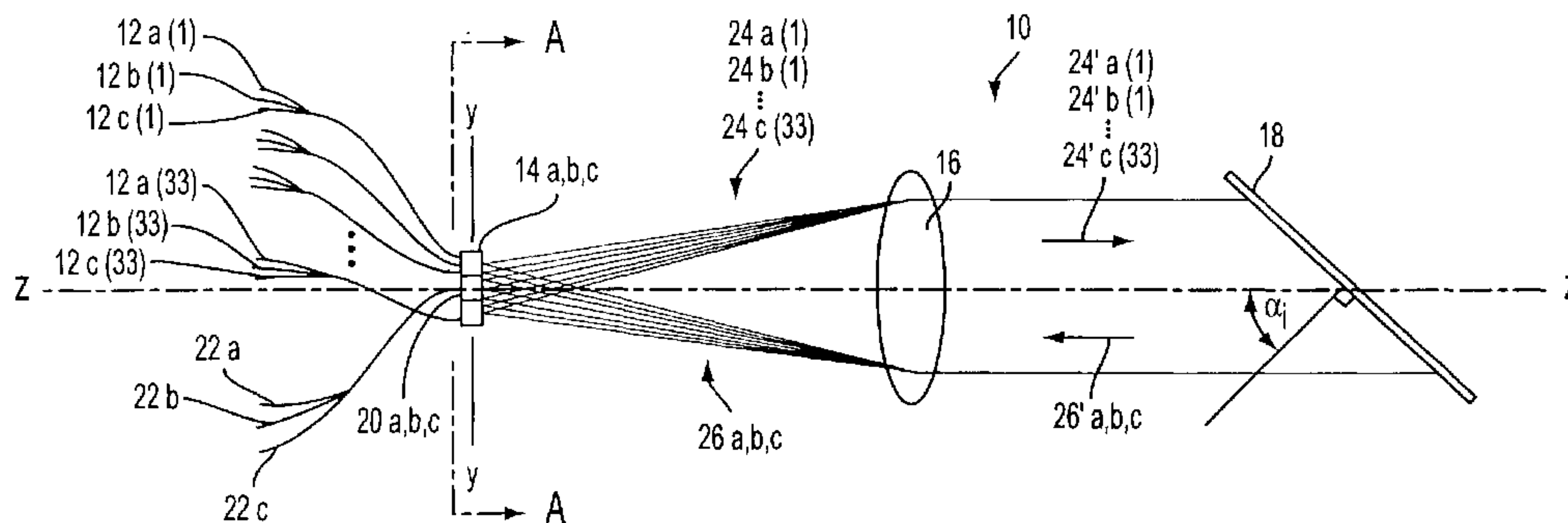




(86) Date de dépôt PCT/PCT Filing Date: 2001/05/31
 (87) Date publication PCT/PCT Publication Date: 2001/12/06
 (85) Entrée phase nationale/National Entry: 2002/12/02
 (86) N° demande PCT/PCT Application No.: US 2001/017503
 (87) N° publication PCT/PCT Publication No.: 2001/092935
 (30) Priorité/Priority: 2000/05/31 (09/583,764) US

(51) Cl.Int.⁷/Int.Cl.⁷ H04J 14/02, G02B 6/34, G02B 6/293
 (71) Demandeur/Applicant:
LIGHTCHIP, INC., US
 (72) Inventeurs/Inventors:
DEMPEWOLF, JOSEPH R., US;
WADE, ROBERT K., US;
TURNER, IAN, US
 (74) Agent: BERESKIN & PARR

(54) Titre : DISPOSITIFS DE MULTIPLEXAGE/DEMULPLEXAGE EN LONGUEUR D'ONDE ULTRA-DENSE
 (54) Title: ULTRA-DENSE WAVELENGTH DIVISION MULTIPLEXING/DEMULPLEXING DEVICES



(57) **Abrégé/Abstract:**

An ultra-dense wavelength division multiplexing device (10) is used for combining at least one plurality of monochromatic optical beams into a corresponding at least one single, multiplexed, polychromatic optical beam, wherein the wavelength division multiplexing device has an input element and an output element. A plurality of optical input devices (12) is disposed proximate the input element; wherein each of the plurality of optical input devices (12) communicates a plurality of monochromatic optical beams to the wavelength division multiplexing device for combining the plurality of monochromatic optical beams into a single, multiplexed, polychromatic optical beam (24). A corresponding plurality of optical output devices (22) is disposed proximate the output element, wherein each of the plurality of optical output devices (22) receives a corresponding single, multiplexed polychromatic optical beam (26).

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

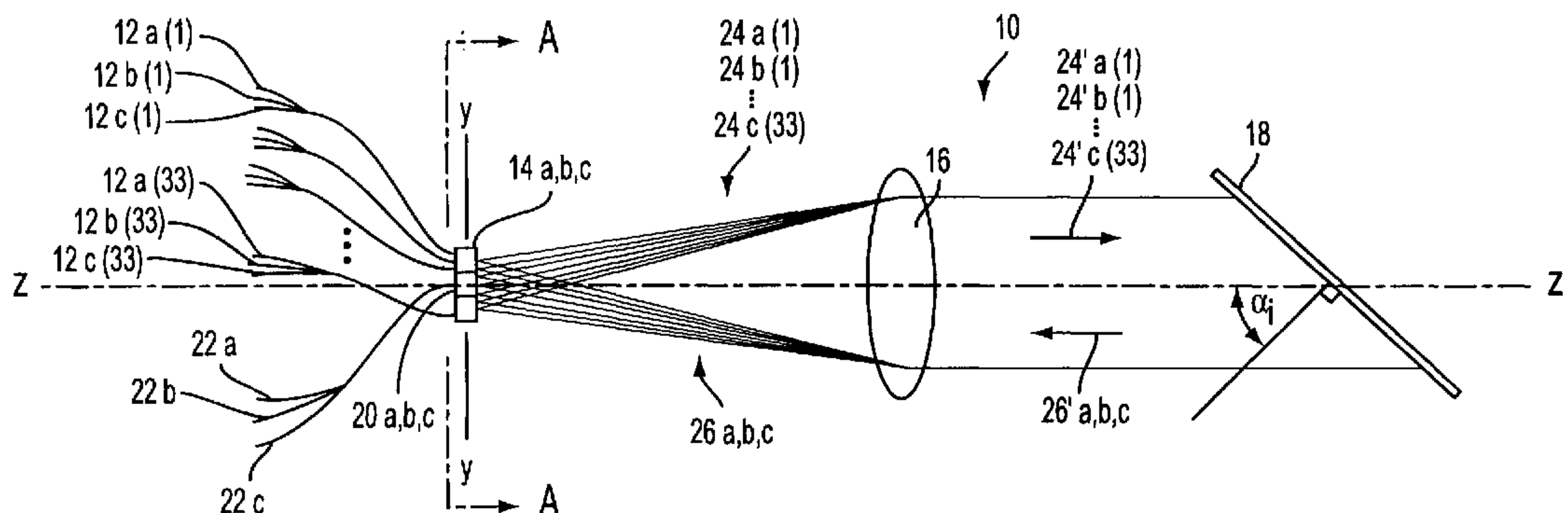
(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
6 December 2001 (06.12.2001)

PCT

(10) International Publication Number
WO 01/92935 A1

- (51) International Patent Classification⁷: G02B 6/34
- (21) International Application Number: PCT/US01/17503
- (22) International Filing Date: 31 May 2001 (31.05.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/583,764 31 May 2000 (31.05.2000) US
- (71) Applicant: LIGHTCHIP, INC. [US/US]; 27 Northwestern Drive, Salem, NH 03079 (US).
- (72) Inventors: DEMPEWOLF, Joseph, R.; 308 Rim Road, Des Moines, NM 87571 (US). WADE, Robert, K.; 2625 NW 31st Street, Boca Raton, FL 33434 (US). TURNER, Ian; 25 Winding Brook Drive, Stratham, NH 03885 (US).
- (74) Agents: ANDERSON, Thomas, E. et al.; Hunton & Williams, 1900 K Street, N.W., Washington, DC 20006 (US).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- Published:**
— with international search report
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: ULTRA-DENSE WAVELENGTH DIVISION MULTIPLEXING/DEMULTIPLEXING DEVICES



(57) **Abstract:** An ultra-dense wavelength division multiplexing device (10) is used for combining at least one plurality of monochromatic optical beams into a corresponding at least one single, multiplexed, polychromatic optical beam, wherein the wavelength division multiplexing device has an input element and an output element. A plurality of optical input devices (12) is disposed proximate the input element; wherein each of the plurality of optical input devices (12) communicates a plurality of monochromatic optical beams to the wavelength division multiplexing device for combining the plurality of monochromatic optical beams into a single, multiplexed, polychromatic optical beam (24). A corresponding plurality of optical output devices (22) is disposed proximate the output element, wherein each of the plurality of optical output devices (22) receives a corresponding single, multiplexed polychromatic optical beam (26).



