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SIRIANI et al.

(54) **BI-MATERIAL MODE MULTIPLEXER**

(71) Applicant: **Cisco Technology, Inc.**, San Jose, CA (US)

(72) Inventors: **Dominic F. SIRIANI**, Lansdale, PA (US); **Jean-Luc J. TAMBASCO**, Macungie, PA (US)

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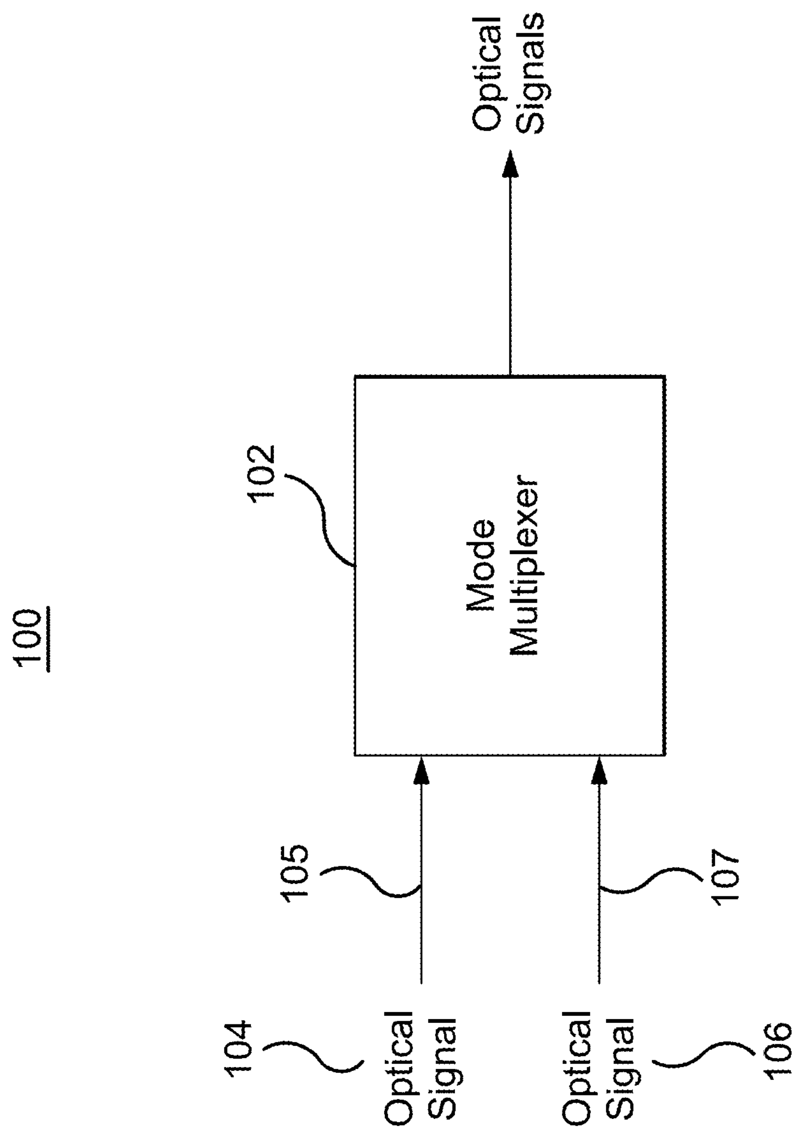
(57) **ABSTRACT**

The present disclosure describes a mode multiplexer with layered optical waveguides formed using different materials. The mode multiplexer includes a first optical waveguide and a second optical waveguide. The first optical waveguide includes a first end and a second end. The first end is wider than the second end. The second optical waveguide includes a third end. The second optical waveguide has a higher index of refraction than the first optical waveguide. The first optical waveguide and the second optical waveguide are arranged such that when the first optical waveguide and the second optical waveguide are viewed along a first axis: a length of the first optical waveguide and a length of the second optical waveguide extend along a second axis orthogonal to the first axis, the first end is non-overlapping with the third end, and the second optical waveguide partially overlaps the second end.



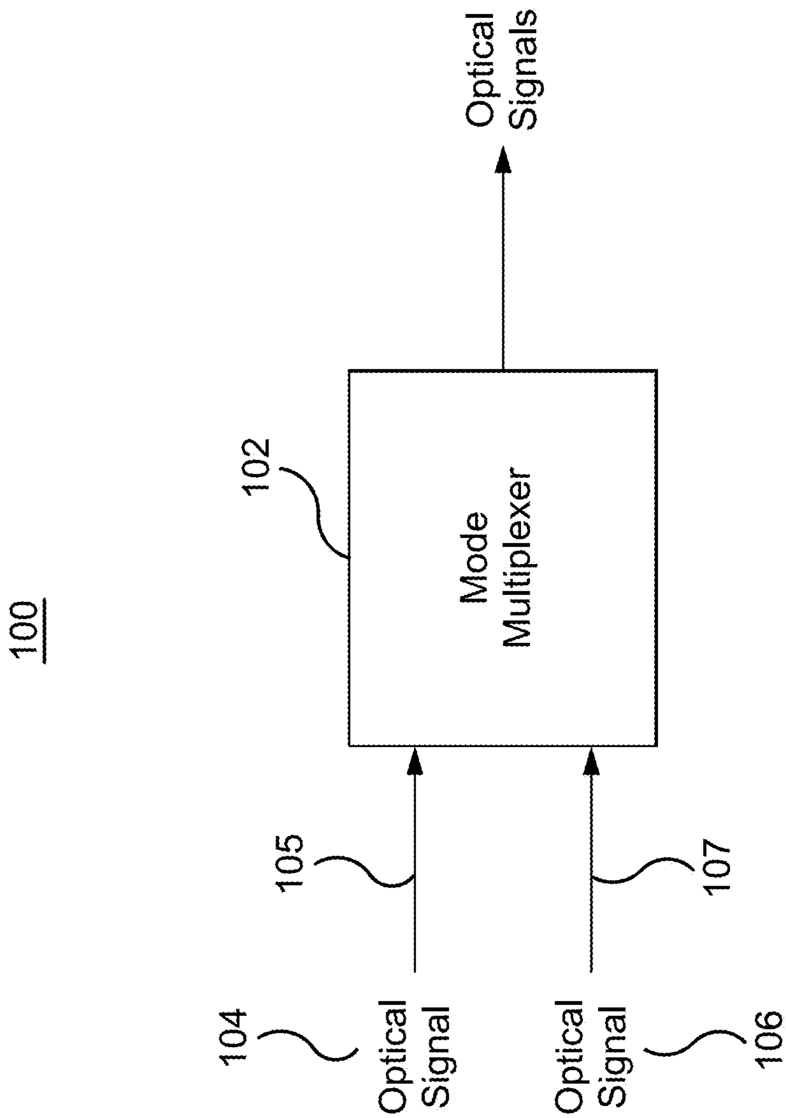

100
102
Mode
Multiplexer
Optical
Signals
104
Optical
Signal
105
106
Optical
Signal
107

