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(54) **OPTICAL AMPLIFICATION APPARATUS, OPTICAL TRANSMISSION SYSTEM, AND OPTICAL AMPLIFICATION METHOD**

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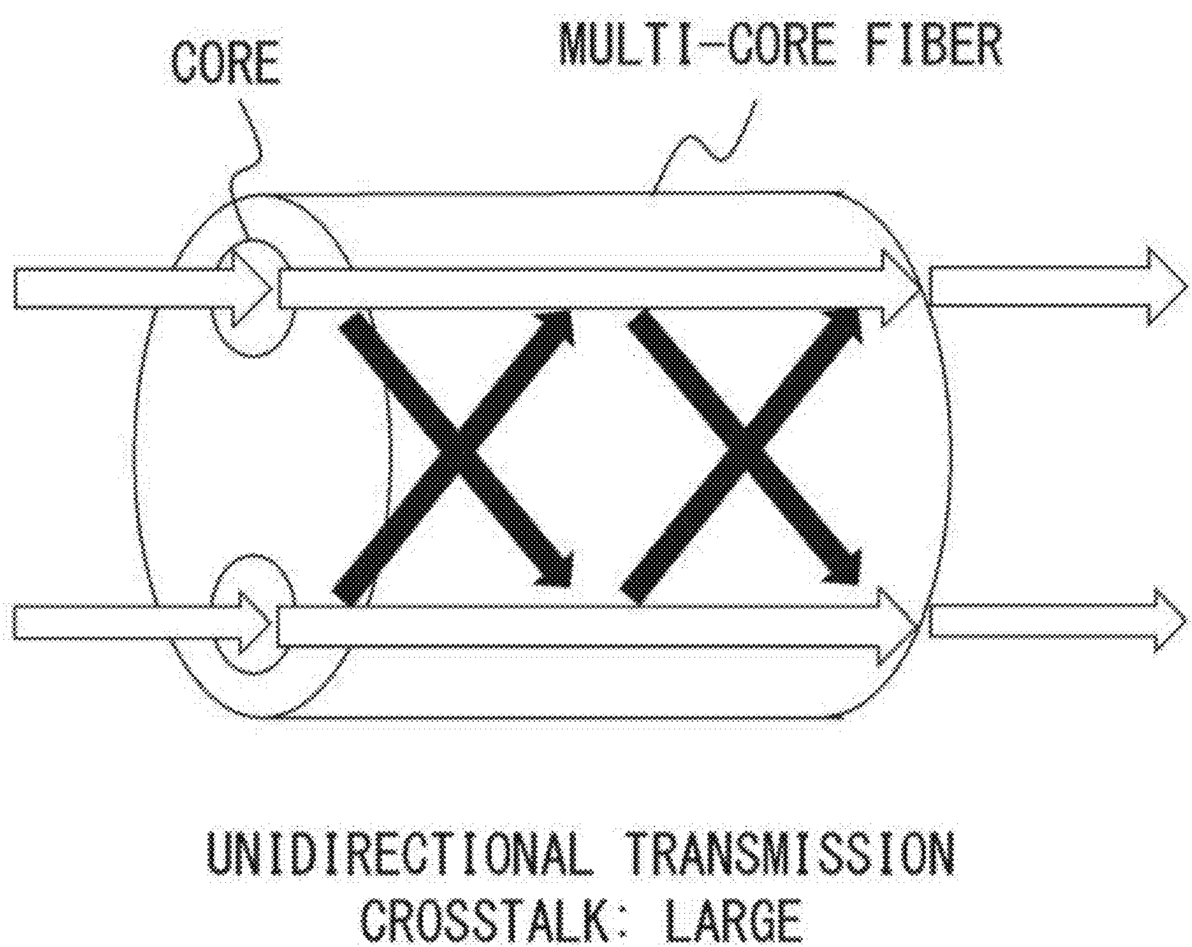
(52) **U.S. Cl.**
CPC ***H01S 3/06716*** (2013.01); ***H01S 3/10023*** (2013.01); ***H04B 10/2589*** (2020.05); ***H04B 10/297*** (2013.01)

(57) **ABSTRACT**

An optical amplification apparatus, an optical transmission system, and an optical amplification method that make it possible to suppress deterioration in signal light quality are provided. An optical amplification apparatus is an optical amplification apparatus connected between a first multi-core fiber and a second multi-core fiber, and includes: a switch configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and an amplifier configured to amplify the signal light being bidirectionally transmitted.



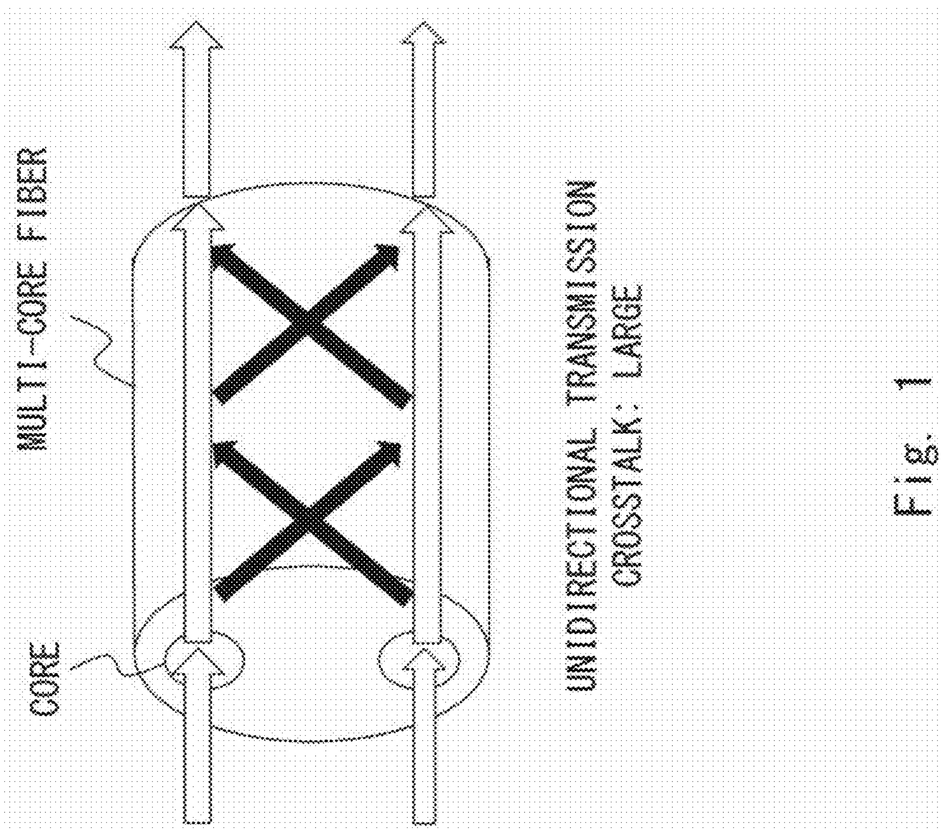

MULTI-CORE FIBER
CORE
UNIDIRECTIONAL TRANSMISSION
CROSSTALK: LARGE

Fig. 1

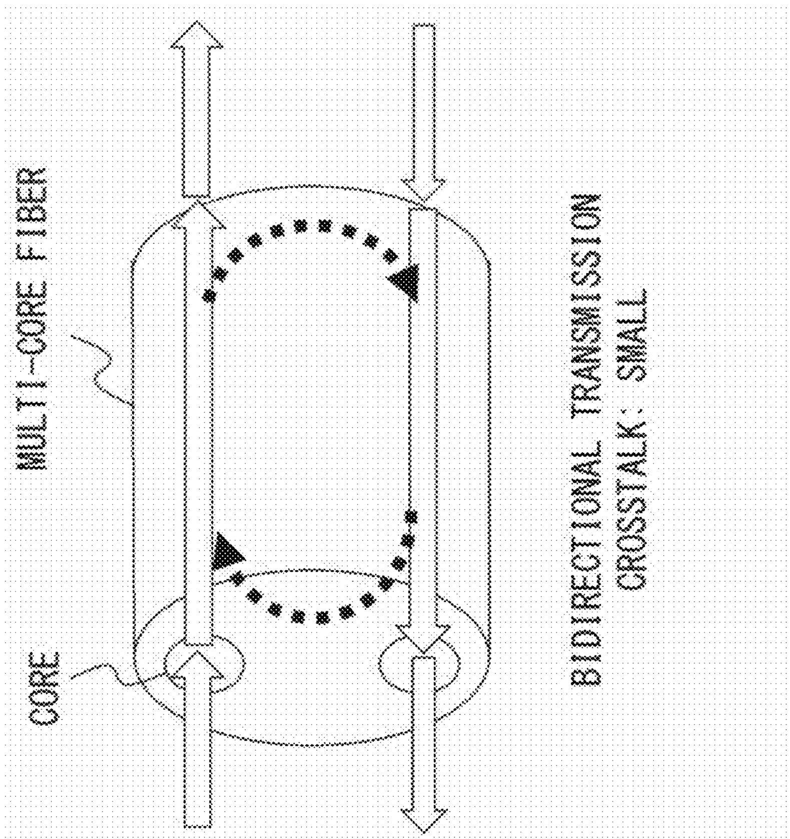

MULTI-CORE FIBER
CORE
BIDIRECTIONAL TRANSMISSION
CROSSTALK: SMALL

Fig. 2

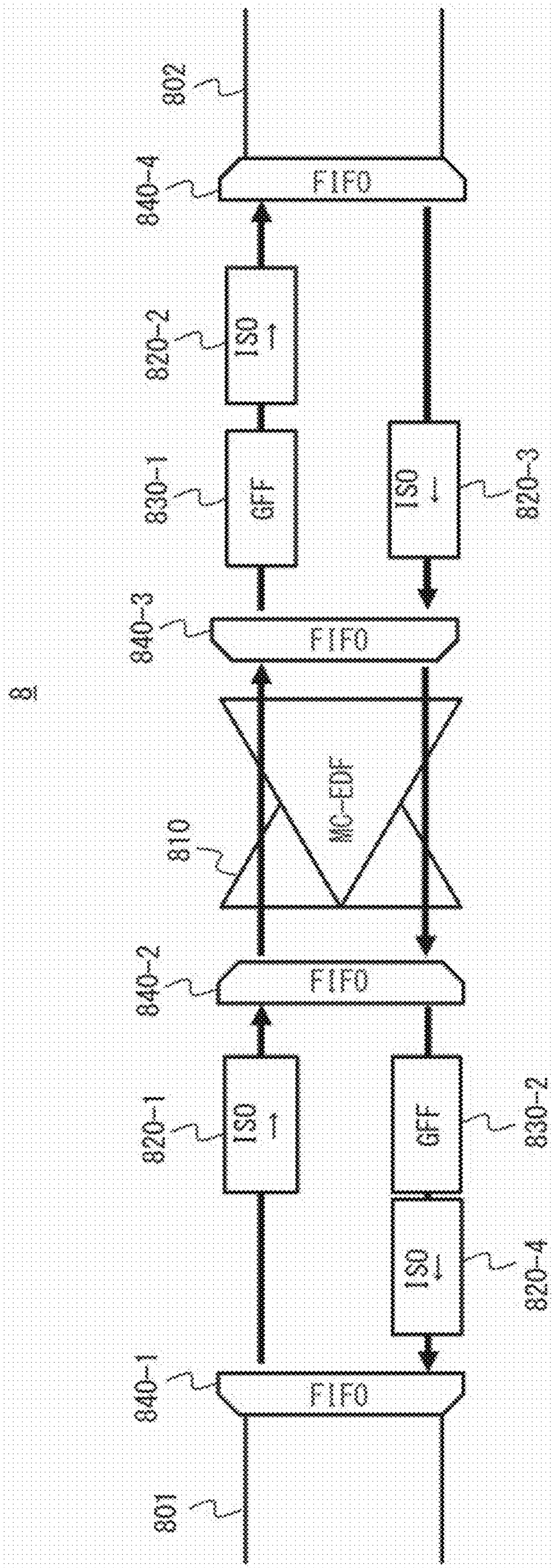

8
802
840-4
FIFO
820-2
ISO
830-1
GFF
820-3
ISO
840-3
FIFO
810
MC-EDF
840-2
FIFO
820-1
ISO
830-2
GFF
820-4
ISO
840-1
FIFO
801

