as described above was bent in the form of a curve having a bending curvature of 10 mm, the additional optical loss was only 0.1 dB. Using a prior art coupler suitable for light signals at a wavelength of $1.3\ \mu\text{m}$, bending a lead under the same conditions demonstrated an additional loss of 0.5 dB.

Examining the wavelength dependance characteristics of the optical fiber coupler 15 manufactured as described above, it was found that the optical fiber coupler 15 was minimally wavelength dependant and could be used over a wide range of wavelengths as a wavelength independent optical fiber coupler (wide band-width type optical fiber coupler).

[Third Embodiment]

In the following section, the third embodiment of the present invention will be described with reference to Fig. 6.

The optical fiber coupler 19 of the present embodiment as shown in Fig. 6 consists of a fused-elongated region 20 formed by thermally fusing and then drawing out a section of each of two component optical fibers, both of which are the same as the dispersion shifted fiber 16 employed in the optical fiber coupler 15 described above for the second embodiment of the present invention.

With the optical fiber coupler 19 of the present embodiment, by appropriately controlling the elongation ratio of the fused-elongated region 20, it is possible to fabricate a selective wavelength splitter type optical fiber coupler in which at certain wavelengths, essentially no light is transmitted and at certain other wavelengths, essentially 100 % transmission is achieved.

By constructing the optical fiber coupler 19 using two of the dispersion shifted fibers 16, of which only one is employed in the optical fiber coupler 15 described above for the second embodiment, an optical fiber coupler 19 with even greater stability characteristics in response to bending can be fabricated.

[Third Experimental Example]

Using two dispersion shifted optical fibers 16, each having a zero wavelength dispersion value at $1.55\ \mu\text{m}$, a portion of each were aligned side by side and thermally fused. The fused portion was then draw out to produce an optical fiber coupler 19 of the same type as that of the third preferred embodiment as shown in Fig. 6. The fused-elongated region 20 thus manufactured had a minimum outer diameter of $55\ \mu\text{m}$, and a length of 10 mm.

Measuring the optical coupling wavelength characteristics of the optical fiber coupler 19 of the present experimental example, it was found that the optical fiber coupler 19 could be used as a selective wavelength splitter type optical fiber coupler. That is to say, of the four ports 2A, 2B, 2C, 2D, when an optical signal containing two wavelength components, one at $1.3\ \mu\text{m}$ and one at $1.55\ \mu\text{m}$, was input at port 2A, it was found that the optical signal was separated into its two components, one emitted from port 2C and one emitted from port 2D.

The various examples of the present invention presented in the above preferred embodiments are merely examples and are in no way to be construed as limiting the present invention. It is possible, for example, to employ three or more optical fibers in the optical fiber coupler of the present invention with acceptable results. It should be understood that the optical fiber coupler of the present invention includes all forms encompassed by the appended claims.

Claims

1. An optical fiber coupler formed by fusing a section of each of two or more component optical fibers, and then elongating the fused section to form a fused-elongated region, in which at least one of said component optical fibers is a single mode optical fiber having a parameter range such that as the diameter of the core of said optical fiber is reduced, the diameter of the mode field for said optical fiber increases monotonically.
2. An optical fiber coupler in accordance with Claim 1, in which said single mode optical fiber is a dispersion shifted single mode fiber for which the wavelength value at which wavelength dispersion becomes zero is $1.4\mu\text{m}$ or greater.
3. An optical fiber coupler in accordance with claim 1, in which said two or more component optical fibers are dispersion shifted single mode fibers for which the wavelength value at which wavelength dispersion become zero is $1.4\mu\text{m}$ or greater.

Patentansprüche

1. Faseroptischer Koppler, der durch Verschmelzen eines Abschnitts von jeder von zwei oder mehr optischen Komponenten-Fasern und das anschließende Dehnen des verschmolzenen Abschnitts hergestellt wird, um einen verschmolzenen Längsbereich zu bilden, bei welchem wenigstens eine der optischen Komponenten-Fasern eine Einmodenfaser ist, die einen solchen Parameterbereich hat, daß der Durchmesser des Modenfelds für die optische Faser monoton zunimmt, wenn der Durchmesser des Kerns der optischen Faser verringert wird.
2. Faseroptischer Koppler nach Anspruch 1, bei dem die genannte Einmodenfaser eine dispersionsverschobene Einmodenfaser ist, für die der Wert der Wellenlänge, bei dem die Wellenlängendispersion gleich Null wird, gleich $1,4\mu\text{m}$ oder größer ist.
3. Faseroptischer Koppler nach Anspruch 1, bei dem die genannten zwei oder mehr optischen Komponenten-Fasern dispersionsverschobene Einmodenfasern sind, für die der Wert der Wellenlänge, bei dem die Wellenlängendispersion gleich Null wird, gleich $1,4\mu\text{m}$ oder größer ist.