FIG. 1

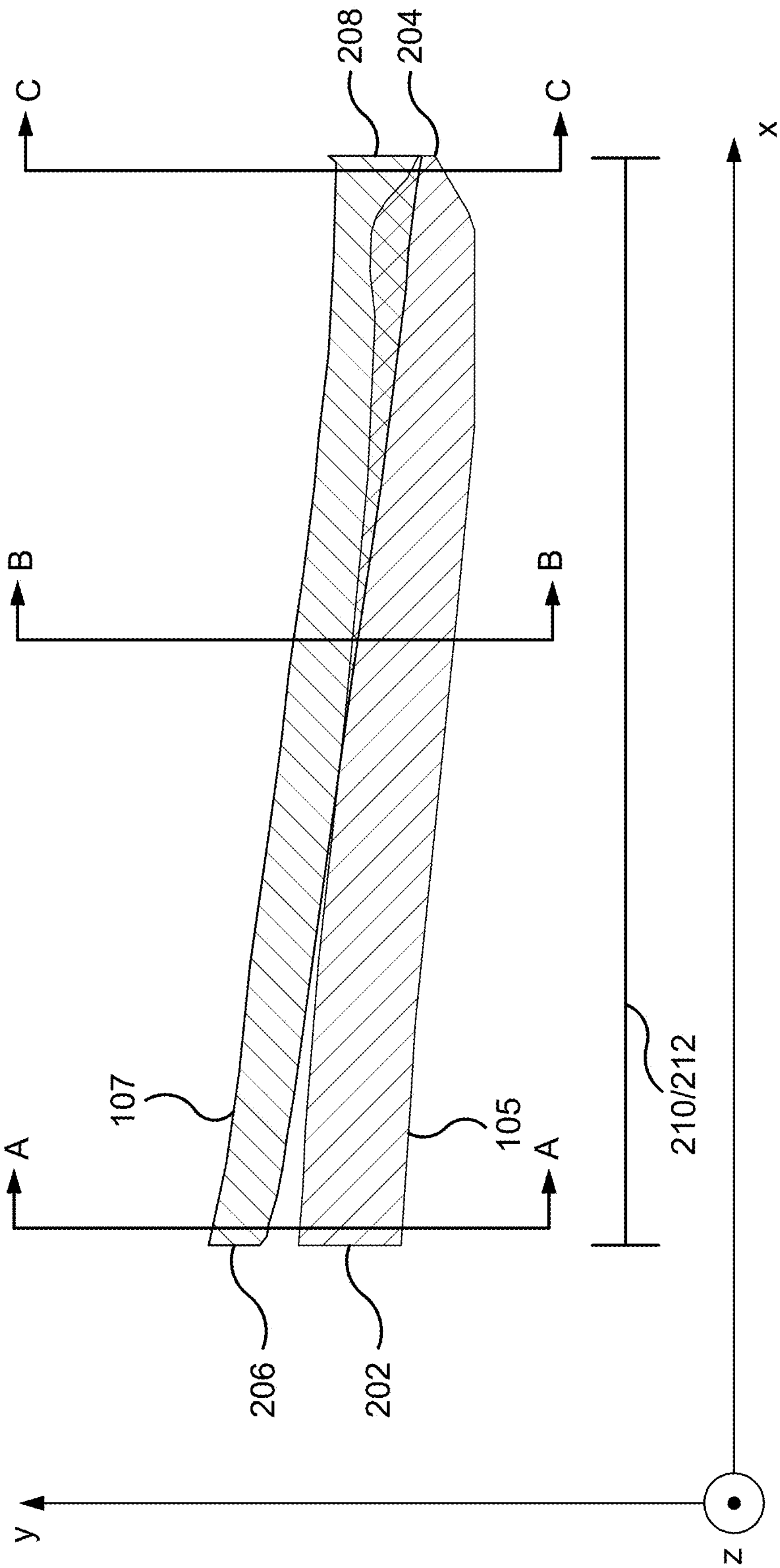


FIG. 2

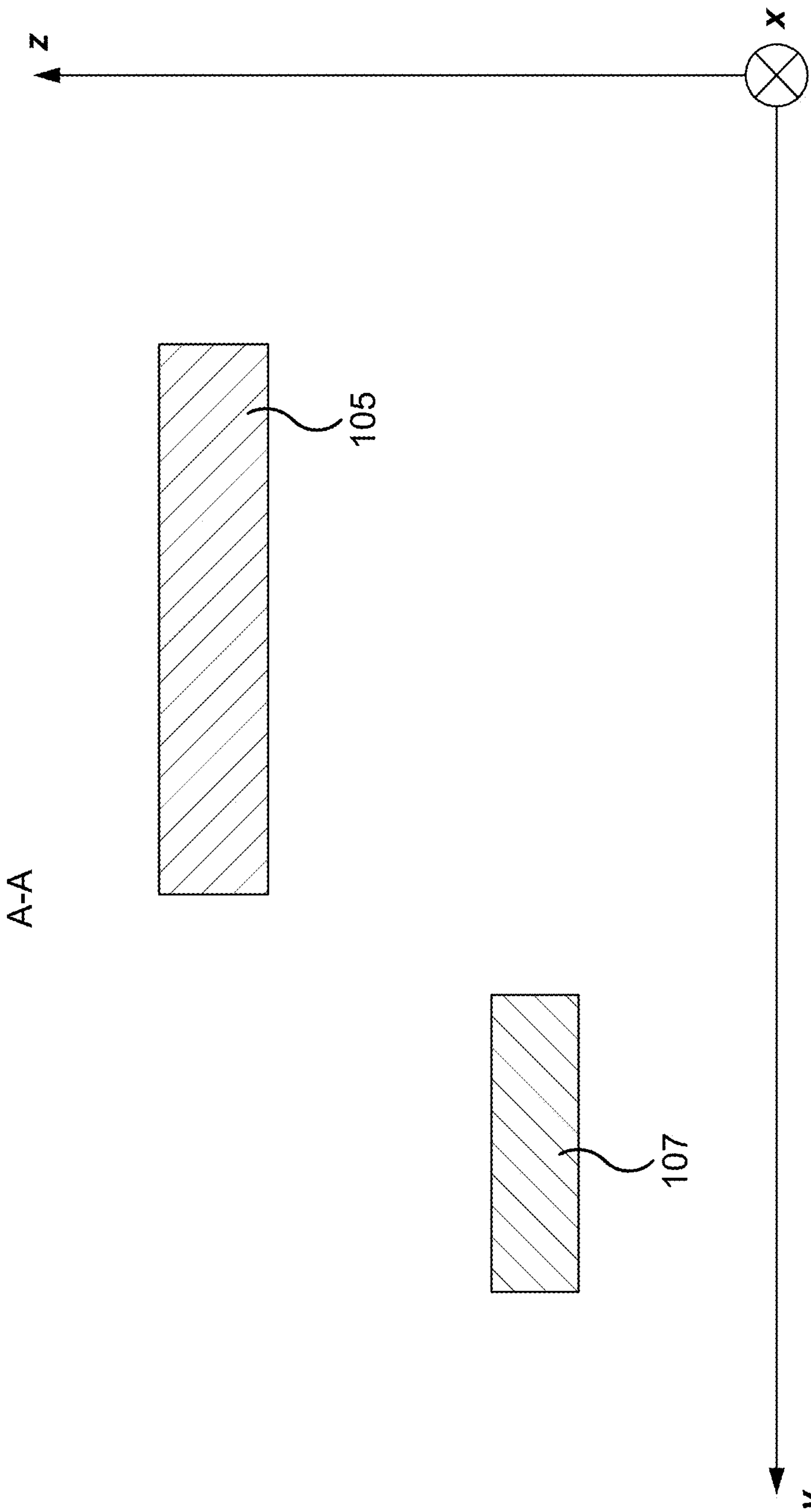


FIG. 3

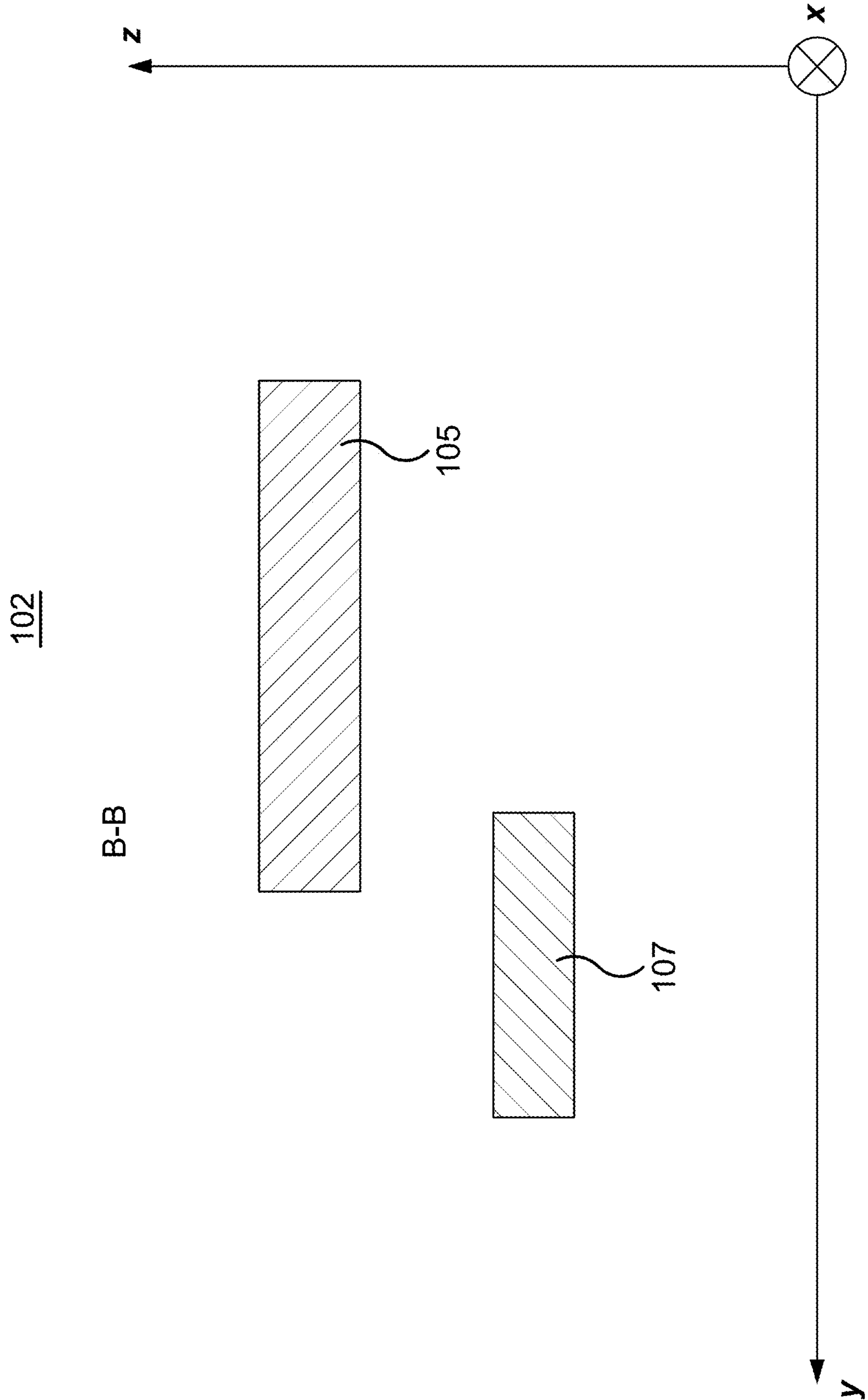


FIG. 4

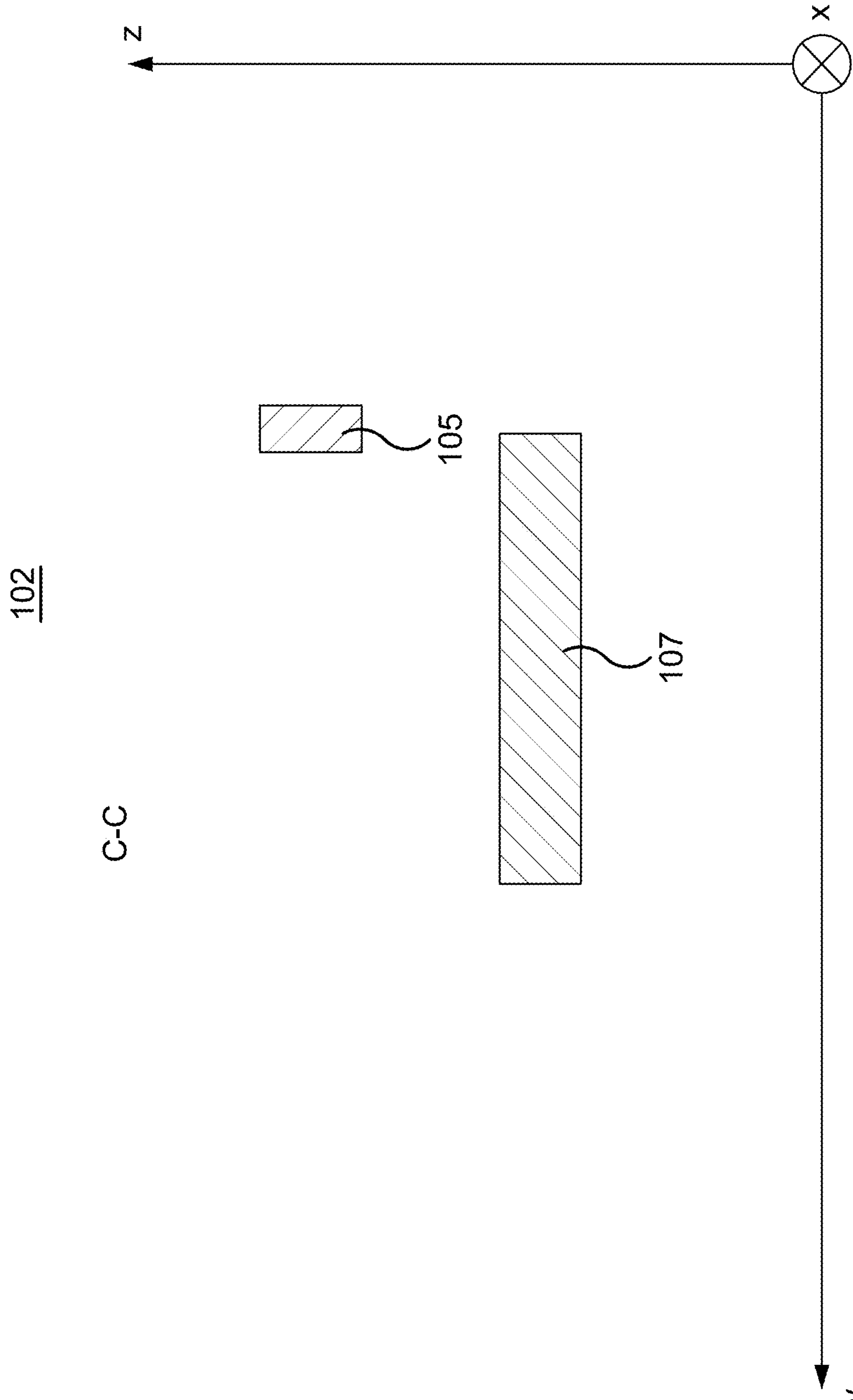


FIG. 5

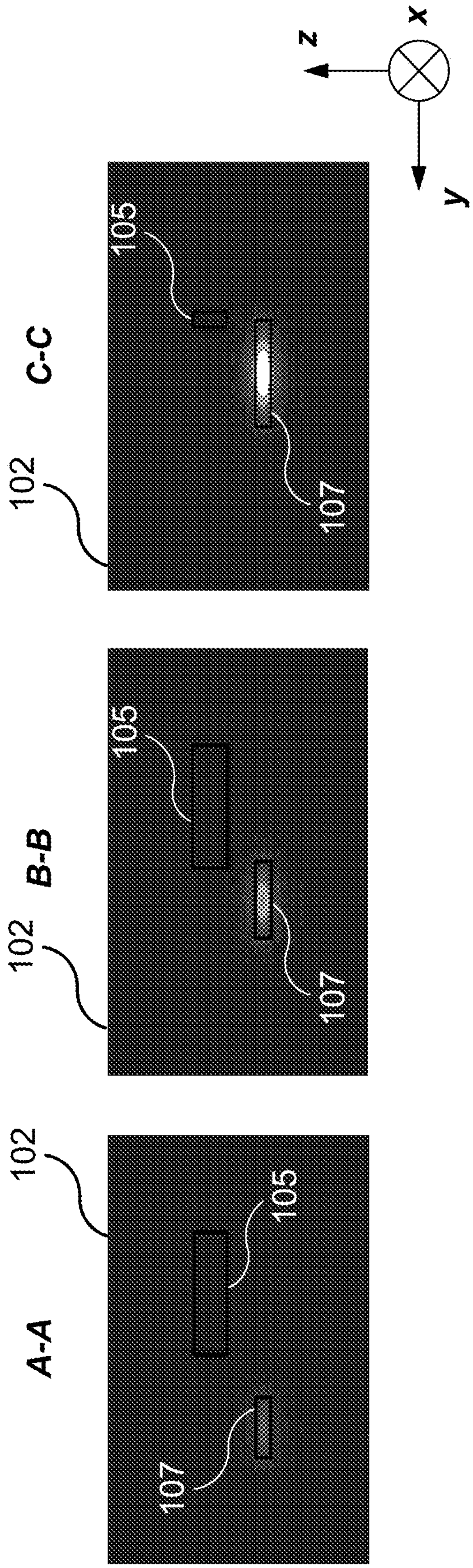


FIG. 6

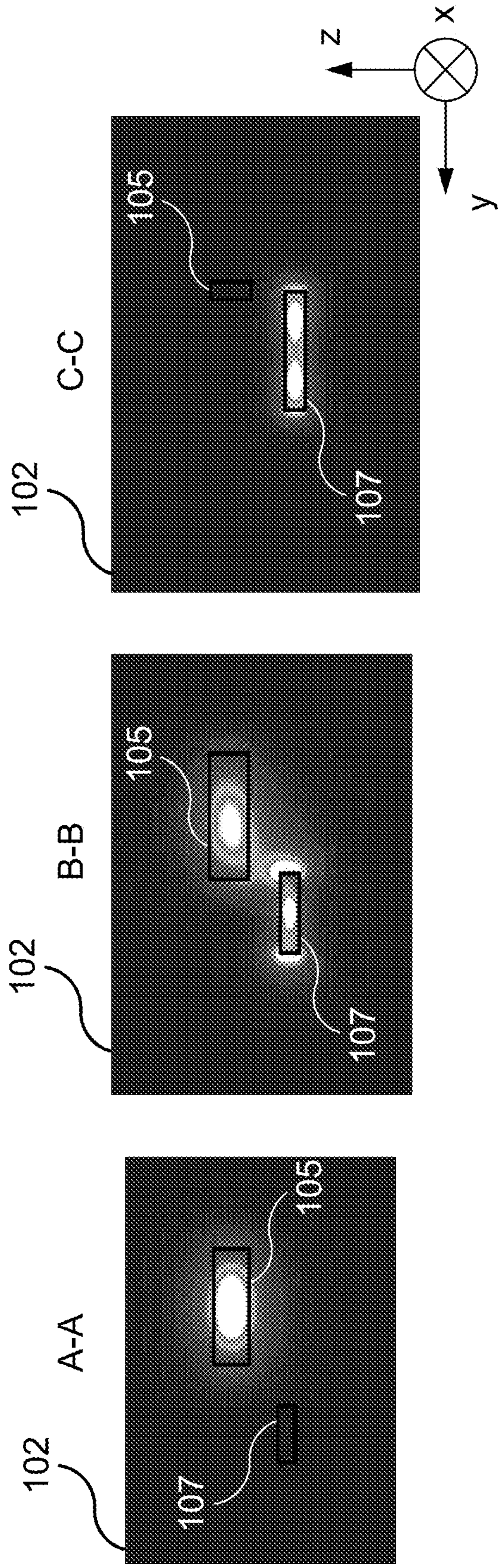


FIG. 7

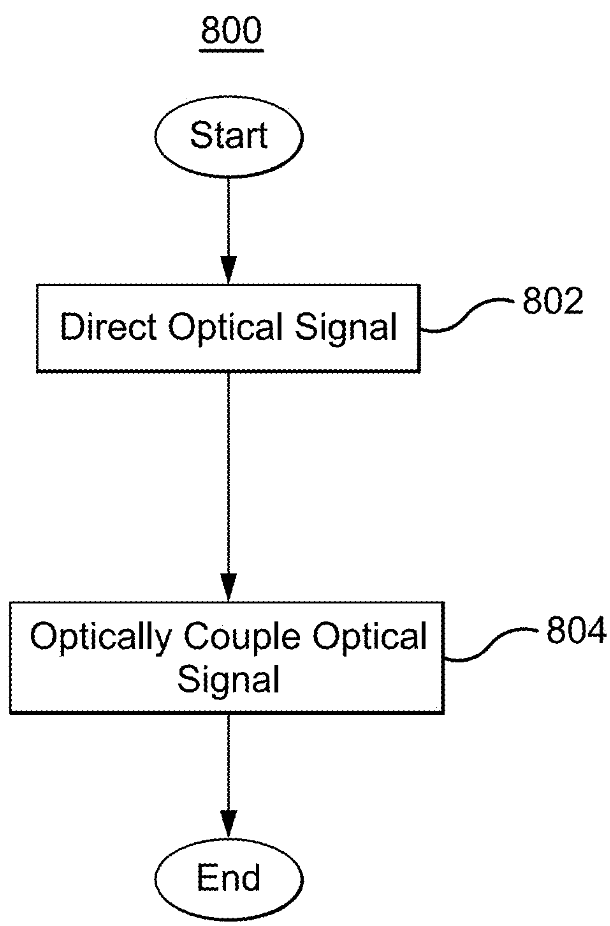

800
Start
Direct Optical Signal
802
Optically Couple Optical Signal
804
End

FIG. 8

BI-MATERIAL MODE MULTIPLEXER

TECHNICAL FIELD

[0001] Embodiments presented in this disclosure generally relate to optical communications. More specifically, embodiments disclosed herein relate to a mode multiplexer.

BACKGROUND

[0002] Optical systems may use mode multiplexers to combine different optical signals onto a single waveguide. For example, the mode multiplexers may combine optical signals on separate optical waveguides onto a multimode optical waveguide. The optical signals may then propagate through the multimode optical waveguide with different modes. For the mode multiplexer to work properly, there should be low modal crosstalk between the optical signals. Existing mode multiplexers reduce the modal crosstalk by increasing the length of the mode multiplexers, which increases the size and cost of the mode multiplexers. For example, some mode multiplexers may be 200 to 400 micrometers (μm) in length.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate typical embodiments and are therefore not to be considered limiting; other equally effective embodiments are contemplated.

[0004] FIG. **1** illustrates an example system.

[0005] FIG. **2** illustrates an example mode multiplexer in the system of FIG. **1**.