Fig. 3

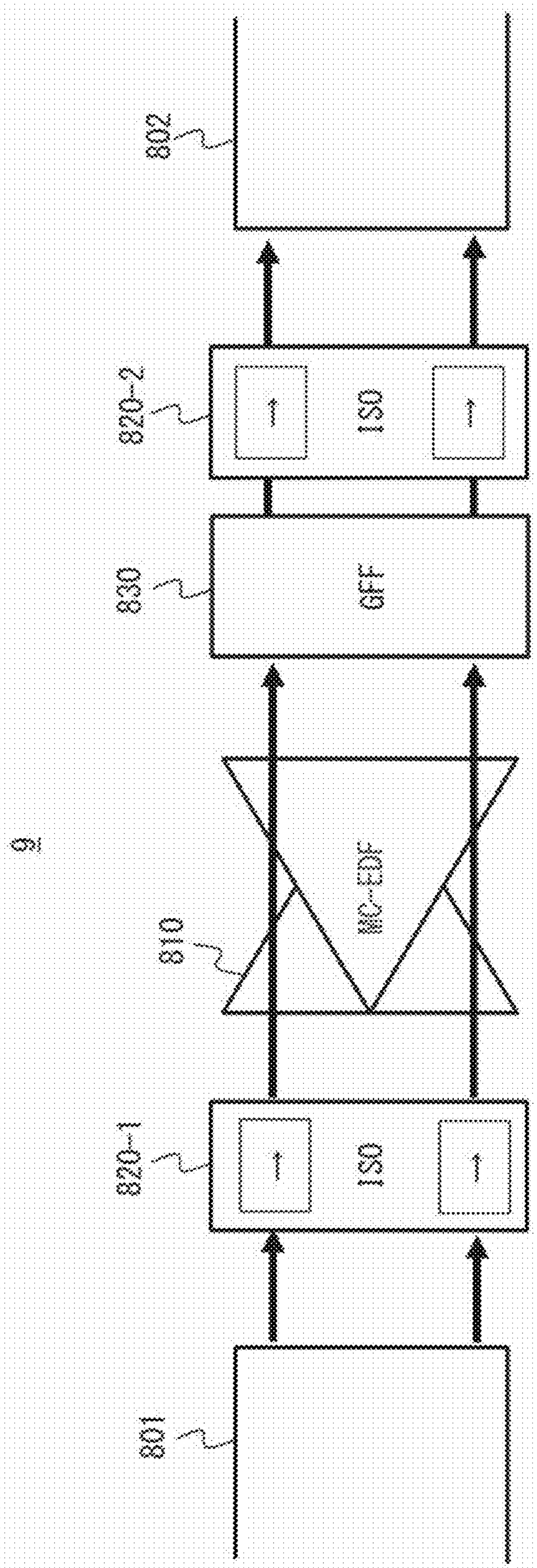


Fig. 4

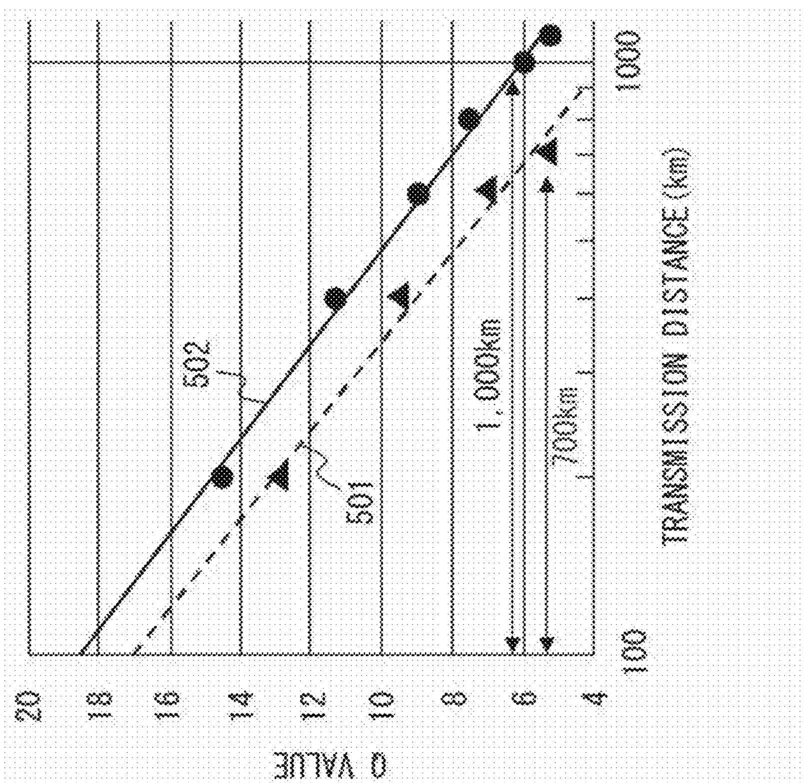

Q VALUE
20
18
16
14
12
10
8
6
4
100
1000
TRANSMISSION DISTANCE (km)
502
501
1,000km
700km

Fig. 5

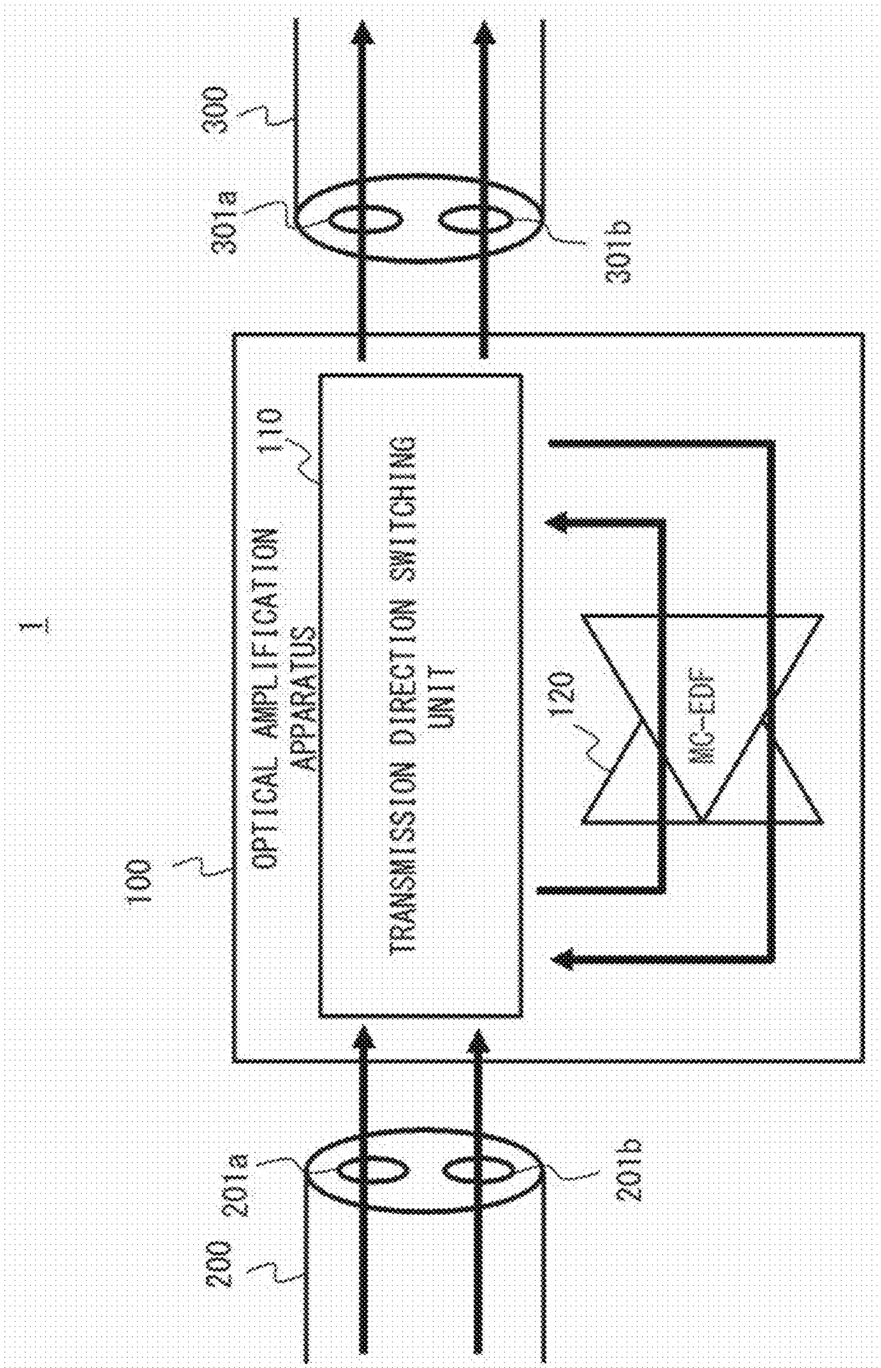

1
100
OPTICAL AMPLIFICATION APPARATUS
110
TRANSMISSION DIRECTION SWITCHING UNIT
120
MC-EDF
200
201a
201b
300
301a
301b

Fig. 6

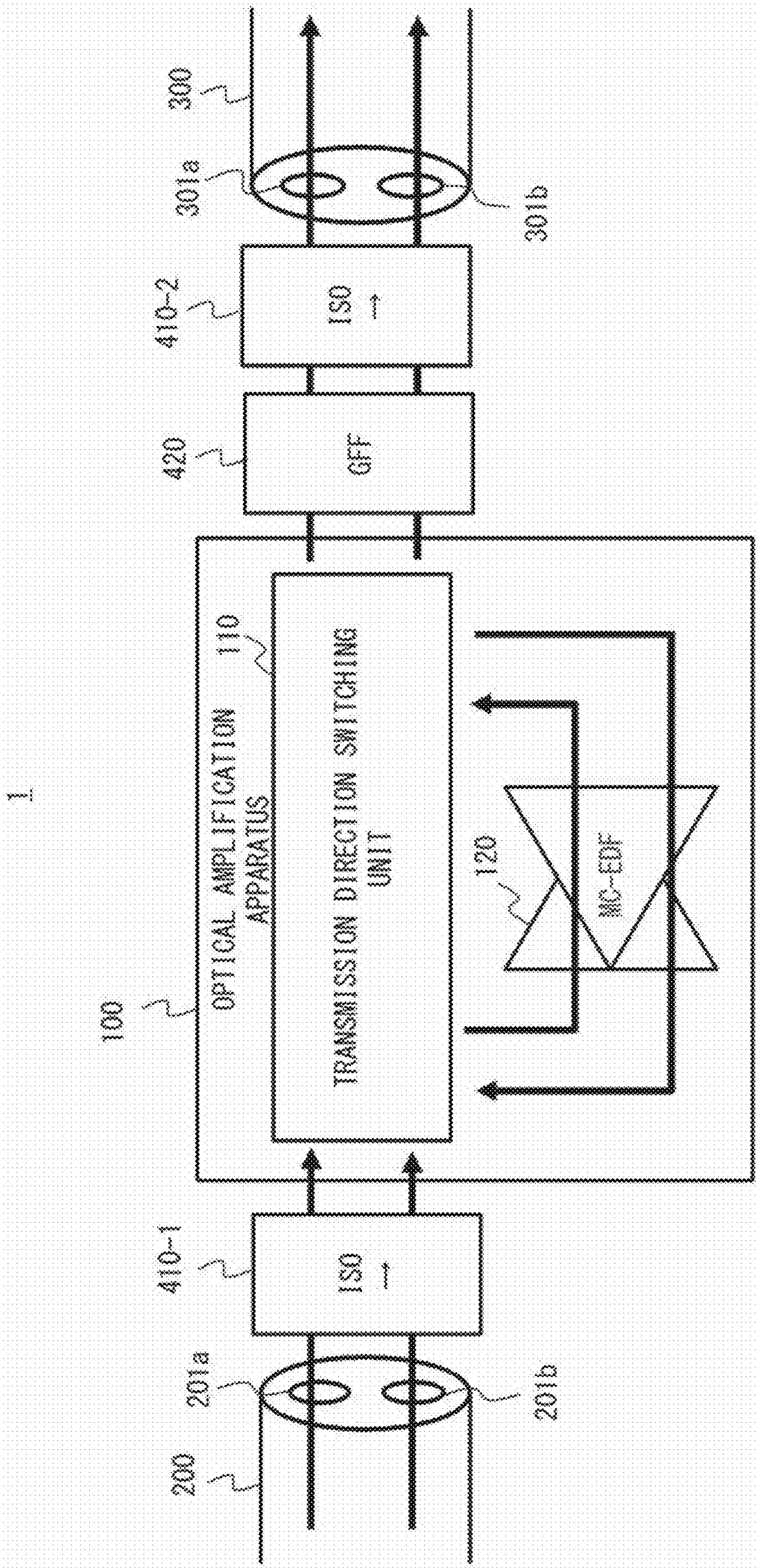

1
100
OPTICAL AMPLIFICATION APPARATUS
110
TRANSMISSION DIRECTION SWITCHING UNIT
120
MC-EDF
200
201a
201b
410-1
ISO
→
420
GFF
410-2
ISO
→
300
301a
301b

Fig. 7

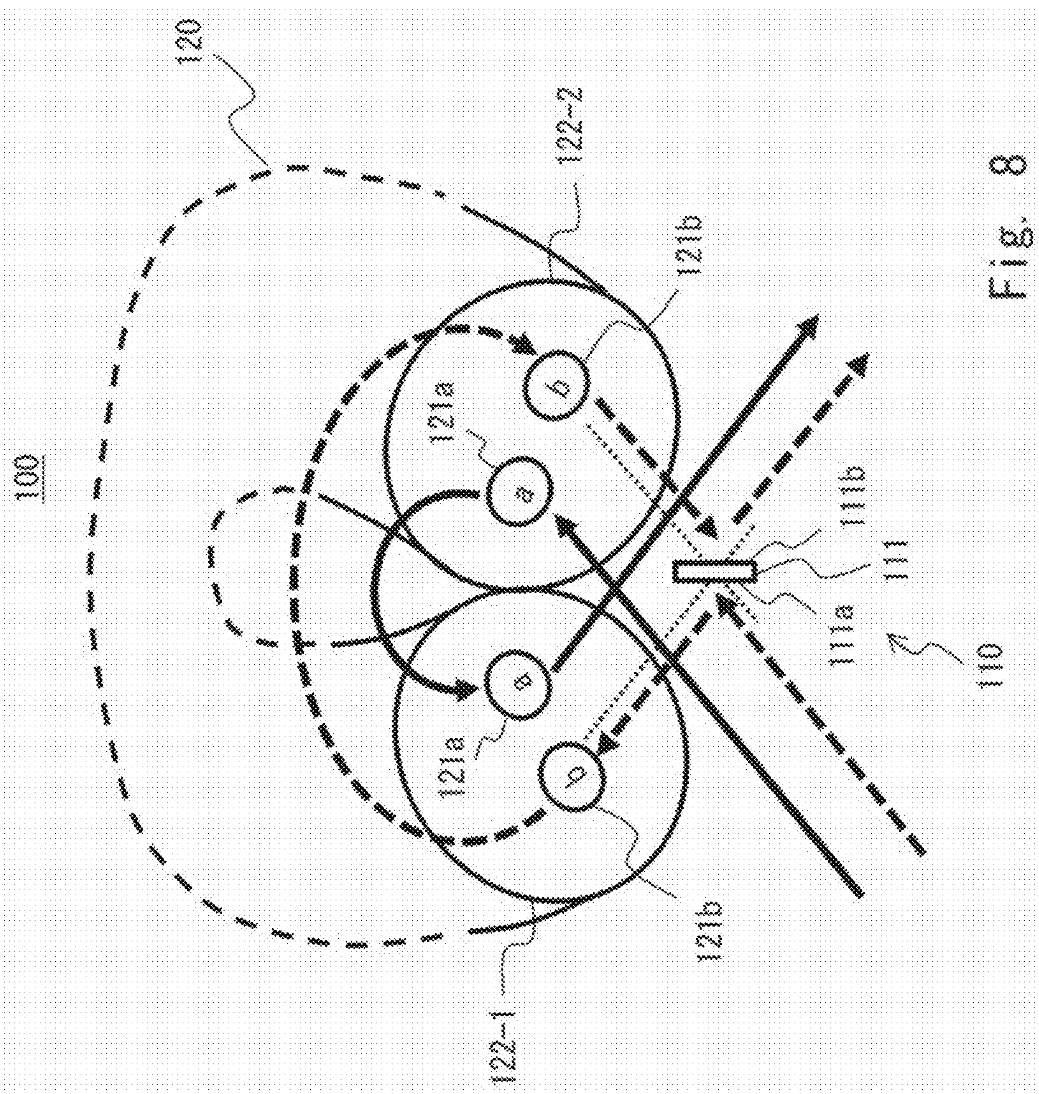


Fig. 8

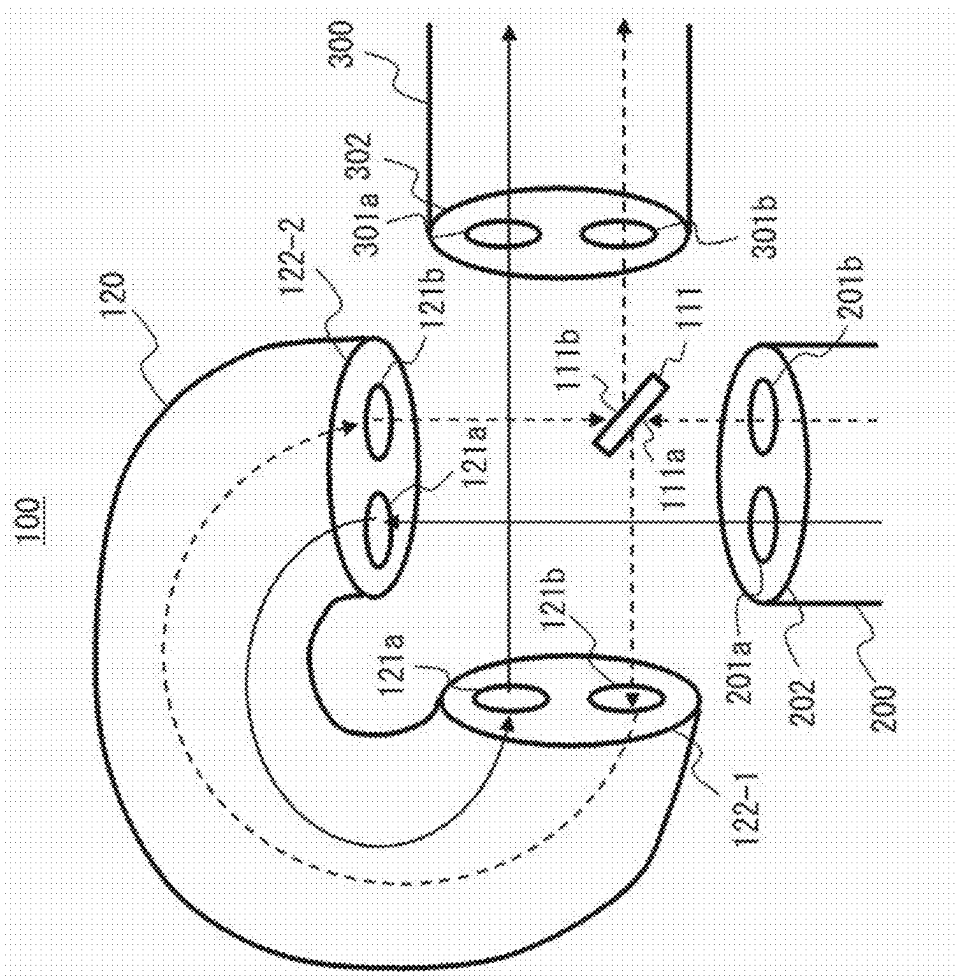

100
120
122-2
121b
121a
111
111b
111a
201b
201a
202
200
300
302
301a
301b
121a
121b
122-1

Fig. 9

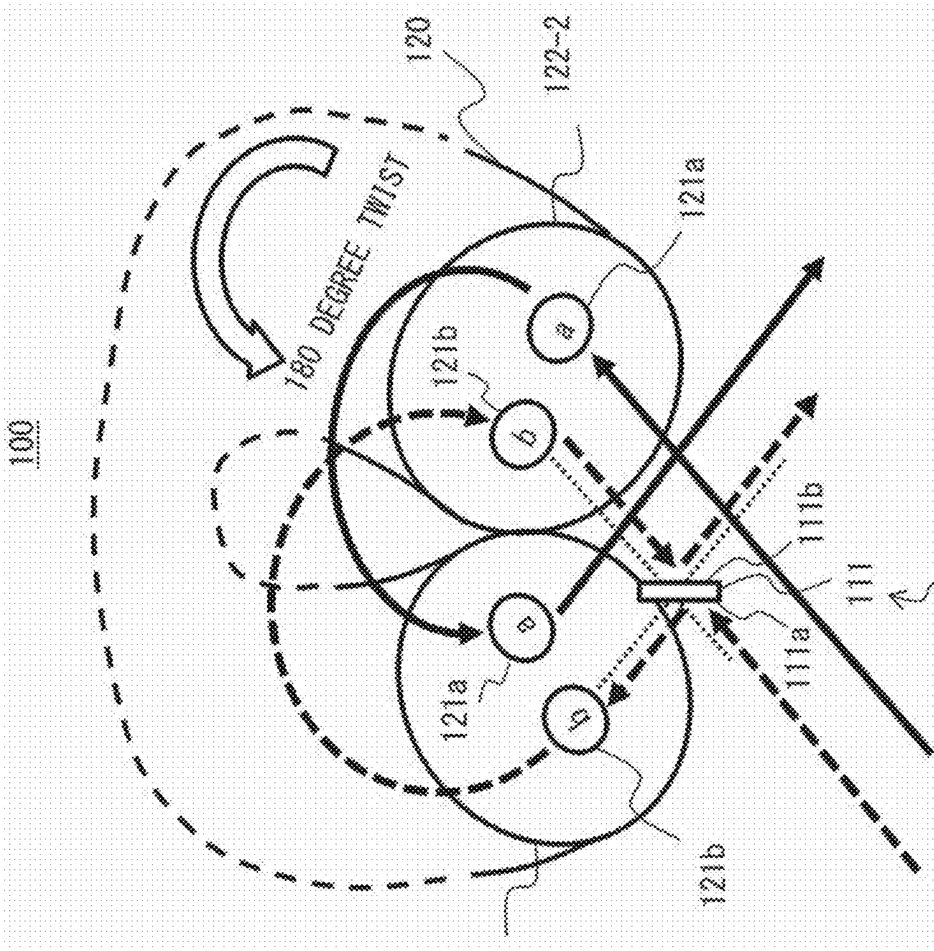

100
120
122-2
121a
121b
180 DEGREE TWIST
a
b
111b
111
110
111a
121a
121b
122-1

Fig. 10

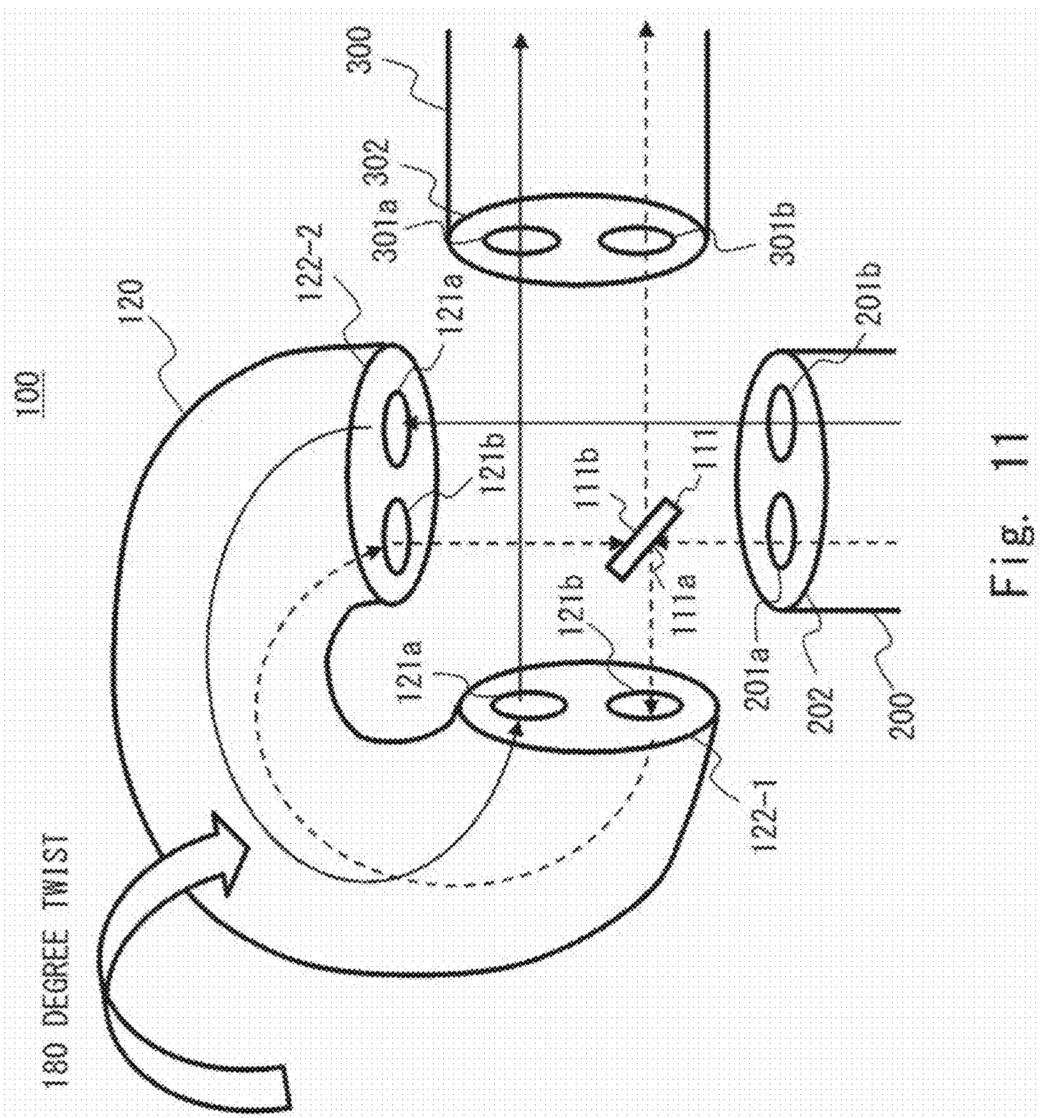

100
180 DEGREE TWIST
120
122-2
121a
121b
111b
111
111a
121b
121a
122-1
201a
202
200
201b
300
302
301a
301b

