

WAVELENGTH DIVISION MULTIPLEXER/DEMULTIPLEXER, PHOTONIC INTEGRATED CHIP, AND OPTICAL MODULE

TECHNICAL FIELD

5 **[0001]** The present disclosure relates to optical communication technology, and particularly relates to a wavelength division multiplexer/demultiplexer, a photonic integrated chip, and an optical module.

BACKGROUND

10 **[0002]** With the continuous development of the information society, the demand for capacity and bandwidth of optical transmission is increasing exponentially, and the demand for large-capacity optical interconnection is also growing rapidly. It is well-known that the wavelength division multiplexing (WDM) technology is an effective means to increase the capacity of optical
15 communication. In addition, the WDM technology is combined with the photonic integrated chip technology, so as to effectively reduce the size of a device and improve integration of a system. With regard to a dense wavelength division multiplexing (DWDM) system having narrow channel spacing (e.g., 0.8 nm), the main difficulty of such a system is in that it's very sensitive to a tiny wavelength
20 shift of laser sources or DWDM filters. For example, the wavelength shift caused by the change of an ambient temperature is usually unfavorable to silicon-based DWDM, so that a silicon-based DWDM device generally requires addition of complex and expensive wavelength tuning and trimming structures.

[0003] On the other hand, the coarse wavelength division multiplexing

(CWDM) technology has become a choice by more people due to its large channel spacing (e.g., 20 nm). An increased channel spacing makes the CWDM system insensitive to the wavelength shift, which can greatly reduce requirements for wavelength control of lasers and WDM filters. As a result, the CWDM technology has become popular in short-reach optical interconnects (such as data centers). Common structure types of CWDM devices include arrayed waveguide gratings (AWG), etched diffraction gratings, and Bragg gratings. A CWDM filter based on AWG/etched diffraction grating can provide low crosstalk, but has disadvantages of having an uneven top of a spectrum and large additional loss. A CWDM filter based on Bragg grating has low additional loss (< 1 dB) and a large 1dB bandwidth, but has high crosstalk.

[0004] Chinese Patent Application No. CN201710257373.0, entitled “A Filter Based on Axial Apodized Grating”, discloses a filter that uses an asymmetric gradient directional coupler and an antisymmetric multimode waveguide grating which are cascaded, in which the antisymmetric multimode waveguide grating embodies apodization through gradual distribution of axial positions of grating teeth on both sides, and has advantages of a large tolerance and a large side mode suppression ratio. However, when the filter serves as a multi-wavelength wavelength division multiplexer, in order to reduce crosstalk of adjacent channels within an application range of the wavelength division multiplexer, e.g., the range of CWDM4 (1261 nm to 1341 nm), an effective refractive index difference between a TE₀ mode and a TE₁ mode transmitted in the antisymmetric multimode waveguide grating needs to be large enough, e.g., greater than 0.35, which can substantially only be satisfied by a strip waveguide on a silicon-on-insulator (SOI)

structure, and such requirement is severe.

SUMMARY

[0005] Objectives of the present disclosure are to provide a wavelength division
5 multiplexer/demultiplexer based on asymmetric Bragg gratings, which can
improve channel crosstalk, is suitable for waveguides of various semiconductor
materials, and has advantages of low loss, a high extinction ratio, high efficiency,
and a large bandwidth.

[0006] In order to achieve one of the above-mentioned objectives, the present
10 disclosure provides a wavelength division multiplexer/demultiplexer based on
asymmetric Bragg gratings, which includes: a substrate, a bus waveguide provided
on the substrate, and at least two wavelength division multiplexing/demultiplexing
units provided on the bus waveguide.

[0007] Each of the wavelength division multiplexing/demultiplexing units
15 includes a mode multiplexer and an asymmetric Bragg grating. The mode
multiplexer is configured to make an input light incident into the asymmetric
Bragg grating in a TE₁ mode or a higher-order mode. The mode multiplexer
includes a first port, a second port, and a third port. The first port and the second
port are configured to input or output optical signals, respectively, and the third
20 port is connected to the asymmetric Bragg grating. The asymmetric Bragg gratings
in different units of the at least two wavelength division
multiplexing/demultiplexing units have different grating periods.

[0008] When the wavelength division multiplexer/demultiplexer based on
asymmetric Bragg gratings serves as a demultiplexer, a light containing multiple

wavelengths is input to one port of the first port and the second port of the mode multiplexer for passing through the mode multiplexer, so that a light in a TE(n+1) mode is output from the third port and is incident into the asymmetric Bragg grating; the asymmetric Bragg grating reflects a light with a resonance wavelength λ_i that satisfies a resonance condition with a grating period of the asymmetric Bragg grating, and converts the reflected light with the resonance wavelength λ_i into a TE0 mode and return it to the mode multiplexer, and the reflected light is output from the other port of the first port and the second port. The asymmetric Bragg grating transmits light containing wavelengths other than the resonance wavelength λ_i , and n is an integer greater than or equal to zero.

[0009] The present disclosure further provides a photonic integrated chip. In the photonic integrated chip is disposed the wavelength division multiplexer/demultiplexer based on asymmetric Bragg gratings as described in any one of the above-mentioned embodiments.

[0010] The present disclosure further provides an optical module. The optical module includes the wavelength division multiplexer/demultiplexer based on asymmetric Bragg gratings as described in any one of the above-mentioned embodiments.

Beneficial Effect

[0011] Beneficial effects of the present disclosure are in that a combination method of the mode multiplexer and the asymmetric Bragg grating is improved, to make no TE0 mode reflections at wavelengths that are greater than the resonance wavelength in the asymmetric Bragg grating, so that there is no reflection peak at long wavelengths in the TE0 mode. Accordingly, wavelength

crosstalk of other modes can be effectively prevented, and no requirement is imposed on an effective refractive index difference between the TE₀ mode and the TE₁ mode. This allows the wavelength division multiplexer/demultiplexer on a waveguide structure of various semiconductor materials to meet requirements of CWDM and to have a wide range of applications.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic diagram of a wavelength division multiplexer/demultiplexer based on asymmetric Bragg gratings of the present disclosure.

[0013] FIG. 2 is a schematic structural view of a single wavelength division multiplexing/demultiplexing unit of the present disclosure.

[0014] FIG. 3 is a schematic cross-sectional view taken along line A-A in FIG. 2.

[0015] FIG. 4 is a schematic structural diagram of a four-channel wavelength division multiplexer/demultiplexer according to an embodiment of the present disclosure.

[0016] FIG. 5 is a schematic diagram showing relations of effective refractive indices of TE₀, TE₁, and (TE₀+TE₁)/2 in a strip waveguide of a silicon material, and a value of $\lambda/2\Lambda$ that respectively varies with a wavelength λ according to the present disclosure.

[0017] FIG. 6 is a schematic structural diagram of the four-channel wavelength division multiplexer/demultiplexer according to another embodiment of the present disclosure.

[0018] FIG. 7 is a schematic structural diagram of one modification of the wavelength division multiplexer/demultiplexer as shown in FIG. 6.

[0019] FIG. 8 is a schematic structural diagram of another modification of the wavelength division multiplexer/demultiplexer as shown in FIG. 6.

5 **[0020]** FIG. 9 is a schematic structural diagram of the four-channel wavelength division multiplexer/demultiplexer according to yet another embodiment of the present disclosure.