[0006] FIG. **3** illustrates an example cross-section of a mode multiplexer in the system of FIG. **1**.

[0007] FIG. **4** illustrates an example cross-section of a mode multiplexer in the system of FIG. **1**.

[0008] FIG. **5** illustrates an example cross-section of a mode multiplexer in the system of FIG. **1**.

[0009] FIG. **6** illustrates example cross-sections of a mode multiplexer in the system of FIG. **1**.

[0010] FIG. **7** illustrates example cross-sections of a mode multiplexer in the system of FIG. **1**.

[0011] FIG. **8** is a flowchart of an example method performed by the system of FIG. **1**.

[0012] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially used in other embodiments without specific recitation.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0013] The present disclosure describes a mode multiplexer with layered optical waveguides formed using different materials. According to an embodiment, a mode multiplexer includes a first optical waveguide and a second optical waveguide. The first optical waveguide includes a first end and a second end. The first end is wider than the second end. The second optical waveguide includes a third end. The second optical waveguide has a higher index of refraction than the first optical waveguide. The first optical waveguide and the second optical waveguide are arranged such that when the first optical waveguide and the second optical waveguide are viewed along a first axis: a length of the first optical waveguide and a length of the second optical waveguide extend along a second axis orthogonal to the first axis, the first end is non-overlapping with the third end, and the second optical waveguide partially overlaps the second end.