Fig. 11

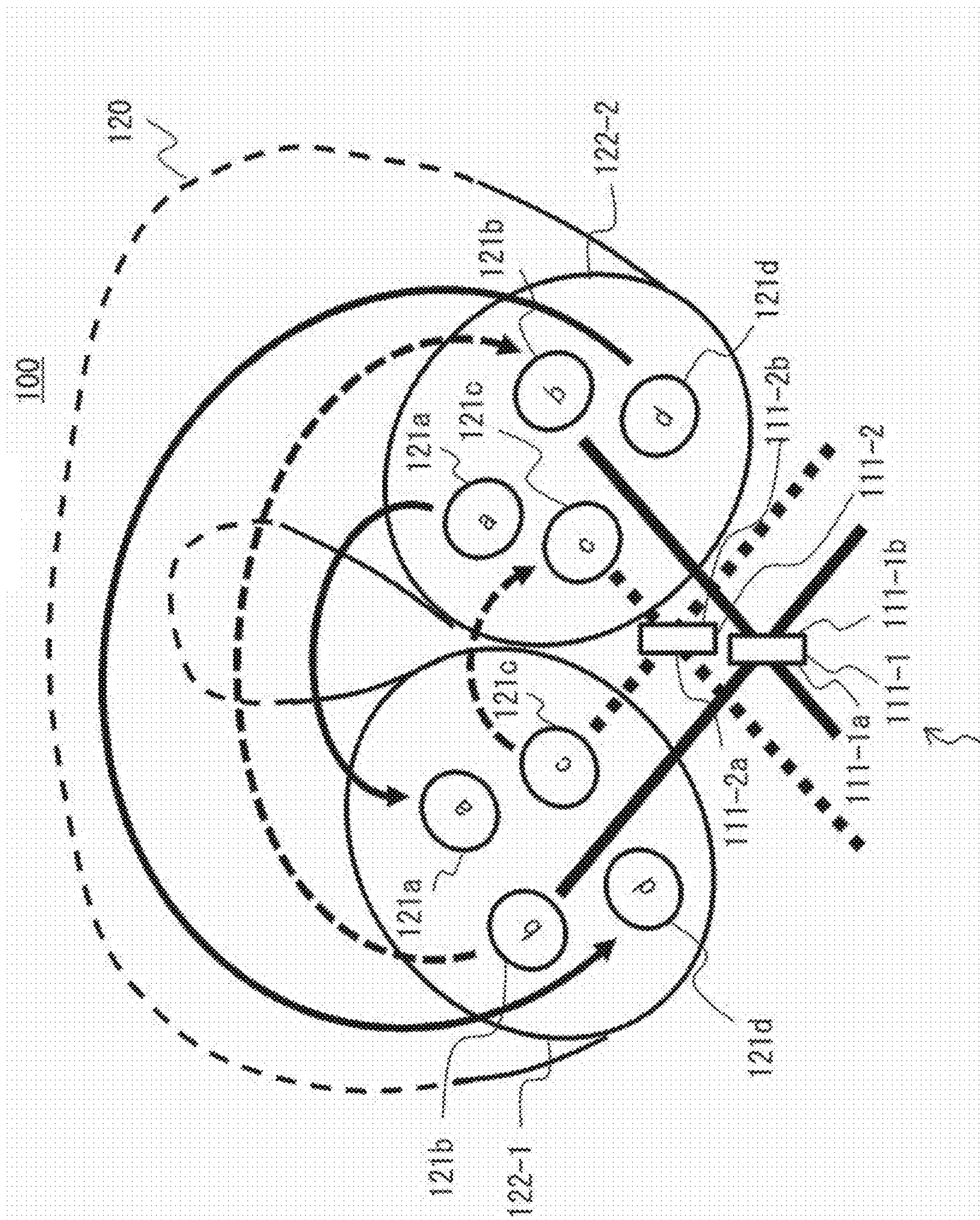

100
120
122-2
121b
121d
121a
121c
111-2b
111-2
111-1b
111-1
111-1a
110
111-2a
121c
121a
121b
122-1
121d

Fig. 12

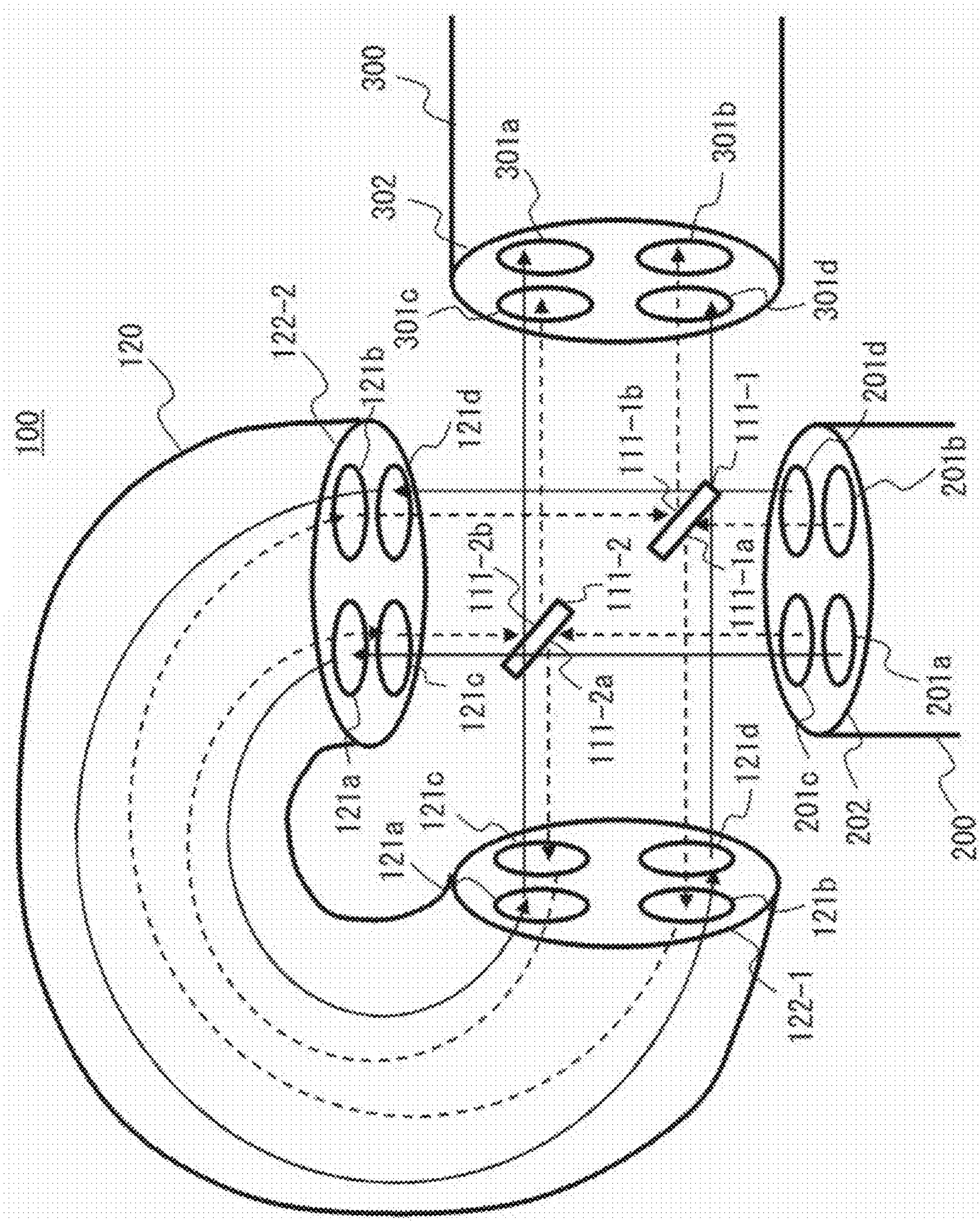

100
120
122-2
121b
121d
121a
121c
111-2b
111-2
111-2a
111-1b
111-1
111-1a
121a
121c
121d
121b
122-1
201d
201b
201a
201c
202
200
300
302
301a
301b
301c
301d

Fig. 13

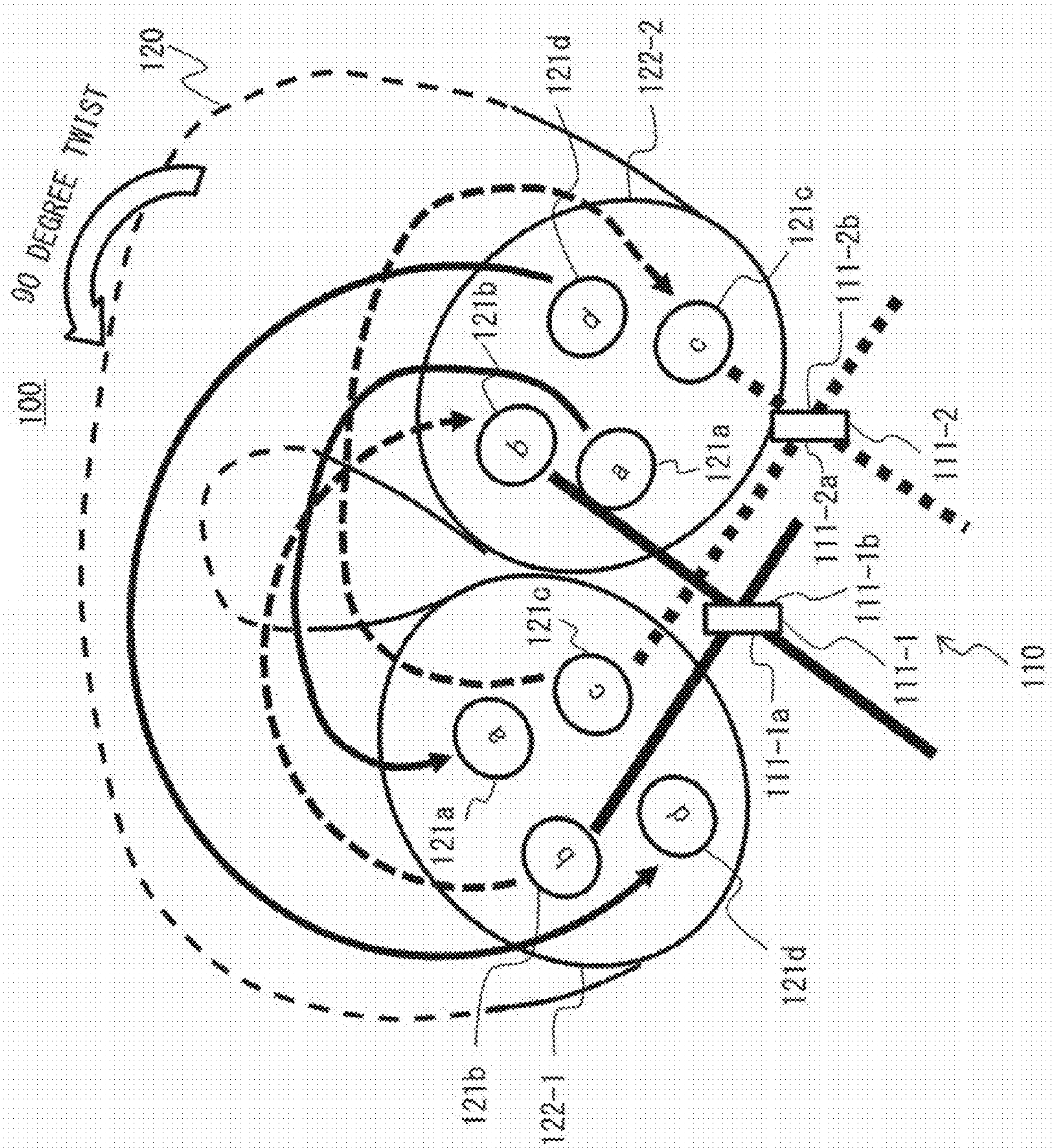

100
90 DEGREE TWIST
120
121a
121b
121c
121d
122-1
122-2
111-1
111-1a
111-1b
111-2
111-2a
111-2b
110
a
b
c
d

Fig. 14

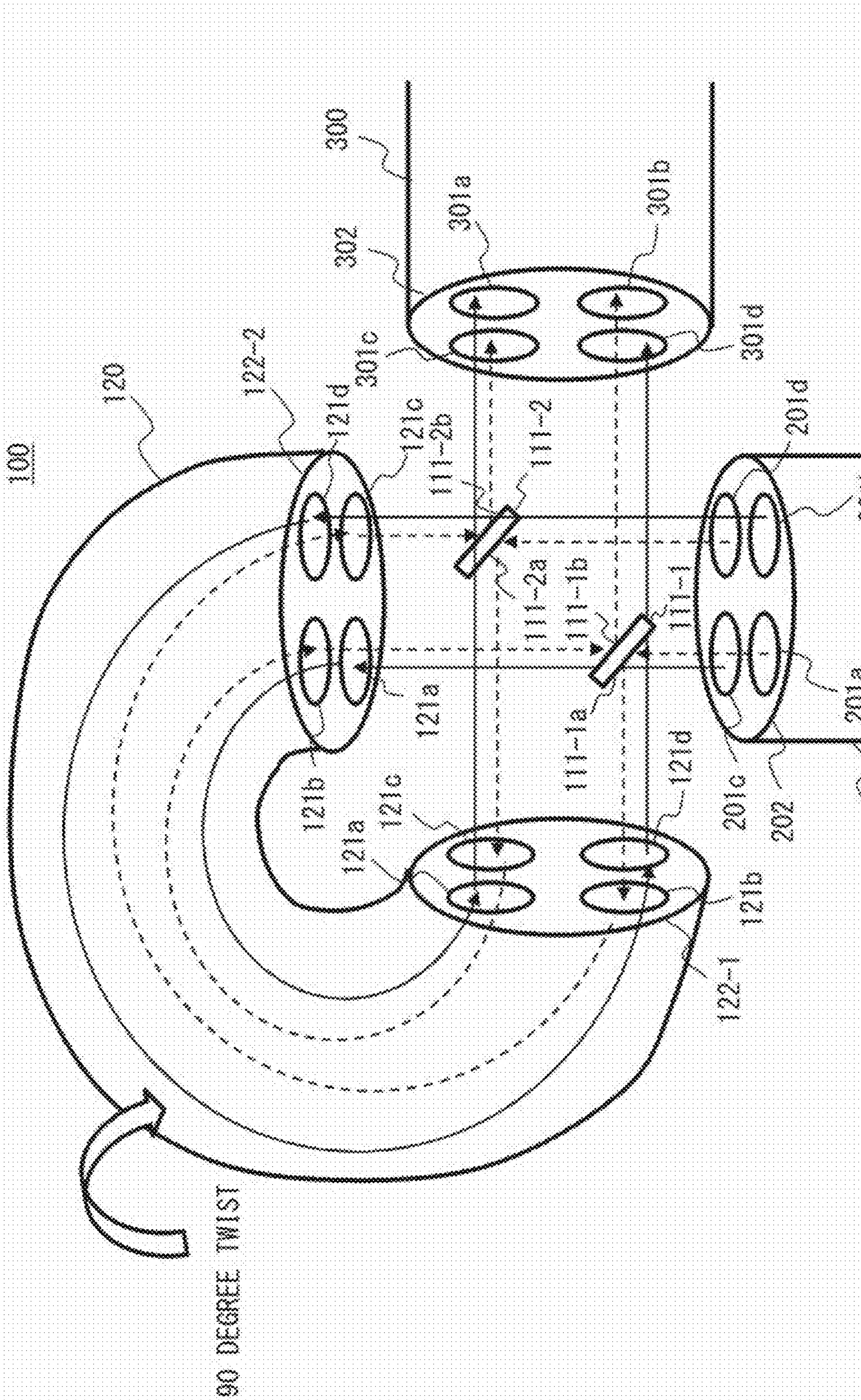

100
120
122-2
121d
121c
111-2b
111-2
111-2a
111-1b
111-1
111-1a
121a
121b
121c
121a
121d
121b
122-1
300
302
301a
301b
301c
301d
201d
201b
201a
201c
202
200
90 DEGREE TWIST

Fig. 15

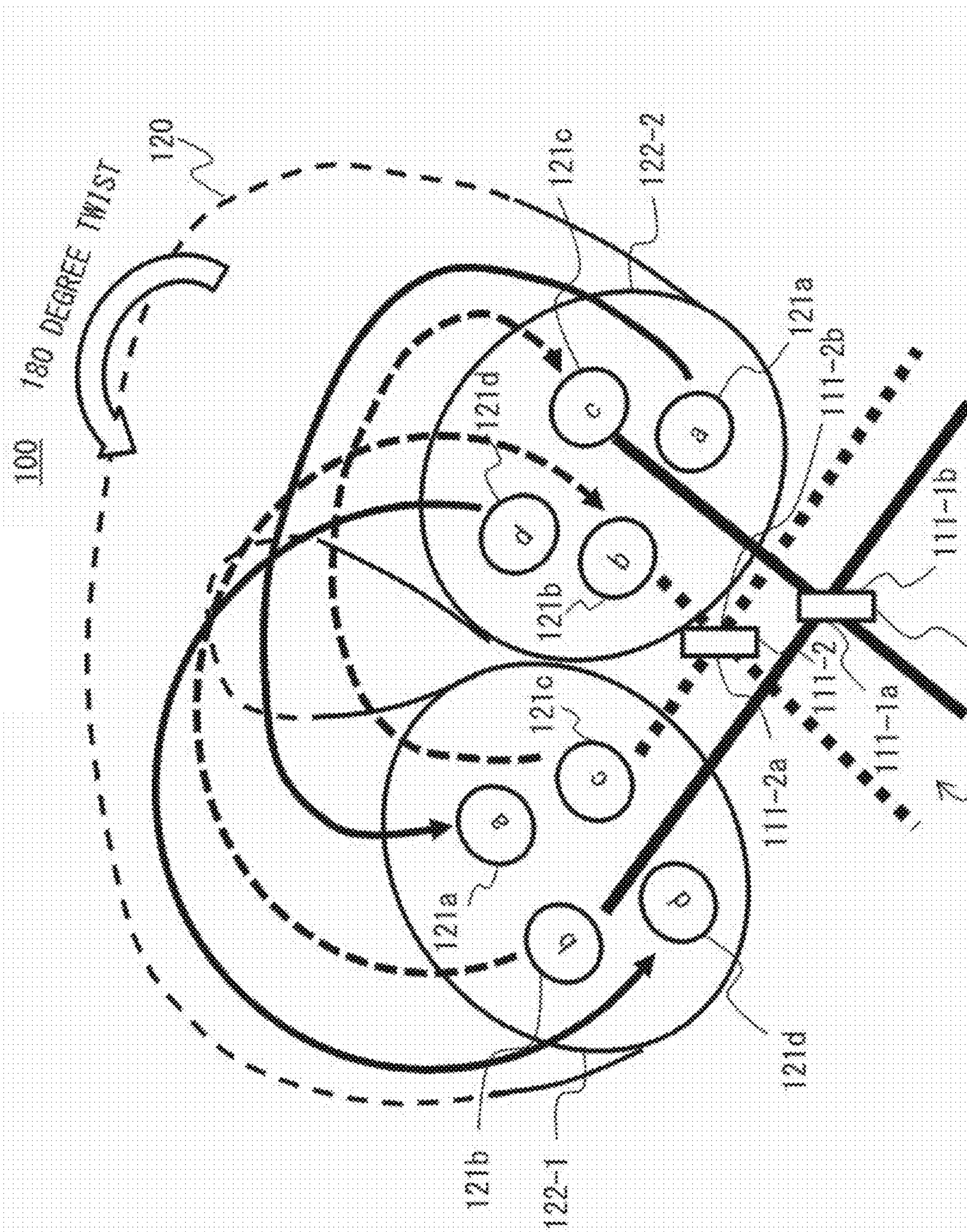

100
180 DEGREE TWIST
120
121c
122-2
121a
121d
121b
111-2b
111-1b
111-1
111-1a
111-2
111-2a
110
121c
121a
121d
121b
122-1
a
b
c
d
a
b
c
d

