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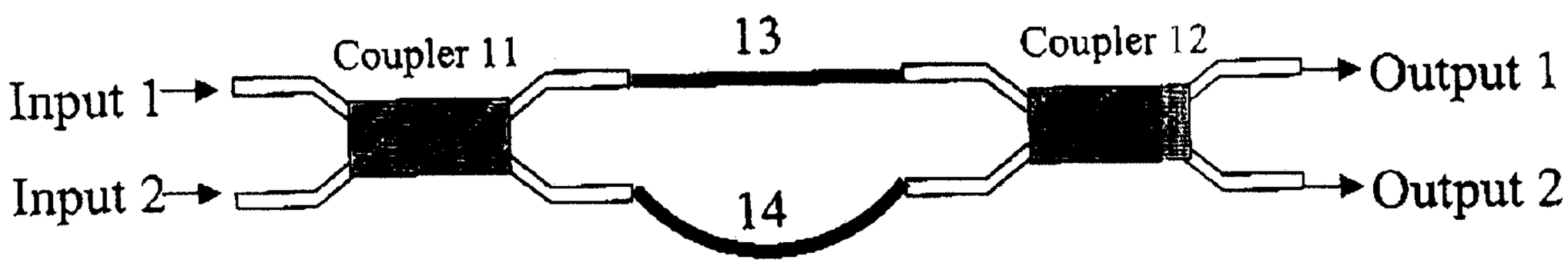
(54) Titre : FILTRES D'INTERFEROMETRES MACH-ZEHNDER A FIBRES OPTIQUES ET INSENSIBLES A LA TEMPERATURE

(54) Title: TEMPERATURE INSENSITIVE FIBER BASED MACH-ZEHNDER INTERFEROMETER FILTER DEVICES



(57) Abrégé/Abstract:
A Mach-Zehnder interferometer having two optical couplers intercommunicated by two optical fibers one or each of which is temperature insensitive. In use, temperature induced changes in the geometrical length and refractive index of the or each of the two temperature insensitive fibers offset each other so that the optical path length of the fiber is unaffected by temperature change. Where two temperature insensitive fibers are included these may be of the same or of different lengths. The interferometer may be used in a Dense Wavelength Division Multiplex system.

ABSTRACT

A Mach-Zehnder interferometer having two optical couplers intercommunicated by two optical fibers one or each of which is temperature insensitive. In use, temperature induced changes in the geometrical length and refractive index of the or each of the two temperature insensitive fibers offset each other so that the optical path length of the fiber is unaffected by temperature change. Where two temperature insensitive fibers are included these may be of the same or of different lengths. The interferometer may be used in a Dense Wavelength Division Multiplex system.

FIELD OF INVENTION

This invention generally relates to optical fiber devices and particularly to fiber based Mach-Zehnder interferometers (MZI) insensitive to temperature changes.

BACKGROUND OF THE INVENTION

Optical filters are very frequently used in modern optical communication systems such as Dense Wavelength Multiplex (DWDM) systems. In these systems, a number of data channels share a single optical fiber as their transmission media and use a unique wavelength of light as their channel signature.

An optical waveguide Mach-Zehnder is composed of two optical splitters/couplers. Two lengths of optical waveguides or arms connect them to each other. When the arms of the MZI have different lengths, we have a so-called asymmetric Mach-Zehnder interferometer (AMZI). The optical waveguides referred to here are optical fibers with circular cross sections and/or planar optical waveguides with non-circular cross sections. A MZI made of optical fibers is called an all-fiber MZI.

Asymmetric MZIs show a periodic response as a function of wavelength. The period is a function of the length difference between the arms of the interferometer. As the length difference increases, the oscillation in the wavelength response decreases and, therefore, the wavelength selectivity increases. Asymmetric MZIs, once connected to each other as an inter-leaver, can multiplex or de-multiplex a large number of optical signals of varying wavelengths such as the standard ITU grid wavelengths. An optical filter inter-leaver can separate the odd and even wavelengths from a WDM signal consisting of several wavelengths.

One problem associated with fiber based asymmetric MZIs is their sensitivity to temperature, and the greater the length difference, the more severe is the problem. The problem originates mainly from a

temperature-induced change in the optical path length of the fiber. As the temperature changes, the refractive index and the geometrical length of the fiber changes. Consequently, a difference in the optical path lengths of two arms is created.