[0014] According to another embodiment, a method includes directing an optical signal in a first optical waveguide comprising a first end and a second end. The first end is wider than the second end. The method also includes optically coupling the optical signal into a second optical waveguide comprising a third end. The second optical waveguide has a higher index of refraction than the first optical waveguide. The first optical waveguide and the second optical waveguide are arranged such that when the first optical waveguide and the second optical waveguide are viewed along a first axis: a length of the first optical waveguide and a length of the second optical waveguide extend along a second axis orthogonal to the first axis, the first end is non-overlapping with the third end, and the second optical waveguide partially overlaps the second end.

[0015] According to another embodiment, a mode multiplexer includes a silicon nitride waveguide and a silicon waveguide. The silicon nitride waveguide includes a first end and a second end. The first end is wider than the second end. The silicon nitride waveguide and the silicon waveguide are arranged such that an optical signal propagating from the first end towards the second end in the silicon nitride waveguide optically couples into the silicon waveguide. A width of the second end prevents the optical signal from propagating to the second end.

EXAMPLE EMBODIMENTS

[0016] The present disclosure describes a mode multiplexer with layered optical waveguides formed using different materials. For example, the mode multiplexer may include a first optical waveguide and a second optical waveguide positioned in a lower layer than the first optical waveguide. The first optical waveguide and