Fig. 16

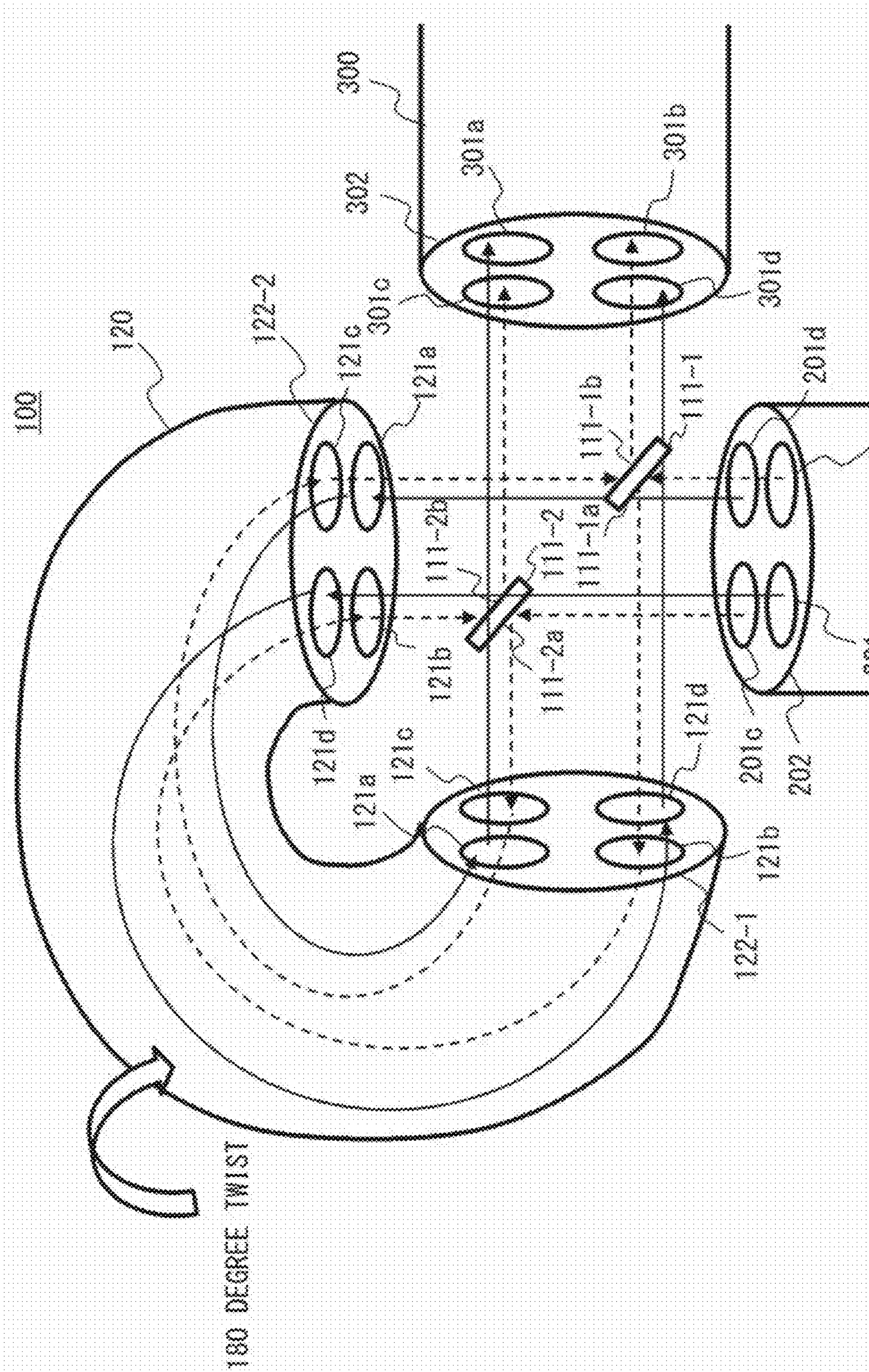

100
120
122-2
121c
121a
121b
121d
121a
121c
121d
121b
122-1
111-2b
111-2
111-2a
111-1b
111-1
111-1a
300
302
301a
301b
301c
301d
201d
201b
201a
201c
202
200
180 DEGREE TWIST

Fig. 17

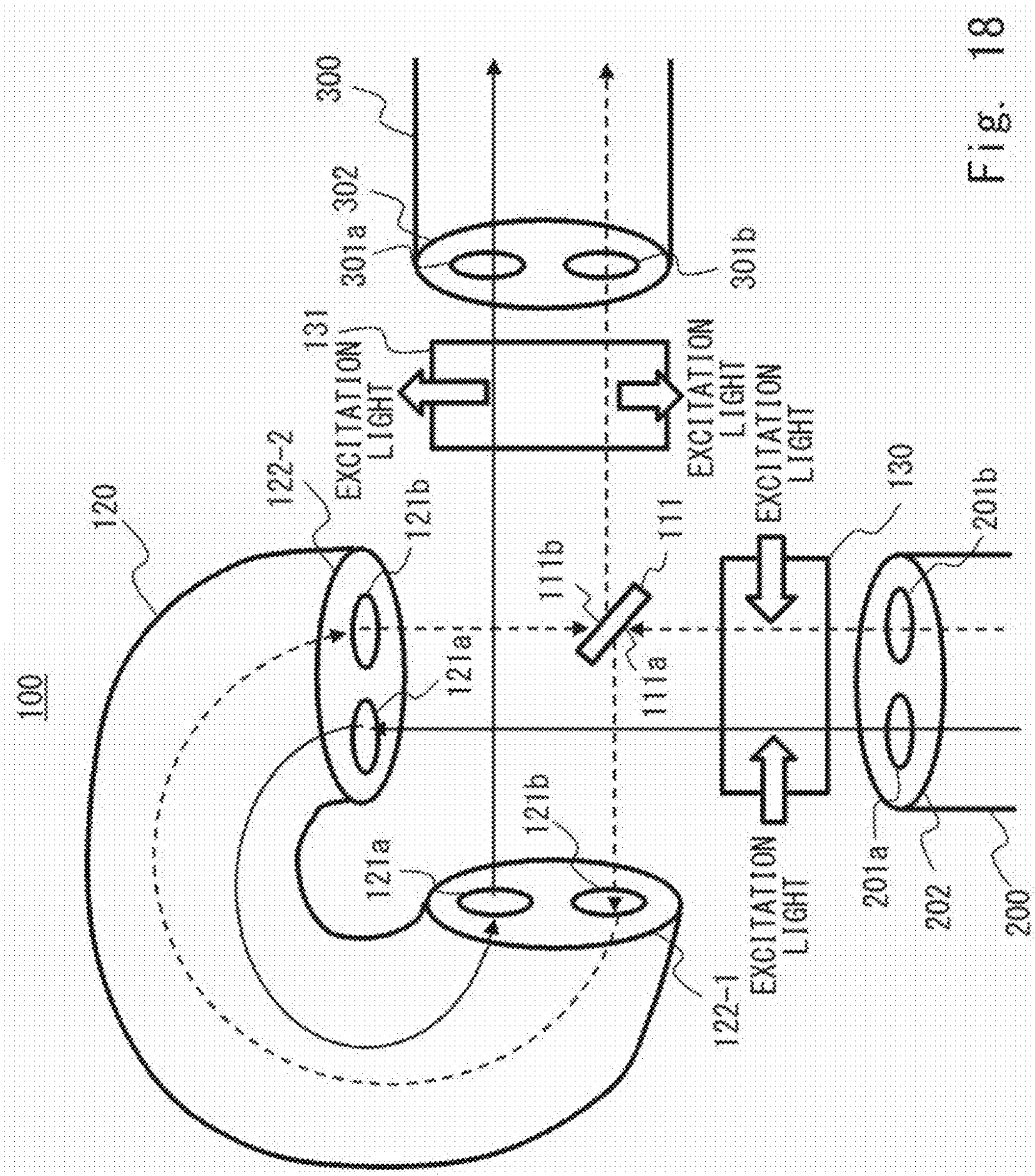

100
120
122-2
121b
121a
121a
121b
122-1
111
111a
111b
130
131
EXCITATION LIGHT
EXCITATION LIGHT
EXCITATION LIGHT
EXCITATION LIGHT
200
201a
201b
202
300
301a
301b
302

Fig. 18

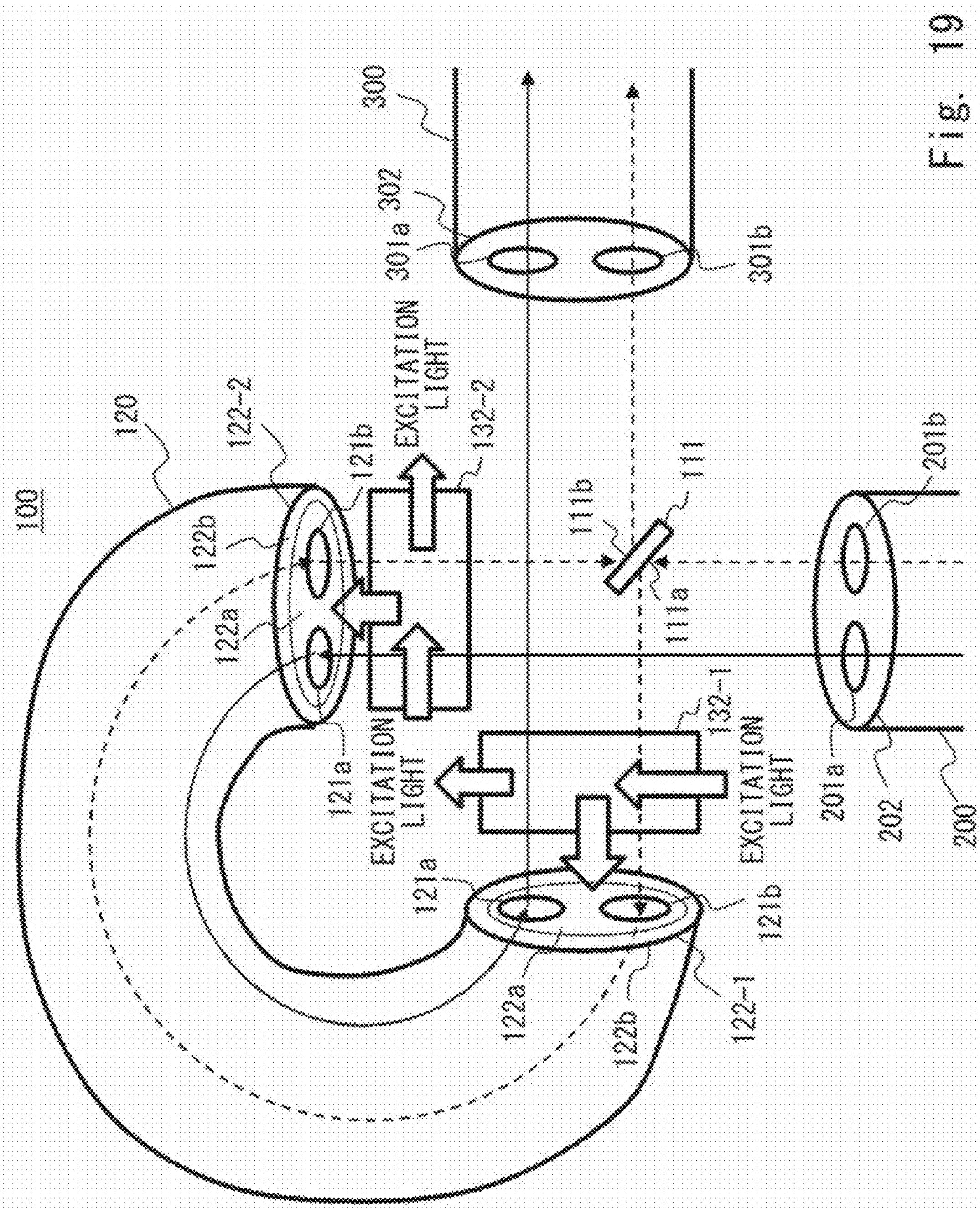

100
120
122-2
122b
121b
122a
121a
EXCITATION LIGHT
132-2
111b
111
111a
132-1
EXCITATION LIGHT
EXCITATION LIGHT
121a
121b
122a
122b
122-1
201a
201b
202
200
300
302
301a
301b

Fig. 19

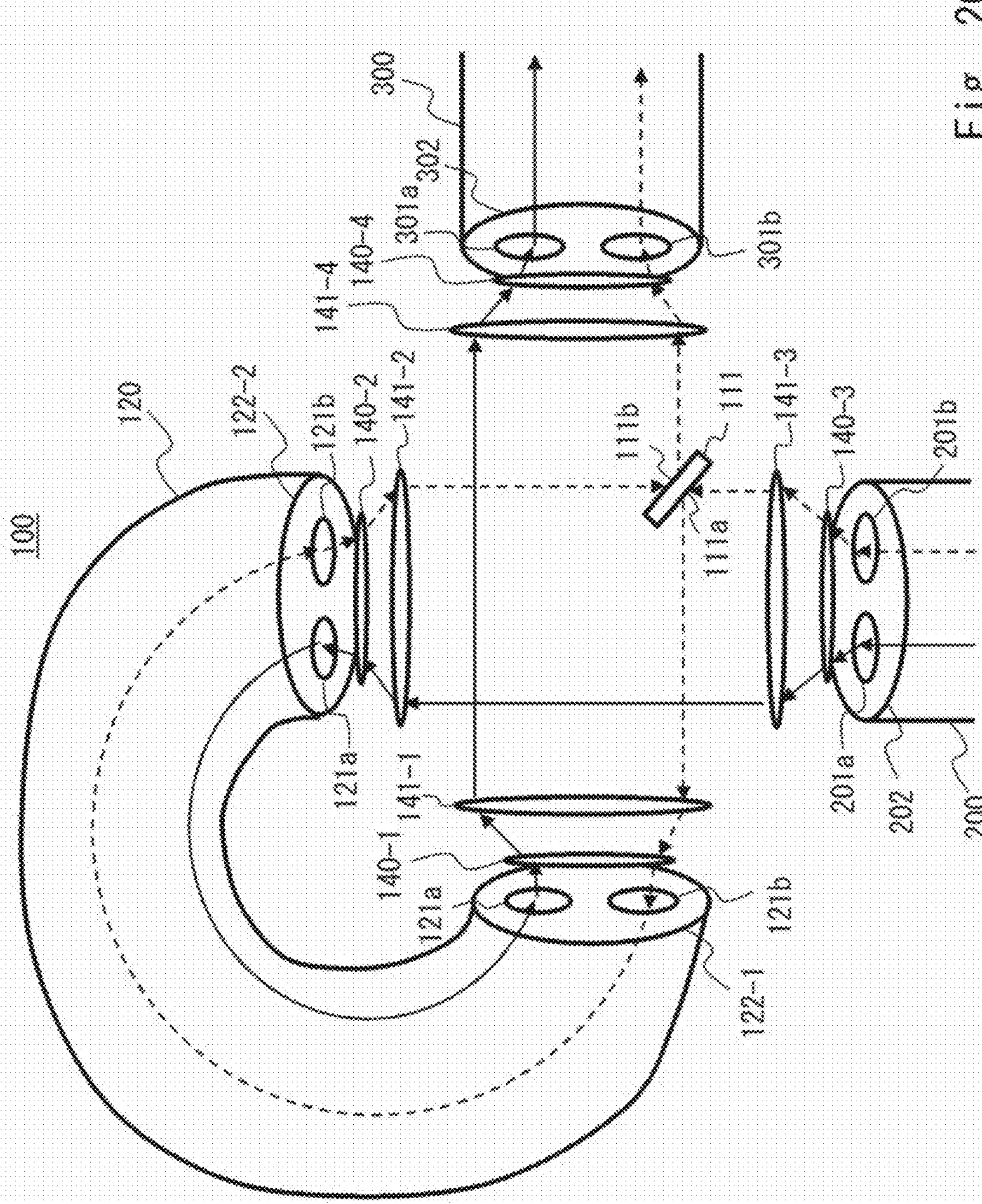

100
120
122-2
121b
140-2
141-2
111b
111
141-3
140-3
201b
111a
121a
141-1
140-1
121a
121b
122-1
201a
202
200
141-4
140-4
301a
302
300
301b

Fig. 20

OPTICAL AMPLIFICATION APPARATUS, OPTICAL TRANSMISSION SYSTEM, AND OPTICAL AMPLIFICATION METHOD

INCORPORATION BY REFERENCE

[0001] This application is based upon and claims the benefit of priority from Japanese patent application No. 2024-018597, filed on Feb. 9, 2024, the disclosure of which is incorporated herein in its entirety by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to an optical amplification apparatus, an optical transmission system, and an optical amplification method.

BACKGROUND ART

[0003] In recent years, in order to expand transmission capacity in optical communication, a multi-core fiber in which a plurality of cores are formed in one optical fiber has been used. For example, Patent Literature 1 describes an optical amplification apparatus using a multi-core erbium-doped fiber (MC-EDF). Further, Non Patent Literature 1 describes a multi-core fiber capable of reducing inter-core crosstalk.

CITATION LIST

Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2021-145255

Non Patent Literature

[0005] Non Patent Literature 1: Masanori Takahashi et al., "Uncoupled 4-core Fibre with Ultra-low Loss and Low Inter Core Crosstalk", 2020 European Conference on Optical Communications (ECOC), IEEE, December 2020

SUMMARY

[0006] For example, in related techniques such as Patent Literature 1 and Non Patent Literature 1, since influence of inter-core crosstalk caused in an optical amplification apparatus using an MC-EDF or the like is not taken into consideration, signal light quality may deteriorate.

[0007] An example object of the present disclosure is to provide an optical amplification apparatus, an optical transmission system, and an optical amplification method that make it possible to suppress deterioration in signal light quality.

[0008] In a first example aspect, an optical amplification apparatus is an optical amplification apparatus connected between a first multi-core fiber and a second multi-core fiber, and includes: a switching unit configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and an amplification unit configured to amplify the signal light being bidirectionally transmitted.

[0009] In a second example aspect, an optical transmission system includes: a first multi-core fiber; a second multi-core fiber; and an optical amplification apparatus connected between the first multi-core fiber and the second multi-core fiber, wherein the optical amplification apparatus includes a switching unit configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission, and an amplification unit configured to amplify the signal light being bidirectionally transmitted.

[0010] In a third example aspect, an optical amplification method is an optical amplification method for an optical amplification apparatus connected between a first multi-core fiber and a second multi-core fiber, and includes: switching a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and amplifying the signal light being bidirectionally transmitted.

[0011] According to the present disclosure, it is possible to suppress deterioration in signal light quality.

BRIEF DESCRIPTION OF DRAWINGS

[0012] The above and other aspects, features, and advantages of the present disclosure will become more apparent from the following description of certain example embodiments when taken in conjunction with the accompanying drawings, in which:

[0013] FIG. **1** is a diagram for describing unidirectional transmission in a multi-core fiber;

[0014] FIG. **2** is a diagram for describing bidirectional transmission in a multi-core fiber;

[0015] FIG. **3** is a configuration diagram illustrating a configuration example of a related optical transmission system;

[0016] FIG. **4** is a configuration diagram illustrating a configuration example of a related optical transmission system;

[0017] FIG. **5** is a graph illustrating a measurement result of signal quality according to some example embodiments;

[0018] FIG. **6** is a configuration diagram illustrating a configuration example of an optical transmission system according to some example embodiments;

[0019] FIG. **7** is a configuration diagram illustrating a configuration example of an optical transmission system according to some example embodiments;

[0020] FIG. **8** is a diagram for describing a transmission direction switching principle of an optical amplification apparatus according to some example embodiments;

[0021] FIG. **9** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0022] FIG. **10** is a diagram for describing a transmission direction switching principle of an optical amplification apparatus according to some example embodiments;

[0023] FIG. **11** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0024] FIG. **12** is a diagram for describing a transmission direction switching principle of an optical amplification apparatus according to some example embodiments;

[0025] FIG. **13** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0026] FIG. **14** is a diagram for describing a transmission direction switching principle of an optical amplification apparatus according to some example embodiments;

[0027] FIG. **15** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0028] FIG. **16** is a diagram for describing a transmission direction switching principle of an optical amplification apparatus according to some example embodiments;

[0029] FIG. **17** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0030] FIG. **18** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments;

[0031] FIG. **19** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments; and

[0032] FIG. **20** is a configuration diagram illustrating a configuration example of an optical amplification apparatus according to some example embodiments.

EXAMPLE EMBODIMENT

[0033] Hereinafter, example embodiments are described with reference to the drawings. In the drawings, the same element is denoted by the same reference numeral, and redundant descriptions are omitted as necessary.

(Study of Related Technique)

[0034] FIG. **1** is a diagram for describing unidirectional transmission in a multi-core fiber. Unidirectional transmission is a transmission scheme in which signal light is transmitted in the same direction through a plurality of cores in a multi-core fiber. In the example of FIG. **1**, two cores transmit signal light in the same direction. In the case of unidirectional transmission, for example, signal light transmitted through two cores interfere with each other, thereby causing crosstalk (inter-core crosstalk) to occur and resulting in a problem that transmission quality deteriorates.

[0035] FIG. **2** is a diagram for describing bidirectional transmission in a multi-core fiber. Bidirectional transmission is a transmission scheme in which signal light is transmitted in different transmission directions for each core in a multi-core fiber. In the example of FIG. **2**, two cores transmit signal light in opposite directions. In the case of bidirectional transmission, for example, interference of signal light transmitted by two cores can be suppressed, and thus inter-core crosstalk can be reduced.

[0036] First, the inventors have studied problems in the case of performing bidirectional transmission and in the case of performing unidirectional transmission with a multi-core fiber. FIG. **3** illustrates a configuration example of a related optical transmission system that performs bidirectional transmission. In the example of FIG. **3**, an optical transmission system **8** is a system which executes amplification and transmission between multi-core transmission line fibers **801** and **802** by using an MC-EDF **810** being an optical amplifier. As illustrated in FIG. **3**, the optical transmission system **8** includes an isolator (ISO) **820**, a gain flattening filter (GFF) **830**, and a fan-in/fan-out (FIFO) **840**.