[0021] FIG. 10 is a schematic structural diagram of one modification of the wavelength division multiplexer/demultiplexer as shown in FIG. 9.

10 **[0022]** FIG. 11 is a schematic structural diagram of the four-channel wavelength division multiplexer/demultiplexer according to still another embodiment of the present disclosure.

[0023] FIG. 12 is a schematic structural diagram of one modification of the wavelength division multiplexer/demultiplexer as shown in FIG. 11.

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DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0024] Hereinafter the present disclosure will be described in detail with reference to specific embodiments shown in the accompanying drawings. However, these embodiments do not limit the present disclosure. Modifications
20 regarding structures, methods, and functions, which are made by those skilled in the art based on these embodiments, fall within the protection scope of the present disclosure.

[0025] In the drawings of the present disclosure, sizes of certain structures or portions may be enlarged relative to other structures or portions for illustrative

purposes, and thus are merely used for illustration of a basic structure of the subject matter of the present disclosure.

[0026] In addition, terms (such as “over,” “above,” “under,” and “below”) indicative of relative spatial positions in the present disclosure are for illustrative purposes to describe a spatial relationship between one unit/feature and another unit/feature as shown in the drawings. These terms indicative of relative spatial positions are intended to include different orientations of a device in use or in operation other than the orientations illustrated in the drawings. For example, when the device in the drawing is turned over, units described as below or under other units or features would then be above the other units or features. Therefore, the exemplary term “below” encompasses both orientations of “above” and “below”. The device may also be otherwise oriented (rotated 90 degrees or at other orientations), and descriptive terms relating to space as used herein is to be interpreted accordingly. When one element/layer is referred to as being disposed “above” or “connected to” another element/layer, the element/layer can be directly disposed above or connected to the another element/layer, or a middle element/layer can be provided therebetween.

[0027] As shown in FIG. 1, the present disclosure provides a wavelength division multiplexer/demultiplexer based on asymmetric Bragg gratings, which includes a substrate, a bus waveguide 10 provided on the substrate, and at least two wavelength division multiplexing/demultiplexing units 20 provided on the bus waveguide 10. As shown in FIG. 2, which is a schematic structural diagram of a single wavelength division multiplexing/demultiplexing unit 20, structures such as the substrate and covering layers are omitted, and only the bus waveguide

and structures of components are shown. FIG. 3 is a schematic cross-sectional view taken along line A-A in FIG. 2. The wavelength division multiplexer/demultiplexer is provided on a planar waveguide of a silicon-on-insulator (SOI) structure, and includes a substrate 101, a buried oxide layer 102, the bus waveguide 10, and a cover layer 103. The substrate 101 is a silicon substrate, the buried oxide layer 102 is silicon dioxide, the bus waveguide 10 is a strip waveguide made of a silicon material, and the cover layer 103 is silicon dioxide. In other embodiments, the bus waveguide 10 can be a ridge waveguide or a waveguide of other materials, such as silicon nitride (SiN), silicon oxynitride (SiON), silicon oxide (SiO₂), indium phosphide (InP), gallium nitride (GaN), or lithium niobate (LiNbO₃). Alternatively, the wavelength division multiplexer/demultiplexer can be provided on a planar waveguide of other structures, and the substrate can be a substrate made of other materials, such as a lithium niobate substrate, an indium phosphide substrate, or a gallium nitride substrate.

[0028] The wavelength division multiplexing/demultiplexing unit 20 includes a mode multiplexer 21 and an asymmetric Bragg grating (ASBG) 22. The mode multiplexer 21 is configured to make an input light incident into the asymmetric Bragg grating 22 in a TE₁ mode or a higher-order mode. The mode multiplexer 21 includes a first port 211, a second port 212 and a third port 213. The first port 211 and the second port 212 are respectively configured to input or output optical signals, and the third port 213 is connected to the asymmetric Bragg grating 22. The asymmetric Bragg gratings 22 in different units of the at least two wavelength division multiplexing/demultiplexing units 20 have different grating periods, and

a light that satisfies a resonance condition with the grating period of the asymmetric Bragg grating 22 has a resonance wavelength λ_i . The resonance condition is $\frac{2\pi}{\Lambda} = (\frac{2\pi}{\lambda_i})n_{TE0} + (\frac{2\pi}{\lambda_i})n_{TE1}$, where Λ is a period of a corresponding asymmetric Bragg grating, λ_i is a wavelength of a transmitted light, and n_{TE0} and n_{TE1} are respectively effective refractive indices of a light when being transmitted in the corresponding asymmetric Bragg grating in the TE0 mode and in the TE1 mode.

[0029] In the embodiment, as shown in FIG. 2, the mode multiplexer 21 includes a straight-through waveguide 214 and a cross waveguide 215. Two ends of the straight-through waveguide 214 are respectively the first port 211 and the third port 213, and an end of the cross waveguide 215 that is adjacent to the first port end 211 is the second port 212. The cross waveguide 215 and the straight-through waveguide 214 perform mode coupling. In other embodiments, the mode multiplexer may also adopt other mode multiplexing structures. The asymmetric Bragg grating 22 has a grating structure that is gradually asymmetrical, an etching depth h of the grating is gradually increased from both ends of the grating toward the middle, and a waveguide width d in the center of the grating gradually narrows from both ends toward the middle, so as to form a certain taper.

[0030] When the wavelength division multiplexer/demultiplexer serves as a demultiplexer, a light containing multiple wavelengths is input to one port of the first port 211 and the second port 212 of the mode multiplexer 21 for passing through the mode multiplexer 21, so that a light in a TE $(n+1)$ mode is output from the third port 213 and incident into the asymmetric Bragg grating 22. The asymmetric Bragg grating 22 reflects a light with a resonance wavelength λ_i that

satisfies a resonance condition with the grating period of the asymmetric Bragg grating 22, and converts the reflected light with the resonance wavelength λ_i into the TE₀ mode, and returns it to the mode multiplexer 21, and the reflected light is output from the other port of the first port 211 and the second port 212. The asymmetric Bragg grating 22 transmits lights containing wavelengths (other than the resonance wavelength λ_i) corresponding to other communication channels. Here, the other port of the first port 211 and the second port 212 corresponds to the above-mentioned one port of the first port 211 and the second port 212 to which the optical signals are input. In the TE₀ and TE_(n+1) modes, n is an integer greater than or equal to zero. For the convenience of description, the explanation below takes n = 0 as an example. That is, the transmission in the asymmetric Bragg grating is exemplified as being the TE₁ mode. In other embodiments, the transmission in the asymmetric Bragg grating can be carried out in a mode higher than the TE₁ mode, e.g., TE₂.