WO 01/92935 A1

ULTRA-DENSE WAVELENGTH DIVISION
MULTIPLEXING/DEMULTIPLEXING DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation-in-part
5 application of U.S. Patent Application No. 09/257,045
(Attorney Docket No. 34013-00008, Client Reference No. D-
97031-CNT), filed February 25, 1999; U.S. Patent Application
No. 09/323,094 (Attorney Docket No. 34013-00010, Client
Reference No. D-99001), filed June 1, 1999; U.S. Patent
10 Application No. 09/342,142 (Attorney Docket No. 34013-00011,
Client Reference No. D-99002), filed June 29, 1999; U.S.
Patent Application No. 09/382,492 (Attorney Docket No. 34013-
00013, Client Reference No. D-99004), filed August 25, 1999;
U.S. Patent Application No. 09/382,624 (Attorney Docket No.
15 34013-00014, Client Reference No. D-99005), filed August 25,
1999; U.S. Patent Application No. 09/363,041 (Attorney Docket
No. 34013-00023, Client Reference No. D-99014), filed July 29,
1999; U.S. Patent Application No. 09/363,042 (Attorney Docket
No. 34013-00024, Client Reference No. D-99015), filed July 29,
20 1999; U.S. Patent Application No. 09/392,670 (Attorney Docket
No. 34013-00025, Client Reference No. D-99016), filed
September 8, 1999; and U.S. Patent Application No. 09/392,831

(Attorney Docket No. 34013-00026, Client Reference No. D-99017), filed September 8, 1999; all of which are hereby incorporated herein by reference.

FIELD OF THE INVENTION

5 The present invention relates generally to wavelength division multiplexing and demultiplexing and, more particularly, to ultra-dense wavelength division multiplexing/demultiplexing devices.

BACKGROUND OF THE INVENTION

10 Wavelength division multiplexing (WDM) is a rapidly emerging technology that enables a very significant increase in the aggregate volume of data that can be transmitted over optical fibers. Prior to the use of WDM, most optical fibers were used to unidirectionally carry only a single data channel
15 at one wavelength. The basic concept of WDM is to launch and retrieve multiple data channels in and out, respectively, of an optical fiber. Each data channel is transmitted at a unique wavelength, and the wavelengths are appropriately selected such that the channels do not interfere with each
20 other, and the optical transmission losses of the fiber are

low. Today, commercial WDM systems exist that allow for the transmission of 2 to 100 simultaneous data channels.

WDM is a cost-effective method of increasing the volume of data (commonly termed bandwidth) transferred over optical fibers. Alternate competing technologies for increasing bandwidth include the burying of additional fiber optic cable or increasing the optical transmission rate over optical fiber. The burying of additional fiber optic cable is quite costly as it is presently on the order of \$15,000 to \$40,000 per kilometer. Increasing the optical transmission rate is limited by the speed and economy of the electronics surrounding the fiber optic system. One of the primary strategies for electronically increasing bandwidth has been to use time division multiplexing (TDM), which groups or multiplexes multiple lower rate electronic data channels together into a single very high rate channel. This technology has for the past 20 years been very effective for increasing bandwidth. However, it is now increasingly difficult to improve transmission speeds, both from a technological and an economical standpoint. WDM offers the potential of both an economical and technological solution to increasing bandwidth by using many parallel channels.

Further, WDM is complimentary to TDM. That is, WDM can allow many simultaneous high transmission rate TDM channels to be passed over a single optical fiber.

5 The use of WDM to increase bandwidth requires two basic devices that are conceptually symmetrical. The first device is a wavelength division multiplexer. This device takes multiple beams, each with discrete wavelengths that are initially spatially separated in space, and provides a means for spatially combining all of the different wavelength beams
10 into a single polychromatic beam suitable for launching into an optical fiber. The multiplexer may be a completely passive optical device or may include electronics that control or monitor the performance of the multiplexer. The input to the multiplexer is typically accomplished with optical fibers,
15 although laser diodes or other optical sources may also be employed. As mentioned above, the output from the multiplexer is a single polychromatic beam which is typically directed into an optical fiber.

The second device for WDM is a wavelength division
20 demultiplexer. This device is functionally the opposite of the wavelength division multiplexer. That is, the wavelength division demultiplexer receives a polychromatic beam from an

optical fiber and provides a means of spatially separating the
different wavelengths of the polychromatic beam. The output
from the demultiplexer is a plurality of monochromatic beams
which are typically directed into a corresponding plurality of
5 optical fibers or photodetectors.

To date, most WDM devices have been directed toward
multiplexing or demultiplexing a standard number of data
channels. For example, many WDM devices are specifically
manufactured to multiplex 33 individual data channels being
10 carried on 33 corresponding monochromatic beams into a single
polychromatic beam carrying all 33 data channels, or to
demultiplex a single polychromatic beam carrying 33 separate
data channels into 33 individual monochromatic beams each
carrying a corresponding data channel. These WDM devices are
15 typically limited to 33 data channels due to the manner in
which they have been manufactured and the technologies
employed to perform the multiplexing and demultiplexing
functions therein. For example, WDM devices employing fiber
Bragg gratings and/or array waveguide gratings to perform
20 multiplexing and demultiplexing functions are typically
limited to the number of data channels that the WDM devices
were specifically manufactured to handle. Thus, if additional

numbers of data channels need to be multiplexed and/or demultiplexed, additional WDM devices are required, at a corresponding additional cost. Alternatively, enhanced WDM devices employing these technologies may be designed to accommodate additional numbers of data channels, but with corresponding additional design, manufacturing, and testing costs. Also, such enhanced WDM devices are typically larger in size so as to accommodate the increased number of data channels, thereby requiring more space to operate, which usually translates into additional packaging costs.

In view of the foregoing, it would be desirable to provide a WDM device which overcomes the above-described inadequacies and shortcomings. More particularly, it would be desirable to provide an ultra-dense WDM device which can accommodate additional data channels without requiring additional WDM devices or significant design modifications.

OBJECTS OF THE INVENTION

The primary object of the present invention is to provide ultra-dense wavelength division multiplexing/demultiplexing devices.

The above-stated primary object, as well as other objects, features, and advantages, of the present invention will become readily apparent from the following summary and detailed descriptions, which are to be read in conjunction with the appended drawings.

SUMMARY OF THE INVENTION

According to the present invention, ultra-dense wavelength division multiplexing/demultiplexing devices are provided. In the case of an ultra-dense wavelength division multiplexing device, a wavelength division multiplexing device is used for combining at least one plurality of monochromatic optical beams into a corresponding at least one single, multiplexed, polychromatic optical beam, wherein the wavelength division multiplexing device has an input element and an output element. A plurality of optical input devices is disposed proximate the input element, wherein each of the plurality of optical input devices communicates a plurality of monochromatic optical beams to the wavelength division multiplexing device for combining the plurality of monochromatic optical beams into a single, multiplexed, polychromatic optical beam. A corresponding plurality of

optical output devices is disposed proximate the output element, wherein each of the plurality of optical output devices receives a corresponding single, multiplexed, polychromatic optical beam.

5 In accordance with other aspects of the present invention, the wavelength division multiplexing device comprises a diffraction grating for combining the at least one plurality of monochromatic optical beams into the corresponding at least one single, multiplexed, polychromatic
10 optical beam. The diffraction grating is preferably a reflective diffraction grating oriented at the Littrow diffraction angle. Alternatively, the diffraction grating can be a transmissive diffraction grating.

 In accordance with further aspects of the present
15 invention, the input element can beneficially be one of several items such as, for example, a collimating lens or a boot lens. Similarly, the output element can beneficially be one of several items such as, for example, a focusing lens or a boot lens.

20 In accordance with still further aspects of the present invention, the plurality of optical input devices is beneficially a plurality of input fiber coupling devices,

wherein each of the plurality of input fiber coupling devices is arranged into an array of optical fibers, and each of the optical fibers transmits a monochromatic optical beam to the wavelength division multiplexing device. Also, the plurality of optical input devices is beneficially a plurality of laser diode coupling devices, wherein each of the plurality of laser diode coupling devices is arranged into an array of laser diodes, and each of the laser diodes transmits a monochromatic optical beam to the wavelength division multiplexing device. Further, the plurality of optical output devices is beneficially a plurality of output fiber coupling devices, wherein each of the plurality of output fiber coupling devices maintains at least one optical fiber, and each optical fiber receives a single, multiplexed, polychromatic optical beam from the wavelength division multiplexing device.

In the case of an ultra-dense wavelength division demultiplexing device, a wavelength division demultiplexing device is used for separating at least one multiplexed, polychromatic optical beam into a corresponding at least one plurality of monochromatic optical beams, wherein the wavelength division demultiplexing device has an input element and an output element. A plurality of optical input devices

is disposed proximate the input element, wherein each of the plurality of optical input devices communicates a single, multiplexed, polychromatic optical beam to the wavelength division demultiplexing device for separating the single, multiplexed, polychromatic optical beam into a plurality of monochromatic optical beams. A corresponding plurality of optical output devices is disposed proximate the output element, wherein each of the plurality of optical output devices receives a corresponding plurality of monochromatic optical beams.