[0037] An ISO is required for inputting and outputting optical signals in one direction for each signal path. In addition, since the power of the light amplified by the MC-EDF **810** varies for each wavelength due to the wavelength dependency, it is necessary to dispose a GFF at a subsequent stage of the MC-EDF **810**. Therefore, in the example of FIG. **3**, on a path for propagating the signal light from the first core of the transmission line fiber **801** to the first core of the transmission line fiber **802**, an ISO **820-1** is disposed in a preceding stage of the MC-EDF **810**, and a GFF **830-1** and an ISO **820-2** are disposed in a subsequent stage of the MC-EDF **810**. Further, on a path for propagating the signal light from the second core of the transmission line fiber **802** to the second core of the transmission line fiber **801**, an ISO **820-3** is disposed in the preceding stage of the MC-EDF **810**, and a GFF **830-2** and an ISO **820-4** are disposed in the subsequent stage of the MC-EDF **810**.

[0038] Further, in order to separate/couple signal light of multiple cores to signal light of a single core, a FIFO **840-1** is disposed between the transmission line fiber **801** and the ISO **820-1** and ISO **820-4**, a FIFO **840-2** is disposed between the ISO **820-1** and GFF **830-2** and the MC-EDF **810**, a FIFO **840-3** is disposed between the MC-EDF **810** and the GFF **830-1** and ISO **820-3**, and a FIFO **840-4** is disposed between the ISO **820-2** and ISO **820-3** and the transmission line fiber **802**.

[0039] As illustrated in FIG. **3**, by performing bidirectional transmission between the transmission line fiber and the MC-EDF, inter-core crosstalk between the transmission line fiber and the MC-EDF can be reduced. However, in order to perform bidirectional transmission, as illustrated in FIG. **3**, a FIFO is required in order to effectively dispose a GFF and an ISO for each core. Therefore, there is a problem that a loss due to the FIFO increases and the number of components increases.

[0040] FIG. **4** illustrates a configuration example of a related optical transmission system that performs unidirectional transmission. In a case where performing unidirectional transmission, as illustrated in FIG. **4**, an optical transmission system **9** has a configuration composed only of an MC-EDF **810**, ISOs **820-1** and **820-2**, and a GFF **830**. That is, in order to propagate signal light from two cores of a transmission line fiber **801** to two cores of a transmission line fiber **802**, the ISO **820-1** is disposed in a preceding stage of the MC-EDF **810**, and the GFF **830** and the ISO **820-2** are disposed in a subsequent stage of the MC-EDF **810**.

[0041] As illustrated in FIG. **4**, in unidirectional transmission, since the transmission direction of the signal light of each cores are the same, ISO and GFF for each core can be integrated. Therefore, in unidirectional transmission, since a FIFO such as bidirectional transmission is unnecessary, it is possible to suppress the occurrence of loss due to the FIFO, and it is possible to reduce the number of components. However, in the case of performing unidirectional transmission, there is a problem that inter-core crosstalk occurs between the transmission line fiber and the MC-EDF as illustrated in FIG. **1**.

[0042] Therefore, according to the example embodiments, it is possible to suppress the occurrence of loss due to optical components while suppressing inter-core crosstalk.

First Example Embodiment

[0043] Next, a first example embodiment is described. In the present example embodiment, a basic example of an optical transmission system including an optical amplification apparatus is described.

[0044] With regard to a transmission line fiber in an optical transmission system, in recent years, due to the advancement of fiber technology, it has become possible to suppress inter-core crosstalk even in unidirectional transmission. For example, as disclosed in Non Patent Literature

1, a multi-core fiber in which crosstalk is suppressed to less than −60 dB/km in unidirectional transmission has already been developed.

[0045] Meanwhile, in an MC-EDF, suppressing crosstalk in unidirectional transmission has not been advanced. Therefore, by using the related technique, inter-core crosstalk can be suppressed in the transmission line fiber, but inter-core crosstalk cannot be suppressed in the MC-EDF.

[0046] In order to study a method of suppressing inter-core crosstalk in an MC-EDF, the inventors measured signal quality in the case of performing unidirectional transmission and in the case of performing bidirectional transmission in the MC-EDF. FIG. **5** illustrates a measurement result of the experiment acquired by the inventor, regarding signal quality (Q value) according to the transmission distance in the optical transmission system. That is, FIG. **5** illustrates the difference in transmittable distance according to the transmission direction of the MC-EDF. I In FIG. **5**, reference numeral **501** denotes the signal quality in a case where unidirectional transmission is performed in the transmission line fiber and unidirectional transmission is performed in the MC-EDF, and reference numeral **502** denotes the signal quality in a case where unidirectional transmission is performed in the transmission line fiber and bidirectional transmission is performed in the MC-EDF.

[0047] From the experimental results of FIG. **5**, it is found that the inter-core crosstalk in the case where the unidirectional transmission is performed in the MC-EDF is relatively large, and the transmission distance is increased by 1.4 times by performing bidirectional transmission in the MC-EDF (for example, 700 km in unidirectional transmission and 1000 km in bidirectional transmission). Therefore, bidirectional transmission is effective as a method for reducing inter-core crosstalk of the MC-EDF. Therefore, in the example embodiment, the inter-core crosstalk can be reduced by performing bidirectional transmission in the MC-EDF.

[0048] FIG. **6** illustrates a configuration example of an optical transmission system **1** according to some example embodiments. In the example of FIG. **6**, the optical transmission system **1** includes an optical amplification apparatus **100** between a transmission line fiber **200** and a transmission line fiber **300**.

[0049] The transmission line fiber **200** (e.g., first multi-core fiber) and the transmission line fiber **300** (e.g., second multi-core fiber) are multi-core fibers. Each of the transmission line fiber **200** and the transmission line fiber **300** may include two cores, or may include more cores.

[0050] The transmission line fiber **200** is an optical fiber that transmits signal light to be input to the optical amplification apparatus **100** on the input side of the optical amplification apparatus **100**. The transmission line fiber **200** includes a core **201***a* (e.g., one of first and second input-side cores) and a core **201***b* (e.g., the other of the first and second input-side cores).

[0051] The transmission line fiber **300** is an optical fiber that transmits signal light output from the optical amplification apparatus **100** on the output side of the optical amplification apparatus **100**. The transmission line fiber **300** includes a core **301***a* (e.g., one of first and second output-side cores) and a core **301***b* (e.g., the other of the first and second output-side cores).

[0052] In the example of FIG. **6**, unidirectional transmission is performed in the transmission line fiber **200** and the transmission line fiber **300**. For example, by using a multi-core fiber capable of suppressing crosstalk as described in Non Patent Literature 1 as the transmission line fiber **200** and the transmission line fiber **300**, inter-core crosstalk in the transmission line fiber **200** and the transmission line fiber **300** can be reduced. Note that other multi-core fibers may be used as the transmission line fiber **200** and the transmission line fiber **300**.

[0053] The optical amplification apparatus **100** is an amplification apparatus configured to amplify light by using an MC-EDF. The optical amplification apparatus **100** is connected between the transmission line fiber **200** and the transmission line fiber **300**. The optical amplification apparatus **100** amplifies two beams of signal light output from the cores **201***a* and **201***b* of the transmission line fiber **200**, and outputs the amplified two beams of signal light to the cores **301***a* and **301***b* of the transmission line fiber **300**.

[0054] The optical amplification apparatus **100** includes a transmission direction switching unit **110** and an MC-EDF **120**. In the optical amplification apparatus **100**, bidirectional transmission is performed in the MC-EDF **120**. Thereby, inter-core crosstalk in the MC-EDF **120** is reduced.

[0055] The transmission direction switching unit **110** is a switching unit configured to switch the transmission direction between the transmission line fibers **200** and **300** and the MC-EDF **120**. In order to perform bidirectional transmission in the MC-EDF **120**, the transmission direction switching unit **110** switches the transmission direction of signal light, being unidirectionally transmitted in the transmission line fibers **200** and **300**, into bidirectional transmission. For example, the transmission direction switching unit **110** bidirectionally (reversely) inputs two beams of signal light, output in the same direction from the cores **201***a* and **201***b* of the transmission line fiber **200**, to the MC-EDF **120**. The transmission direction switching unit **110** unidirectionally outputs the two beams of signal light, amplified by the MC-EDF **120** and bidirectionally output, to the cores **301***a* and **301***b* of the transmission line fiber **300**.

[0056] The MC-EDF **120** is an amplification unit configured to amplify signal light being input. Excitation light is input to the MC-EDF **120** together with signal light, then the signal light is excited and amplified. The excitation method thereof may be core excitation for inputting excitation light to a core or cladding excitation for inputting excitation light to a cladding. The MC-EDF **120** is a multi-core optical amplification fiber, and, similarly to the transmission line fibers **200** and **300**, may include two cores, or may include more cores.

[0057] For example, the MC-EDF **120** includes two cores (a first amplification core and a second amplification core), and amplifies the signal light bidirectionally input from the transmission direction switching unit **110**, and outputs the amplified bidirectional signal light to the transmission direction switching unit **110**.

[0058] For example, the transmission direction switching unit **110** may input the signal light output from the first input-side core (one of the cores **201***a* and **201***b*) of the transmission line fiber **200** to the first amplification core on the first end face of the MC-EDF **120**, and input the signal light output from the first amplification core on the second end face of the MC-EDF **120** to the first output-side core (one of the cores **301***a* and **301***b*) of the transmission line fiber **300**. The transmission direction switching unit **110** may input the signal light output from the second input-side core (the other of the cores **201***a* and **201***b*) of the transmission line fiber **200** to the second amplification core in the second end face of the MC-EDF **120**, and may input the signal light output from the second amplification core in the first end face of the MC-EDF **120** to the second output-side core (the other of the cores **301***a* and **301***b*) of the transmission line fiber **300**. The configuration of the transmission direction switching unit **110** is not limited to the above as long as such an input-output relationship can be achieved. For example, as in the examples described below, the transmission direction switching unit **110** may be configured to switch the transmission direction by using a mirror.

[0059] Although an ISO, a GFF, and the like are omitted in the example of FIG. **6**, the optical transmission system **1** may include an ISO, a GFF, and the like as necessary. FIG. **7** illustrates a configuration example of the optical transmission system **1** according to some example embodiments. In the example of FIG. **7**, similarly to FIG. **4**, the optical transmission system **1** includes an ISO **410-1**, a GFF **420**, and an ISO **410-2**.

[0060] The ISO **410-1** is disposed between the transmission line fiber **200** and the optical amplification apparatus **100**. The ISO **410-1** passes multi-core signal light output from the transmission line fiber **200** to the optical amplification apparatus **100**. For example, the ISO **410-1** may be configured by integrating a plurality of isolators that each pass signal light of each core.

[0061] The GFF **420** is disposed between the optical amplification apparatus **100** and the ISO **410-2**. The GFF **420** flattens the wavelength dependency of the multi-core signal light amplified by the MC-EDF **120**. For example, the GFF **420** may be configured by integrating a plurality of filters each for the signal light of each core.

[0062] The ISO **410-2** is disposed between the GFF **420** and the transmission line fiber **300**. The ISO **410-2** passes the multi-core signal light flattened by the GFF **420** to the transmission line fiber **300**. For example, the ISO **410-2** may be configured by integrating a plurality of isolators that each pass signal light of each core.

[0063] As described above, in the present example embodiment, the optical transmission system includes the optical amplification apparatus having the transmission direction switching function. Specifically, unidirectional transmission is performed in the transmission line fiber, and transmission is switched to bidirectional transmission in an optical amplification apparatus (MC-EDF) having a large inter-core crosstalk. Thus, by performing bidirectional transmission in the optical amplification apparatus, it is possible to reduce the occurrence of inter-core crosstalk in the optical amplification apparatus. Further, by performing unidirectional transmission in the transmission line fiber, it is possible to reduce the number of optical components such as a FIFO, a GFF, and an isolator, and reduce loss due to the optical components.

Second Example Embodiment

[0064] Next, a second example embodiment is described. In the present example embodiment, an example in which a two-core MC-EDF is used is described as a specific example of the optical amplification apparatus described in the first example embodiment.

[0065] A transmission direction switching principle of an optical amplification apparatus **100** according to some example embodiments is described with reference to FIG. **8**. FIG. **8** is a front view of end faces **122-1** and **122-2** of an MC-EDF **120**.

[0066] In the example of FIG. **8**, the MC-EDF **120** is a two-core MC-EDF. That is, the MC-EDF **120** includes cores **121***a* and **121***b*. Signal light is bidirectionally input and output to and from the cores **121***a* and **121***b* at the end faces **122-1** and **122-2** at both ends of the MC-EDF **120**.

[0067] As illustrated in FIG. **8**, a transmission direction switching unit **110** includes a double-sided mirror **111**. The double-sided mirror **111** (reflection unit) switches the direction of signal light by reflecting the signal light being input and output to or from either of the core **121***a* and the core **121***b*. For example, the double-sided mirror **111** switches the direction of the signal light being input and output to and from the core **121***b*. One side **111***a* (e.g., the first reflection unit) of the double-sided mirror **111** switches the direction of the signal light being input to the core **121***b*. One side **111***b* (e.g., the second reflection unit) of the double-sided mirror **111** switches the direction of the signal light being output from the core **121***b*. The one side **111***a* and the one side **111***b* of the double-sided mirror **111** are mirrors that totally reflect light. The transmission direction switching unit **110** is not limited to include the double-sided mirror **111**, and may be provided with a first single-sided mirror having the same configuration as the one side **111***b* and a second single-sided mirror having the same configuration as the one side **111***b*.

[0068] The transmission direction switching function of the transmission direction switching unit **110** is implemented by a positional relationship (including an angle) between a core (e.g., the core **121***b*) in which the transmission direction change in the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111**. That is, the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111** are fixed in such a way that the core that changes the transmission direction in the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111** have a predetermined positional relationship. The transmission direction switching unit **110** may include a fixing unit (not illustrated) that fixes the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111** in such a way that the core that changes the transmission direction in the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111** have a predetermined positional relationship.

[0069] In the example of FIG. **8**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a predetermined angle in a state where the MC-EDF **120** is folded back. That is, the MC-EDF **120** is folded back without being twisted. The end face **122-1** and the end face **122-2** face each other without rotating. For example, the core **121***a* at the end face **122-1** and the core **121***a* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. If the end face **122-1** and the end face **122-2** are faced with each other, it can also be said that the core **121***a* at the end face **122-1** and the core **121***a* at the end face **122-2** oppose each other. The core **121***b* at the end face **122-1** and the core **121***b* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other. If the end face **122-1** and the end face **122-2** are faced with each other, it can also be said that the core **121***b* at the end face **122-1** and the core **121***b* at the end face **122-2** oppose each other.

[0070] In the example of FIG. **8**, it is assumed that the core **121***a* is a core in which the transmission direction is not switched, and the core **121***b* is a core in which the transmission direction is switched. Note that, the core **121***b* may be a core in which the transmission direction is not switched, and the core **121***a* may be a core in which the transmission direction is switched. That is, one of the two cores is a core in which the transmission direction is not switched, and the other core is a core in which the transmission direction is switched. Thus, inter-core crosstalk in the MC-EDF **120** can be reduced.

[0071] As illustrated in FIG. **8**, in a case where the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a certain angle, the double-sided mirror **111** is disposed at an intersection of the cores **121***b* that change the transmission direction in the MC-EDF **120**. Specifically, the double-sided mirror **111** is disposed at an intersection of central axis lines (straight lines extending in the optical input/output direction) of the cores **121***b* that change the transmission direction in the MC-EDF **120**. Thus, the transmission direction of the signal light of the core **121***b* can be switched in the reverse direction with respect to the transmission direction of the signal light of the core **121***a*.

[0072] In a path of the core **121***a*, the signal light is input to the core **121***a* at the end face **122-2**, and the signal light amplified by the MC-EDF **120** is output from the core **121***a* at the end face **122-1**. In a path of the core **121***b*, the input signal light is reflected by the one side **111***a* of the double-sided mirror **111**, is input to the core **121***b* at the end face **122-1**, and the signal light amplified by the MC-EDF **120** is output from the core **121***b* at the end face **122-1**. The double-sided mirror **111** is fixed in such a way that the one side **111***a* is set at an angle to reflect the signal light input from the transmission line fiber **200** to the core **121***b* at the end face **122-1**. The signal light output from the core **121***b* is reflected by and output from the other one side **111***b* of the double-sided mirror **111**. The double-sided mirror **111** is fixed in such a way that the one side **111***b* is set at an angle to reflect the signal light output from the core **121***b* to a transmission line fiber **300**. In such a way, by fixing the positional relationship between the core **121***b* in which the transmission direction changes and the double-sided mirror **111** as illustrated in FIG. **8**, the transmission direction in the MC-EDF **120** can be switched to bidirectional transmission.

[0073] FIG. **9** illustrates a specific configuration example of the optical amplification apparatus **100** described in FIG. **8**. FIG. **9** is a top view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0074] As described with reference to FIG. **8**, the optical amplification apparatus **100** includes the MC-EDF **120** and the double-sided mirror **111**. The optical amplification apparatus **100** may include a fixing unit configured to fix the MC-EDF **120** and the double-sided mirror **111**. The end face **122-1** and the end face **122-2** of the MC-EDF **120** and the double-sided mirror **111** are fixed in such a way as to have the positional relationship illustrated in FIG. **8**.

[0075] In the example of FIG. **9**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** are fixed in such a way as to face each other at a right angle. For example, the end face **122-1** and the end face **122-2** are fixed in such a way as to face each other at right angles by folding back the MC-EDF **120** without twisting. The MC-EDF **120** may be circulated to draw out the end face **122-1** and the end face **122-2** as necessary. The MC-EDF **120** may be twisted by 360 degrees×n (n is an integer).

[0076] As described with reference to FIG. **8**, the core **121***a* at the end face **122-1** and the core **121***a* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. The core **121***b* at the end face **122-1** and the core **121***b* at the end face **122-1** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0077] In the example of FIG. **9**, the input-side transmission line fiber **200** is disposed in such a way that an end face **202** of the transmission line fiber **200** opposes the end face **122-2** of the MC-EDF **120**. Specifically, a core **201***a* at the end face **202** of the transmission line fiber **200** opposes the core **121***a* at the end face **122-2** of the MC-EDF **120**. It can also be said that the central axis line of the core **201***a* at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121***a* at the end face **122-2** of the MC-EDF **120**. A core **201***b* at the end face **202** of the transmission line fiber **200** opposes the core **121***b* at the end face **122-2** of the MC-EDF **120** (via the double-sided mirror **111**). It can also be said that the central axis line of the core **201***b* at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**.

[0078] The output-side transmission line fiber **300** is fixed in such a way that an end face **302** of the transmission line fiber **300** opposes the end face **122-1** of the MC-EDF **120**. Specifically, a core **301***a* at the end face **302** of the transmission line fiber **300** opposes the core **121***a* at the end face **122-1** of the MC-EDF **120**. It can also be said that the central axis line of the core **301***a* at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121***a* at the end face **122-1** of the MC-EDF **120**. Further, a core **301***b* at the end face **302** of the transmission line fiber **300** opposes the core **121***b* at the end face **122-1** of the MC-EDF **120** (via the double-sided mirror **111**). It can also be said that the central axis line of the core **301***b* at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0079] As described with reference to FIG. **8**, for example, the core **121***b* of the MC-EDF **120** is a core in which the transmission direction changes. Therefore, the double-sided mirror **111** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. It can also be said that the double-sided mirror **111** is disposed at an intersection of a central axis line connecting the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0080] The one side **111***a* of the double-sided mirror **111** is disposed in such a way as to face the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111***a* of the double-sided mirror **111** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***b* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111***a* of the double-sided mirror

111 reflects, at a right angle, light from the core **201***b* at the end face **202** of the transmission line fiber **200** toward the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0081] The one side **111***b* of the double-sided mirror **111** is disposed in such a way as to face the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111***b* of the double-sided mirror **111** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***b* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111***b* of the double-sided mirror **111** reflects, at a right angle, light from the core **121***b* at the end face **122-2** of the MC-EDF **120** toward the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0082] The signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** is input to the core **121***a* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***a* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***a* at the end face **122-1** to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0083] The signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111***a* of the double-sided mirror **111**, and is input from the one side **111***a* to the core **121***b* at the end face **122-1**. The signal light input to the core **121***b* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***b* at the end face **122-1** toward the double-sided mirror **111**. The signal light output from the core **121***b* is reflected by the one side **111***b* of the double-sided mirror **111**, and is output from the one side **111***b* to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0084] As described above, the function of the transmission direction switching unit in the optical amplification apparatus may be implemented by a mirror that switches the transmission direction. For example, the transmission direction of the MC-EDF can be switched to bidirectional transmission by disposing a mirror and a core for switching the transmission direction in the two-core MC-EDF, in such a way as to have a predetermined positional relationship.