[0031] Wavelength division multiplexing/demultiplexing of four wavelengths that range from 1261 nm to 1341 nm as required by CWDM4 (which is commonly used in light communications) is taken as an example. Assuming that the four wavelengths are λ_1 , λ_2 , λ_3 , and λ_4 , at least three wavelength division multiplexing/demultiplexing units are needed for cascading. FIG. 4 shows the wavelength division multiplexer/demultiplexer based on the asymmetric Bragg gratings according to an embodiment of the present disclosure. The wavelength division multiplexer/demultiplexer includes a first wavelength division multiplexing/demultiplexing unit 20a, a second wavelength division multiplexing/demultiplexing unit 20b, a third wavelength division

multiplexing/demultiplexing unit 20c, and a fourth wavelength division
 multiplexing/demultiplexing unit 20d that are cascaded. The asymmetric Bragg
 gratings corresponding to the four wavelength division
 multiplexing/demultiplexing units are a first asymmetric Bragg grating 22a, a
 5 second asymmetric Bragg grating 22b, a third asymmetric Bragg grating 22c, and
 a fourth asymmetric Bragg grating 22d, respectively. Taking the demultiplexer as
 an example, the first port 211 of the mode multiplexer 21 is an input port Input,
 the second port 212 of the mode multiplexer 21 is an output port Drop1, and the
 third port 213 of the mode multiplexer 21 is connected to an incident end of the
 10 asymmetric Bragg grating 22a, and a transmission end of the asymmetric Bragg
 grating 22a is connected to the first port 211 of a mode multiplexer 21 at a next
 stage. Here, the mode multiplexer 21 is designed in such a manner that the light
 in the TE0 mode that is input to the first port 211 will be directly transmitted
 through the straight-through waveguide and output from the third port 213, and
 15 the light in the TE1 mode that is input to the third port 213 will be mode-coupled
 to the cross waveguide and output from the second port 212 in the TE0 mode.

[0032] For the wavelength division multiplexer/demultiplexer shown in FIG. 4,
 a demultiplexing process thereof is as follows. A composite light containing the
 four wavelengths λ_1 , λ_2 , λ_3 , and λ_4 in the TE0 mode is input from the first port
 20 211 of the mode multiplexer 21 of the first wavelength division
 multiplexing/demultiplexing unit 20a, is transmitted through the straight-through
 waveguide of the mode multiplexer 21 and output from the third port 213, and is
 incident into the first asymmetric Bragg grating 22a of the first wavelength
 division multiplexing/demultiplexing unit 20a. The first asymmetric Bragg grating

22a is designed to transmit the lights containing the wavelengths λ_2 , λ_3 , λ_4 , and to reflect the light with the wavelength λ_1 and perform a mode conversion. The light with the wavelength λ_1 is reflected and converted into the TE1 mode by the first asymmetric Bragg grating 22a, then is returned to the third port 213 of the mode multiplexer 21, and is converted into the TE0 mode through the mode coupling of the straight-through waveguide and the cross waveguide of the mode multiplexer 21 and output from the second port 212. The light containing the wavelengths λ_2 , λ_3 , λ_4 is transmitted through the first asymmetric Bragg grating 22a, then continues to be transmitted in the TE0 mode along the bus waveguide 10 to a wavelength division multiplexing/demultiplexing unit at a next stage, that is, the second wavelength division multiplexing/demultiplexing unit 20b, and is input from the first port 211 of the mode multiplexer 21 of the second wavelength division multiplexing/demultiplexing unit 20b. The second asymmetric Bragg grating 22b of the second wavelength division multiplexing/demultiplexing unit 20b is designed to transmit the lights containing the wavelengths λ_3 , λ_4 , and to reflect the light with the wavelength λ_2 and perform the mode conversion. A demultiplexing process of the second wavelength division multiplexing/demultiplexing unit 20b is the same as that of a previous stage, the light with the wavelength λ_2 in the TE0 mode will be output from the second port 212 of the mode multiplexer 21 of the second wavelength division multiplexing/demultiplexing unit 20b, and the light containing the wavelengths λ_3 , λ_4 continues to be transmitted in the TE0 mode along the bus waveguide 10 to a wavelength division multiplexing/demultiplexing unit at a next stage, that is, the third wavelength division multiplexing/demultiplexing unit 20c. At this stage,

the third asymmetric Bragg grating 22c of the third wavelength division multiplexing/demultiplexing unit 20c is designed to transmit the light with the wavelength λ_4 , and to reflect the light with the wavelength λ_3 and perform the mode conversion. Afterwards, the light with the wavelength λ_3 in the TE0 mode is output from the second port 212 of the mode multiplexer 21 of the third wavelength division multiplexing/demultiplexing unit 20c, and then the light with the wavelength λ_4 is transmitted through the third asymmetric Bragg grating 22c and output in the TE0 mode. The light with the wavelength λ_4 in the TE0 mode transmitted through the third asymmetric Bragg grating 22c continues to be transmitted to the fourth wavelength division multiplexing/demultiplexing unit 20d along the bus waveguide 10. The fourth asymmetric Bragg grating 22d of the fourth wavelength division multiplexing/demultiplexing unit 20d is designed to reflect the light with the wavelength λ_4 and perform the mode conversion. Finally, the light with the wavelength λ_4 in the TE0 mode is output from the second port 212 of the mode multiplexer 21 of the fourth wavelength division multiplexing/demultiplexing unit 20d, and demultiplexing of λ_1 , λ_2 , λ_3 , λ_4 is completed. When the wavelength division multiplexer/demultiplexer serves as a multiplexer, a wavelength division multiplexing process is opposite to the above-mentioned demultiplexing process, and the details thereof will not be described herein. The fourth wavelength division multiplexing/demultiplexing unit 20d can filter the light containing wavelengths such as λ_1 , λ_2 , λ_3 , and other wavelengths that may be transmitted through previous stages and to the fourth stage, and works as a filter, so that an extinction ratio can be increased, and crosstalk of other wavelengths can be prevented from being introduced into a light channel of the

wavelength λ .

[0033] As shown in FIG. 2, the asymmetric Bragg grating 22 employed in the present disclosure is a Bragg grating that is gradually asymmetrical. Compared with a Bragg grating that is completely asymmetrical, this grating can effectively suppress occurrences of side lobes and has a high extinction ratio. The asymmetric Bragg grating 22 is designed to simultaneously realize the functions of filtering and mode conversion. When the grating period satisfies the Bragg condition $\frac{2\pi}{\Lambda} = (\frac{2\pi}{\lambda}) n_{TE0} + (\frac{2\pi}{\lambda}) n_{TE1}$, the light with a wavelength λ satisfies a resonance relationship with the grating period. When the light with the wavelength λ is incident into the asymmetric Bragg grating in the TE0 mode, the asymmetric Bragg grating 22 can convert the light into the TE1 mode and reflect the light back. In the above formula, Λ is the grating period of the asymmetric Bragg grating, λ is the wavelength of a transmitted light, and n_{TE0} and n_{TE1} are respectively effective refractive indices of the light transmitted in the TE0 mode and in the TE1 mode in the asymmetric Bragg grating 22. The above formula can be simplified into $\frac{\lambda}{2\Lambda} = \frac{n_{TE0} + n_{TE1}}{2}$. That is, for one specific wavelength λ , when the grating period Λ is reasonably selected such that a value of $\frac{\lambda}{2\Lambda}$ is equal to a mean value of the effective refractive indices of the TE0 mode and the TE1 mode, conversion between the two modes can be realized. FIG. 5 shows relations of parameters respectively varying with the wavelength λ in a typical silicon-on-insulator (SOI) structure, and the parameters are the effective refractive indices of the TE0 mode and the TE1 mode in the strip waveguide of the silicon material having a width of 550 nm and a height of 220 nm, the mean value of the effective refractive indices

of the TE0 mode and the TE1 mode, and the value of $\frac{\lambda}{2\Lambda}$ under a specific grating period with respect to the wavelength λ . In the range of the CWDM4 (1261 nm to 1341 nm), a curve of the $\frac{\lambda}{2\Lambda}$ and a curve of the mean value of the effective refractive indices of the TE0 mode and the TE1 mode are intersected at a point A.

