

Description

The present invention relates to a method of producing optical couplers, and in particular to couplers for distributing light from one single mode optical fibre between two or more single mode optical fibres.

It is an object of the present invention to provide an optical coupler in which the light is transferred equally from the one single mode fibre to the other fibres independently of wavelength.

A method of manufacture of such couplers is disclosed e.g. in JP-A-57 186 730.

The present invention provides a method of forming a $1 \times N$ optical star coupler having an input, single mode fibre and N identical output, single mode fibres where N is two or more, the method comprising the steps of:

- (a) forming $N+1$ fibre portions each comprising a single mode optical fibre fusion spliced to a coreless fibre;
- (b) placing the $N+1$ fibre portions into a former such that the N output, single mode fibres extend from one end of the former, and one single mode input fibre extends from the other end of the former, the N output fibres being positioned centrosymmetrically with respect to the input fibre, and the distribution of the output fibres with respect to a given output fibre being identical to that with respect to any other output fibre, the former being such as to maintain the fibres in their positions and comprising material having a refractive index that is the same as, or is slightly less than, that of the cladding of the fibre portions;
- (c) positioning all the fusion splices in substantially the same plane; and
- (d) forming a taper from the former and fibre arrangement such that the fundamental mode fields on each side of the fusion splices are substantially matched at some region of the taper.

The present method provides an optical star coupler having an input, single mode fibre spliced to two or more identical output, single mode fibres at a tapered coupler portion, which output fibres form an output fibre assembly, wherein the output fibre assembly is tapered, the output fibres are positioned centrosymmetrically with respect to the input fibre so that the output fibres are illuminated by the input fibre with the same optical field amplitude and phase, the distribution of output fibres with respect to a given output fibre is identical to that with respect to any other output fibre throughout the taper, whereby the energy of the light in the input fibre is equally distributed into the output fibres, and the fundamental mode fields of the input fibre and the output fibre assembly are substantially matched on each side of the splice.

The positions of the fibres ensure that in use the output fibres are illuminated with the same optical field amplitude and phase and because the distribu-

tion of fibres with respect to a given output fibre is identical to that with respect to any other the energy of the light in the input fibre is equally distributed into the output fibres.

To produce a low loss device, there must be a gradual change in the mode field from that of the single input fibre to that of the output fibres. This mode transformation is accomplished by means of the taper.

The former supports the fibre portions and maintains their correct relative positions during the tapering process by providing material which fills the gaps between the fibres. Conveniently, the material is the same as the fibre cladding material, for example silica.

Embodiments of the invention and methods of fabrication will now be described by way of example only with reference to the accompanying drawings of which

Figure 1 is a perspective view of a glass former for holding the fibres in position while forming a taper;

Figure 2 is a diagrammatic cross-sectional view of a single mode fibre fused to a coreless fibre prior to tapering using the former of Figure 1;

Figure 3 is a diagrammatic cross-section view of the former of Figure 1 and fibres of Figure 2 prior to forming a taper; Figure 4 is a diagrammatic cross-sectional end view of a former with no central hole;

Figure 5 is a diagrammatic longitudinal view of a coupler according to the present invention.

The fibres may be held in their correct relative position for tapering by a glass former 2 as shown in Figure 1. This structure, which consists of one central hole 4 surrounded by eight equally spaced holes 6 at a constant radius, may conveniently be made by drawing down a large drilled glass rod. The rod is pulled such that the holes are just large enough to accept a single fibre each. Nine lengths of fibre 10 are prepared and each comprises a single mode fibre 12 fusion spliced to a length of coreless or 'dummy' fibre 14 as shown in Figure 2. Referring to Figure 3, the fibres 10 are inserted into the former 2 so that the splices all lie in the same plane A so that a central fibre protrudes from the former 2 from the opposite end to the outer ring of fibres, only two of which are shown for clarity in Figure 3. The central fibre forms the one input fibre (I), the remaining eight, the output fibres $O_1 - O_8$. The assembly is then heated to a temperature sufficient for the glass former to shrink due to surface tension. Vacuum may be employed at this stage to assist the collapse and/or to remove air which may become trapped. Heating is continued until a homogeneous rod of silica is formed. The glass former is heated around the splice position and is pulled to form a taper, the heated length being sufficient to ensure small taper angles and hence a low loss device. Ta-

(measured signal higher than reference signal) indicative of a blockage or negative (measured signal lower than reference signal) indicative of a hole. At the same time a signal from the level detector on line 27 stops the clock 28 which then provides a readout of time elapsed to the display; the elapsed time may be displayed in terms of distance rather than time. The significant value may be adjustable, particularly in response to temperature change in order to vary the sensitivity.