Modified Example of Second Example Embodiment

[0085] In a modified example of the second example embodiment, an example in which 180 degrees of twist is added to the MC-EDF in the optical amplification apparatus described in the second example embodiment is described.

[0086] A transmission direction switching principle of the optical amplification apparatus **100** according to some example embodiments is described with reference to FIG. **10**. FIG. **10** is a front view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0087] In the example of FIG. **10**, the positional relationship between the cores **121***a* and **121***b* at the end faces **122-1** and **122-2** of the MC-EDF **120** is different from that in FIG. **8**. That is, the MC-EDF **120** is folded back with a 180 degree twist added about the central axis of the fiber. The end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a predetermined angle in a state where the MC-EDF **120** is folded back while being twisted by 180 degrees. It can also be said that the end face **122-1** and the end face **122-2** face each other in a state where either one is rotated by 180 degrees. The 180 degrees of twist is an angle at which the core **121** rotates, from a state in which the end face **122** is not rotated (FIG. **8**), to the position of an adjacent core **121**. For example, the core **121***a* at the end face **122-1** and the core **121***b* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***a* at the end face **122-1** and the core **121***b* at the end face **122-2** oppose each other. The core **121***b* at the end face **122-1** and the core **121***a* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***b* at the end face **122-1** and the core **121***a* at the end face **122-2** oppose each other.

[0088] Similarly to FIG. **8**, in a case where the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a certain angle, the double-sided mirror **111** is disposed at an intersection between the cores **121***b* that change the transmission direction in the MC-EDF **120**. In the example of FIG. **10**, since the position of the core **121***b* at the end face **122-2** is different from that of FIG. **8**, the position of the double-sided mirror **111** is shifted from that of FIG. **8**. That is, the double-sided mirror **111** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2**, being on the inner side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***b* at the end face **122-1**, being on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0089] As illustrated in FIG. **10**, in the path of the core **121***a*, signal light is input to the core **121***a* at the end face **122-2** on the outer side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***a* at the end face **122-1** on the inner side of where the end face **122-1** and the end face **122-2** face each other. Further, in the path of the core **121***b*, the input signal light is reflected by the one side **111***a* of the double-sided mirror **111**, the reflected light is input to the core **121***b* at the end face **122-1** on the outer side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***b* at the end face **122-1** on the inner side of where the end face **122-1** and the end face **122-2** face each other. The signal light output from the core **121***b* is reflected by and output from the other one side **111***b* of the double-sided mirror **111**.

[0090] FIG. **11** illustrates a specific configuration example of the optical amplification apparatus **100** described with reference to FIG. **10**. FIG. **11** is a top view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0091] In the example of FIG. **11**, the positions of the cores **121***a* and **121***b* at the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirror **111** are different from those in FIG. **9**.

[0092] In the example of FIG. **11**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** are fixed in such a way as to face each other at a right angle. For example, the MC-EDF **120** is folded back with a twist of 180 degrees, and the end face **122-1** and the end face **122-2** are fixed in such a way as to face each other at a right angle. The MC-EDF **120** may be circulated to draw out the end face **122-1** and the end face **122-2** as necessary. The MC-EDF **120** may be twisted by 180 degrees+360 degrees×n (n is an integer).

[0093] As described with reference to FIG. **10**, the core **121***a* at the end face **122-1** and the core **121***b* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. The core **121***b* at the end face **122-1** and the core **121***a* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0094] Similarly to FIG. **9**, the input-side transmission line fiber **200** is fixed in such a way that the end face **202** of the transmission line fiber **200** faces the end face **122-2** of the MC-EDF **120**. The output-side transmission line fiber **300** is fixed in such a way that the end face **302** of the transmission line fiber **300** faces the end face **122-1** of the MC-EDF **120**.

[0095] As illustrated in FIG. **10**, for example, the core **121***b* of the MC-EDF **120** is a core in which the transmission direction changes. Therefore, the double-sided mirror **111** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**, being on the inner side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**, being on the outer side of where the end face **122-1** and the end face **122-2** face each other. It can also be said that the double-sided mirror **111** is disposed at an intersection of a central axis line connecting the core **201***a* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0096] The one side **111***a* of the double-sided mirror **111** is disposed in such a way as to face the core **201***a* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111***a* of the double-sided mirror **111** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***a* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111***a* of the double-sided mirror **111** reflects, at a right angle, light from the core **201***a* at the end face **202** of the transmission line fiber **200** toward the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0097] The one side **111***b* of the double-sided mirror **111** is disposed in such a way as to face the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111***b* of the double-sided mirror **111** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***b* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111***b* of the double-sided mirror **111** reflects, at a right angle, light from the core **121***b* at the end face **122-2** of the MC-EDF **120** toward the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0098] The signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** is input to the core **121***a* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***a* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***a* at the end face **122-1** to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0099] The signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** is reflected by one side **111***a* of the double-sided mirror **111**, and the reflected signal light is input to the core **121***b* at the end face **122-1** from the one side **111***a*. The signal light input to the core **121***b* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***b* at the end face **122-1** toward the double-sided mirror **111**. The signal light output from the core **121***b* is reflected by the one side **111***b* of the double-sided mirror **111**, and is output from the one side **111***b* to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0100] As described above, in a case where the transmission direction of the two-core MC-EDF is switched in the optical amplification apparatus, a twist of 180 degrees may be applied to the MC-EDF. Even in such a case, the transmission direction of the MC-EDF can be switched to bidirectional transmission by disposing a mirror and a core for switching the transmission direction in the two-core MC-EDF, in such a way as to have a predetermined positional relationship.

Third Example Embodiment

[0101] Next, a third example embodiment is described. In the present example embodiment, an example in which a four-core MC-EDF is used is described as a specific example of the optical amplification apparatus described in the first example embodiment.

[0102] A transmission direction switching principle of an optical amplification apparatus **100** according to some example embodiments is described with reference to FIG. **12**. FIG. **12** is a front view of end faces **122-1** and **122-2** of an MC-EDF **120**.

[0103] In the example of FIG. **12**, the MC-EDF **120** is a four-core MC-EDF. That is, the MC-EDF **120** includes cores **121***a* to **121***d*. Signal light is bidirectionally input and output to and from the cores **121***a* to **121***d* at the end faces **122-1** and **122-2** at both ends of the MC-EDF **120**. In bidirectional transmission, the transmission direction in adjacent cores is set to be the reverse direction.

[0104] In the example of FIG. **12**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a predetermined angle in a state where the MC-EDF **120** is folded back. That is, the MC-EDF **120** is folded back without being twisted. The end face **122-1** and the end face **122-2** face each other without rotating. For example, the cores **121***a* and **121***c* at the end face **122-1** and the cores **121***a* and **121***c* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***a* is located on the upper side (inner upper side) of the end faces **122-1** and **122-2**, and the core **121***c* is located on the lower side (inner lower side) of the end faces **122-1** and **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***a* of the end face **122-1** and the core **121***a* of the end face **122-2** oppose each other, and the core **121***c* of the end face **122-1** and the core **121***c* the end face **122-2** oppose each other.

[0105] The cores **121***b* and **121***d* at the end face **122-1** and the cores **121***b* and **121***d* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***b* is located on the upper side (outer upper side) of the end faces **122-1**

and **122-2**, and the core **121**_d_ is located on the lower side (outer lower side) of the end faces **122-1** and **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121**_b_ at the end face **122-1** and the core **121**_b_ at the end face **122-2** oppose each other, and the core **121**_d_ at the end face **122-1** and the core **121**_d_ at the end face **122-2** oppose each other.

[0106] In the example of FIG. **12**, the cores **121**_a_ and **121**_d_ are cores in which transmission directions do not change, and the cores **121**_b_ and **121**_c_ are cores in which transmission directions change. Combinations of a core with no transmission direction change and a core with a transmission direction change is not limited to this. Combinations of other cores may be used as long as the traveling direction of light propagating between adjacent cores can be reversed. Thus, inter-core crosstalk can be effectively reduced.

[0107] As illustrated in FIG. **12**, in a case where the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a certain angle, double-sided mirrors **111-1** and **111-2** are disposed at an intersection of the cores **121**_b_ that change the transmission direction in the MC-EDF **120** and the intersection of the cores **121**_c_. Specifically, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121**_b_ that changes the transmission direction in the MC-EDF **120**, and the double-sided mirror **111-2** is disposed at an intersection of the central axis of the core **121**_c_ that changes the transmission direction in the MC-EDF **120**. Thus, the transmission direction of the signal light of the cores **121**_b_ and **121**_c_ can be switched in the reverse direction with respect to the transmission direction of the cores **121**_a_ and **121**_d_.

[0108] In a path of the core **121**_a_, signal light is input to the core **121**_a_ at the end face **122-2**, and the signal light amplified by the MC-EDF **120** is output from the core **121**_a_ at the end face **122-1**. Further, in a path of the core **121**_b_, input signal light is reflected by one side **111-1**_a_ of the double-sided mirror **111-1**, is input to the core **121**_b_ at the end face **122-1**, and the signal light amplified by the MC-EDF **120** is output from the core **121**_b_ at the end face **122-1**. The signal light output from the core **121**_b_ is reflected by and output from the other one side **111-1**_b_ of the double-sided mirror **111-1**.

[0109] In a path of the core **121**_c_, input signal light is reflected by one side **111-2**_a_ of the double-sided mirror **111-2**, is input to the core **121**_c_ at the end face **122-1**, and the signal light amplified by the MC-EDF **120** is output from the core **121**_c_ at the end face **122-1**. The signal light output from the core **121**_c_ is reflected by and output from the other one side **111-2**_b_ of the double-sided mirror **111-2**. In a path of the core **121**_d_, signal light is input to the core **121**_d_ at the end face **122-2**, and the signal light amplified by the MC-EDF **120** is output from the core **121**_d_ at the end face **122-1**.

[0110] FIG. **13** illustrates a specific configuration example of the optical amplification apparatus **100** described with reference to FIG. **12**. FIG. **13** is a top view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0111] In the example of FIG. **13**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** are fixed in such a way as to face each other at a right angle. For example, the MC-EDF **120** is folded back without being twisted, and the end face **122-1** and the end face **122-2** are fixed in such a way as to face each other at right angles. The MC-EDF **120** may be circulated to draw out the end face **122-1** and the end face **122-2** as necessary. The MC-EDF **120** may be twisted by 360 degrees×n (n is an integer).

[0112] As described with reference to FIG. **12**, the cores **121**_a_ and **121**_c_ at the end face **122-1** and the cores **121**_a_ and **121**_c_ at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. The cores **121**_b_ and **121**_d_ at the end face **122-1** and the cores **121**_b_ and **121**_d_ at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0113] In the example of FIG. **13**, an input-side transmission line fiber **200** is fixed in such a way that an end face **202** of the transmission line fiber **200** faces the end face **122-2** of the MC-EDF **120**. Specifically, a core **201**_a_ at the end face **202** of the transmission line fiber **200** faces the core **121**_a_ at the end face **122-2** of the MC-EDF **120**. It can also be said that the central axis line of the core **201**_a_ at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121**_a_ at the end face **122-2** of the MC-EDF **120**. A core **201**_b_ at the end face **202** of the transmission line fiber **200** faces the core **121**_b_ at the end face **122-2** of the MC-EDF **120**. It can also be said that the central axis line of the core **201**_b_ at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121**_b_ at the end face **122-2** of the MC-EDF **120**.

[0114] A core **201**_c_ at the end face **202** of the transmission line fiber **200** faces the core **121**_c_ at the end face **122-2** of the MC-EDF **120**. It can also be said that the central axis line of the core **201**_c_ at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121**_c_ at the end face **122-2** of the MC-EDF **120**. A core **201**_d_ at the end face **202** of the transmission line fiber **200** faces the core **121**_d_ at the end face **122-2** of the MC-EDF **120**. It can also be said that the central axis line of the core **201**_d_ at the end face **202** of the transmission line fiber **200** overlaps with the central axis line of the core **121**_d_ at the end face **122-2** of the MC-EDF **120**.

[0115] An output-side transmission line fiber **300** is fixed in such a way that an end face **302** of the transmission line fiber **300** faces the end face **122-1** of the MC-EDF **120**. Specifically, a core **301**_a_ at the end face **302** of the transmission line fiber **300** faces the core **121**_a_ at the end face **122-1** of the MC-EDF **120**. It can also be said that the central axis line of the core **301**_a_ at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121**_a_ at the end face **122-1** of the MC-EDF **120**. A core **301**_b_ at the end face **302** of the transmission line fiber **300** faces the core **121**_b_ at the end face **122-1** of the MC-EDF **120**. It can also be said that the central axis line of the core **301**_b_ at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121**_b_ at the end face **122-1** of the MC-EDF **120**.

[0116] A core **301**_c_ at the end face **302** of the transmission line fiber **300** faces the core **121**_c_ at the end face **122-1** of the MC-EDF **120**. It can also be said that the central axis line of the core **301**_c_ at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121**_c_ at the end face **122-1** of the MC-EDF **120**. A core **301**_d_ at the end face **302** of the transmission line fiber **300** faces the core **121**_d_ at the end face **122-1** of the MC-EDF **120**. It can also be said that the central axis line of the core **301**_d_ at the end face **302** of the transmission line fiber **300** overlaps with the central axis line of the core **121**_d_ at the end face **122-1** of the MC-EDF **120**.

[0117] As described in FIG. **12**, for example, the cores **121***b* and **121***c* of the MC-EDF **120** are cores in which the transmission direction change. Therefore, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. It can also be said that the double-sided mirror **111-1** is disposed at an intersection of a central axis line connecting the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0118] The double-sided mirror **111-2** is disposed at an intersection of the central axis line of the core **121***c* at the end face **122-2** of the MC-EDF **120** and the central axis line of the core **121***c* at the end face **122-1** of the MC-EDF **120**. It can also be said that the double-sided mirror **111-2** is disposed at an intersection of a central axis line connecting the core **201***c* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0119] The one side **111-1***a* of the double-sided mirror **111-1** is disposed in such a way as to face the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***b* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** reflects, at a right angle, light from the core **201***b* at the end face **202** of the transmission line fiber **200** toward the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0120] The one side **111-1***b* of the double-sided mirror **111-1** is disposed in such a way as to face the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***b* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** reflects, at a right angle, light from the core **121***b* at the end face **122-2** of the MC-EDF **120** toward the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0121] The one side **111-2***a* of the double-sided mirror **111-2** is disposed in such a way as to face the core **201***c* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***c* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **201***c* at the end face **202** of the transmission line fiber **200** toward the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0122] The one side **111-2***b* of the double-sided mirror **111-2** is disposed in such a way as to face the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***c* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **121***c* at the end face **122-2** of the MC-EDF **120** toward the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0123] The signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** is input to the core **121***a* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***a* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***a* at the end face **122-1** to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0124] The signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-1***a* of the double-sided mirror **111-1**, and is input from the one side **111-1***a* to the core **121***b* at the end face **122-1**. The signal light input to the core **121***b* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***b* at the end face **122-1** toward the double-sided mirror **111-1**. The signal light output from the core **121***b* is reflected by the one side **111-1***b* of the double-sided mirror **111-1**, and is output from the one side **111-1***b* to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0125] The signal light output from the core **201***c* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-2***a* of the double-sided mirror **111-2**, and is input from the one side **111-2***a* to the core **121***c* at the end face **122-1**. The signal light input to the core **121***c* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***c* at the end face **122-1** toward the double-sided mirror **111-2**. The signal light output from the core **121***c* is reflected by the one face **111-2***b* of the double-sided mirror **111-2**, and is output from the one face **111-2***b* to the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0126] The signal light output from the core **201***d* at the end face **202** of the transmission line fiber **200** is input to the core **121***d* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***d* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***d* at the end face **122-1** to the core **301***d* at the end face **302** of the transmission line fiber **300**.

[0127] As described above, in a case where the transmission direction of the MC-EDF is switched in the optical amplification apparatus, the four-core MC-EDF may be used. Even in such a case, the transmission direction of the MC-EDF can be switched to bidirectional transmission by disposing a mirror and a core that switches the transmission direction in the four-core MC-EDF, in such a way as to have a predetermined positional relationship.

First Modified Example of Third Example Embodiment

[0128] In a first modified example of the third example embodiment, an example in which 90 degrees of twist is applied to the MC-EDF **120** in the optical amplification apparatus **100** illustrated in the third example embodiment is described.

[0129] A transmission direction switching principle of the optical amplification apparatus **100** according to some example embodiments is described with reference to FIG. **14**. FIG. **14** is a front view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0130] In the example of FIG. **14**, the positional relationship between the cores **121***a* to **121***d* at the end faces **122-1** and **122-2** of the MC-EDF **120** is different from that in FIG. **12**. That is, the MC-EDF **120** is folded back with a 90 degree twist about the central axis of the fiber. The end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a predetermined angle in a state where the MC-EDF **120** is folded back while being twisted by 90 degrees. It can also be said that the end face **122-1** and the end face **122-2** face each other in a state where either one is rotated by 90 degrees. The 90 degrees of twist is an angle at which the core **121** rotates, from a state in which the end face **122** is not rotated (FIG. **12**), to the position of the adjacent core **121**.

[0131] For example, the cores **121***a* and **121***c* at the end face **122-1** and the cores **121***b* and **121***a* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***a* is located on the upper side (inner upper side) of the end face **122-1**, the core **121***c* is located on the lower side (inner lower side) of the end face **122-1**, the core **121***b* is located on the upper side (inner upper side) of the end face **122-2**, and the core **121***a* is located on the lower side (inner lower side) of the end face **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***a* of the end face **122-1** and the core **121***b* of the end face **122-2** oppose each other, and the core **121***c* at the end face **122-1** and the core **121***a* at the end face **122-2** oppose each other. The cores **121***b* and **121***d* at the end face **122-1** and the cores **121***d* and **121***c* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***b* is located on the upper side (outer upper side) of the end face **122-1**, the core **121***d* is located on the lower side (outer lower side) of the end face **122-1**, the core **121***d* is located on the upper side (outer upper side) of the end face **122-2**, and the core **121***c* is located on the lower side (outer lower side) of the end face **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***b* at the end face **122-1** and the core **121***d* at the end face **122-2** oppose each other, and the core **121***d* at the end face **122-1** and the core **121***c* at the end face **122-2** oppose each other.

[0132] Similarly to FIG. **12**, in a case where the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a certain angle, the double-sided mirror **111-1** is disposed at an intersection of the cores **121***b* that change the transmission direction in the MC-EDF **120**, and the double-sided mirror **111-2** is disposed at an intersection of the cores **121***c* that change the transmission direction in the MC-EDF **120**. In the example of FIG. **14**, since the positions of the cores **121***b* and **121***c* at the end face **122-2** are different from those of FIG. **12**, the positions of the double-sided mirrors **111-1** and **111-2** are shifted from those of FIG. **12**. That is, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***b* at the end face **122-1**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other. The double-sided mirror **111-2** is disposed at an intersection of a central axis line of the core **121***c* at the end face **122-2**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other, and a central axis line of the core **121***c* at the end face **122-1**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other.

[0133] As illustrated in FIG. **14**, in a path of the core **121***a*, signal light is input to the core **121***a* at the end face **122-2**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***a* at the end face **122-1**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other.

[0134] In a path of the core **121***b*, input signal light is reflected by the one side **111-1***a* of the double-sided mirror **111-1**, the reflected signal light is input to the core **121***b* at the end face **122-1**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***b* at the end face **122-1**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other. The signal light output from the core **121***b* is reflected by and output from the other one side **111-1***b* of the double-sided mirror **111-1**.