5 That is, the above equation is satisfied at the point A. The asymmetric Bragg grating of the grating period will perform the conversion between the TE0 mode and the TE1 mode on the light with a wavelength corresponding to the point A, and reflect the light. In addition, the curve of $\frac{\lambda}{2\Lambda}$ and a curve of the refractive index of the TE0 mode are also intersected at a point B around 1340 nm. That is, the

10 equation $\frac{\lambda}{2\Lambda} = n_{TE0}$ is satisfied at the point B. When the light transmitted in the waveguide is in the TE0 mode, reflection will also occur at a wavelength corresponding to the point B. In order to prevent crosstalk caused by the asymmetric Bragg grating reflecting the light in the TE0 mode with the wavelength corresponding to the point B, it needs a large difference between the

15 effective refractive indexes of the TE0 mode and the TE1 mode of the waveguide. In this way, spacing between the wavelengths respectively corresponding to the point A and the point B is large enough to meet requirements of a wavelength range (> 80 nm) of the CWDM4.

[0034] FIG. 5 illustrates a curve diagram from simulation of the strip

20 waveguide of the silicon material in the typical silicon-on-insulator (SOI) structure which is reasonable design. The point B is outside the wavelength range of from 1261 nm to 1341 nm as required by the CWDM4, and crosstalk of the wavelength corresponding to the point B will not be introduced. However, in a ridge

waveguide structure of silicon material of a silicon-on-insulator, or in waveguide structures of other materials (such as SiN, SiON, SiO₂, or lithium niobate) that have a small difference between the effective refractive indexes of the TE₀ mode and the TE₁ mode, wavelength spacing between the point A and the point B (< 80 nm) is smaller than the wavelength spacing as required by the CWDM4, which will cause severe wavelength crosstalk and cannot meet the requirements of the wavelength division multiplexer. Therefore, the wavelength division multiplexer/demultiplexer shown in FIG. 4 is only suitable for the strip waveguide of the silicon material in the silicon-on-insulator. In the strip waveguide of the silicon material, the difference between the effective refractive indexes of the TE₀ mode and the TE₁ mode is so large as to allow the wavelength spacing between the wavelengths respectively corresponding to the point A and the point B shown in FIG. 5 to meet the wavelength range (> 80 nm) as required by the CWDM4.

[0035] FIG. 6 illustrates another embodiment of the present disclosure. In the wavelength division multiplexer/demultiplexer of the present embodiment, the light is incident into the asymmetric Bragg grating in the TE₁ mode, and the light transmitted in the asymmetric Bragg grating and the bus waveguide is mainly in the TE₁ mode. A reflection peak of the TE₀ mode at the point B illustrated in FIG. 5 will not appear. In addition, although there will appear a reflection peak of the TE₁ mode at the wavelength corresponding to the intersection point of the curve of $\frac{\lambda}{2\Lambda}$ and the curve of the refractive index of the TE₁ mode, the wavelength corresponding to the reflection peak of the TE₁ mode is outside the wavelength range of the CWDM4 and is at shorter wavelengths, so that the wavelength division multiplexing/demultiplexing within the wavelength range as required by

the CWDM4 is not affected. Moreover, modes (such as TE2/TE3) which may be converted into from the TE1 mode also appear at shorter wavelengths, which similarly will not affect use of the wavelength division multiplexer/demultiplexer.

[0036] Specifically, as shown in FIG. 6, wavelength division
 5 multiplexing/demultiplexing of the four wavelengths in that range from 1261 nm to 1341 nm as required by the CWDM4 (which is commonly used in the light communications) is also taken as an example in the present embodiment. Assuming that the four wavelengths are λ_1 , λ_2 , λ_3 , λ_4 . The wavelength division multiplexer/demultiplexer includes three wavelength division
 10 multiplexing/demultiplexing units 30a, 30b, and 30c that are sequentially cascaded. Each of the wavelength division multiplexing/demultiplexing units 30a, 30b, and 30c includes a mode multiplexer 31 and a corresponding asymmetric Bragg grating of asymmetric Bragg gratings 32a, 32b, and 32c. The three cascaded wavelength division multiplexing/demultiplexing units are respectively the first
 15 wavelength division multiplexing/demultiplexing unit 30a, the second wavelength division multiplexing/demultiplexing unit 30b, and the third wavelength division multiplexing/demultiplexing unit 30c. The three wavelength division multiplexing/demultiplexing units respectively correspond to the first asymmetric Bragg grating 32a, the second asymmetric Bragg grating 32b, and the third
 20 asymmetric Bragg grating 32c. The asymmetric Bragg gratings of the three wavelength division multiplexing/demultiplexing units have different grating periods, and are used to respectively reflect the lights with the wavelengths λ_1 , λ_2 , λ_3 but transmit the light with the wavelength λ_4 . The mode multiplexer 31 includes a first port 311, a second port 312, and a third port 313. The first port 311

and the second port 312 are respectively configured to input or output the optical signals, and the third port 313 is connected to the asymmetric Bragg gratings 32a, 32b, and 32c. The demultiplexer is taken as an example. The first port 311 of the mode multiplexer 31 is used as an input port, the second port 312 is used as an output port, and the third port 313 is connected to incident ends of the asymmetric Bragg gratings 32a, 32b, and 32c. Transmission ends of the symmetric Bragg gratings 32a, 32b, and 32c are connected to the first port 311 of a mode multiplexer 31 at a next stage. Here, the mode multiplexer 31 is designed in such a manner that the light in the TE1 mode that is input to the first port 311 will be directly transmitted through the straight-through waveguide and output from the third port 313, and the light in the TE0 mode that is input to the third port 313 will be mode-coupled to the cross waveguide and output from the second port 312 in the TE1 mode.

[0037] A demultiplexing process of the wavelength division multiplexer/demultiplexer shown in FIG. 6 is as follows. A composite light containing the four wavelengths λ_1 , λ_2 , λ_3 , λ_4 in the TE1 mode is input from the first port 311 of the mode multiplexer 31 of the first wavelength division multiplexing/demultiplexing unit 30a, is transmitted through the straight-through waveguide of the mode multiplexer 31 and output from the third port 313, and is incident into the first asymmetric Bragg grating 32a of the first wavelength division multiplexing/demultiplexing unit 30a in the TE1 mode. The first asymmetric Bragg grating 32a is designed to transmit the light containing the wavelengths λ_2 , λ_3 , λ_4 , and to reflect the light with the wavelength λ_1 and perform the mode conversion. The light with the wavelength λ_1 is reflected by the first

asymmetric Bragg grating 32a and converted into the TE₀ mode, is transmitted to the third port 313 of the mode multiplexer 31, and then is converted into the TE₁ mode through mode coupling of the straight-through waveguide and the cross waveguide of the mode multiplexer 31 and output from the second port 312. The

5 light containing the wavelengths λ_2 , λ_3 , λ_4 is transmitted through the first asymmetric Bragg grating 32a, then continues to be transmitted in the TE₁ mode along the bus waveguide 10 to the second wavelength division multiplexing/demultiplexing unit 30b at a next stage, and is input from the first

10 port 311 of the mode multiplexer 31 of the second multiplexing/demultiplexing unit 30b. The second asymmetric Bragg grating 32b of the second wavelength division multiplexing/demultiplexing unit 30b is designed to transmit the light containing the wavelengths λ_3 , λ_4 , and to reflect the light with the wavelength λ_2 and perform the mode conversion. A demultiplexing process of the second