In accordance with other aspects of the present invention, the wavelength division demultiplexing device comprises a diffraction grating for separating the at least one multiplexed, polychromatic optical beam into the corresponding at least one plurality of monochromatic optical beams. The diffraction grating is preferably a reflective diffraction grating oriented at the Littrow diffraction angle. Alternatively, the diffraction grating can be a transmissive diffraction grating.

In accordance with further aspects of the present invention, the input element can beneficially be one of several items such as, for example, a collimating lens or a

boot lens. Similarly, the output element can beneficially be one of several items such as, for example, a focusing lens or a boot lens.

In accordance with still further aspects of the present invention, the plurality of optical input devices is beneficially a plurality of input fiber coupling devices, wherein each of the plurality of input fiber coupling devices maintains at least one optical fiber, and each optical fiber transmits a single, multiplexed, polychromatic optical beam to the wavelength division demultiplexing device. Also, the plurality of optical output devices is beneficially a plurality of output fiber coupling devices, wherein each of the plurality of output fiber coupling devices is arranged into an array of optical fibers, and each of the optical fibers receives a monochromatic optical beam from the wavelength division demultiplexing device. Further, the plurality of optical output devices is beneficially a plurality of photodetector coupling devices, wherein each of the plurality of photodetector coupling devices is arranged into an array of photodetectors, and each of the photodetectors receives a monochromatic optical beam from the wavelength division demultiplexing device.

In accordance with still further aspects of the present invention, the at least one multiplexed, polychromatic optical beam can be at least two multiplexed, polychromatic optical beams. If such is the case, the ultra-dense wavelength division demultiplexing device may further comprise a splitter for splitting a single, pre-split, multiplexed, polychromatic optical beam into the at least two multiplexed, polychromatic optical beams. The single, pre-split, multiplexed, polychromatic optical beam can be split equally or unequally. Also, the single, pre-split, multiplexed, polychromatic optical beam can be split in several manners such as, for example, according to beam wavelengths or according to beam intensity.

The present invention also encompasses a method for increasing channel throughput in a wavelength division demultiplexing device. The method comprises splitting a single, multiplexed, polychromatic optical beam into at least two multiplexed, polychromatic optical beams, and then simultaneously separating each of the at least two multiplexed, polychromatic optical beams into a corresponding at least two pluralities of monochromatic optical beams. The method also preferably comprises collimating each of the at

least two multiplexed, polychromatic optical beams, and focusing the corresponding at least two pluralities of monochromatic optical beams.

BRIEF DESCRIPTION OF THE DRAWINGS

5 In order to facilitate a fuller understanding of the present invention, reference is now made to the appended drawings. These drawings should not be construed as limiting the present invention, but are intended to be exemplary only.

10 Figure 1a is a side view of an ultra-dense wavelength division multiplexing device having a plurality of optical input devices and a plurality of optical output devices in accordance with the present invention.

Figure 1b is a top view of the ultra-dense wavelength division multiplexing device shown in Figure 1a.

15 Figure 1c is an end view of a portion of the ultra-dense wavelength division multiplexing device shown in Figure 1a.

20 Figure 2a is a perspective view of a coupling device containing a plurality of laser diodes for replacing the plurality of optical input fibers in the multiplexing device shown in Figure 1a.

Figure 2b is a perspective view of a coupling device containing a plurality of photodetectors for replacing the plurality of optical input fibers in the demultiplexing device shown in Figure 3a.

5 Figure 3a is a side view of an ultra-dense wavelength division demultiplexing device having a plurality of optical input devices and a plurality of optical output devices in accordance with the present invention.

10 Figure 3b is a top view of the ultra-dense wavelength division demultiplexing device shown in Figure 3a.

Figure 4 is a top view of a demultiplexing system employing an ultra-dense wavelength division demultiplexing device having a plurality of optical input devices and a plurality of optical output devices in accordance with the present invention.

15

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figures 1a and 1b, there are shown a side view and a top view, respectively, of a preferred embodiment of an ultra-dense wavelength division multiplexing/demultiplexing device 10 in accordance with the present invention. The multiplexing device 10 comprises a

20

plurality of optical input fibers 12, a plurality of input
fiber coupling devices 14, a collimating/focusing lens 16, a
reflective diffraction grating 18, a plurality of output fiber
coupling devices 20, and a plurality of optical output fibers
5 22. All of the above-identified components of the
multiplexing device 10 are disposed along an optical axis Z-Z
of the multiplexing device 10, as will be described in more
detail below.

At this point it should be noted that the optical input
10 fibers 12 and the optical output fibers 22, as well as any
other optical fibers described herein as being used in
conjunction with WDM devices in accordance with the present
invention, are single mode optical fibers. Of course,
however, this does not limit the present invention WDM devices
15 to use with only single mode optical fibers. For example, the
present invention WDM devices can also be used with multimode
optical fibers.

The plurality of optical input fibers 12 are grouped into
three one-dimensional input fiber arrays (i.e., three 1 x 33
20 arrays) by the plurality of input fiber coupling devices 14,
while each of the plurality of optical output fibers 22 is
secured to a corresponding one of the plurality of output

fiber coupling devices 20. Both the input fiber coupling devices 14 and the output fiber coupling devices 20 are used for purposes of ease of optical fiber handling and precision placement, and can be formed of, for example, silicon V-groove assemblies. Referring to Figure 1c, there is shown an end view of the plurality of input fiber coupling devices 14 and the plurality of output fiber coupling devices 20, along section A-A of Figures 1a and 1b. Each of the plurality of input fiber coupling devices 14 is arranged as a 1 x 33 array for precisely and securely positioning thirty-three of the plurality of optical input fibers 12, while each of the plurality of output fiber coupling devices 20 precisely and securely positions a corresponding one of the plurality of optical output fibers 22.

Returning to Figures 1a and 1b, each of the plurality of optical input fibers 12 transmits a single, monochromatic optical input beam 24, while each of the plurality of optical output fibers 22 receives a single, multiplexed, polychromatic optical output beam 26. Each of the monochromatic optical input beams 24 being transmitted from the plurality of optical input fibers 12 is carrying a single channel of data at a unique wavelength, which is preferably, but not required to

be, within the infrared (IR) region of the electromagnetic spectrum. The single channel of data that is being carried by each monochromatic optical input beam 24 is superimposed on each corresponding unique wavelength by means (e.g., laser diodes connected to the plurality of optical input fibers 12), which are not shown here and which do not form a part of this invention, but are well known in the art. The unique wavelengths of the monochromatic optical input beams 24 are appropriately preselected such that the data channels do not interfere with each other (i.e., there is sufficient channel spacing), and the optical transmission losses through both the optical input fibers 12 and the optical output fibers 22 are low, as is also well known in the art.

Each of the multiplexed, polychromatic optical output beams 26 being received by the plurality of optical output fibers 22 is carrying a plurality of channels of data at the unique wavelengths of corresponding ones of the plurality of monochromatic optical input beams 24. That is, a first of the multiplexed, polychromatic optical output beams 26a is carrying a plurality of channels of data (e.g., 33 channels of data) at the unique wavelengths of the monochromatic optical input beams 24a that are transmitted from the optical input

fibers 12a being precisely and securely positioned by a first
of the plurality of input fiber coupling devices 14a.
Similarly, a second of the multiplexed, polychromatic optical
output beams 26b is carrying a plurality of channels of data
5 (e.g., 33 channels of data) at the unique wavelengths of the
monochromatic optical input beams 24b that are transmitted
from the optical input fibers 12b being precisely and securely
positioned by a second of the plurality of input fiber
coupling devices 14b. Similarly still, a third of the
10 multiplexed, polychromatic optical output beams 26c is
carrying a plurality of channels of data (e.g., 33 channels of
data) at the unique wavelengths of the monochromatic optical
input beams 24c that are transmitted from the optical input
fibers 12c being precisely and securely positioned by a third
15 of the plurality of input fiber coupling devices 14c.

The plurality of monochromatic optical input beams 24a
are combined into the multiplexed, polychromatic optical
output beam 26a through the combined operation of the
collimating/focusing lens 16 and the reflective diffraction
20 grating 18, as will be described in more detail below.
Similarly, the plurality of monochromatic optical input beams
24b are combined into the multiplexed, polychromatic optical

output beam 26b through the combined operation of the collimating/focusing lens 16 and the reflective diffraction grating 18, as will be described in more detail below. Similarly still, the plurality of monochromatic optical input beams 24c are combined into the multiplexed, polychromatic optical output beam 26c through the combined operation of the collimating/focusing lens 16 and the reflective diffraction grating 18, as will be described in more detail below.

At this point it should be noted that the input fiber coupling device 14a and the output fiber coupling device 20a are disposed offset from, but symmetrically about, the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26a is directed to the optical output fiber 22a secured to the output fiber coupling device 20a, and not to any of the other optical output fibers 22, or anywhere else. This offset spacing of the input fiber coupling device 14a and the output fiber coupling device 20a is determined based upon the focusing power of the collimating/focusing lens 16, as well as the characteristics of the diffraction grating 18 and the wavelengths of each of the monochromatic optical input beams 24a.