the second optical waveguide may have different indexes of refraction. The first and second optical waveguides may gradually overlap along the lengths of the first and second optical waveguides. The first optical waveguide may taper such that the first optical waveguide does not support the mode of an optical signal at the output of the first optical waveguide. The second optical waveguide may widen such that the second optical waveguide supports multiple modes at the output of the second optical waveguide. An optical signal propagating through the first optical waveguide may optically couple into the second optical waveguide as the first optical waveguide and the second optical waveguide begin to gradually overlap.

[0017] In certain embodiments, the mode multiplexer presents several technical advantages. For example, because the first optical waveguide and the second optical waveguide have different indexes of refraction, the mode multiplexer reduces modal crosstalk relative to existing mode multiplexers. As a result, the mode multiplexer may be more compact (e.g., 60 μm in length) relative to existing mode multiplexers. In some tests, the mode multiplexer provides less than −36 dB of loss or crosstalk at 1310 nanometers (nm) for devices longer than 40 μm. For a 60 μm device, loss or crosstalk may be low across an entire 1260 to 1340 nm wavelength band.

[0018] FIG. **1** illustrates an example system **100**. The system **100** may be an optical circuit or device (e.g., a portion of an optical transceiver). As seen in FIG. **1**, the system **100** includes a mode multiplexer **102**. Generally, the mode multiplexer **102** combines one or more optical signals onto a single optical waveguide.