15 wavelength division multiplexing/demultiplexing unit 30b is the same as that of a previous stage, the light with the wavelength λ_2 in the TE₁ mode will be output from the second port 312 of the mode multiplexer 31 of the second wavelength division multiplexing/demultiplexing unit 30b, and the light containing the

20 wavelengths λ_3 , λ_4 will continue to be transmitted along the bus waveguide 10 in the TE₁ mode to the third wavelength division multiplexing/demultiplexing unit 30c at a next stage. At this stage, the third asymmetric Bragg grating 32c is designed to transmit the light with the wavelength λ_4 , and to reflect the light with the wavelength λ_3 and perform the mode conversion. Finally, the light with the wavelength λ_3 in the TE₁ mode is output from the second port 312 of the mode multiplexer 31 of the third wavelength division multiplexing/demultiplexing unit

30c, and the light with the wavelength λ_4 in the TE1 mode is transmitted through the third asymmetric Bragg grating 32c and output. In this way, demultiplexing of λ_1 , λ_2 , λ_3 , λ_4 is completed. When the wavelength division multiplexer/demultiplexer serves as a multiplexer, the wavelength division
 5 multiplexing process is opposite to the above-mentioned demultiplexing process, and the details thereof will not be described herein.

[0038] In the present embodiment, the light is incident into the asymmetric Bragg grating in the TE1 mode, so that the light transmitted in the asymmetric Bragg grating is in the TE1 mode. Accordingly, crosstalk caused by reflection of
 10 the asymmetric Bragg grating to the TE0 mode can be prevented. In addition, crosstalk caused by reflection peaks of the TE1 mode or higher-order modes that may exist at short wavelengths can be effectively prevented by reflecting and filtering light with short wavelengths first and sequentially increasing filtered wavelengths in a cascade manner. For example, in the above demultiplexing
 15 process, the wavelengths are $\lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$, so that the crosstalk caused by the reflection peaks of the TE1 mode or a higher-order mode at short wavelengths can be prevented. Moreover, there is no need to additionally dispose filter devices on the bus waveguides between the wavelength division multiplexing/demultiplexing units at each stage, which simplifies a manufacturing process.

20 **[0039]** The wavelength division multiplexer/demultiplexer shown in FIG. 7, on the basis of the embodiment shown in FIG. 6, is cascaded with a fourth wavelength division multiplexing/demultiplexing unit 30d after the third wavelength division multiplexing/demultiplexing unit 30c. A fourth asymmetric Bragg grating 32d of the fourth wavelength division multiplexing/demultiplexing unit 30d is designed

to reflect the light with the wavelength λ_4 and perform the mode conversion. Finally, the light with the wavelength λ_4 in the TE1 mode is output from a second port of the mode multiplexer 31 of the fourth multiplexing/demultiplexing unit 30d. The fourth wavelength division multiplexing/demultiplexing unit 30d is used to filter the light containing wavelengths such as λ_1 , λ_2 , λ_3 and other wavelengths that may be transmitted through previous stages and to the fourth stage, and works as a filter, so that an extinction ratio can be increased, and crosstalk of other wavelengths can be prevented from being introduced into the light channel of the wavelength λ_4 .

10 **[0040]** The wavelength division multiplexer/demultiplexer shown in FIG. 8, on the basis of the embodiment shown in FIG. 6 or FIG. 7, is further provided with a first mode converter 33 at an output port of each wavelength division multiplexing/demultiplexing unit. That is, the wavelength division multiplexing/demultiplexing units 30a, 30b, 30c, and 30d further include the first mode converters 33. The first mode converter 33 is connected to the second port 312 of the mode multiplexer 31. During the wavelength division multiplexing process, the first mode converters 33 of the wavelength division multiplexing/demultiplexing units 30a, 30b, 30c, and 30d at each stage are respectively used to convert the light in the TE1 mode that is output from the second port 312 of the corresponding mode multiplexer 31 into the TE0 mode. In the embodiment, a structure of the first mode converter 33 is the same as that of the mode multiplexer 31, and includes a straight-through waveguide and a cross waveguide. Two ends of the straight-through waveguide are respectively a first port and a third port, and one end of the cross waveguide that is adjacent to the

first port is a second port. But, the first mode converter 33 only makes use of the second port and the third port to perform the mode conversion. In other embodiments, the first mode converter 33 may also adopt other mode conversion structures.

- 5 **[0041]** An embodiment shown in FIG. 9, the same as the embodiment shown in FIG. 6, is a wavelength division multiplexer/demultiplexer used for four wavelengths. The wavelength division multiplexer/demultiplexer includes three wavelength division multiplexing/demultiplexing units that are sequentially cascaded. Wherein, each of wavelength division multiplexing/demultiplexing
- 10 units 40a, 40b, and 40c includes a mode multiplexer 41 and a corresponding asymmetric Bragg grating of asymmetric Bragg gratings 42a, 42b, and 42c. The three cascaded wavelength division multiplexing/demultiplexing units are respectively the first wavelength division multiplexing/demultiplexing unit 40a, the second wavelength division multiplexing/demultiplexing unit 40b, and the
- 15 third wavelength division multiplexing/demultiplexing unit 40c. The three wavelength division multiplexing/demultiplexing units respectively correspond to the first asymmetric Bragg grating 42a, the second asymmetric Bragg grating 42b, and the third asymmetric Bragg grating 42c. The asymmetric Bragg gratings of the three wavelength division multiplexing/demultiplexing units have different
- 20 grating periods, and are used to respectively reflect the light with the wavelengths λ_1 , λ_2 , and λ_3 but transmit the light with the wavelength λ_4 . The difference between the present embodiment and the embodiment shown in FIG. 6 is as follows. In the present embodiment, the mode multiplexer 41 is designed in such a manner that the light in the TE₀ mode input to the second port 412 is converted

into the TE1 mode through mode coupling of the cross waveguide and the straight-through waveguide and output from the third port 413. Then, the light in the TE0 mode that is input to the third port 413 will be directly transmitted through the straight-through waveguide and output from the first port 411, and the light in the

5 TE1 mode that is input to the third port 413 will be converted into the TE0 mode through mode coupling of the straight-through waveguide and the cross waveguide and output from the second port 412. Moreover, there is a second mode converter 50 provided between every two adjacent ones of the wavelength division multiplexing/demultiplexing units 40a, 40b, and 40c. The second mode converter

10 50 includes two ports, and the two ports are respectively connected to the asymmetric Bragg grating 42a or 42b at a previous stage on one side of the second mode converter 50 and the second port 412 of a mode multiplexer 41 at a next stage on the other side of the second mode converter 50. When the wavelength division multiplexer/demultiplexer serves as a demultiplexer, the second port 412

15 of the mode multiplexer 41 of the first wavelength division multiplexer/demultiplexer unit 40a is used as an input port for receiving a composite light in the TE0 mode, the third port 413 is connected to an incident end of the first asymmetric Bragg grating 42a, a transmission end of the first asymmetric Bragg grating 42a is connected to one port of the second mode

20 converter 50, another port of the second mode converter 50 is connected to the second port of the mode multiplexer 41 of the second wavelength division multiplexing/demultiplexing unit 40b at a next stage, and so on. The second mode converter 50 is used to convert the light transmitted through the asymmetric Bragg grating from the TE1 mode to the TE0 mode, and then transmit the light to the

second port 412 of the mode multiplexer 41 of a wavelength division multiplexer/demultiplexer unit at a next stage. The first port 411 of each mode multiplexer 41 and the third asymmetric Bragg grating 42c of the third wavelength division multiplexing/demultiplexing unit 40c are respectively used to output a demultiplexed light of each channel. A structure of the second mode converter 50 is the same as that of the mode multiplexer 41, and includes a straight-through waveguide and a cross waveguide. Two ends of the straight-through waveguide are respectively a first port and a third port, and one end of the cross waveguide that is adjacent to the first port is a second port. But, the second mode converter 50 only makes use of the second port and the third port to perform the mode conversion. In other embodiments, the second mode converter 50 may also adopt other mode conversion structures.