Several temperature compensation methods have been proposed to solve the temperature sensitivity of these photonic devices. However, most of these methods work within a limited range of temperatures and cannot be applied easily to the asymmetric MZI cases where large differences in the optical paths exist. Active temperature compensation of photonic devices is typically carried out by maintaining the temperature of the fibers' environment above a chosen temperature (e.g., above 60°C). This is achieved by including a heater controller inside the package of the device. However, the high power demands of the active temperature compensation and its low reliability have made the search for passive methods and on-going effort within the photonic industry.

It is the purpose of this invention to describe a novel temperature insensitive asymmetric fiber based MZI.

SUMMARY OF THE INVENTION

Asymmetric interferometer apparatuses are known to have periodic response as a function of wavelength. Therefore, they can be used as optical filters. It is also known that, in particular, cascaded asymmetric MZIs can act as an optical filter with good filtering characteristics. One of the advantages of the asymmetric MZI is the narrow channel spacing that may be attained. In addition, the fiber-based device displays low insertion loss and low polarization effects.

The thermal variability of a MZI with unequal fiber lengths arises from the different optical path lengths between the two arms. The primary cause of thermal drift is the sensitivity of the refractive index of the silica fiber to changes in temperature. The thermal expansion of the fiber is a smaller contributor to the observed thermal drift. In order to

obtain narrower channel spacing by this filtering method one has to increase the difference between the optical lengths of the interferometer arms. Increasing the differential optical path length is achieved by increasing the geometrical length difference between the two fibers of the two couplers. This will in turn worsen the temperature sensitivity of the interferometer making it imperative to reduce the thermal variability of these filters.

The present invention proposes a fiber-based interferometer with a Mach-Zehnder configuration in which temperature sensitivity is eliminated. The primary challenge of temperature compensation for these devices can be overcome by instead using unequal lengths of an insensitive fiber. The present invention describes a MZI made of two 2x2 splitters with equal lengths at each side fused with two unequal lengths of an insensitive optical fiber. Alternatively one can start with a symmetric MZI and insert a predetermined length of temperature insensitive fiber between one of the arms of MZI to get the desired asymmetric MZI, which is insensitive to temperature. Temperature insensitive fibers can be built by a method that, for example, has been disclosed in the United States Patent #5,018,827. In the named patent, an insensitive optical fiber is produced when an optical fiber core made of a first material is enclosed within a cladding made of a second material having a different coefficient of thermal expansion, α_2. Another method of decreasing the temperature sensitivity of the silica fiber is to use dopants such as boron oxide.

This approach yields an inherently passive device, therefore eliminating the need other methods of temperature compensation. By forming an insensitive MZI, a complex for bimetallic packaging structure for passive temperature compensation is not needed, nor is an active method necessary. The use of expensive composite materials in the packaging of the device is eliminated as well.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 shows a fiber based Mach-Zehnder interferometer using temperature insensitive fiber according to the present invention.

Fig. 2 shows another embodiment of a fiber based Mach-Zehnder interferometer using temperature insensitive fiber.

DETAILED DESCRIPTION

In the present invention, a temperature insensitive fiber is used to make a MZI to be used in a DWDM system and/or an interleaver. This approach yields an inherently passive device, therefore eliminating the need for other methods of temperature compensation.

The two general approaches to temperature compensation of fiber optic components are active and passive control. The former is a more costly solution and involves far greater power consumption. In addition, an increase in the total size of the component and lower reliability over a wide temperature range makes active control a far inferior method of temperature compensation than passive control. There are a number of ways of passively compensating for the thermal variability of fiber-based devices. However, as the channel spacing decreases to below 1nm, a temperature stability of less than 1 pm/°C becomes necessary.

In a recent US patent (#6081641), a passive temperature compensating method is presented for a fused-fiber DWDM system. In this invention, two dissimilar materials with different thermal expansion coefficients are used to construct a fixture containing the DWDM device. By using this structure, it is possible to artificially create a negative coefficient of thermal expansion. The DWDM device is typically assembled on a pre-stressed fixture. However, the device can also be built under tension and then assembled on the relaxed bi-substrate fixture. In the former design, the whole assembly can exert tension on, or release tension from, the fiber. Temperature compensation is then established by adjusting the

applied tension on the fused-fiber DWDM. It is shown that, as tension is relieved, the thermal drift due to an increase in temperature is compensated. Conversely, by increasing tension, wavelength shifts due to a decrease in temperature are compensated. By using such a temperature-compensating device, a bulky package is inevitable. In addition, dimensional design and choice of material can be demanding requirements.

The present invention proposes an improvement in the manufacturing cost and reliability of an interleaver, with potential expendability to a DWDM system with very narrow channel spacing. The need for more bandwidth/channels is increasing very rapidly as more information is being transmitted through the Internet everyday.