As mentioned previously, the circuit includes a temperature sensor, referenced 29, which senses the temperature in the proximity of the circuit and activates a heater 30 to maintain the temperature at a predetermined operating temperature. It has been found convenient to set the predetermined temperature at 35°C, which is a little higher than the natural temperature of the circuit environment. The temperature sensor is also connected to the ROM 18 to change the addressed set of reference values in the event of uncompensated temperature variation.

It has presently been found convenient to analyse ducts in sections of 0 to 50 metres, 50 to 300 metres and 300 to 1,000 metres, although these ranges may be altered, and it is possible to extend the ranges beyond 1,000 metres. For this purpose, prior to starting the test the operating range is selected so that the correct range of reference curve is read out from the ROM and the comparison is delayed until the wavefront will have reached the relevant section of duct. It is also possible to enter other selection data such as pulse duration (which is preferably increased by increasing the opening time of the solenoid valve to increase the signal level for longer ranges) and type of reference duct best matched to the duct being tested: e.g. diameter, material type or even a previous quality control or blowability measurement if known.

If the type of duct being tested has not been previously tested, or is an unknown type, it may be necessary to run several comparison tests with different reference duct values. This may be done manually by systematically changing the selectable input data, or by storing the measured data (for example in a RAM interposed between the auto zero 13 and comparator 20) and then automatically repeatedly reading out the measured data into the comparator with different references. If the reference values that are used in the comparison do not accurately reflect the decay curve for a perfect duct of the type being tested then the deviations that this poor matching causes give rise to 'false alarm' faults and incorrect location of actual faults. However it is found that a poorly matched reference always indicates faults at a shorter distance from the launch end of the duct than the correct

location. Thus when comparing a measured decay pulse with a series of reference pulses, (whether manually or automatically) it is the reference that indicates the furthest distance to a fault (or in extreme instances, no fault) that is the correct reference.

It is preferable to have a display for the actual trace as well as a fault location indicator, as there are some duct characteristics or decay patterns that may be recognisable to engineers but are too sophisticated to be easily adapted to automatic diagnosis.

A modification of the system is to utilise it for determining the relative propagation velocities of an air burst within different ducts. In this technique a pulse is launched into a duct and a signal level reading taken after a preselected period of time. On the assumption of perfect ducts (which may for example have previously been tested for holes and blockages, and/or may have been recently fabricated and be wound on a drum) the faster the pulse travels through the tube then the more rapid is the decay, thus ducts with higher signal levels after the predetermined interval are those in which the pulse is travelling more slowly and which may therefore be slower to blow fibres along. If the signal level representing pressure (e.g. voltages) is recorded for standard air bursts (or for a normalised signal) and particular duct dimensions, then it is possible to quantify the 'blowability' of ducts for example after production and/or after installation.

Claims

1. A method of testing a duct (6) having first and second ends, the method comprising the steps of:
 - introducing a pulse of compressed gas into the duct (6) to establish a pressure wavefront advancing through the duct, characterised in that the pulse is introduced at or adjacent said first end,
 - determining after at least one time interval following said introduction and during travel of the wavefront along the duct, a value indicative of pressure decay at a particular location (4) to give an indication of a characteristic of the duct (6) that influences the rate of pressure decay at a given location of the duct intermediate said first and second ends as the wavefront advances therethrough, and comparing said value with stored reference values.
2. A method according to claim 1 including the steps of:
 - monitoring the pressure decay at the particular location as the wavefront advances through the



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A modification of the system is to utilise it for determining the relative propagation velocities of an air burst within different ducts. In this technique a pulse is launched into a duct and a signal level reading taken after a preselected period of time. On the assumption of perfect ducts (which may for example have previously been tested for holes and blockages, and/or may have been recently fabricated and be wound on a drum) the faster the pulse travels through the tube then the more rapid is the decay, thus ducts with higher signal levels after the predetermined interval are those in which the pulse is travelling more slowly and which may therefore be slower to blow fibres along. If the signal level representing pressure (e.g. voltages) is recorded for standard air bursts (or for a normalised signal) and particular duct dimensions, then it is possible to quantify the 'blowability' of ducts for example after production and/or after installation.