[0019] The mode multiplexer **102** receives an optical signal **104** over a waveguide **105** and an optical signal **106** over a waveguide **107**. The mode multiplexer **102** then combines and outputs the optical signals **104** and **106** over a single waveguide. For example, the mode multiplexer **102** may combine the optical signals over the waveguide **107** by optically coupling the optical signal **104** to the waveguide **107**. The mode multiplexer **102** then outputs the optical signals **104** and **106** over the waveguide **107**. The optical signals **104** and **106** may have different modes over the waveguide **107**. For example, the optical signal **104** may have a single lobe mode, and the optical signal **106** may have a two lobe mode. The waveguide **107** may support multiple modes. Additionally, the waveguides **105** and **107** may be formed using different materials that have different indexes of refraction, which reduces modal crosstalk while reducing the length of the mode multiplexer **102** relative to existing mode multiplexers. In certain embodiments, the mode multiplexer **102** may reduce modal crosstalk relative to existing mode multiplexers while having a length around 60 μm.

[0020] FIGS. **2** through **5** illustrate a design of the mode multiplexer **102**. Although FIGS. **2** through **5** show the mode multiplexer **102** including two optical waveguides **105** and **17**, the mode multiplexer **102** may include any number of optical waveguides, and the mode multiplexer **102** may combine any number of optical signals over the optical waveguides onto a single waveguide. Generally, the shapes and arrangement of the optical waveguides in the mode multiplexer **102** allow optical signals in one optical waveguide **105** to optically couple into the other optical waveguide **107**.

[0021] The mode multiplexer **102** will be described using the x, y, and z axes shown in FIG. **2**. These axes are orthogonal to each other and will establish the orientation of the components of the mode multiplexer **102**. In the example of FIG. **2**, the x axis extends towards the right, the y axis extends upwards, and the z axis extends out of the page. FIG. **2** shows the mode multiplexer **102** when viewed along the z axis.

[0022] As seen in FIG. **2**, the mode multiplexer **102** includes the waveguide **105** and the waveguide **107**. The waveguide **105** includes an end **202** and an end **204** opposite the end **202**. The waveguide **107** includes an end **206** and an end **208** opposite the end **206**. Additionally, the waveguide **105** has a length **210**, and the waveguide **107** has a length **212**. The waveguides **105** and **107** are arranged such that the lengths **210** and **212** extend along the x axis.

[0023] The waveguide **105** and the waveguide **107** may be made using different materials such that the waveguides **105** and **107** have different indexes of refraction. For example, the waveguide **105** may be formed using silicon nitride, and the waveguide **107** may be formed using silicon. The different indexes of refraction may reduce modal crosstalk between the waveguides **105** and **107**.

[0024] An optical signal may be input into the waveguide **105** at the end **202**. The waveguide **105** may then direct the optical signal towards the end **204**. Both the waveguides **105** and **107** may be wide enough to support a single mode at the ends **202** and **206**. As seen in FIG. **2**, the waveguide **105** tapers from the end **202** to the end **204**. Specifically, the waveguide **105** narrows such that the end **202** is wider than the end **204** along the y axis. In some embodiments, the waveguide **105** narrows such that the end **204** does not support any modes of an optical signal, which may prevent an optical signal from propagating to the end **204**. Likewise, the waveguide **107** receives an optical signal at the end **206** and directs the optical signal towards the end **208**. The waveguide **107**, however, widens such that the end **208** is wider than the end **206** along the y axis. In some embodiments, the waveguide **107** widens such that the end **208** supports multiple modes.

[0025] The waveguides **105** and **107** are arranged such that the waveguides **105** and **107** gradually overlap with each other along the lengths **210** and **212**. Specifically, the waveguides **105** and **107** may be positioned at different heights along the z axis. For example, the waveguide **105** may be positioned higher than the waveguide **107** along the z axis. When viewed along the z axis, the end **202** is non-overlapping with the end **206**. Stated differently, the end **202** does not have the same coordinates on the y axis or the z axis as the end **206**. In some embodiments, the end **202** is aligned with the end **206** even though the ends **202** and **206** are non-overlapping. For example, the end **202** shares the same coordinates on the x axis as the end **206**, and the end **202** does not share the same coordinates on the y axis as the end **206**.

[0026] Additionally, when viewed along the z axis, the end **204** partially overlaps the end **208**. Portions of the waveguide **105** also overlap portions of the waveguide **107** moving along the lengths **210** and **212** towards the ends **204** and **208**. Stated differently, these overlapping portions, including the ends **204** and **208**, share the same coordinates on the y axis. This partial overlap may be gradual, and may be referred to as an adiabatic overlap. In some embodiments, the ends **204** and **208** are aligned. Stated differently, the end **204** shares the same coordinates on the x axis as the end **206**.

[0027] As an optical signal is directed through the waveguide **105** from the end **202** towards the end **204**, the optical signal may optically couple into the waveguide **107**. None of the optical signal may remain in the waveguide **105** near the end **204** (e.g., because the waveguide **105** tapers such that the end **204** does not support any mode of an optical signal). As a result, the mode multiplexer **102** optically couples an optical signal in the waveguide **105** into the waveguide **107**. The mode multiplexer **102** then outputs the optical signal at the end **208** of the waveguide **107**.

[0028] As an example, the waveguide **105** may be a low index waveguide formed using silicon nitride. An optical signal may be input at the end **202** of the waveguide **105** in the first transverse electric (TE_0) mode. The waveguide **107** may be a higher index, multimode waveguide formed using silicon. The gradual overlap of the waveguides **105** and **107** may cause the optical signal to adiabatically transfer from the waveguide **105** to the waveguide **107** in the second transverse electric (TE_1) mode. The optical signal may then be output at the end **208** of the waveguide **107**. In this manner, the mode multiplexer **102** provides low modal crosstalk due to the effective indices of TE_0 and TE_1 are different when the multiplexing occurs. Additionally, using silicon in the multiplexing process provides for a more compact device (e.g., 60 μm in length).

[0029] FIG. **3** illustrates a cross-sectional view of the mode multiplexer **102**. Specifically, FIG. **3** shows the cross-section labeled as A-A in FIG. **2**, which is near the ends **202** and **206** of the waveguides **105** and **107**. As seen in FIG. **3**, the waveguides **105** and **107** are positioned according to the x, y, and z axes. The waveguide **105** is positioned higher than the waveguide **107** along the z axis. Additionally, the waveguides **105** and **107** are non-overlapping when viewed along the z axis. Specifically, the waveguides **105** and **107** do not share the same coordinates along the y axis. Furthermore, the waveguide **105** is wider than the waveguide **107** along the y axis.

[0030] FIG. **4** shows a cross-sectional view of the mode multiplexer **102** at the cross-section labeled B-B in FIG. **2**, which is around the middle of the waveguides **105** and **107** (or between the ends **202** and **204** and the ends **206** and **208**). As seen in FIG. **4**, the waveguides **105** and **107** are positioned according to the x, y, and z axes. The waveguide **105** is positioned higher than the waveguide **107** along the z axis. Additionally, the waveguides **105** and **107** partially overlap each other when viewed along the z axis. Specifically, portions of the waveguides **105** and **107** have the same coordinate on the y axis. Because of this partial overlap, an optical signal in the waveguide **107** may optically couple into the waveguide **105** near the cross-section B-B.