Revendications

1. Coupleur à fibres optiques formé en fondant une section de chacune de deux ou plusieurs fibres optiques élémentaires et en allongeant ensuite la section fondue pour former une région fondue et allongée dans laquelle au moins l'une desdites fibres optiques élémentaires est une fibre optique monomode ayant une gamme de paramètres telle que, quand le diamètre du cœur de ladite fibre optique est diminué, le diamètre du champ de mode de ladite fibre optique augmente de manière monotone.
2. Coupleur à fibres optiques selon la revendication 1, dans lequel ladite fibre optique monomode est une fibre monomode à déplacement de dispersion, pour laquelle la valeur de la longueur d'onde à laquelle la dispersion de longueur d'onde devient égale à zéro est $1,4\mu\text{m}$ ou plus grande.
3. Coupleur à fibres optiques selon la revendication 1, dans lequel lesdites deux ou plusieurs fibres optiques élémentaires sont des fibres monomode à déplacement de dispersion, pour lesquelles la valeur de la longueur d'onde à laquelle la dispersion de longueur d'onde devient égale à zéro est $1,4\mu\text{m}$ ou plus grande.

The various examples of the present invention presented in the above preferred embodiments are merely examples and are in no way to be construed as limiting the present invention. It is possible, for example, to employ three or more optical fibers in the optical fiber coupler of the present invention with acceptable results. It should be understood that the optical fiber coupler of the present invention includes all forms encompassed by the appended claims.

Claims

1. An optical fiber coupler formed by fusing a section of each of two or more component optical fibers, and then elongating the fused section to form a fused-elongated region, in which at least one of said component optical fibers is a single mode optical fiber having a parameter range such that as the diameter of the core of said optical fiber is reduced, the diameter of the mode field for said optical fiber increases monotonically.
2. An optical fiber coupler in accordance with Claim 1, in which said single mode optical fiber is a dispersion shifted single mode fiber for which the wavelength value at which wavelength dispersion becomes zero is $1.4\mu\text{m}$ or greater.
3. An optical fiber coupler in accordance with claim 1, in which said two or more component optical fibers are dispersion shifted single mode fibers for which the wavelength value at which wavelength dispersion become zero is $1.4\mu\text{m}$ or greater.

Patentansprüche

1. Faseroptischer Koppler, der durch Verschmelzen eines Abschnitts von jeder von zwei oder mehr optischen Komponenten-Fasern und das anschließende Dehnen des verschmolzenen Abschnitts hergestellt wird, um einen verschmolzenen Längsbereich zu bilden, bei welchem wenigstens eine der optischen Komponenten-Fasern eine Einmodenfaser ist, die einen solchen Parameterbereich hat, daß der Durchmesser des Modenfelds für die optische Faser monoton zunimmt, wenn der Durchmesser des Kerns der optischen Faser verringert wird.
2. Faseroptischer Koppler nach Anspruch 1, bei dem die genannte Einmodenfaser eine dispersionsverschobene Einmodenfaser ist, für die der Wert der Wellenlänge, bei dem die Wellenlängendispersion gleich Null wird, gleich $1,4\mu\text{m}$ oder größer ist.
3. Faseroptischer Koppler nach Anspruch 1, bei dem die genannten zwei oder mehr optischen Komponenten-Fasern dispersionsverschobene Einmodenfasern sind, für die der Wert der Wellenlänge, bei dem die Wellenlängendispersion gleich Null wird, gleich $1,4\mu\text{m}$ oder größer ist.

Revendications

1. Coupleur à fibres optiques formé en fondant une section de chacune de deux ou plusieurs fibres optiques élémentaires et en allongeant ensuite la section fondue pour former une région fondue et allongée dans laquelle au moins l'une desdites fibres optiques élémentaires est une fibre optique monomode ayant une gamme de paramètres telle que, quand le diamètre du coeur de ladite fibre optique est diminué, le diamètre du champ de mode de ladite fibre optique augmente de manière monotone.
2. Coupleur à fibres optiques selon la revendication 1, dans lequel ladite fibre optique monomode est une fibre monomode à déplacement de dispersion, pour laquelle la valeur de la longueur d'onde à laquelle la dispersion de longueur d'onde devient égale à zéro est $1,4\mu\text{m}$ ou plus grande.
3. Coupleur à fibres optiques selon la revendication 1, dans lequel lesdites deux ou plusieurs fibres optiques élémentaires sont des fibres monomode à déplacement de dispersion, pour lesquelles la valeur de la longueur d'onde à laquelle la dispersion de longueur d'onde devient égale à zéro est $1,4\mu\text{m}$ ou plus grande.