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determining after at least one time interval following said introduction and during travel of the wavefront along the duct, a value indicative of pressure decay at a particular location (4) to give an indication of a characteristic of the duct (6) that influences the rate of pressure decay at a given location of the duct intermediate said first and second ends as the wavefront advances therethrough, and comparing said value with stored reference values.
2. A method according to claim 1 including the steps of:
monitoring the pressure decay at the particular location as the wavefront advances through the



1 or claim 2, wherein a lubricant is applied to the former prior to the insertion of the fibres.

5. A method of forming a coupler as claimed in claim 3 or claim 4, in which the lubricant is ethanol. 5
6. A method of forming a coupler as claimed in any one of claims 1 to 4, in which equalisation of the fundamental mode fields is determined by tapering until maximum power transmission from the input fibre is obtained. 10
7. A method of forming a coupler as claimed in any preceding claim, wherein N is 4. 15
8. A method of forming a coupler as claimed in any one of claims 1 to 6, in which N is 8.

Patentansprüche 20

1. Verfahren zum Bilden eines optischen 1xN-Sternkopplers mit einer Eingangs-Einmodenfaser (I) und N identischen Ausgangs-Einmodenfasern ($O_1, \dots, O_N$), wobei N zwei oder mehr ist, wobei das Verfahren folgende Schritte umfaßt: 25
 - (a) Bilden von N + 1 Faserabschnitten (10), von denen jeder eine an eine kernlose Faser (14) schmelzgespleißte optische Einmodenfaser (12) umfaßt; 30
 - (b) Anbringen der N + 1 Faserabschnitte in einem Former (2), so daß die N Ausgangs-Einmodenfasern ($O_1, \dots, O_N$) von einem Ende der Former aus verlaufen und die Eingangs-Einmodenfaser (I) vom anderen Ende der Former aus verläuft, wobei die N Ausgangsfasern zentralsymmetrisch bezüglich der Eingangs-faser positioniert werden und die Verteilung der Ausgangsfasern bezüglich einer gegebenen Ausgangsfaser identisch mit der bezüglich einer beliebigen anderen Ausgangsfaser ist, wobei der Former ausgebildet ist, um die Fasern in ihren Positionen zu halten und Material mit einem Brechungsindex umfaßt, der genauso groß oder geringfügig kleiner als der des Mantels der Faserabschnitte ist; 35
 - (c) Positionieren aller Schmelzspalte in im wesentlichen derselben Ebene in der Former (A); und 40
 - (d) Bilden eines Verjüngungsabschnitts (22, 26) aus der Former und Faseranordnung, so daß die Grundmodenfelder beiderseits der Schmelzspalte in einem Bereich des Verjüngungsabschnitts im wesentlichen angepaßt sind. 45
2. Verfahren zum Bilden eines optischen 1xN-Sternkopplers, wobei N zwei oder mehr ist, wobei das 50

Verfahren folgende Schritte umfaßt:

- (a) Einführen von N identischen Ausgangs-Einmodenfasern ($O_1, \dots, O_N$) in einen Former (2), so daß sie von derselben Seite des Formers aus verlaufen, wobei die Verteilung der Ausgangsfasern bezüglich einer gegebenen Ausgangsfaser identisch mit der bezüglich einer beliebigen anderen Ausgangsfaser ist, wobei der Former ausgebildet ist, um die Fasern in ihren Positionen zu halten und Material mit einem Brechungsindex umfaßt, der genauso groß oder geringfügig kleiner als der des Mantels der Faserabschnitte ist; 55
- (b) Bilden eines Verjüngungsabschnitts aus der Former- und Faseranordnung, mit einem Taillendurchmesser, der im wesentlichen dem Durchmesser einer einzelnen Faser gleicht;
- (c) Spalten des Verjüngungsabschnitts an der Taille (24);
- (d) Schmelzspalten des gespaltenen Verjüngungsabschnitts an eine Eingangs-Einmodenfaser, so daß die N Ausgangsfasern zentralsymmetrisch bezüglich der Eingangs-faser positioniert sind; und
- (e) weiteres Verjüngen des Verjüngungsabschnitts, um die Grundmodenfelder beiderseits des Spaltens anzugleichen.
3. Verfahren zum Bilden eines Kopplers nach Anspruch 1 oder Anspruch 2, bei dem ein Schmiermittel auf die Fasern vor ihrer Einführung in den Former angewandt wird. 60
4. Verfahren zum Bilden eines Kopplers nach Anspruch 1 oder Anspruch 2, bei dem ein Schmiermittel auf den Former vor der Einführung der Fasern angewandt wird. 65
5. Verfahren zum Bilden eines Kopplers nach Anspruch 3 oder Anspruch 4, bei dem das Schmiermittel Ethanol ist.
6. Verfahren zum Bilden eines Kopplers nach einem der Ansprüche 1 bis 4, bei dem die Angleichung der Grundmodenfelder bestimmt wird durch Verjüngen, bis maximale Leistungstransmission von der Eingangs-faser erreicht wird.
7. Verfahren zum Bilden eines Kopplers nach einem der vorhergehenden Ansprüche, bei dem N gleich 4 ist.
8. Verfahren zum Bilden eines Kopplers nach einem der Ansprüche 1 bis 6, bei dem N gleich 8 ist.