[0042] The above-mentioned demultiplexing process is as follows. A composite light containing the four wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ in the TE0 mode is input from the second port 412 of the mode multiplexer 41 of the first wavelength division multiplexing/demultiplexing unit 40a, and output from the third port 413 in the TE1 mode through the mode coupling of the cross wavelength and the straight-through waveguide of the mode multiplexer 41. The light in the TE1 mode is incident into the first asymmetrical waveguide 42a of the first wavelength division multiplexing/demultiplexing unit 40a. The first asymmetric Bragg grating 42a is designed to transmit the light containing the wavelengths $\lambda_2, \lambda_3, \lambda_4$, and to reflect the light with the wavelength λ_1 and perform the mode conversion. The light with the wavelength λ_1 is reflected by the first asymmetric Bragg grating 42a and converted into the TE0 mode, is returned to the third port 413 of the mode

multiplexer 41, and then is output from the first port 411 after being transmitted through the straight-through waveguide of the mode multiplexer 41. After being transmitted through the first asymmetric Bragg grating 42a, the light containing the wavelengths λ_2 , λ_3 , λ_4 continues to be transmitted to the second mode converter 50 in the TE1 mode, then is converted into the TE0 mode by the second mode converter 50 and transmitted in the bus waveguide 10, the light in the TE0 mode is transmitted into the second wavelength division multiplexing/demultiplexing unit 40b at a next stage through the bus waveguide 10, and is input from the second port 412 of the mode multiplexer 41 of the second wavelength division multiplexing/demultiplexing unit 40b. The second asymmetric Bragg grating 42b of the second wavelength division multiplexing/demultiplexing unit 40b is designed to transmit the light containing the wavelengths λ_3 , λ_4 , and to reflect the light with the wavelength λ_2 and perform the mode conversion. A demultiplexing process of the second wavelength division multiplexing/demultiplexing unit 40b is the same as that of a previous stage. The light with the wavelength λ_2 in the TE0 mode is output from the first port 411 of the mode multiplexer 41 of the second wavelength division multiplexing/demultiplexing unit 40b, and the light containing the wavelengths λ_3 , λ_4 continues to be transmitted to the second mode converter 50 in the TE1 mode, then is converted into the TE0 mode by the second mode converter 50 and transmitted in the bus waveguide 10, the light in the TE0 mode is transmitted into the third wavelength division multiplexing/demultiplexing unit 40c at a next stage through the bus waveguide 10, and is input from the second port 412 of the mode multiplexer 41 of the third wavelength division multiplexing/demultiplexing unit

40c. At this stage, the third asymmetric Bragg grating 42c is designed to transmit the light with the wavelength λ_4 , and to reflect the light with the wavelength λ_3 and perform the mode conversion. Finally, the light with the wavelength λ_3 in the TE0 mode is output from the first port 411 of the mode multiplexer 41 of the third wavelength division multiplexing/demultiplexing unit 40c, and the light with the wavelength λ_4 in the TE1 mode is transmitted through the third asymmetric Bragg grating 42c and output. In this way, demultiplexing of the four wavelengths λ_1 , λ_2 , λ_3 , λ_4 is completed. When the wavelength division multiplexer/demultiplexer is used as a multiplexer, the wavelength division multiplexing process is opposite to the above-mentioned demultiplexing process, and the details thereof will not be described herein. In the structure of the present embodiment, the light transmitted in the bus waveguide 10 is still in the TE0 mode, transmission loss is small, and requirements on a size of the waveguide are few.

[0043] The wavelength division multiplexer/demultiplexer shown in FIG. 10, on the basis of the embodiment shown in FIG. 9, is cascaded with a second mode converter 50 and a fourth wavelength division multiplexing/demultiplexing unit 40d after the third wavelength division multiplexing/demultiplexing unit 40c. The light with the wavelength λ_4 in the TE1 mode, which is transmitted and output from the third asymmetric Bragg grating 42c of the third wavelength division multiplexing/demultiplexing unit 40c, is converted into the TE0 mode by the second mode converter 50 and transmitted along the bus waveguide 10, and then is transmitted to the fourth wavelength division multiplexing/demultiplexing unit 40d through the bus waveguide 10. The fourth asymmetric Bragg grating 42d of the fourth wavelength division multiplexing/demultiplexing unit 40d is designed

to reflect the light with the wavelength λ_4 and perform the mode conversion. Finally, the light with the wavelength λ_4 in the TE0 mode is output from the first port 411 of the mode multiplexer 41 of the fourth wavelength division multiplexing/demultiplexing unit 40d. The fourth wavelength division multiplexing/demultiplexing unit 40d is used to filter the light containing wavelength such as λ_1 , λ_2 , λ_3 , and other wavelengths that may be transmitted through previous stages and to the fourth stage, and works as a filter, so that an extinction ratio can be increased, and crosstalk of other wavelengths can be prevented from being introduced into the light channel of the wavelength λ_4 .

10 **[0044]** The embodiment shown in FIG. 11, the same as the embodiment shown in FIG. 6, is a wavelength division multiplexer/demultiplexer used for four wavelengths. The wavelength division multiplexer/demultiplexer includes three wavelength division multiplexing/demultiplexing units that are sequentially cascaded. Wherein, each of the wavelength division multiplexing/demultiplexing units 60a, 60b, and 60c includes a mode multiplexer 61, and a corresponding asymmetric Bragg grating of asymmetric Bragg gratings 62a, 62b, and 62c. The three cascaded wavelength division multiplexing/demultiplexing units are respectively the first wavelength division multiplexing/demultiplexing unit 60a, the second wavelength division multiplexing/demultiplexing unit 60b, and the third wavelength division multiplexing/demultiplexing unit 60c. The three wavelength division multiplexing/demultiplexing units respectively correspond to the first asymmetric Bragg grating 62a, the second asymmetric Bragg grating 62b, and the third asymmetric Bragg grating 62c. The asymmetric Bragg gratings of the three wavelength division multiplexing/demultiplexing units have different

grating periods, and are used to respectively reflect the light with the wavelengths λ_1 , λ_2 , and λ_3 but transmit the light with the wavelength λ_4 . The difference between the present embodiment and the embodiment shown in FIG. 6 is as follows. In the present embodiment, the first port 611 of the mode multiplexer 61 of the wavelength division multiplexing/demultiplexing unit is designed to transmit the light in the TE1 mode, and the second port 612 is used to transmit the light in TE0 mode. That is, the light that is transmitted from the first port 611 to the third port 613 of the mode multiplexer 61 is in the TE1 mode, the mode of the light is unchanged from input to output, and the light that is transmitted from the third port 613 to the second port 612 is in the TE0 mode, the mode of the light is also unchanged from input to output. For example, the light in the TE1 mode that is input from the third port 613 will be output from the first port 611 in the TE1 mode, and the light in the TE0 mode that is input from the third port 613 will be output from the second port 612 in the TE0 mode. The asymmetric Bragg gratings 62a and 62b corresponding to the wavelength division multiplexing/demultiplexing units 60a and 60b at each stage are respectively connected to the first port 611 of the first mode multiplexer 61 of the wavelength division multiplexing/demultiplexing units 60b and 60c at a next stage. When the wavelength division multiplexer/demultiplexer serves as a demultiplexer, the first port 611 of the mode multiplexer 61 of the first wavelength division multiplexer/demultiplexer unit 60a is used as an input port for receiving the composite light in the TE1 mode. The second port 612 of the mode multiplexer 61 at each stage and the third asymmetric Bragg grating 62c of the third wavelength division multiplexing/demultiplexing unit 60c are respectively used to output a

demultiplexed light of each channel in the TE0 mode.