Similarly, the input fiber coupling device 14b and the output fiber coupling device 20b are disposed offset from, but symmetrically about, the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26b is directed to the optical output fiber 22b secured to the output fiber coupling device 20b, and not to any of the other optical output fibers 22, or anywhere else. This offset spacing of the input fiber coupling device 14b and the output fiber coupling device 20b is determined based upon the focusing power of the collimating/focusing lens 16, as well as the characteristics of the diffraction grating 18 and the wavelengths of each of the monochromatic optical input beams 24b.

Similarly still, the input fiber coupling device 14c and the output fiber coupling device 20c are disposed offset from, but symmetrically about, the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26c is directed to the optical output fiber 22c secured to the output fiber coupling device 20c, and not to any of the other optical output fibers 22, or anywhere else. This offset spacing of the input fiber coupling device 14c and the output fiber coupling device 20c

is determined based upon the focusing power of the collimating/focusing lens 16, as well as the characteristics of the diffraction grating 18 and the wavelengths of each of the monochromatic optical input beams 24c.

5 Each of the plurality of monochromatic optical input beams 24 are transmitted from their corresponding optical input fiber 12 into the air space between the plurality of input fiber coupling devices 14 and the collimating/focusing lens 16. Within this air space, the plurality of
10 monochromatic optical input beams 24 are expanded in diameter until they become incident upon the collimating/focusing lens 16. The collimating/focusing lens 16 collimates each of the plurality of monochromatic optical input beams 24, and then transmits each collimated, monochromatic optical input beam
15 24' to the reflective diffraction grating 18.

 At this point it should be noted that the optical axis of the collimating/focusing lens 16 coincides with the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26a is
20 directed to the optical output fiber 22a secured to the output fiber coupling device 20a, and not to any of the other optical output fibers 22, or anywhere else, as will be described in

more detail below. Similarly, the optical axis of the collimating/focusing lens 16 coincides with the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26b is directed to the optical output fiber 22b secured to the output fiber coupling device 20b, and not to any of the other optical output fibers 22, or anywhere else, as will be described in more detail below. Similarly still, the optical axis of the collimating/focusing lens 16 coincides with the optical axis Z-Z of the multiplexing device 10 so as to insure that the multiplexed, polychromatic optical output beam 26c is directed to the optical output fiber 22c secured to the output fiber coupling device 20c, and not to any of the other optical output fibers 22, or anywhere else, as will be described in more detail below.

The reflective diffraction grating 18 operates to angularly disperse the plurality of collimated, monochromatic optical input beams 24' by an amount that is dependent upon the wavelength of each of the plurality of collimated, monochromatic optical input beams 24'. Also, the reflective diffraction grating 18 is oriented at a special angle (i.e., the Littrow diffraction angle, α_1) relative to the optical

axis Z-Z of the multiplexing device 10 in order to obtain the Littrow diffraction condition for an optical beam having a wavelength that lies within or near the wavelength range of the plurality of collimated, monochromatic optical input beams 24'. The Littrow diffraction condition requires that an optical beam be incident on and reflected back from a reflective diffraction grating at the exact same angle. Therefore, it will be readily apparent to one skilled in the art that the reflective diffraction grating 18 is used to obtain near-Littrow diffraction for each of the plurality of collimated, monochromatic optical input beams 24'.

The Littrow diffraction angle, α_i , is determined by the well-known diffraction grating equation,

$$m\lambda = 2d(\sin \alpha_i)$$

wherein m is the diffraction order, λ is the wavelength, d is the diffraction grating groove spacing, and α_i is the common angle of incidence and reflection. It will be readily apparent to one skilled in the art that the Littrow diffraction angle, α_i , depends upon numerous variables, which may be varied as necessary to optimize the performance of the multiplexing device 10. For example, variables affecting the Littrow diffraction angle, α_i , include the desired grating

diffraction order, the grating blaze angle, the number of data channels, the spacing of the data channels, and the wavelength range of the multiplexing device 10.

At this point it should be noted that the reflective
5 diffraction grating 18 can be formed from a variety of materials and by a variety of techniques. For example, the reflective diffraction grating 18 can be formed by a three-dimensional hologram in a polymer medium, or by replicating a mechanically ruled master with a polymer material. In both
10 cases, the polymer is overcoated with a thin, highly reflective metal layer such as, for example, gold or aluminum. Alternatively, the reflective diffraction grating 18 can be formed by chemically etching into a planar material such as, for example, glass or silicon, which is also overcoated with
15 a thin, highly reflective metal layer such as, for example, gold or aluminum.

As previously mentioned, the reflective diffraction grating 18 operates to angularly disperse the plurality of collimated, monochromatic optical input beams 24'. Thus, the
20 reflective diffraction grating 18 removes the angular separation of the plurality of collimated, monochromatic optical input beams 24'a, and reflects a collimated,

polychromatic optical output beam 26'a back towards the collimating/focusing lens 16. The collimated, polychromatic optical output beam 26'a contains each of the unique wavelengths of the plurality of collimated, monochromatic optical input beams 24'a. Thus, the collimated, polychromatic optical output beam 26'a is a collimated, multiplexed, polychromatic optical output beam 26'a. The collimating/focusing lens 16 focuses the collimated, multiplexed, polychromatic optical output beam 26'a, and then transmits the resulting multiplexed, polychromatic optical output beam 26a to the output fiber coupling device 20a where it becomes incident upon the optical output fiber 22a. The multiplexed, polychromatic optical output beam 26a is then coupled into the optical output fiber 22a for transmission therethrough.

Similarly, the reflective diffraction grating 18 removes the angular separation of the plurality of collimated, monochromatic optical input beams 24'b, and reflects a collimated, polychromatic optical output beam 26'b back towards the collimating/focusing lens 16. The collimated, polychromatic optical output beam 26'b contains each of the unique wavelengths of the plurality of collimated

monochromatic optical input beams 24'b. Thus, the collimated,
polychromatic optical output beam 26'b is a collimated,
multiplexed, polychromatic optical output beam 26'b. The
collimating/focusing lens 16 focuses the collimated,
5 multiplexed, polychromatic optical output beam 26'b, and then
transmits the resulting multiplexed, polychromatic optical
output beam 26b to the output fiber coupling device 20b where
it becomes incident upon the optical output fiber 22b. The
multiplexed, polychromatic optical output beam 26b is then
10 coupled into the optical output fiber 22ba for transmission
therethrough.

Similarly still, the reflective diffraction grating 18
removes the angular separation of the plurality of collimated,
monochromatic optical input beams 24'c, and reflects a
15 collimated, polychromatic optical output beam 26'c back
towards the collimating/focusing lens 16. The collimated,
polychromatic optical output beam 26'c contains each of the
unique wavelengths of the plurality of collimated,
monochromatic optical input beams 24'c. Thus, the collimated,
20 polychromatic optical output beam 26'c is a collimated,
multiplexed, polychromatic optical output beam 26'c. The
collimating/focusing lens 16 focuses the collimated,

5 multiplexed, polychromatic optical output beam 26'c, and then transmits the resulting multiplexed, polychromatic optical output beam 26c to the output fiber coupling device 20c where it becomes incident upon the optical output fiber 22c. The multiplexed, polychromatic optical output beam 26c is then coupled into the optical output fiber 22c for transmission therethrough.

10 At this point it should be noted that the plurality of optical input fibers 12 could be replaced in the multiplexing device 10 by a corresponding plurality of laser diodes 28 secured within a plurality of coupling devices 30, such as shown in Figure 2a (although Figure 2a shows only a single 1 x 4 array). The coupling device 30 performs a similar function to that of each of the plurality of input fiber coupling devices 14, that being to precisely group the 15 plurality of laser diodes 28 into a one-dimensional input array. The plurality of laser diodes 28 are used in place of the plurality of optical input fibers 12 to transmit the plurality of monochromatic optical input beams 24 to the 20 multiplexing device 10. The array of laser diodes 28, as well as the plurality of optical input fibers 12, may operate alone, or may be used with appropriate focusing lenses (not

shown) to provide the best coupling and the lowest amount of signal loss and channel crosstalk.