[0031] FIG. **5** shows a cross-sectional view of the mode multiplexer **102** at the cross-section labeled C-C in FIG. **2**, which is near the ends **204** and **208** of the waveguides **105** and **107**. As seen in FIG. **5**, the waveguides **105** and **107** are positioned according to the x, y, and z axes. The waveguide **105** is positioned higher than the waveguide **107** along the z axis. Additionally, the waveguides **105** and **107** partially overlap each other when viewed along the z axis. Specifically, portions of the waveguides **105** and **107** have the same coordinates on the y axis.

[0032] Furthermore, the widths of the waveguides **105** and **107** along the y axis have changed from the other cross-sectional views. For example, in FIG. **5**, the waveguide **107** is wider than the waveguide **105** along the y axis. In the cross-sectional view A-A shown in FIG. **3**, the waveguide **105** is wider than the waveguide **107** along the y axis. Stated differently, along the lengths **210** and **212** of the waveguides **105** and **107**, the waveguide **105** has tapered and narrowed such that the width of the waveguide **105** along the y axis reduces along the length **210** of the waveguide **105**. The width of the waveguide **107** increases along the length **212** of the waveguide **107**. In some embodiments, the waveguide **105** tapers or narrows such that the narrow end **204** of the waveguide **105** does not support any modes of an optical signal. As a result, an optical signal directed through the waveguide **105** may optically couple completely into the waveguide **107** such that none of the optical signal remains in the waveguide **105** near the end **204** of the waveguide **105**.

[0033] FIG. **6** shows cross-sectional views of the mode multiplexer **102**. Specifically, FIG. **6** shows the cross-sectional views A-A, B-B, and C-C as an optical signal is directed through the waveguide **107**. The waveguides **105** and **107** are positioned according to the x, y, and z axes.

[0034] The cross-section A-A shows the waveguides **105** and **107** near the ends **202** and **206** of the waveguides **105** and **107**. As seen in the cross-sectional view A-A, the waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides **105** and **107** are non-overlapping when viewed along the z axis (e.g., the waveguides **105** and **107** do not share the same coordinates on the y axis). An optical signal is input into the waveguide **107**.

[0035] The cross-section B-B shows the waveguides **105** and **107** around the middle (or somewhere between the ends **202** and **204** and the ends **206** and **208**) of the waveguides **105** and **107**. As seen in the cross-section B-B, the waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides **105** and **107** partially overlap each other when viewed along the z axis (e.g., portions of the waveguides **105** and **107** share the same coordinates on the y axis). The optical signal continues to be directed through the waveguide **107**.

[0036] The cross-section C-C shows the waveguides **105** and **107** near the ends **204** and **208** of the waveguides **105** and **107**. As seen in the cross-section C-C, the waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides **105** and **107** partially overlap each other when viewed along the z axis (e.g., portions of the waveguides **105** and **107** share the same coordinates on the y axis). Furthermore the optical signal continues to be directed through the waveguide **107**.

[0037] As shown in FIG. **6**, the mode multiplexer **102** directs the optical signal input to the waveguide **107** through the waveguide **107**. The optical signal may have a single mode, and the waveguide **107** may maintain that single mode as the optical signal is directed through the waveguide **107**.

[0038] FIG. **7** illustrates cross-sectional views of the mode multiplexer **102**. Specifically, FIG. **7** shows the cross-sections A-A, B-B, and C-C as an optical signal is directed into the waveguide **105**. As seen in FIG. **7**, the waveguides **105** and **107** are positioned according to the x, y, and z axes.

[0039] The cross-section A-A shows the waveguides **105** and **107** near the ends **202** and **206** of the waveguides **105** and **107**. The waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides **105** and **107** do not overlap each other when viewed along the z axis (e.g., the waveguides **105** and **107** do not share the same coordinates on the y axis). An optical signal is input into the waveguide **105**. As seen in FIG. **7**, the optical signal has a single lobe when input into the waveguide **105**.

[0040] The cross-section B-B shows the waveguides **105** and **107** near the middle (or somewhere between the ends **202** and **204** and the ends **206** and **208**) of the waveguides **105** and **107**. The waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides **105** and **107** partially overlap each other when viewed along the z axis (e.g., portions of the waveguides **105** and **107** share the same coordinates on the y axis). The optical signal optically couples into the waveguide **107**. As a result, portions of the optical signal remain in the waveguide **105**, and portions of the optical signal couple into the waveguide **107**.

[0041] The cross-section C-C shows the waveguides **105** and **107** near the ends **204** and **208** of the waveguides **105** and **107**. The waveguide **105** is positioned higher than the waveguide **107** on the z axis. Additionally, the waveguides

105 and **107** partially overlap each other when viewed along the z axis (e.g., portions of the waveguides **105** and **107** share the same coordinates on the y axis). The optical signal has optically coupled into the waveguide **107**. The waveguide **105** has narrowed or tapered such that the waveguide **105** does not support any optical modes of the optical signal. As a result, the optical signal is fully contained in the waveguide **107**. As seen in FIG. **7**, when the optical signal is fully coupled into the waveguide **107**, the optical signal has a two lobe mode in the waveguide **107**. The mode multiplexer **102** then outputs the optical signal on the waveguide **107** with the two lobe mode. In this manner, the mode multiplexer **102** optically couples the optical signal in the waveguide **105** to the waveguide **107**.

[0042] FIG. **8** is a flowchart of an example method **800** performed by the system **100** of FIG. **1**. In particular embodiments, the mode multiplexer **102** performs the method **800**. By performing the method **800**, the mode multiplexer **102** reduces modal crosstalk and the length of the mode multiplexer **102** relative to existing mode multiplexers.

[0043] In block **802**, the mode multiplexer **102** directs an optical signal through the waveguide **105**. In block **804**, the mode multiplexer **102** optically couples the optical signal in the waveguide **105** into the waveguide **107**. The mode multiplexer **102** may then output the optical signal on the waveguide **107**.

[0044] The waveguides **105** and **107** may be formed using different materials with different indexes of refraction. For example, the waveguide **105** may be formed using silicon nitride, and the waveguide **107** may be formed using silicon. Additionally, the waveguides **105** and **107** may be positioned such that the waveguides **105** and **107** gradually overlap each other along the lengths **210** and **212** of the waveguides **105** and **107**. For example, at an end **202** where the optical signal was input into the waveguide **105**, the waveguides **105** and **107** may not overlap each other when viewed along an axis. At an end **208** of the waveguide **107** where the optical signal is output, the waveguides **105** and **107** may partially overlap each other. The partial overlap of the waveguides **105** and **107** allows the optical signal to optically couple from the waveguide **105** into the waveguide **107**.