[0045] A demultiplexing process is as follows. A composite light containing the four wavelengths λ_1 , λ_2 , λ_3 , λ_4 in the TE1 mode is input from the first port 611 of the mode multiplexer 61 of the first wave demultiplexing/demultiplexing unit 60a, and is transmitted through the mode multiplexer 61 and output from the third port 613 in the TE1 mode, then the light in the TE1 mode is incident into the first asymmetric Bragg grating 62a of the first wavelength division multiplexing/demultiplexing unit 60a. The first asymmetric Bragg grating 62a is designed to transmit the light containing the wavelengths λ_2 , λ_3 , λ_4 , and to reflect the light with the wavelength λ_1 and perform the mode conversion. The light with the wavelength λ_1 is reflected by the first asymmetric Bragg grating 62a and converted into the TE0 mode, and then is returned to the third port 613 of the mode multiplexer 61, and then is output from the second port 612 in the TE0 mode after being transmitted through the mode multiplexer 61. After being transmitted through the first asymmetric Bragg grating 62a, the light containing the wavelengths λ_2 , λ_3 , λ_4 continues to be transmitted in the bus waveguide 10 in the TE1 mode, then is transmitted to the second wavelength division multiplexing/demultiplexing unit 60b at a next stage through the bus waveguide 10, and is input from the first port 611 of the mode multiplexer 61 of the second wavelength division multiplexing/demultiplexing unit 60b. The second asymmetric Bragg grating 62b of the second wavelength division multiplexing/demultiplexing unit 60b is designed to transmit the light containing the wavelengths λ_3 , λ_4 , and to reflect the light with the wavelength λ_2 and perform the mode conversion. A demultiplexing process of the second wavelength division

multiplexing/demultiplexing unit 60b is the same as that of the previous stage. The light with the wavelength λ_2 is output from the second port 612 of the mode multiplexer 61 of the second wavelength division multiplexing/demultiplexing unit 60b in the TE0 mode, the light containing the wavelengths λ_3 , λ_4 continues to be transmitted in the bus waveguide 10 in the TE1 mode, then is transmitted to the third wavelength division multiplexing/demultiplexing unit 60c at a next stage through the bus waveguide 10, and is input from the first port 611 of the mode multiplexer 61 of the wavelength division multiplexing/demultiplexing unit 60c. At this stage, the third asymmetric Bragg grating 62c is designed to transmit the light with the wavelength λ_4 , and to reflect the light with the wavelength λ_3 and perform the mode conversion. Finally, the light with the wavelength λ_3 is output from the second port 612 of the mode multiplexer 61 of the third wavelength division multiplexing/demultiplexing unit 60c in the TE0 mode, and the light with the wavelength λ_4 in the TE1 mode is transmitted through the third asymmetric Bragg grating 62c and output. In this way, demultiplexing of the four wavelengths λ_1 , λ_2 , λ_3 , λ_4 is completed. When the wavelength division multiplexer/demultiplexer is used as a multiplexer, the wavelength division multiplexing process is opposite to the above-mentioned demultiplexing process, and the details thereof will not be described herein.

[0046] The wavelength division multiplexer/demultiplexer shown in FIG. 12, on the basis of the embodiment shown in FIG. 11, is cascaded with a fourth wavelength division multiplexing/demultiplexing unit 60d after the third wavelength division multiplexing/demultiplexing unit 60c. A fourth asymmetric Bragg grating 62d of the fourth wavelength division multiplexing/demultiplexing

unit 60d is designed to reflect the light with the wavelength λ_4 and perform the mode conversion. Finally, the light with the wavelength λ_4 in the TE0 mode is output from a second port 612 of the mode multiplexer 61 of the fourth wavelength division multiplexing/demultiplexing unit 60d. The fourth wavelength division multiplexing/demultiplexing unit 60d is used to filter the light containing wavelengths such as λ_1 , λ_2 , λ_3 , and other wavelengths that may be transmitted through previous stages and to the fourth stage, and works as a filter, so that an extinction ratio can be increased, and crosstalk of other wavelengths can be prevented from being introduced into the light channel of the wavelength λ_4 .

10 **[0047]** The above-mentioned embodiments are described by taking a wavelength division multiplexer/demultiplexer for four wavelengths as an example. Certainly, different numbers of wavelength division multiplexing/demultiplexing units can be cascaded to realize wavelength division multiplexing/demultiplexing of different numbers of channels. Various cascading
15 modifications are within the protection scope of the present disclosure. For example, an eight-channel wavelength division multiplexer/demultiplexer may include at least seven wavelength division multiplexing/demultiplexing units as described above for cascading or for a combination of cascading and parallel connection, so as to perform wavelength division multiplexing or demultiplexing
20 on lights of eight different wavelengths. Naturally, the eight-channel wavelength division multiplexing/demultiplexing unit may include at least eight wavelength division multiplexing/demultiplexing units for cascading or a combination of cascading and parallel connection.

[0048] The present disclosure further provides an optical module that includes

a photonic integrated chip, in which the wavelength division multiplexer/demultiplexer in any one of the above embodiments is disposed. The wavelength division multiplexer/demultiplexer is used as a wavelength division multiplexer at a light transmitting end, and is used as a wavelength division
5 demultiplexer at a light receiving end. Naturally, optical active devices (such as signal modulators and/or photodetectors) or optical passive devices (such as couplers) can also be disposed in the photonic integrated chip.

[0049] The series of detailed descriptions above is only intended to provide specific descriptions of feasible embodiments of the present disclosure. They are
10 not to be construed as limiting the protection scope of the present disclosure. All equivalent embodiments or changes without departing from the spirit of the present disclosure should fall within the protection scope of the present disclosure.