At this point it should be noted that the multiplexing device 10, as well as all of the multiplexing devices described herein, may be operated in a converse configuration as a demultiplexing device 40, such as shown in Figures 3a and 3b. The demultiplexing device 40 is physically identical to the multiplexing device 10, and is therefore numerically identified as such. However, the demultiplexing device 40 is functionally opposite to the multiplexing device 10. That is, a plurality of multiplexed, polychromatic optical input beams 42 are transmitted from the plurality of optical fibers 22, and a plurality of monochromatic optical output beams 44 are transmitted to the plurality of optical fibers 12, wherein each one of the plurality of monochromatic optical output beams 44 is transmitted to a corresponding one of the plurality of optical fibers 12. For example, the multiplexed, polychromatic optical input beam 42a is simultaneously carrying a plurality of channels of data, each at a unique wavelength which is preferably, but not required to be, within the infrared (IR) region of the electromagnetic spectrum. The plurality of monochromatic optical output beams 44a are each

carrying a single channel of data at a corresponding one of
the unique wavelengths of the multiplexed, polychromatic
optical input beam 42a. The multiplexed, polychromatic
optical input beam 42a is separated into the plurality of
5 monochromatic optical output beams 44a through the combined
operation of the collimating/focusing lens 16 and the
reflective diffraction grating 18. Thus, the
collimating/focusing lens 16 and the reflective diffraction
grating 18 operate to perform a demultiplexing function.

10 Similarly, the multiplexed, polychromatic optical input
beam 42b is simultaneously carrying a plurality of channels of
data, each at a unique wavelength which is preferably, but not
required to be, within the infrared (IR) region of the
electromagnetic spectrum. The plurality of monochromatic
15 optical output beams 44b are each carrying a single channel of
data at a corresponding one of the unique wavelengths of the
multiplexed, polychromatic optical input beam 42b. The
multiplexed, polychromatic optical input beam 42b is separated
into the plurality of monochromatic optical output beams 44b
20 through the combined operation of the collimating/focusing
lens 16 and the reflective diffraction grating 18. Thus, the

collimating/focusing lens 16 and the reflective diffraction grating 18 operate to perform a demultiplexing function.

5 Similarly still, the multiplexed, polychromatic optical input beam 42c is simultaneously carrying a plurality of channels of data, each at a unique wavelength which is preferably, but not required to be, within the infrared (IR) region of the electromagnetic spectrum. The plurality of monochromatic optical output beams 44c are each carrying a single channel of data at a corresponding one of the unique
10 wavelengths of the multiplexed, polychromatic optical input beam 42c. The multiplexed, polychromatic optical input beam 42c is separated into the plurality of monochromatic optical output beams 44c through the combined operation of the collimating/focusing lens 16 and the reflective diffraction
15 grating 18. Thus, the collimating/focusing lens 16 and the reflective diffraction grating 18 operate to perform a demultiplexing function.

At this point it should be noted that the plurality of optical fibers 12 could be replaced in the demultiplexing
20 device 40 by a corresponding plurality of photodetectors 48 secured within a plurality of coupling devices 50, such as shown in Figure 2b (although Figure 2b shows only a single 1

x 13 array). The coupling device 50 performs a similar function to that of each of the plurality of fiber coupling devices 14, that being to precisely group the plurality of photodetectors 48 into a one-dimensional input array. The plurality of photodetectors 48 are used in place of the plurality of optical fibers 12 to receive the plurality of monochromatic optical output beams 44 from the demultiplexing device 40. The array of photodetectors 48, as well as the plurality of optical fibers 12, may operate alone, or may be used with appropriate focusing lenses (not shown) to provide the best coupling and the lowest amount of signal loss and channel crosstalk.

Referring to Figure 4, there is shown a demultiplexing system 60 wherein the demultiplexing device 40 of Figures 3a and 3b is used in a practical manner to demultiplex additional data channels without requiring additional WDM devices or significant design modifications in accordance with the present invention. The demultiplexing system 60 is physically identical to the multiplexing device 40, except for the addition of optical input fiber 62 and optical filter 64, and is therefore numerically identified as such. The optical input fiber 62 communicates a single, multiplexed,

polychromatic optical input beam to the optical filter 64. The single, multiplexed, polychromatic optical input beam being communicated by the optical input fiber 62 is simultaneously carrying a plurality of channels of data (e.g., 5 99 channels of data), each at a unique wavelength which is preferably, but not required to be, within the infrared (IR) region of the electromagnetic spectrum. The optical filter 64 equally splits the single, multiplexed, polychromatic optical input beam according to wavelength into three multiplexed, 10 polychromatic optical input beams 42. That is, each of the three resulting multiplexed, polychromatic optical input beams 42 is simultaneously carrying a plurality of channels of data (e.g., 33 channels of data) at the unique wavelengths of corresponding ones of the unique wavelengths of the single, 15 multiplexed, polychromatic optical input beam. For example, the multiplexed, polychromatic optical input beam 42a is simultaneously carrying a plurality of channels of data (e.g., 33 channels of data) at the unique wavelengths of corresponding ones of the unique wavelengths of the single, 20 multiplexed, polychromatic optical input beam. Then, the plurality of monochromatic optical output beams 44a are each carrying a single channel of data at a corresponding one of

the unique wavelengths of the multiplexed, polychromatic optical input beam 42a. The multiplexed, polychromatic optical input beam 42a is separated into the plurality of monochromatic optical output beams 44a through the combined operation of the collimating/focusing lens 16 and the reflective diffraction grating 18. Thus, the collimating/focusing lens 16 and the reflective diffraction grating 18 operate to perform a demultiplexing function.

Similarly, the multiplexed, polychromatic optical input beam 42b is simultaneously carrying a plurality of channels of data (e.g., 33 channels of data) at the unique wavelengths of corresponding ones of the unique wavelengths of the single, multiplexed, polychromatic optical input beam. Then, the plurality of monochromatic optical output beams 44b are each carrying a single channel of data at a corresponding one of the unique wavelengths of the multiplexed, polychromatic optical input beam 42b. The multiplexed, polychromatic optical input beam 42b is separated into the plurality of monochromatic optical output beams 44b through the combined operation of the collimating/focusing lens 16 and the reflective diffraction grating 18. Thus, the

collimating/focusing lens 16 and the reflective diffraction grating 18 operate to perform a demultiplexing function.

5 Similarly still, the multiplexed, polychromatic optical input beam 42c is simultaneously carrying a plurality of channels of data (e.g., 33 channels of data) at the unique wavelengths of corresponding ones of the unique wavelengths of the single, multiplexed, polychromatic optical input beam. Then, the plurality of monochromatic optical output beams 44c are each carrying a single channel of data at a corresponding
10 one of the unique wavelengths of the multiplexed, polychromatic optical input beam 42c. The multiplexed, polychromatic optical input beam 42c is separated into the plurality of monochromatic optical output beams 44c through the combined operation of the collimating/focusing lens 16 and
15 the reflective diffraction grating 18. Thus, the collimating/focusing lens 16 and the reflective diffraction grating 18 operate to perform a demultiplexing function.

20 At this point it should be noted that there are many alternate embodiments and uses for the present invention ultra-dense wavelength division multiplexing/demultiplexing device. For example, the single, multiplexed, polychromatic optical input beam could be split unequally according to

wavelength. Alternatively, the single, multiplexed, polychromatic optical input beam could be split either equally or unequally according to beam intensity. Alternatively still, the single, multiplexed, polychromatic optical input beam could be split such that any or all of the resultant multiplexed, polychromatic optical input beams are identical so as to create redundant channels. Alternatively still, the single, multiplexed, polychromatic optical input beam could be split such that certain data channels are routed separately so as to provide security as to those data channels. Thus, the optical filter 64 could be, for example, a standard coupler, a fiber Bragg grating, an interference filter, a bandpass filter, a power splitter, or any other suitable splitting means.

At this point it should also be noted that the present invention ultra-dense wavelength division multiplexing/demultiplexing device can be used simultaneously for multiplexing and demultiplexing operations. For example, the plurality of optical fibers 12a can be used to transmit a corresponding plurality of monochromatic optical input beams 24a and the optical fiber 22a can be used to receive a multiplexed, polychromatic, optical output beam 26a, while

simultaneously the optical fiber 22b can be used to transmit
a multiplexed, polychromatic, optical input beam 42b and the
plurality of optical fibers 12b can be used to receive a
corresponding plurality of monochromatic optical output beams
5 44b.

At this point it should further be noted that it is
within the scope of the present invention to provide an ultra-
dense wavelength division multiplexing/demultiplexing device
in accordance with the present invention using any or all of
10 the concepts and/or features described in U.S. Patent
Application No. 09/257,045 (Attorney Docket No. 34013-00008,
Client Reference No. D-97031-CNT), filed February 25, 1999;
U.S. Patent Application No. 09/323,094 (Attorney Docket No.
34013-00010, Client Reference No. D-99001), filed June 1,
15 1999; U.S. Patent Application No. 09/342,142 (Attorney Docket
No. 34013-00011, Client Reference No. D-99002), filed June 29,
1999; U.S. Patent Application No. 09/382,492 (Attorney Docket
No. 34013-00013, Client Reference No. D-99004), filed August
25, 1999; U.S. Patent Application No. 09/382,624 (Attorney
20 Docket No. 34013-00014, Client Reference No. D-99005), filed
August 25, 1999; U.S. Patent Application No. 09/363,041
(Attorney Docket No. 34013-00023, Client Reference No. D-

99014), filed July 29, 1999; U.S. Patent Application No. 09/363,042 (Attorney Docket No. 34013-00024, Client Reference No. D-99015), filed July 29, 1999; U.S. Patent Application No. 09/392,670 (Attorney Docket No. 34013-00025, Client Reference
5 No. D-99016), filed September 8, 1999; and U.S. Patent Application No. 09/392,831 (Attorney Docket No. 34013-00026, Client Reference No. D-99017), filed September 8, 1999; all of which are hereby incorporated herein by reference. For example, an ultra-dense wavelength division
10 multiplexing/demultiplexing device in accordance with the present invention may be wholly or partially integrated, and different types of lenses and lens configurations may be used.