[0135] In a path of the core **121***c*, input signal light is reflected by the one side **111-2***a* of the double-sided mirror **111-2**, the reflected signal light is input to the core **121***c* at the end face **122-1**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***c* at the end face **122-1**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other. The signal light output from the core **121***c* is reflected by and output from the other one side **111-2***b* of the double-sided mirror **111-2**.

[0136] In a path of the core **121***d*, signal light is input to the core **121***d* at the end face **122-2**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***d* at the end face **122-1**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other.

[0137] FIG. **15** illustrates a specific configuration example of the optical amplification apparatus **100** described with reference to FIG. **14**. FIG. **15** is a top view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0138] In the example of FIG. **15**, the positions of the cores **121***a* to **121***d* in the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirrors **111-1** and **111-2** are different from those in FIG. **13**.

[0139] In the example of FIG. **15**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** are fixed in such a way as to face each other at a right angle. For example, the MC-EDF **120** is folded back with a twist of 90 degrees, and the end face **122-1** and the end face **122-2** are fixed in such a way as to face each other at right angles. The MC-EDF **120**

may be circulated to draw out the end face **122-1** and the end face **122-2** as necessary. The MC-EDF **120** may be twisted by 90 degrees+360 degrees×n (n is an integer).

[0140] As described with reference to FIG. **14**, the cores **121***a* and **121***c* at the end face **122-1** and the cores **121***b* and **121***a* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. The cores **121***b* and **121***d* at the end face **122-1** and the cores **121***d* and **121***c* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0141] Similarly to FIG. **13**, the input-side transmission line fiber **200** is fixed in such a way that the end face **202** of the transmission line fiber **200** faces the end face **122-2** of the MC-EDF **120**. The output-side transmission line fiber **300** is fixed in such a way that the end face **302** of the transmission line fiber **300** faces the end face **122-1** of the MC-EDF **120**.

[0142] As described in FIG. **14**, for example, the cores **121***b* and **121***c* of the MC-EDF **120** are cores in which the transmission direction change. Therefore, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other. It can also be said that the double-sided mirror **111-1** is disposed at an intersection of a central axis line connecting the core **201***a* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0143] The double-sided mirror **111-2** is disposed at an intersection of the central axis line of the core **121***c* at the end face **122-2** of the MC-EDF **120**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***c* at the end face **122-1** of the MC-EDF **120**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other. It can also be said that the double-sided mirror **111-2** is disposed at an intersection of a central axis line connecting the core **201***d* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0144] The one side **111-1***a* of the double-sided mirror **111-1** is disposed in such a way as to face the core **201***a* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis of the core **201***a* at the end face **202** of the transmission line fiber **200** and the central axis of the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** reflects, at a right angle, light from the core **201***a* at the end face **202** of the transmission line fiber **200** toward the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0145] The one side **111-1***b* of the double-sided mirror **111-1** is disposed in such a way as to face the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis of the core **301***b* at the end face **302** of the transmission line fiber **300** and the central axis of the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** reflects, at a right angle, light from the core **121***b* at the end face **122-2** of the MC-EDF **120** toward the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0146] The one side **111-2***a* of the double-sided mirror **111-2** is disposed in such a way as to face the core **201***d* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis of the core **201***d* at the end face **202** of the transmission line fiber **200** and the central axis of the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **201***d* at the end face **202** of the transmission line fiber **200** toward the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0147] The one side **111-2***b* of the double-sided mirror **111-2** is disposed in such a way as to face the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis of the core **301***c* at the end face **302** of the transmission line fiber **300** and the central axis of the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **121***c* at the end face **122-2** of the MC-EDF **120** toward the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0148] The signal light output from the core **201***c* at the end face **202** of the transmission line fiber **200** is input to the core **121***a* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***a* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***a* at the end face **122-1** to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0149] The signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-1***a* of the double-sided mirror **111-1**, and is input from the one side **111-1***a* to the core **121***b* at the end face **122-1**. The signal light input to the core **121***b* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***b* at the end face **122-1** toward the double-sided mirror **111-1**. The signal light output from the core **121***b* is reflected by the one side **111-1***b* of the double-sided mirror **111-1**, and is output from the one side **111-1***b* to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0150] The signal light output from the core **201***d* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-2***a* of the double-sided mirror **111-2**, and is input from the one side **111-2***a* to the core **121***c* at the end face **122-1**. The signal light input to the core **121***c* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***c* at the end face **122-1** toward the double-sided mirror **111-2**. The signal light output from the core **121***c* is reflected by the one face **111-2***b* of the double-sided mirror **111-2**, and is output from the one face **111-2***b* to the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0151] The signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** is input to the core **121***d* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***d* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***d* at the end face **122-1** to the core **301***d* at the end face **302** of the transmission line fiber **300**.

[0152] As described above, in a case where the transmission direction of the four-core MC-EDF is switched in the optical amplification apparatus, a twist of 90 degrees may be applied to the MC-EDF. Even in such a case, the transmission direction of the MC-EDF can be switched to bidirectional transmission by disposing a mirror and a core for switching the transmission direction in the four-core MC-EDF, in such a way as to have a predetermined positional relationship.

Second Modified Example of Third Example Embodiment

[0153] In a second modified example of the third example embodiment, an example in which 180 degrees of twist is applied to the MC-EDF **120** in the optical amplification apparatus **100** illustrated in the third example embodiment is described.

[0154] A transmission direction switching principle of the optical amplification apparatus **100** according to some example embodiments is described with reference to FIG. **16**. FIG. **16** is a front view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0155] In the example of FIG. **16**, the positional relationship between the cores **121***a* to **121***d* at the end faces **122-1** and **122-2** of the MC-EDF **120** is different from that in FIG. **12**. That is, the MC-EDF **120** is folded back with a 180 degree twist about the central axis of the fiber. The end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other in a state where the MC-EDF **120** is folded back while being twisted by 180 degrees. It can also be said that the end face **122-1** and the end face **122-2** face each other while either one is rotated by 180 degrees. The 180 degrees of twist is an angle at which the core **121** rotates, from a state in which the end face **122** is not rotated (FIG. **12**), to the position of a core **121** being two cores away.

[0156] For example, the cores **121***a* and **121***c* at the end face **122-1** and the cores **121***d* and **121***b* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***a* is located on the upper side (inner upper side) of the end face **122-1**, the core **121***c* is located on the lower side (inner lower side) of the end face **122-1**, the core **121***d* is located on the upper side (inner upper side) of the end face **122-2**, and the core **121***b* is located on the lower side (inner lower side) of the end face **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***a* and the end face **122-1** and the core **121***d* of the end face **122-2** oppose each other, and the core **121***c* at the end face **122-1** and the core **121***b* at the end face **122-2** oppose each other. The cores **121***b* and **121***d* at the end face **122-1** and the cores **121***c* and **121***a* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other. For example, the core **121***b* is located on the upper side (outer upper side) of the end face **122-1**, the core **121***d* is located on the lower side (outer lower side) of the end face **122-1**, the core **121***c* is located on the upper side (outer upper side) of the end face **122-2**, and the core **121***a* is located on the lower side (outer lower side) of the end face **122-2**. If the end face **122-1** and the end face **122-2** face each other, it can also be said that the core **121***b* at the end face **122-1** and the core **121***c* at the end face **122-2** oppose each other, and the core **121***d* at the end face **122-1** and the core **121***a* at the end face **122-2** oppose each other.

[0157] In the example of FIG. **16**, the cores **121***b* and **121***c* of the MC-EDF **120** are cores (group) in which the transmission direction change. As illustrated in FIG. **16**, if the four-core MC-EDF **120** is twisted by 180 degrees and the end face **122-1** and the end face **122-2** face each other, the central axis lines of cores in which the transmission direction change do not intersect with each other. Therefore, in a case where the end face **122-1** and the end face **122-2** of the MC-EDF **120** face each other at a certain angle, the double-sided mirrors **111-1** and **111-2** are disposed at intersections of one core and the other core from the group of the cores **121***b* and **121***c* that change the transmission direction in the MC-EDF **120**. That is, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***c* at the end face **122-1**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other. The double-sided mirror **111-2** is disposed at an intersection of the central axis line of the core **121***c* at the end face **122-2**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other, and a central axis line of the core **121***b* at the end face **122-1**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other.

[0158] As illustrated in FIG. **16**, in a path of the core **121***a*, signal light is input to the core **121***a* at the end face **122-2**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***a* at the end face **122-2**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other.

[0159] In a path of the core **121***b*, input signal light is reflected by the one side **111-1***a* of the double-sided mirror **111-1**, the reflected signal light is input to the core **121***b* at the end face **122-1**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***b* at the end face **122-1**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other. The signal light output from the core **121***b* is reflected by and output from the other one side **111-2***b* of the double-sided mirror **111-2**.

[0160] In a path of the core **121***c*, input signal light is reflected by the one side **111-2***a* of the double-sided mirror **111-2**, the reflected signal light is input to the core **121***c* at the end face **122-1**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***c* at the end face **122-1**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other. The signal light output from the core **121***c* is reflected by and output from the other one side **111-2***b* of the double-sided mirror **111-1**.

[0161] In a path of the core **121***d*, signal light is input to the core **121***d* at the end face **122-2**, being on the inner upper side of where the end face **122-1** and the end face **122-2** face each other, and the signal light amplified by the MC-EDF **120** is output from the core **121***d* at the end face **122-1**, being on the outer lower side of where the end face **122-1** and the end face **122-2** face each other.

[0162] FIG. **17** illustrates a specific configuration example of the optical amplification apparatus **100** described with reference to FIG. **16**. FIG. **17** is a top view of the end faces **122-1** and **122-2** of the MC-EDF **120**.

[0163] In the example of FIG. **17**, the positions of the cores **121***a* to **121***d* in the end faces **122-1** and **122-2** of the MC-EDF **120** and the double-sided mirrors **111-1** and **111-2** are different from those in FIG. **13**.

[0164] In the example of FIG. **17**, the end face **122-1** and the end face **122-2** of the MC-EDF **120** are fixed in such a way as to face each other at a right angle. For example, the MC-EDF **120** is folded back with a twist of 180 degrees, and the end face **122-1** and the end face **122-2** are fixed in such a way as to face each other at a right angle. The MC-EDF **120** may be circulated to draw out the end face **122-1** and the end face **122-2** as necessary. The MC-EDF **120** may be twisted by 180 degrees+360 degrees×n (n is an integer).

[0165] As described with reference to FIG. **16**, the cores **121***a* and **121***c* at the end face **122-1** and the cores **121***d* and **121***b* at the end face **122-2** are located on the inner side of where the end face **122-1** and the end face **122-2** face each other. The cores **121***b* and **121***d* at the end face **122-1** and the cores **121***c* and **121***a* at the end face **122-2** are located on the outer side of where the end face **122-1** and the end face **122-2** face each other.

[0166] Similarly to FIG. **13**, the input-side transmission line fiber **200** is fixed in such a way that the end face **202** of the transmission line fiber **200** faces the end face **122-2** of the MC-EDF **120**. The output-side transmission line fiber **300** is fixed in such a way that the end face **302** of the transmission line fiber **300** faces the end face **122-1** of the MC-EDF **120**.

[0167] As described in FIG. **16**, the cores **121***b* and **121***c* of the MC-EDF **120** are, for example, cores (group) in which the transmission direction change. Therefore, the double-sided mirror **111-1** is disposed at an intersection of the central axis line of the core **121***c* at the end face **122-2** of the MC-EDF **120**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**, being on the outer upper side of where the end face **122-1** and the end face **122-2** face each other. It can also be said that the double-sided mirror **111-1** is disposed at an intersection of a central axis line connecting the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0168] The double-sided mirror **111-2** is disposed at an intersection of the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other, and the central axis line of the core **121***c* at the end face **122-1** of the MC-EDF **120**, being on the inner lower side of where the end face **122-1** and the end face **122-2** face each other. It can also be said that the double-sided mirror **111-2** is disposed at an intersection of a central axis line connecting the core **201***c* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-2** of the MC-EDF **120**, and a central axis line connecting the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0169] The one side **111-1***a* of the double-sided mirror **111-1** is disposed in such a way as to face the core **201***b* at the end face **202** of the transmission line fiber **200** and the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***b* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***b* at the end face **122-1** of the MC-EDF **120**. The one side **111-1***a* of the double-sided mirror **111-1** reflects light, at a right angle, from the core **201***b* at the end face **202** of the transmission line fiber **200** toward the core **121***b* at the end face **122-1** of the MC-EDF **120**.

[0170] The one side **111-1***b* of the double-sided mirror **111-1** is disposed in such a way as to face the core **301***b* at the end face **302** of the transmission line fiber **300** and the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***b* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***c* at the end face **122-2** of the MC-EDF **120**. The one side **111-1***b* of the double-sided mirror **111-1** reflects, at a right angle, light from the core **121***c* at the end face **122-2** of the MC-EDF **120** toward the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0171] The one side **111-2***a* of the double-sided mirror **111-2** is disposed in such a way as to face the core **201***c* at the end face **202** of the transmission line fiber **200** and the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis line of the core **201***c* at the end face **202** of the transmission line fiber **200** and the central axis line of the core **121***c* at the end face **122-1** of the MC-EDF **120**. The one side **111-2***a* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **201***c* at the end face **202** of the transmission line fiber **200** toward the core **121***c* at the end face **122-1** of the MC-EDF **120**.

[0172] The one side **111-2***b* of the double-sided mirror **111-2** is disposed in such a way as to face the core **301***c* at the end face **302** of the transmission line fiber **300** and the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** is fixed at an angle of 45 degrees with respect to the central axis line of the core **301***c* at the end face **302** of the transmission line fiber **300** and the central axis line of the core **121***b* at the end face **122-2** of the MC-EDF **120**. The one side **111-2***b* of the double-sided mirror **111-2** reflects, at a right angle, light from the core **121***b* at the end face **122-2** of the MC-EDF **120** toward the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0173] The signal light output from the core **201***d* at the end face **202** of the transmission line fiber **200** is input to the core **121***a* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***a* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***a* at the end face **122-1** to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0174] The signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-1***a* of the double-sided mirror **111-1**, and is input from the one side **111-1***a* to the core **121***b* at the end face **122-1**. The signal light input to the core **121***b* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***b* at the end face **122-1** toward the double-sided mirror **111-2**. The signal light output from the core **121***b* is reflected by the one face **111-2***b* of the double-sided mirror **111-2**, and is output from the one face **111-2***b* to the core **301***c* at the end face **302** of the transmission line fiber **300**.

[0175] The signal light output from the core **201***c* at the end face **202** of the transmission line fiber **200** is reflected by the one side **111-2***a* of the double-sided mirror **111-2**, and is input from the one side **111-2***a* to the core **121***c* at the end face **122-1**. The signal light input to the core **121***c* at the end face **122-1** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***c* at the end face **122-1** toward the double-sided mirror **111-1**. The signal light output from the core **121***c* is reflected by the one side **111-1***b* of the double-sided mirror **111-1**, and is output from the one side **111-1***b* to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0176] The signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** is input to the core **121***d* at the end face **122-2** of the MC-EDF **120**. The signal light input to the core **121***d* at the end face **122-2** of the MC-EDF **120** propagates through the MC-EDF **120** and is amplified, and the amplified signal light is output from the core **121***d* at the end face **122-1** to the core **301***d* at the end face **302** of the transmission line fiber **300**.

[0177] As described above, in a case where the transmission direction of the four-core MC-EDF is switched in the optical amplification apparatus, a twist of 180 degrees may be applied to the MC-EDF. Even in such a case, the transmission direction of the MC-EDF can be switched to bidirectional transmission by disposing a mirror and a core for switching the transmission direction in the four-core MC-EDF, in such a way as to have a predetermined positional relationship.

[0178] In the first modified example of the third example embodiment, a twist of 90 degrees is applied to the MC-EDF, and in the second modified example of the third example embodiment, a twist of 180 degrees is applied to the MC-EDF, but the angle of the twist is not limited thereto. If a mirror can be placed at the intersection of cores in which the transmission direction change, the angle of twist of the MC-EDF may be any angle. However, with respect to the core arrangement at the time of incidence, the core arrangement at the time of emission is shifted by the angle of the twist. The same applies not only to multi-cores of two cores and four cores but also to multi-cores in which even-numbered cores, such as six cores and eight cores, are arranged concentrically.

Fourth Example Embodiment

[0179] Next, a fourth example embodiment is described. In the present example embodiment, a specific example of an excitation method in the optical amplification apparatus illustrated in the second example embodiment is described. Note that, the excitation method according to the present example embodiment may be applied to the first modified example of the second example embodiment, the third example embodiment, and the first modified example and the second modified example of the third example embodiment.

[0180] FIG. **18** illustrates a configuration example in which core excitation is performed in an optical amplification apparatus **100** according to some example embodiments. In the example of FIG. **18**, in addition to the configuration of FIG. **9**, a multiplexing unit **130** and a demultiplexing unit **131** are provided.

[0181] The multiplexing unit **130** (coupler) multiplexes signal light and excitation light for each core for core excitation. The multiplexing unit **130** multiplexes, for each core, signal light and excitation light input from a transmission line fiber **200**, and inputs the multiplexed light to an MC-EDF **120**.

[0182] In the example of FIG. **18**, the multiplexing unit **130** is disposed between an end face **202** of the transmission line fiber **200**, and an end face **122-2** of the MC-EDF **120** and a double-sided mirror **111** (disposed in front of the end face **202** of the transmission line fiber **200**). The multiplexing unit **130** multiplexes signal light and excitation light from a core **201***a* of the transmission line fiber **200**, and inputs the multiplexed light to a core **121***a* at the end face **122-2** of the MC-EDF **120**. As a result, the signal light input to the core **121***a* is excited by the core excitation and amplified.

[0183] The multiplexing unit **130** multiplexes signal light and the excitation light from a core **201***b* of the transmission line fiber **200**, and inputs the multiplexed light to a core **121***b* at an end face **122-1** of the MC-EDF **120** via one face **111***a* of the double-sided mirror **111**. As a result, the signal light input to the core **121***b* is excited by the core excitation and amplified.

[0184] The demultiplexing unit **131** (separator) demultiplexes the optical signal and the excitation light amplified by the core excitation. The demultiplexing unit **131** demultiplexes, for each core, the excitation light from the light output from the MC-EDF **120** and outputs the amplified signal light to a transmission line fiber **300**.

[0185] In the example of FIG. **18**, the demultiplexing unit **131** is disposed between an end face **302** of the transmission line fiber **300**, and the end face **122-1** of the MC-EDF **120** and the double-sided mirror **111** (disposed in front of the end face **302** of the transmission line fiber **300**). The demultiplexing unit **131** demultiplexes the light output from the core **121***a* at the end face **122-1** of the MC-EDF **120** into excitation light and signal light, and outputs the demultiplexed signal light to a core **301***a* of the transmission line fiber **300**. As a result, only the signal light amplified by the core **121***a* of the MC-EDF **120** is propagated.

[0186] The demultiplexing unit **131** demultiplexes the light output from the core **121***b* at the end face **122-1** of the

MC-EDF **120** via one side **111***b* of the double-sided mirror **111** into excitation light and signal light, and outputs the demultiplexed signal light to a core **301***b* of the transmission line fiber **300**. As a result, only the signal light amplified by the core **121***b* of the MC-EDF **120** is propagated.

[0187] FIG. **19** illustrates a configuration example of a case where cladding excitation is performed in the optical amplification apparatus **100** according to some example embodiments. In such a case, the MC-EDF **120** is a fiber having a double-clad structure including an inner cladding **122***a* (central-axis-side cladding) and an outer cladding **122***b* (outer-peripheral-side cladding).

[0188] In the example of FIG. **19**, in addition to the configuration of FIG. **9**, multiplexing/demultiplexing units **132-1** and **132-2** are provided. In order to perform cladding excitation, the multiplexing/demultiplexing units **132-1** and **132-2** (coupler-separators) multiplex the signal light for each core and the excitation light for cladding excitation, and also demultiplex the amplified optical signal and the excitation light by cladding excitation. The multiplexing/demultiplexing units **132-1** and **132-2** perform bidirectional excitation on the MC-EDF **120**.