Optical filters with sharp wavelength characteristics are vital components of WDM technology. Interferometer devices, and in particular fiber based interferometer devices such as the MZI, show useful filtering characteristics, are easily expandable, and exhibit low insertion loss. A fiber based optical MZI consists of two optical couplers or splitters with predetermined coupling or splitting ratios connected together through two lengths of optical fiber. In order to decrease the channel spacing, the length difference (Δl)between the two arms should increase. As a result, the optical path length difference also increases, generating a higher sensitivity within the MZI to fluctuations in its temperature.

The challenge also lies in correctly achieving the desired channel spacing. This is accomplished by measuring the correct Δl between the two arms connecting the two couplers of the MZI. As a result of the different optical paths between the two arms of the two couplers, a sinusoidal wavelength response can be obtained with low polarization dependence and low insertion loss. Using a precision reflectometer or an optical spectrum analyzer, the difference between the two arms of the MZI can be measured to within, $\pm$ 10μm.

Shown in Fig. 1 is a MZI made of two couplers (11 and 12) fused together in the middle with two different lengths of an insensitive fiber, where the fiber length 14 is longer than the fiber length 13.

It is proposed that a MZI be made using a specialty fiber that produces a temperature insensitive device. The United States patent #5,018,827 proposes a speciality fiber with unique characteristics. An insensitive optical fiber can be tailored such that temperature-induced changes in its geometrical length and in its refractive index offset each other in such a fashion that the optical path length is, for all intents and purposes, independent of temperature. By carefully choosing two different glasses for the core and cladding, and by appropriately adjusting their radii, the observed shift sensitivity of the fiber can be eliminated. The radius of the cladding is adjusted so that the coefficient of thermal expansion of the fiber is equal to the product of a reciprocal of the negative of the index of refraction, n, of the first material and its rate of change with temperature, i.e.

$$\alpha = \left(-\frac{1}{n}\right)\left(\frac{dn}{dT}\right)$$

Eq.1

This type of fiber can also be spliced with the silica fiber contained in two couplers 11 and 12.

In one embodiment, the two arms of couplers 11 and 12 are cut into equal lengths and are fusion spliced to two insensitive optical fibers with a pre-determined Δl. By cutting the two insensitive fibers to different lengths, an optical path length difference is produced. Using a fiber cleaving stage equipped with a micro-positional fixture it is possible to make a precise Δl between the two arms of an MZI. Polishing the fiber to obtain the desired channel spacing before the arms are spliced to form the MZI can then do the final length adjustment.

In another embodiment, the two arms of coupler 11 are cut as close in length to each other as possible and are spliced to two arbitrary lengths of the insensitive fiber. The new coupler formed is then cut to the desired Δl and be fused to the two equal arms of coupler 12.

Figure 2 shows another embodiment of a fiber based insensitive asymmetric MZI made of couplers 31 and 32 in which the insensitive fiber, 33, has been used only in one of the arms of MZI. The length of the insensitive fiber, 33, in this case precisely equals the predetermined Δl. The other arm of MZI made of conventional single mode silica fiber (F_1 and F_2) will be fusion spliced together at the dashed line to form a MZI. The MZI in Fig. 3 will be symmetric MZI if the insensitive part, 33, is taken out.

By forming an insensitive MZI, a complex bimetallic packaging structure for passive temperature compensation is not needed, nor is an active method necessary. The use of expensive composite materials in the packaging of the device is eliminated as well. An insensitive MZI of this invention can be easily made to any desired Δl. The novel design of this invention easily provides higher Δl and thus higher channel number without the problem of temperature sensitivity due to different optical path lengths.

CLAIMS

1. A Mach-Zehnder interferometer comprising two optical couplers intercommunicated together by two optical fibers at least one of which is a temperature insensitive fiber in which temperature induced changes in the geometrical length and refracture index of the temperature insensitive fiber offset each other whereby the optical path length of the temperature insensitive fiber is unaffected by change in temperature.

2. A Mach-Zehnder interferometer according to Claim 1 wherein each of the two optical fibers is a temperature insensitive fiber.

3. A Mach-Zehnder interferometer according to Claim 2 wherein the two optical fibers are of different length.

4. A Mach-Zehnder interferometer according to Claim 3 wherein each optical coupler has arms of substantially equal length and with each arm connected to an individual one of the two optical fibers.