Finally, it should be noted that the maximum number of arrays is only dependent upon the ability of the lens design
15 to handle more than one array. Specifically, this relates to a basic tradeoff in performance as arrays are stacked next to one another. The farther away an array is placed from the optical axis Z-Z of the device, typically there is a degradation in fiber coupling efficiency since the lens cannot
20 typically perform at very large field heights with high efficiency. Also, as arrays are placed away from the optical axis Z-Z of the device, there is an increased probability of

crosstalk. However, by careful lens design, the performance of each array can be made to be the same as other arrays. For example, the inner-most array can be made to have the same performance as the outermost array. This could be useful for

5 WDM systems requiring a very flat response between each of the data channels. Alternately, the placement of the arrays can be such that there is a non-flat, or unusual response (efficiency versus wavelength). The beauty of the present invention approach is that there is no significant insertion

10 loss for creating a WDM device with very high data channel counts. This approach allows processing of more data channels in a more efficient manner than other WDM technologies such as, for example, fiber Bragg gratings or array waveguide gratings (AWGs). Also, the robustness of this approach allows

15 a very large number of data channels to be processed (multiplexed or demultiplexed) in one single WDM device. Thus, the present invention ultra-dense wavelength division multiplexing/demultiplexing device has the benefits of low insertion loss, low crosstalk, low cost, and a very high

20 number of data channels. More specifically, the present invention ultra-dense wavelength division multiplexing/demultiplexing device offers the new and non-

obvious advantages of: (1) the ability to increase the data channel throughput (# of data channels) in a WDM device by simply splitting a signal and then attaching corresponding split signal optical fibers to extra input and output positions on the WDM device; (2) the ability to use a WDM device for the multiplexing or demultiplexing for more than one array of data channels without major changes to the lens design of the WDM device; (3) the ability to use a WDM device for bi-directional and simultaneous multiplexing and demultiplexing (use as a duplex mux/demux); (4) the ability to create a redundant or secure WDM device; and (5) the other new and non-obvious advantages that are apparent from the foregoing description.

The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the present invention, in addition to those described herein, will be apparent to those of skill in the art from the foregoing description and accompanying drawings. Thus, such modifications are intended to fall within the scope of the appended claims.

CLAIMS

What is claimed is:

- 1 1. An ultra-dense wavelength division multiplexing device
2 comprising:
3 a wavelength division multiplexing device for combining
4 at least one plurality of monochromatic optical beams into a
5 corresponding at least one single, multiplexed, polychromatic
6 optical beam, the wavelength division multiplexing device
7 having an input element and an output element;
8 a plurality of optical input devices disposed proximate
9 the input element, each of the plurality of optical input
10 devices for communicating a plurality of monochromatic optical
11 beams to the wavelength division multiplexing device for
12 combining the plurality of monochromatic optical beams into a
13 single, multiplexed, polychromatic optical beam; and
14 a corresponding plurality of optical output devices
15 disposed proximate the output element, each of the plurality
16 of optical output devices for receiving a corresponding
17 single, multiplexed, polychromatic optical beam.

1 2. The device as defined in claim 1, wherein the wavelength
2 division multiplexing device comprises:

3 a diffraction grating for combining the at least one
4 plurality of monochromatic optical beams into the
5 corresponding at least one single, multiplexed, polychromatic
6 optical beam.

1 3. The device as defined in claim 2, wherein the diffraction
2 grating is a reflective diffraction grating oriented at the
3 Littrow diffraction angle.

1 4. The device as defined in claim 2, wherein the diffraction
2 grating is a transmissive diffraction grating.

1 5. The device as defined in claim 1, wherein the input
2 element is a collimating lens.

1 6. The device as defined in claim 1, wherein the input
2 element is a boot lens.

1 7. The device as defined in claim 1, wherein the output
2 element is a focusing lens.

1 8. The device as defined in claim 1, wherein the output
2 element is a boot lens.

1 9. The device as defined in claim 1, wherein the plurality
2 of optical input devices is a plurality of input fiber
3 coupling devices, wherein each of the plurality of input fiber
4 coupling devices is arranged into an array of optical fibers,
5 each of the optical fibers for transmitting a monochromatic
6 optical beam to the wavelength division multiplexing device.

1 10. The device as defined in claim 1, wherein the plurality
2 of optical input devices is a plurality of laser diode
3 coupling devices, wherein each of the plurality of laser diode
4 coupling devices is arranged into an array of laser diodes,
5 each of the laser diodes for transmitting a monochromatic
6 optical beam to the wavelength division multiplexing device.

1 11. The device as defined in claim 1, wherein the plurality
2 of optical output devices is a plurality of output fiber
3 coupling devices, wherein each of the plurality of output
4 fiber coupling devices maintains at least one optical fiber,

5 each optical fiber for receiving a single, multiplexed,
6 polychromatic optical beam from the wavelength division
7 multiplexing device.

1 12. An ultra-dense wavelength division demultiplexing device
2 comprising:

3 a wavelength division demultiplexing device for
4 separating at least one multiplexed, polychromatic optical
5 beam into a corresponding at least one plurality of
6 monochromatic optical beams, the wavelength division
7 demultiplexing device having an input element and an output
8 element;

9 a plurality of optical input devices disposed proximate
10 the input element, each of the plurality of optical input
11 devices for communicating a single, multiplexed, polychromatic
12 optical beam to the wavelength division demultiplexing device
13 for separating the single, multiplexed, polychromatic optical
14 beam into a plurality of monochromatic optical beams; and

15 a corresponding plurality of optical output devices
16 disposed proximate the output element, each of the plurality
17 of optical output devices for receiving a corresponding
18 plurality of monochromatic optical beams.

1 13. The device as defined in claim 12, wherein the wavelength
2 division demultiplexing device comprises:

3 a diffraction grating for separating the at least one
4 multiplexed, polychromatic optical beam into the corresponding
5 at least one plurality of monochromatic optical beams.

1 14. The device as defined in claim 13, wherein the
2 diffraction grating is a reflective diffraction grating
3 oriented at the Littrow diffraction angle.

1 15. The device as defined in claim 13, wherein the
2 diffraction grating is a transmissive diffraction grating.

1 16. The device as defined in claim 12, wherein the input
2 element is a collimating lens.

1 17. The device as defined in claim 12, wherein the input
2 element is a boot lens.

1 18. The device as defined in claim 12, wherein the output
2 element is a focusing lens.

1 19. The device as defined in claim 12, wherein the output
2 element is a boot lens.

1 20. The device as defined in claim 12, wherein the plurality
2 of optical input devices is a plurality of input fiber
3 coupling devices, wherein each of the plurality of input fiber
4 coupling devices maintains at least one optical fiber, each
5 optical fiber for transmitting a single, multiplexed,
6 polychromatic optical beam to the wavelength division
7 demultiplexing device.

1 21. The device as defined in claim 12, wherein the plurality
2 of optical output devices is a plurality of output fiber
3 coupling devices, wherein each of the plurality of output
4 fiber coupling devices is arranged into an array of optical
5 fibers, each of the optical fibers for receiving a
6 monochromatic optical beam from the wavelength division
7 demultiplexing device.

1 22. The device as defined in claim 12, wherein the plurality
2 of optical output devices is a plurality of photodetector

3 coupling devices, wherein each of the plurality of
4 photodetector coupling devices is arranged into an array of
5 photodetectors, each of the photodetectors for receiving a
6 monochromatic optical beam from the wavelength division
7 demultiplexing device.

1 23. The device as defined in claim 12, wherein the at least
2 one multiplexed, polychromatic optical beam is at least two
3 multiplexed, polychromatic optical beams, further comprising:
4 a splitter for splitting a single, pre-split,
5 multiplexed, polychromatic optical beam into the at least two
6 multiplexed, polychromatic optical beams.

1 24. The device as defined in claim 23, wherein the single,
2 pre-split, multiplexed, polychromatic optical beam is split
3 equally.

1 25. The device as defined in claim 23, wherein the single,
2 pre-split, multiplexed, polychromatic optical beam is split
3 unequally.

1 26. The device as defined in claim 23, wherein the single,
2 pre-split, multiplexed, polychromatic optical beam is split
3 according to beam wavelengths.

1 27. The device as defined in claim 23, wherein the single,
2 pre-split, multiplexed, polychromatic optical beam is split
3 according to beam intensity.