[0189] In the example of FIG. **19**, the multiplexing/demultiplexing unit **132-1** is disposed between the end face **122-1** of the MC-EDF **120** and the double-sided mirror **111** (in front of the end face **122-1** of the MC-EDF **120**). The multiplexing/demultiplexing unit **132-1** multiplexes the signal light and the excitation light input from the core **201***b* of the transmission line fiber **200** via one side **111***a* of the double-sided mirror **111**, inputs the signal light to the core **121***b* at the end face **122-1**, and inputs the excitation light to an inner cladding **122***a* at the end face **122-1**. As a result, the signal light input to the core **121***b* is excited and amplified by cladding excitation.

[0190] The multiplexing/demultiplexing unit **132-2** is disposed between the end face **122-2** of the MC-EDF **120** and the double-sided mirror **111** (in front of the end face **122-2** of the MC-EDF **120**). The multiplexing/demultiplexing unit **132-2** multiplexes the signal light and the excitation light input from the core **201***a* of the transmission line fiber **200**, inputs the signal light to the core **121***a* at the end face **122-2**, and inputs the excitation light to the inner cladding **122***a* at the end face **122-2**. As a result, the signal light input to the core **121***a* is excited and amplified by cladding excitation.

[0191] Further, the multiplexing/demultiplexing unit **132-1** demultiplexes the light output from the core **121***a* at the end face **122-1** of the MC-EDF **120** and the inner cladding **122***a* into excitation light and signal light, and outputs the demultiplexed signal light to the core **301***a* of the transmission line fiber **300**. As a result, only the signal light amplified by the core **121***a* of the MC-EDF **120** is propagated.

[0192] The multiplexing/demultiplexing unit **132-2** demultiplexes the light output from the core **121***b* at the end face **122-2** of the MC-EDF **120** and the inner cladding **122***a* into excitation light and signal light, and outputs the demultiplexed signal light to the core **301***b* of the transmission line fiber **300** via the one face **111***b* of the double-sided mirror **111**. As a result, only the signal light amplified by the core **121***b* of the MC-EDF **120** is propagated.

[0193] As described above, in the MC-EDF of the optical amplification apparatus, core excitation may be performed or cladding excitation may be performed. Signal light of each core can be individually excited by core excitation. Signal light of a plurality of cores can be efficiently excited by one beam of excitation light by cladding excitation. For example, in the cladding excitation, by disposing a multiplexing/demultiplexing unit immediately before both end faces of the MC-EDF and performing bidirectional excitation, it is possible to prevent changes in gain and noise figure (NF) due to the transmission direction of signal light.

Fifth Example Embodiment

[0194] Next, a fifth example embodiment is described. In the present example embodiment, an example in which a propagation region of signal light is expanded between an MC-EDF and a transmission line fiber in the optical amplification apparatus illustrated in the second example embodiment is described. Note that, a method for expanding the propagation region of signal light according to the present example embodiment may be applied to the first modified example of the second example embodiment, the third example embodiment, and the first modified example and the second modified example of the third example embodiment.

[0195] FIG. **20** illustrates a configuration example of an optical amplification apparatus **100** according to some example embodiments. In the example of FIG. **20**, in addition to the configuration of FIG. **9**, expansion lenses **140-1** to **140-4** and parallel lenses **141-1** to **141-4** are provided. As illustrated in FIG. **20**, the expansion lenses **140-1** to **140-4** and the parallel lenses **141-1** to **141-4** are disposed in this order in front of the end faces of each fiber.

[0196] The expansion lenses **140-1** to **140-4** expand (in the width direction) the propagation region of signal light output from a fiber. Expanding a propagation region of signal light is to shift the optical axis of signal light (parallel light) in such a way that the distance between signal light being input and output by the plurality of cores is increased. The parallel lenses **141-1** to **141-4** convert the signal light the propagation region of which is expanded by the expansion lenses **140-1** to **140-4** into parallel light (collimated light). The expansion lenses **140-1** to **140-4** and the parallel lenses **141-1** to **141-4** may shift only the optical axis of the signal light being input and output to and from a double-sided mirror **111**. Note that, by inputting the signal light to the fiber via the parallel lenses **141-1** to **141-4** and the expansion lenses **140-1** to **140-4**, the propagation region of the signal light can be reduced to a size between the cores in the fiber. That is, the expansion lenses **140-1** to **140-4** and the parallel lenses **141-1** to **141-4** are also scaling units that expand and reduce the propagation region of the signal light.

[0197] In the example of FIG. **20**, the expansion lens **140-1** and the parallel lens **141-1** are disposed in front of an end face **122-1** of an MC-EDF **120**. The expansion lens **140-1** emits signal light output from a core **121***a* at the end face **122-1** toward a direction in which the propagation region expands (a side on which a distance from a core **121***b* increases). The parallel lens **141-1** emits the signal light output from the core **121***a* at the end face **122-1** and directed in the direction in which the propagation region is expanded by the expansion lens **140-1** toward the direction in which the signal light becomes parallel light. Specifically, the signal light is emitted to the parallel lens **141-4** on a transmission line fiber **300** side. Thus, the signal light output from the core **121***a* at the end face **122-1** can be propagated as parallel light the propagation region of which is expanded.

[0198] Further, the parallel lens **141-1** emits signal light input from a core **201***b* of a transmission line fiber **200** via the expansion lens **140-3**, the parallel lens **141-3**, and one face **111***a* of the double-sided mirror **111**, toward a direction in which the propagation region narrows (a core **121***b*-side of the end face **122-1**). The expansion lens **140-1** emits the signal light input via the one face **111***a* of the double-sided mirror **111** and directed in a direction in which the propagation region is narrowed by the parallel lens **141-1**, toward the core **121***b* of the end face **122-1**. Thus, the signal light from the core **201***b* of the transmission line fiber **200** and being parallel light the propagation region of which is expanded, can be input to the core **121***b* at the end face **122-1**.

[0199] The expansion lens **140-2** and the parallel lens **141-2** are disposed in front of an end face **122-2** of the MC-EDF **120**. The expansion lens **140-2** emits signal light output from the core **121***b* at the end face **122-2**, toward a direction in which the propagation region expands (a side on which the distance from the core **121***a* increases). The parallel lens **141-2** emits the signal light output from the core **121***b* at the end face **122-2** and directed in the direction in which the propagation region is expanded by the expansion lens **140-2**, toward a direction in which the signal light becomes parallel light. Specifically, the signal light is emitted to one side **111***b* of the double-sided mirror **111**. Thus, the signal light output from the core **121***b* at the end face **122-2** can be propagated as parallel light the propagation region of which is expanded.

[0200] Further, the parallel lens **141-2** emits signal light input from a core **201***a* of the transmission line fiber **200** via the expansion lens **140-3** and the parallel lens **141-3**, toward a direction in which the propagation region narrows (a core **121***a*-side of the end face **122-2**). The expansion lens **140-2** emits signal light input via the parallel lens **141-3** and directed in a direction in which the propagation region is narrowed by the parallel lens **141-2**, toward the core **121***a* at the end face **122-2**. As a result, the signal light from the core **201***a* of the transmission line fiber **200**, being parallel light the propagation region of which is expanded, can be input to the core **121***a* at the end face **122-2**.

[0201] The expansion lens **140-3** and the parallel lens **141-3** are disposed in front of the end face **202** of the transmission line fiber **200**. The expansion lens **140-3** emits the signal light output from the core **201***a* at the end face **202**, toward a direction in which the propagation region expands (a side on which the distance from the core **201***b* increases). The parallel lens **141-3** emits the signal light output from the core **201***a* at the end face **202** and directed in a direction in which the propagation region is expanded by the expansion lens **140-3**, toward a direction in which the signal light becomes parallel light. Specifically, the signal light is output to the parallel lens **141-2** on the end face **122-2**-side of the MC-EDF **120**. Thus, the signal light output from the core **201***a* at the end face **202** of the transmission line fiber **200** can be propagated as parallel light the propagation region of which is expanded.

[0202] Further, the expansion lens **140-3** emits the signal light output from the core **201***b* at the end face **202** toward a direction in which the propagation region expands (a side on which the distance from the core **201***a* increases). The parallel lens **141-3** emits the signal light output from the core **201***b* at the end face **202** and directed in a direction in which the propagation region is expanded by the expansion lens **140-3**, toward a direction in which the signal light becomes parallel light. Specifically, the signal light is output to the one side **111***a* of the double-sided mirror **111**. Thus, the signal light output from the core **201***b* at the end face **202** of the transmission line fiber **200** can be propagated as parallel light the propagation region of which is expanded.

[0203] The expansion lens **140-4** and the parallel lens **141-4** are disposed in front of an end face **302** of the transmission line fiber **300**. The parallel lens **141-4** emits the signal light output from the core **121***a* at the end face **122-1** of the MC-EDF **120** via the expansion lens **140-1** and the parallel lens **141-1**, toward a direction in which the propagation region narrows (a core **301***b*-side of the end face **302**). The expansion lens **140-4** emits signal light output via the parallel lens **141-1** and directed in a direction in which the propagation region is narrowed by the parallel lens **141-4**, toward a core **301***a* at the end face **302**. Thus, the signal light from the core **121***a* at the end face **122-1** of the MC-EDF **120**, being parallel light the propagation region of which is expanded, can be input to the core **301***a* at the end face **302** of the transmission line fiber **300**.

[0204] Further, the parallel lens **141-4** emits the signal light output from the core **121***b* at the end face **122-2** of the MC-EDF **120** via the expansion lens **140-2**, the parallel lens **141-2**, and the one side **111***b* of the double-sided mirror **111**, toward a direction in which the propagation region narrows (a core **301***a*-side of the end face **302**). The expansion lens **140-4** emits the signal light output from the one side **111***b* of the double-sided mirror **111** and directed in a direction in which the propagation region is narrowed by the parallel lens **141-4**, toward the core **301***b* at the end face **302**. Thus, the signal light from the core **121***b* at the end face **122-2** of the MC-EDF **120** via the one side **111***b* of the double-sided mirror **111**, being parallel light the propagation region of which is expanded, can be input to the core **301***b* at the end face **302** of the transmission line fiber **300**.

[0205] As described above, in the optical amplification apparatus, an optical component such as a lens may be added in front of each fiber to expand a propagation region of signal light. Thus, the double-sided mirror can be easily disposed. For example, merely collimating the light output from the core requires micron-level processing in order to dispose the double-sided mirror. By shifting in parallel the optical axis of light output from the core by the optical component, it is possible to dispose the double-sided mirror with an accuracy of mm to cm level.

[0206] Although the present disclosure has been described with reference to the example embodiments, the present disclosure is not limited to the above-described example embodiments. Various changes that can be understood by a person skilled in the art within the scope of the present disclosure can be made to the configuration and details of the present disclosure. Each example embodiment can be combined with other example embodiments as appropriate.

[0207] The drawings are merely illustrative of one or more example embodiments.

[0208] Each drawing may not be associated with only one particular example embodiment, but may be associated with one or more other example embodiments. As those skilled in the art will appreciate, various features or steps described with reference to any one of the drawings may be combined with features or steps illustrated in one or more other figures, for example, to generate example embodiments not explicitly illustrated or described. All of the features or steps illustrated in any one of the figures to describe the example embodiments are not necessarily essential, and some features or steps may be omitted. The order of the steps described in any of the figures may be changed as appropriate.

[0209] Some or all of the above-described example embodiments may be described as the following supplementary notes, but are not limited thereto.

(Supplementary Note 1)

[0210] An optical amplification apparatus being connected between a first multi-core fiber and a second multi-core fiber, including:

- **[0211]** a switching unit configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and
- **[0212]** an amplification unit configured to amplify the signal light being bidirectionally transmitted.

(Supplementary Note 2)

[0213] The optical amplification apparatus according to supplementary note 1, wherein

- **[0214]** the amplification unit includes a multi-core optical amplification fiber,
- **[0215]** the multi-core optical amplification fiber is fixed in such a way that a first end face of the multi-core optical amplification fiber and a second end face of the multi-core optical amplification fiber face each other at a predetermined angle, and
- **[0216]** the switching unit includes:
  - **[0217]** a first reflection unit configured to reflect signal light being output from a first input-side core of the first multi-core fiber in such a way as to input the reflected signal light into a first amplification core at the first end face of the multi-core optical amplification fiber; and
  - **[0218]** a second reflection unit configured to reflect signal light being output from the first amplification core at the second end face of the multi-core optical amplification fiber in such a way as to input the reflected signal light into a first output-side core of the second multi-core fiber.

(Supplementary Note 3)

[0219] The optical amplification apparatus according to supplementary note 2, wherein the first reflection unit and the second reflection unit are disposed at an intersection of a central axis line of the first amplification core at the first end face of the multi-core optical amplification fiber and a central axis line of the first amplification core at the second end face.

(Supplementary Note 4)

[0220] The optical amplification apparatus according to supplementary note 2 or 3, wherein the first reflection unit is a first single-sided mirror, and the second reflection unit is a second single-sided mirror.

(Supplementary Note 5)

[0221] The optical amplification apparatus according to supplementary note 2 or 3, wherein the first reflection unit and the second reflection unit are a double-sided mirror.

(Supplementary Note 6)

[0222] The optical amplification apparatus according to supplementary note 2 or 3, wherein the first end face and the second end face are fixed in such a way as to face each other in a state where one of the first end face and the second end face is rotated at a predetermined angle.

(Supplementary Note 7)

[0223] The optical amplification apparatus according to supplementary note 2 or 3, wherein the switching unit is configured to input signal light being output from a second input-side core of the first multi-core fiber, to a second amplification core at the second end face of the multi-core optical amplification fiber, and input signal light being output from the second amplification core at the first end face of the multi-core optical amplification fiber, to a second output-side core of the second multi-core fiber.

(Supplementary Note 8)

[0224] The optical amplification apparatus according to supplementary note 2 or 3, wherein

- **[0225]** the multi-core optical amplification fiber is a multi-core fiber having a double-clad structure, and
- **[0226]** the optical amplification apparatus further includes:
  - **[0227]** a first multiplexing unit configured to multiplex signal light being input to the first end face of the multi-core optical amplification fiber with excitation light, and input the multiplexed excitation light to a cladding on a central axis side at the first end face; and
- **[0228]** a second multiplexing unit configured to multiplex signal light being input to the second end face of the multi-core optical amplification fiber with excitation light, and input the multiplexed excitation light to a cladding on a central axis side at the second end face.

(Supplementary Note 9)

[0229] The optical amplification apparatus according to supplementary note 2 or 3, further including an expansion unit configured to expand a propagation region of signal light being input/output, the expansion unit being disposed between the first end face of the multi-core optical amplification fiber and the first multi-core fiber, and between the second end face of the multi-core optical amplification fiber and the second multi-core fiber.

(Supplementary Note 10)

[0230] An optical transmission system including:

- **[0231]** a first multi-core fiber;
- **[0232]** a second multi-core fiber; and
- **[0233]** an optical amplification apparatus connected between the first multi-core fiber and the second multi-core fiber,

[0234] wherein the optical amplification apparatus includes

[0235] a switching unit configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission, and

[0236] an amplification unit configured to amplify the signal light being bidirectionally transmitted.

(Supplementary Note 11)

[0237] An optical amplification method for an optical amplification apparatus being connected between a first multi-core fiber and a second multi-core fiber, the method including:

[0238] switching a transmission direction of signal light, being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and

[0239] amplifying the signal light being bidirectionally transmitted.

[0240] Some or all of the elements (e.g., configurations and functions) described in supplementary notes 2 to 9 depending on supplementary note 1 (optical amplification apparatus) may be dependent on supplementary note 10 (optical transmission system) and supplementary note 11 (optical amplification method) according to the same dependencies as supplementary notes 2 to 9. Some or all of the elements described in any supplementary note may be applied to various hardware, software, recording means for recording software, systems, and methods.

What is claimed is:

1. An optical amplification apparatus being connected between a first multi-core fiber and a second multi-core fiber, comprising:

a switch configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and

an amplifier configured to amplify the signal light being bidirectionally transmitted.

2. The optical amplification apparatus according to claim **1**, wherein

the amplifier includes a multi-core optical amplification fiber,

the multi-core optical amplification fiber is fixed in such a way that a first end face of the multi-core optical amplification fiber and a second end face of the multi-core optical amplification fiber face each other at a predetermined angle, and

the switch includes:

a first reflector configured to reflect signal light being output from a first input-side core of the first multi-core fiber in such a way as to input the reflected signal light into a first amplification core at the first end face of the multi-core optical amplification fiber; and

a second reflector configured to reflect signal light being output from the first amplification core at the second end face of the multi-core optical amplification fiber in such a way as to input the reflected signal light into a first output-side core of the second multi-core fiber.

3. The optical amplification apparatus according to claim **2**, wherein the first reflector and the second reflector are disposed at an intersection of a central axis line of the first amplification core at the first end face of the multi-core optical amplification fiber and a central axis line of the first amplification core at the second end face.

4. The optical amplification apparatus according to claim **2**, wherein the first reflector is a first single-sided mirror and the second reflector is a second single-sided mirror.

5. The optical amplification apparatus according to claim **2**, wherein the first reflector and the second reflector are a double-sided mirror.

6. The optical amplification apparatus according to claim **2**, wherein the first end face and the second end face are fixed in such a way as to face each other in a state where one of the first end face and the second end face is rotated at a predetermined angle.

7. The optical amplification apparatus according to claim **2**, wherein the switch is configured to input signal light being output from a second input-side core of the first multi-core fiber, to a second amplification core at the second end face of the multi-core optical amplification fiber, and input signal light being output from the second amplification core at the first end face of the multi-core optical amplification fiber, to a second output-side core of the second multi-core fiber.

8. The optical amplification apparatus according to claim **2**, wherein

the multi-core optical amplification fiber is a multi-core fiber having a double-clad structure, and

the optical amplification apparatus further comprises:

a first multiplexer configured to multiplex signal light being input to the first end face of the multi-core optical amplification fiber with excitation light, and input the multiplexed excitation light to a cladding on a central axis side at the first end face; and

a second multiplexer configured to multiplex signal light being input to the second end face of the multi-core optical amplification fiber with excitation light, and input the multiplexed excitation light to a cladding on a central axis side at the second end face.

9. The optical amplification apparatus according to claim **2**, further comprising an expander configured to expand a propagation region of signal light being input/output, the expander being disposed between the first end face of the multi-core optical amplification fiber and the first multi-core fiber, and between the second end face of the multi-core optical amplification fiber and the second multi-core fiber.

10. An optical transmission system comprising:

a first multi-core fiber;

a second multi-core fiber; and

an optical amplification apparatus connected between the first multi-core fiber and the second multi-core fiber,

wherein the optical amplification apparatus includes

a switch configured to switch a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission, and

an amplifier configured to amplify the signal light being bidirectionally transmitted.

11. The optical transmission system according to claim **10**, wherein

the amplifier includes a multi-core optical amplification fiber, the multi-core optical amplification fiber is fixed in such a way that a first end face of the multi-core optical amplification fiber and a second end face of the multi-core optical amplification fiber face each other at a predetermined angle, and

the switch includes:

a first reflector configured to reflect signal light being output from a first input-side core of the first multi-core fiber in such a way as to input the reflected signal light into a first amplification core at the first end face of the multi-core optical amplification fiber; and

a second reflector configured to reflect signal light being output from the first amplification core at the second end face of the multi-core optical amplification fiber in such a way as to input the reflected signal light into a first output-side core of the second multi-core fiber.

12. An optical amplification method for an optical amplification apparatus being connected between a first multi-core fiber and a second multi-core fiber, the method comprising:

switching a transmission direction of signal light being unidirectionally transmitted in the first multi-core fiber and the second multi-core fiber, into bidirectional transmission; and

amplifying the signal light being bidirectionally transmitted.

13. The optical amplification method according to claim **12**, wherein

the amplification is performed in a multi-core optical amplification fiber,

the multi-core optical amplification fiber is fixed in such a way that a first end face of the multi-core optical amplification fiber and a second end face of the multi-core optical amplification fiber face each other at a predetermined angle, and

the switching includes:

reflecting, by a first reflector, signal light being output from a first input-side core of the first multi-core fiber in such a way as to input the reflected signal light into a first amplification core at the first end face of the multi-core optical amplification fiber; and

reflecting, by a second reflector, signal light being output from the first amplification core at the second end face of the multi-core optical amplification fiber in such a way as to input the reflected signal light into a first output-side core of the second multi-core fiber.

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