[0045] Additionally, the widths of the waveguides **105** and **107** may change along the lengths **210** and **212** of the waveguides **105** and **107**. For example, the waveguide **105** may taper or narrow moving from the end of **202** of the waveguide **105** towards an end **204** of the waveguide **105**. The width of the waveguide **105** may narrow or taper such that the end **204** of the waveguide **105** does not support modes of an optical signal. As a result, an optical signal in the waveguide **105** fully couples into the waveguide **107** and does not remain in the waveguide **105** near the end **204** of the waveguide **105**. As another example, the waveguide **107** may widen along the length **212** of the waveguide **107** moving from an end **206** of the waveguide **107** towards the end **208** of the waveguide **107**. As a result of the wider end **208** of the waveguide **107**, the waveguide **107** may support multiple modes of optical signals. Thus, an optical signal input into the waveguide **105** may have a single mode, but after that optical signal couples into the waveguide **107**, the optical signal may have a two lobe mode in the waveguide **107**.

[0046] In some embodiments, due to the different indexes of refraction of the waveguides **105** and **107** and the positioning and arrangement of the waveguides **105** and **107**, the mode multiplexer **102** reduces modal crosstalk and the length of the mode multiplexer **102** relative to existing mode multiplexers. For example, the mode multiplexer **102** may provide the same or reduced modal crosstalk while having a length of around 60 μm as existing mode multiplexers with lengths of 200 to 400 μm.

[0047] In summary, the mode multiplexer **102** includes layered optical waveguides **105** and **107** formed using different materials. For example, the mode multiplexer **102** may include a first optical waveguide **105** and a second optical waveguide **107** positioned in a lower layer than the first optical waveguide **105**. The first optical waveguide **105** and the second optical waveguide **107** may have different indexes of refraction. The first and second optical waveguides **105** and **107** may gradually overlap along the lengths **210** and **212** of the first and second optical waveguides **105** and **107**. The first optical waveguide **105** may taper such that the first optical waveguide **105** does not support the mode of an optical signal at the output of the first optical waveguide **105**. The second optical waveguide **107** may widen such that the second optical waveguide **107** supports multiple modes at the output of the second optical waveguide **107**. An optical signal propagating through the first optical waveguide **105** may optically couple into the second optical waveguide **107** as the first optical waveguide **105** and the second optical waveguide **107** begin to gradually overlap.

[0048] In the current disclosure, reference is made to various embodiments. However, the scope of the present disclosure is not limited to specific described embodiments. Instead, any combination of the described features and elements, whether related to different embodiments or not, is contemplated to implement and practice contemplated embodiments. Additionally, when elements of the embodiments are described in the form of "at least one of A and B," or "at least one of A or B," it will be understood that embodiments including element A exclusively, including element B exclusively, and including element A and B are each contemplated. Furthermore, although some embodiments disclosed herein may achieve advantages over other possible solutions or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the scope of the present disclosure. Thus, the aspects, features, embodiments and advantages disclosed herein are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the invention" shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

[0049] In view of the foregoing, the scope of the present disclosure is determined by the claims that follow.

We claim:

1. A mode multiplexer comprising:

a first optical waveguide comprising a first end and a second end, wherein the first end is wider than the second end; and

a second optical waveguide comprising a third end, wherein the second optical waveguide has a higher index of refraction than the first optical waveguide, wherein the first optical waveguide and the second optical waveguide are arranged such that when the first optical waveguide and the second optical waveguide are viewed along a first axis:

a length of the first optical waveguide and a length of the second optical waveguide extend along a second axis orthogonal to the first axis;

the first end is non-overlapping with the third end; and

the second optical waveguide partially overlaps the second end.

2. The mode multiplexer of claim **1**, wherein, when the first optical waveguide and the second optical waveguide are viewed along the first axis, the first end is aligned with the third end.

3. The mode multiplexer of claim **1**, wherein the second optical waveguide comprises a fourth end wider than the third end.

4. The mode multiplexer of claim **3**, wherein, when the first optical waveguide and the second optical waveguide are viewed along the first axis, the second end is aligned with the fourth end.

5. The mode multiplexer of claim **3**, wherein an optical signal in the first optical waveguide optically couples into the second optical waveguide as the optical signal propagates from the first end towards the second end.

6. The mode multiplexer of claim **5**, wherein the optical signal comprises a first mode when the optical signal is in the first optical waveguide, wherein the optical signal comprises a second mode when the optical signal is in the second optical waveguide, and wherein the second mode has more lobes than the first mode.

7. The mode multiplexer of claim **5**, wherein a width of the second end prevents the optical signal from propagating to the second end.

8. The mode multiplexer of claim **1**, wherein the first optical waveguide comprises silicon, and wherein the second optical waveguide comprises silicon nitride.

9. A method comprising:

directing an optical signal in a first optical waveguide comprising a first end and a second end, wherein the first end is wider than the second end; and

optically coupling the optical signal into a second optical waveguide comprising a third end, wherein the second optical waveguide has a higher index of refraction than the first optical waveguide, wherein the first optical waveguide and the second optical waveguide are arranged such that when the first optical waveguide and the second optical waveguide are viewed along a first axis:

a length of the first optical waveguide and a length of the second optical waveguide extend along a second axis orthogonal to the first axis;

the first end is non-overlapping with the third end; and

the second optical waveguide partially overlaps the second end.

10. The method of claim **9**, wherein, when the first optical waveguide and the second optical waveguide are viewed along the first axis, the first end is aligned with the third end.

11. The method of claim **9**, wherein the second optical waveguide comprises a fourth end wider than the third end.

12. The method of claim **11**, wherein, when the first optical waveguide and the second optical waveguide are viewed along the first axis, the second end is aligned with the fourth end.

13. The method of claim **11**, wherein the optical signal in the first optical waveguide optically couples into the second optical waveguide as the optical signal propagates from the first end towards the second end.

14. The method of claim **13**, wherein the optical signal comprises a first mode when the optical signal is in the first optical waveguide, wherein the optical signal comprises a second mode when the optical signal is in the second optical waveguide, and wherein the second mode has more lobes than the first mode.

15. The method of claim **13**, wherein a width of the second end prevents the optical signal from propagating to the second end.

16. The method of claim **9**, wherein the first optical waveguide comprises silicon, and wherein the second optical waveguide comprises silicon nitride.

17. A mode multiplexer comprising:

a silicon nitride waveguide comprising a first end and a second end, wherein the first end is wider than the second end; and

a silicon waveguide, wherein the silicon nitride waveguide and the silicon waveguide are arranged such that an optical signal propagating from the first end towards the second end in the silicon nitride waveguide optically couples into the silicon waveguide, and wherein a width of the second end prevents the optical signal from propagating to the second end.

18. The mode multiplexer of claim **17**, wherein the silicon waveguide comprises a third end and a fourth end wider than the third end.

19. The mode multiplexer of claim **18**, wherein first end is aligned with the third end.

20. The mode multiplexer of claim **17**, wherein the optical signal comprises a first mode when the optical signal is in the silicon nitride waveguide, wherein the optical signal comprises a second mode when the optical signal is in the silicon waveguide, and wherein the second mode has more lobes than the first mode.

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