CLAIMS

1. A wavelength division multiplexer/demultiplexer, comprising:
 - a substrate;
 - 5 a bus waveguide provided on the substrate; and
 - at least two wavelength division multiplexing/demultiplexing units provided on the bus waveguide,
 - wherein each of the at least two wavelength division multiplexing/demultiplexing units comprises a mode multiplexer and an asymmetric Bragg grating, and the mode multiplexer is configured to make
 - 10 an input light incident into the asymmetric Bragg grating in a TE₁ mode or a higher-order mode; the mode multiplexer comprises a first port, a second port, and a third port, the first port and the second port are configured to input or output optical signals, respectively, and the third port is connected to the
 - 15 asymmetric Bragg grating; the asymmetric Bragg gratings in different units of the at least two wavelength division multiplexing/demultiplexing units have different grating periods, respectively;
 - when the wavelength division multiplexer/demultiplexer serves as a demultiplexer and light with multiple wavelengths is input to one of the first
 - 20 port and the second port of the mode multiplexer for passing through the mode multiplexer, light in a TE_(n+1) mode is output from the third port and is incident into the asymmetric Bragg grating, and the asymmetric Bragg grating reflects, of the light in the TE_(n+1) mode, light with a resonance wavelength λ_i that satisfies a resonance condition with a grating period of the

asymmetric Bragg grating while transmitting the rest of the light in the TE(n+1) mode, converts the reflected light with the resonance wavelength λ_i into light in a TE0 mode, and returns the light in the TE0 mode to the mode multiplexer for being output from the other of the first port and the second port, where n is an integer greater than or equal to zero.

2. The wavelength division multiplexer/demultiplexer according to claim 1, wherein the resonance condition is:

$$\frac{2\pi}{\Lambda} = \left(\frac{2\pi}{\lambda_i}\right) n_{TE0} + \left(\frac{2\pi}{\lambda_i}\right) n_{TE1} ,$$

where Λ represents the grating period of the asymmetric Bragg grating, λ_i represents a wavelength of a transmitted light, and n_{TE0} and n_{TE1} respectively represent effective refractive indices of light in the TE0 mode and light in the TE1 mode when being transmitted in the asymmetric Bragg grating.

3. The wavelength division multiplexer/demultiplexer according to claim 1, wherein the wavelength division multiplexer/demultiplexer is a four-channel wavelength division multiplexer/demultiplexer that comprises a first wavelength division multiplexing/demultiplexing unit, a second wavelength division multiplexing/demultiplexing unit, and a third wavelength division multiplexing/demultiplexing unit that are sequentially cascaded;

the asymmetric Bragg grating of the first wavelength division multiplexing/demultiplexing unit is configured to reflect light with a wavelength λ_1 and transmit light with wavelengths λ_2 , λ_3 , and λ_4 , the

asymmetric Bragg grating of the second wavelength division multiplexing/demultiplexing unit is configured to reflect light with the wavelength λ_2 and transmit light with the wavelengths λ_3 and λ_4 , and the asymmetric Bragg grating of the third wavelength division multiplexing/demultiplexing unit is configured to reflect light with the wavelength λ_3 and transmit light with the wavelength λ_4 , where the wavelengths λ_1 , λ_2 , λ_3 , and λ_4 represent four-channel wavelengths that are unequal to each other.

4. The wavelength division multiplexer/demultiplexer according to claim 3, wherein the mode multiplexer comprises a straight-through waveguide and a cross waveguide, two ends of the straight-through waveguide are respectively the first port and the third port, an end of the cross waveguide that is adjacent to the first port is the second port, and the cross waveguide is mode-coupled to the straight-through waveguide.

5. The wavelength division multiplexer/demultiplexer according to claim 4, wherein the asymmetric Bragg grating of a wavelength division multiplexing/demultiplexing unit of the cascaded wavelength division multiplexing/demultiplexing units at each stage is connected to the first port of the mode multiplexer of a wavelength division multiplexing/demultiplexing unit of the cascaded wavelength division multiplexing/demultiplexing units at a next stage;

when the wavelength division multiplexer/demultiplexer serves as the

demultiplexer, the first port of the mode multiplexer of the first wavelength division multiplexing/demultiplexing unit is configured to receive composite light in the TE(n+1) mode, and the second port of the mode multiplexer of each of the cascaded wavelength division multiplexing/demultiplexing units and the asymmetric Bragg grating of the third wavelength division multiplexing/demultiplexing unit are configured to output demultiplexed light of each channel.

6. The wavelength division multiplexer/demultiplexer according to claim 5, wherein each of the wavelength division multiplexing/demultiplexing units further comprises a first mode converter connected to the second port of the mode multiplexer; when the wavelength division multiplexer/demultiplexer serves as the demultiplexer, the first mode converter is configured to convert light output from the second port of the mode multiplexer from the TE(n+1) mode to the TE0 mode.

7. The wavelength division multiplexer/demultiplexer according to claim 4, wherein a second mode converter is further provided between every two adjacent ones of the wavelength division multiplexing/demultiplexing units, the second mode converter comprises two ports respectively connected to the asymmetric Bragg grating on one side of the second mode converter and the second port of the mode multiplexer on the other side of the second mode converter;

when the wavelength division multiplexer/demultiplexer serves as the

demultiplexer, the second port of the mode multiplexer of the first wavelength division multiplexing/demultiplexing unit is configured to receive composite light in the TE0 mode, the second mode converter is configured to convert light transmitted through the asymmetric Bragg grating from the TE(n+1) mode to the TE0 mode and transmit the converted light to the second port of the mode multiplexer of the wavelength division multiplexing/demultiplexing unit at a next stage, and the first port of the mode multiplexer of each of the cascaded wavelength division multiplexing/demultiplexing units and the asymmetric Bragg grating of the third wavelength division multiplexing/demultiplexing unit are configured to output demultiplexed light of each channel.

8. The wavelength division multiplexer/demultiplexer according to claim 3, wherein the first port of the mode multiplexer is configured to transmit light in the TE(n+1) mode, and the second port is configured to transmit light in the TE0 mode;

the asymmetric Bragg grating of a wavelength division multiplexing/demultiplexing unit of the cascaded wavelength division multiplexing/demultiplexing units at each stage is connected to the first port of the mode multiplexer of a wavelength division multiplexing/demultiplexing unit of the cascaded wavelength division multiplexing/demultiplexing units at a next stage;

when the wavelength division multiplexer/demultiplexer serves as the demultiplexer, the first port of the mode multiplexer of the first wavelength

division multiplexing/demultiplexing unit is configured to receive composite light in the TE(n+1) mode, and the second port of the mode multiplexer of each of the cascaded wavelength division multiplexing/demultiplexing units and the asymmetric Bragg grating of the third wavelength division multiplexing/demultiplexing unit are configured to output demultiplexed light of each channel.

9. The wavelength division multiplexer/demultiplexer according to any one of claims 3-8, wherein the four-channel wavelength division multiplexer/demultiplexer further comprises a fourth wavelength division multiplexing/demultiplexing unit that is cascaded with the third wavelength division multiplexing/demultiplexing unit;

the fourth wavelength division multiplexing/demultiplexing unit comprises the mode multiplexer and the asymmetric Bragg grating that is configured to reflect the light with the wavelength λ_4 .

10. The wavelength division multiplexer/demultiplexer according to any one of claims 1-8, wherein the bus waveguide is a strip waveguide or a ridge waveguide;

the substrate is a silicon substrate, an indium phosphide substrate, a gallium nitride substrate, or a lithium niobate substrate; the bus waveguide is a silicon waveguide, a silicon nitride waveguide, a silicon oxynitride waveguide, a silicon oxide waveguide, an indium phosphide waveguide, a gallium nitride waveguide, or a lithium niobate waveguide.

11. A photonic integrated chip, characterized in that the wavelength division multiplexer/demultiplexer according to any one of claims 1-10 is disposed in the photonic integrated chip.

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12. An optical module, comprising the wavelength division multiplexer/demultiplexer according to any one of claims 1-10.