Revendications

1. Un procédé de formation d'un coupleur optique en étoile $1 \times N$ comprenant une fibre monomode d'entrée (1) et N fibres monomodes de sortie identiques ($O_1 \dots O_N$), où N est de deux ou plus, le procédé comprenant les étapes:
 - (a) de formation de $N + 1$ parties de fibres (10), chacune d'elles comprenant une fibre optique monomode (12) épissée par fusion sur une fibre sans cœur (14);
 - (b) de positionnement des $N + 1$ parties de fibres dans un gabarit de formation (2) de manière que les fibres monomodes de sortie N ($O_1 \dots O_N$) se prolongent à partir d'une extrémité du gabarit de formation, et une fibre monomode d'entrée (1) se prolonge à partir de l'autre extrémité du gabarit de formation, les N fibres de sortie étant positionnées symétriquement au centre par rapport à la fibre d'entrée, et la distribution des fibres de sortie par rapport à une fibre de sortie donnée étant identique à la distribution par rapport à toute autre fibre de sortie, le gabarit de formation étant agencé pour maintenir les fibres dans leurs positions et comprenant un matériau ayant un indice de réfraction identique ou légèrement inférieur à celui du blindage des parties de fibres;
 - (c) de positionnement de toutes les épissures par fusion, sensiblement dans le même plan; et
 - (d) de formation d'un cône (22, 26) à partir du gabarit de formation et de l'agencement des fibres, de manière que les champs modaux fondamentaux de chaque côté des épissures par fusion soient sensiblement adaptés dans une zone quelconque du cône.
2. Un procédé de formation d'un coupleur optique en étoile $1 \times N$, dans lequel N est de deux ou plus, le procédé comprenant les étapes:
 - (a) d'introduction de N fibres monomodes de sortie uniques identiques ($O_1 \dots O_N$) dans un gabarit de formation (2) de manière à se prolonger à partir du même côté du gabarit de formation, la distribution des fibres de sortie autour de l'une des fibres de sortie données étant identique à celle se faisant autour d'une autre fibre de sortie quelconque, le gabarit de formation étant agencé de manière à maintenir les fibres dans leurs positions et comprenant un matériau ayant un indice de réfraction égal ou légèrement inférieur à celui de la gaine des parties de fibres;
 - (b) de formage d'un cône de transition à partir du gabarit de formation et d'agencement des fibres avec un diamètre de rétrécissement
- sensiblement égal au diamètre d'une fibre unique;
- (c) de collage du cône dans la partie rétrécie (24);
- (d) d'épissage par fusion du cône clivé sur une fibre monomode d'entrée de manière que les N fibres de sortie soient disposées symétriquement autour du centre par rapport à la fibre d'entrée; et
- (e) d'effilement progressif du cône pour égaliser les champs de mode fondamental de chaque côté de l'épissure.
3. Un procédé de formation d'un coupleur selon la revendication 1 ou 2, dans lequel un lubrifiant est appliqué sur les fibres avant leur introduction dans le gabarit de formation.
4. Un procédé de formation d'un coupleur selon la revendication 1 ou 2, dans lequel un lubrifiant est appliqué sur le gabarit de formation avant l'introduction des fibres.
5. Un procédé de formation d'un coupleur selon la revendication 3 ou 4, dans lequel le lubrifiant est de l'éthanol.
6. Un procédé de formation d'un coupleur selon l'une quelconque des revendications 1 à 4, dans lequel l'égailisation des champs de mode fondamental est déterminée par effilement progressif jusqu'à ce que la puissance de la transmission obtenue de la fibre d'entrée soit maximale.
7. Un procédé de formation d'un coupleur selon l'une quelconque des précédentes revendications, dans lequel N est de 4.
8. Un procédé de formation d'un coupleur selon l'une quelconque des revendications 1 à 6, dans lequel N est de 8.