5. A Dense Wavelength Division Multiplex system comprising a Mach-Zehnder interferometer comprising two optical couplers intercommunicated together by two optical fibers at least one of which is temperature insensitive fiber in which temperature induced changes in the geometrical length and refracture index of the temperature insensitive fiber offset each other whereby the optical path length of the temperature insensitive fiber is unaffected by change in temperature.

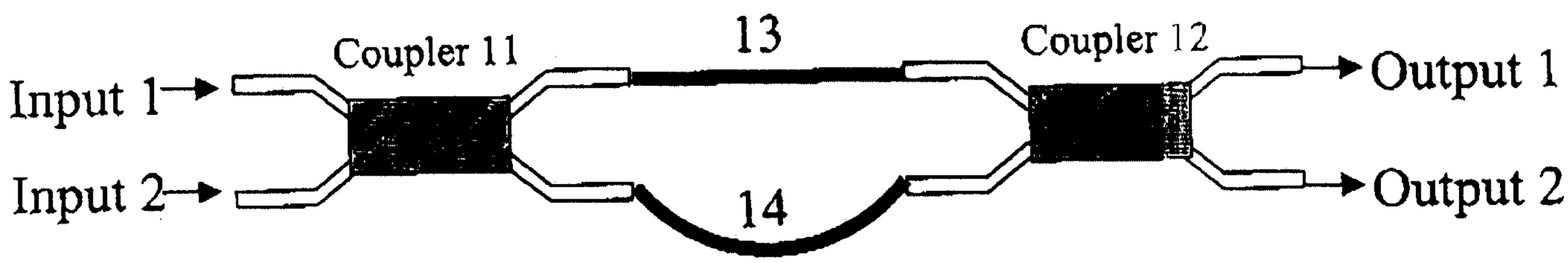

Coupler 11
13
Coupler 12
Input 1
Output 1
Input 2
14
Output 2

Fig. 1

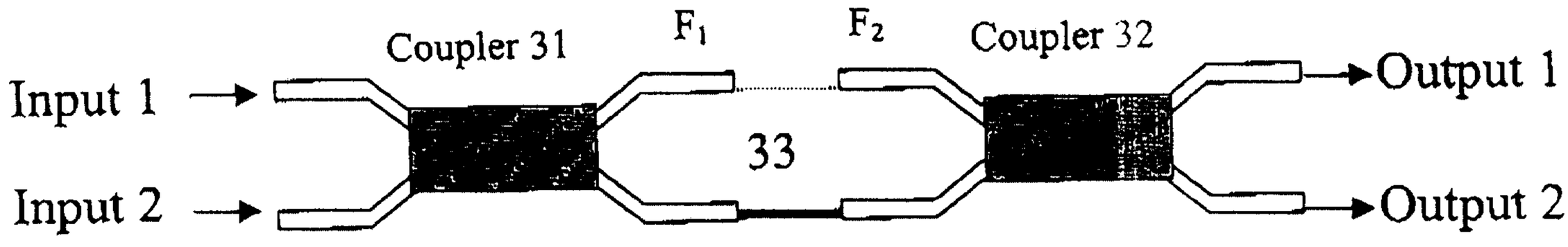
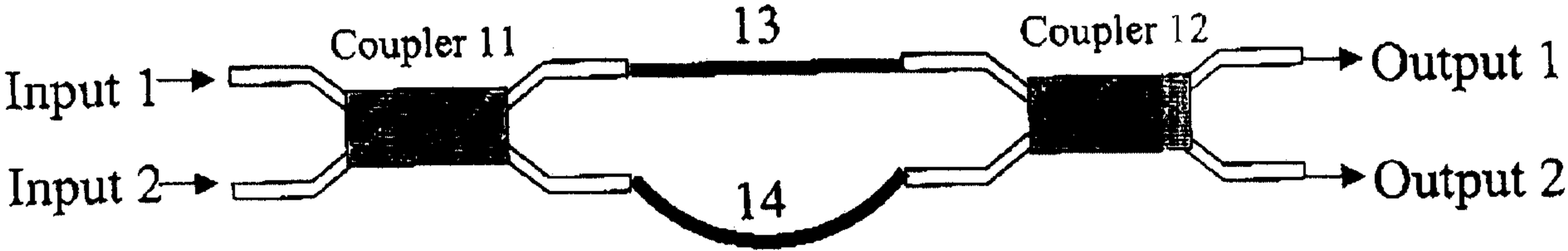

Coupler 31
F1
F2
Coupler 32
Input 1
Output 1
33
Input 2
Output 2

Fig. 2


Coupler 11
13
Coupler 12
Input 1
Input 2
Output 1
Output 2
14