1 28. A method for increasing channel throughput in a
2 wavelength division demultiplexing device, the method
3 comprising the steps of:

4 splitting a single, multiplexed, polychromatic optical
5 beam into at least two multiplexed, polychromatic optical
6 beams; and

7 simultaneously separating each of the at least two
8 multiplexed, polychromatic optical beams into a corresponding
9 at least two pluralities of monochromatic optical beams.

1 29. The method as defined in claim 28, further comprising the
2 step of:

3 collimating each of the at least two multiplexed,
4 polychromatic optical beams.

1 30. The method as defined in claim 28, further comprising the
2 step of:
3 focusing the corresponding at least two pluralities of
4 monochromatic optical beams.

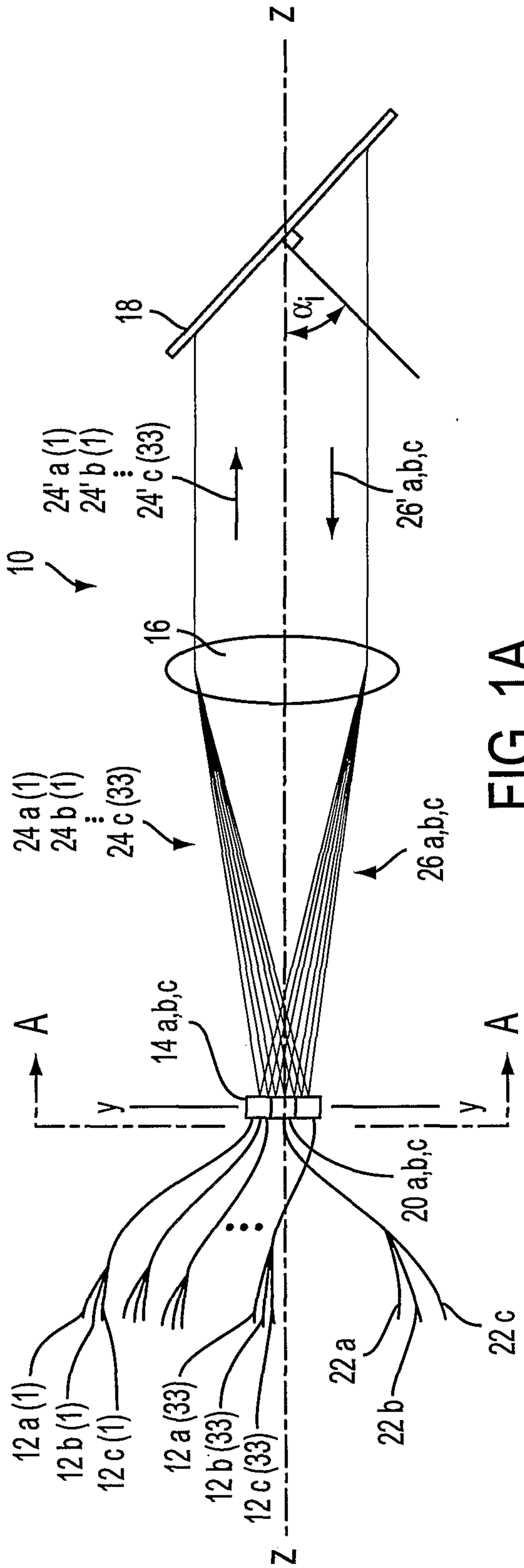


FIG. 1A

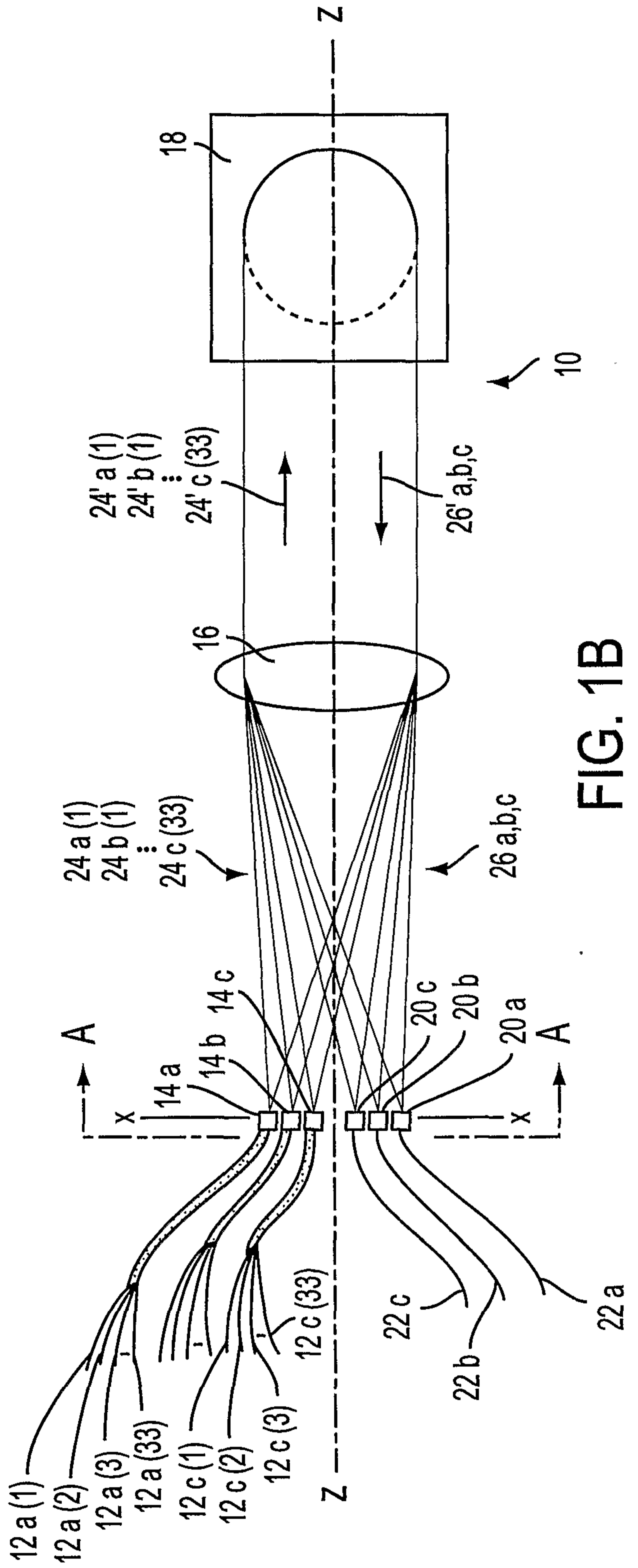


FIG. 1B

2/5

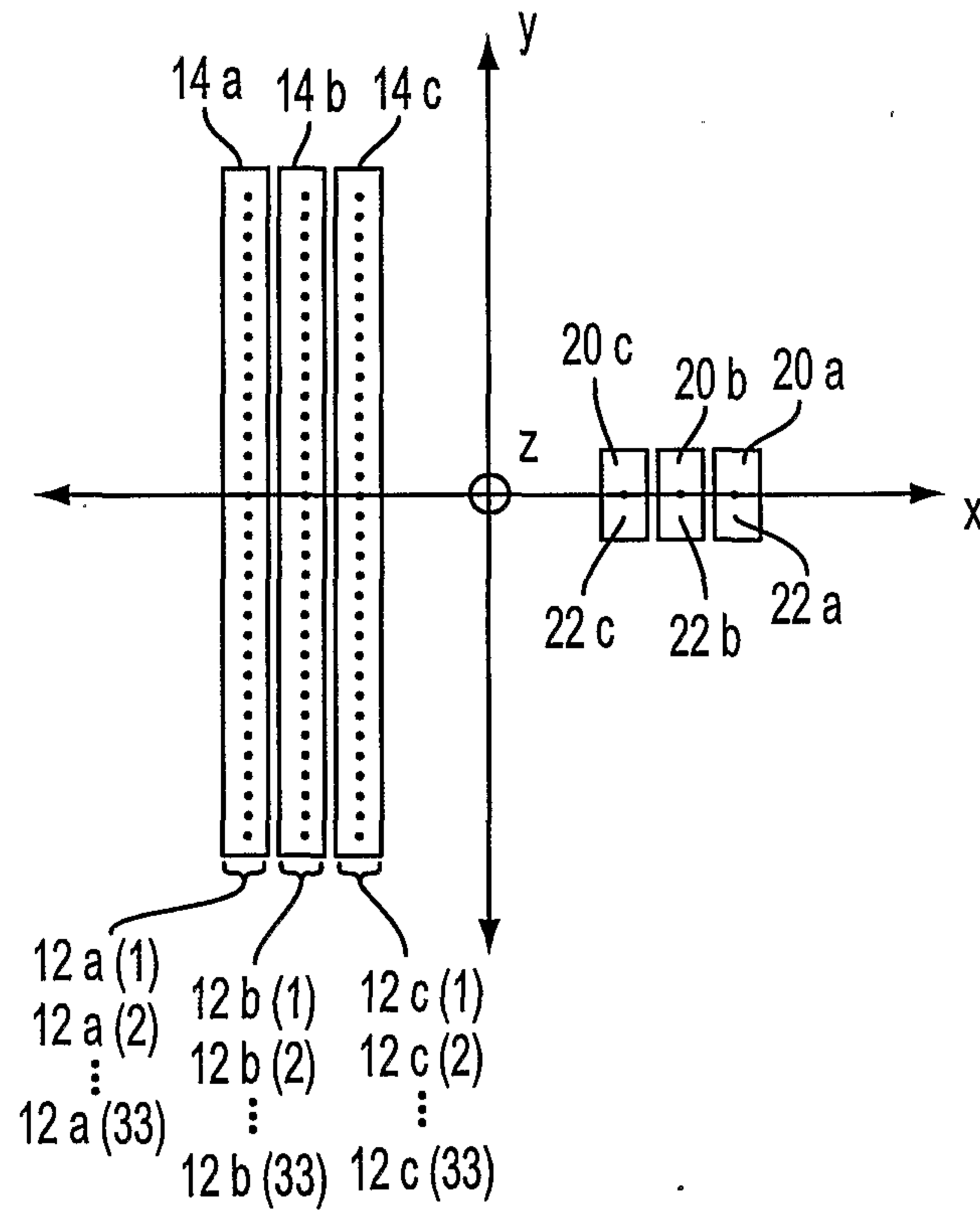


FIG. 1C

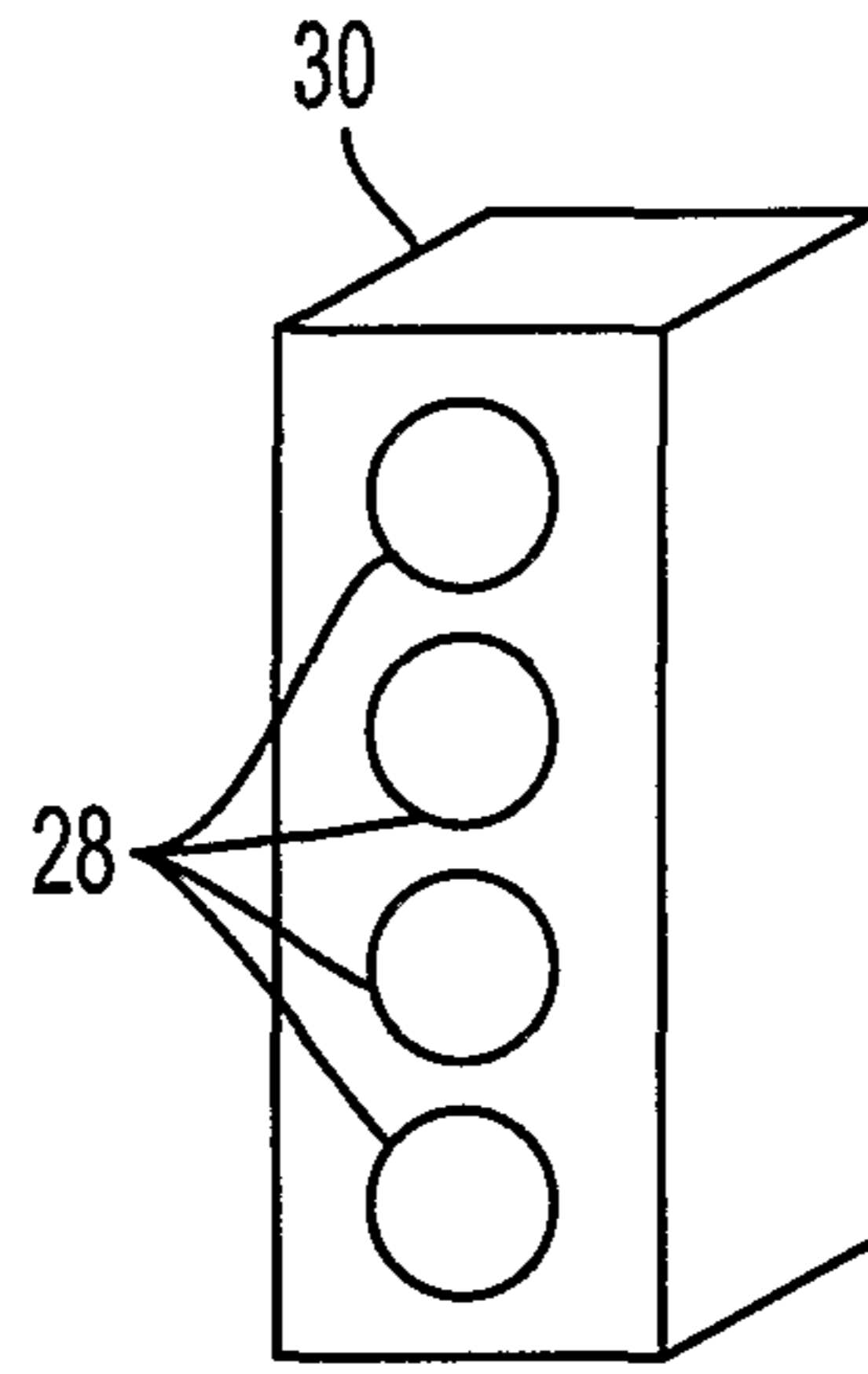


FIG. 2A

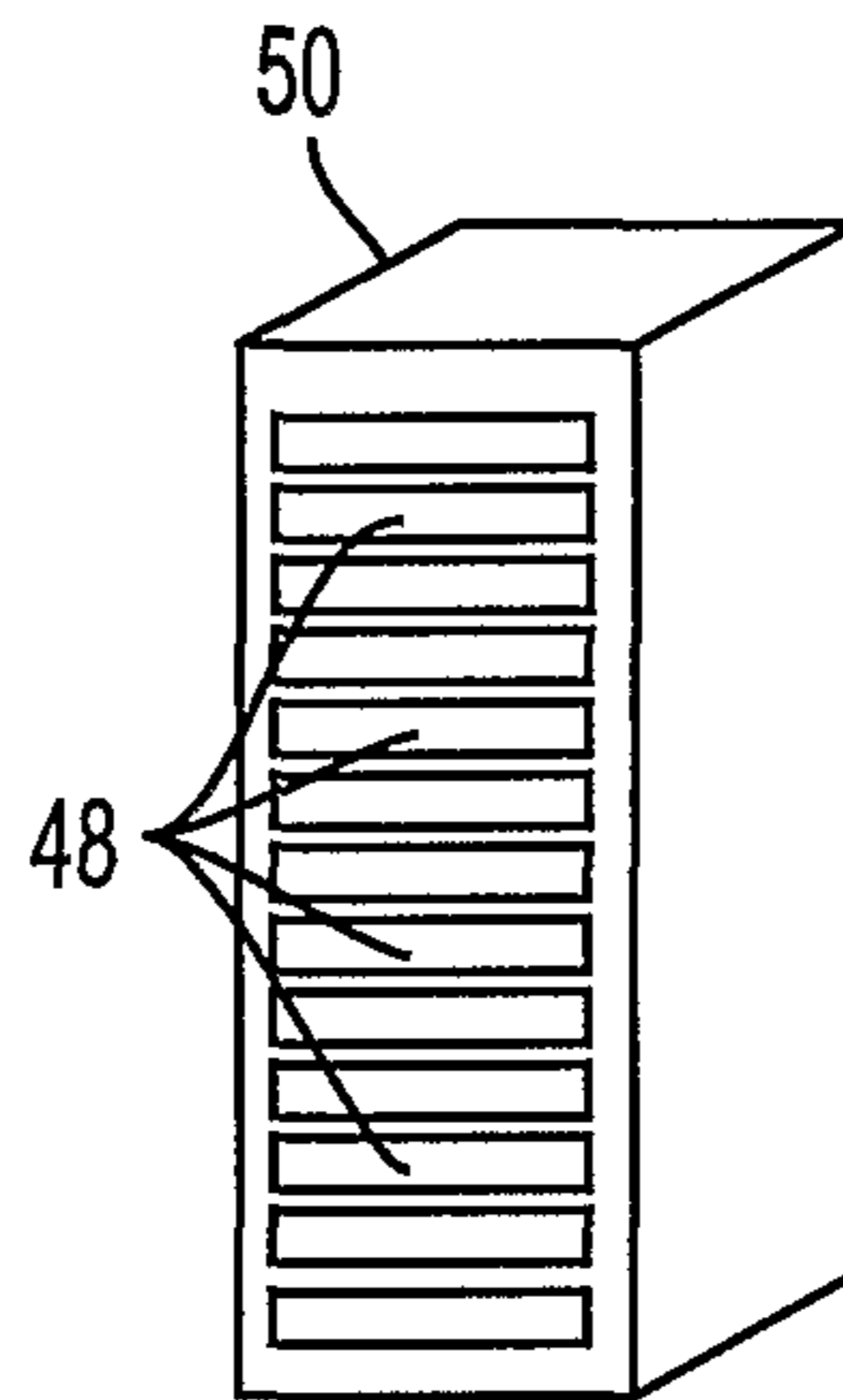


FIG. 2B

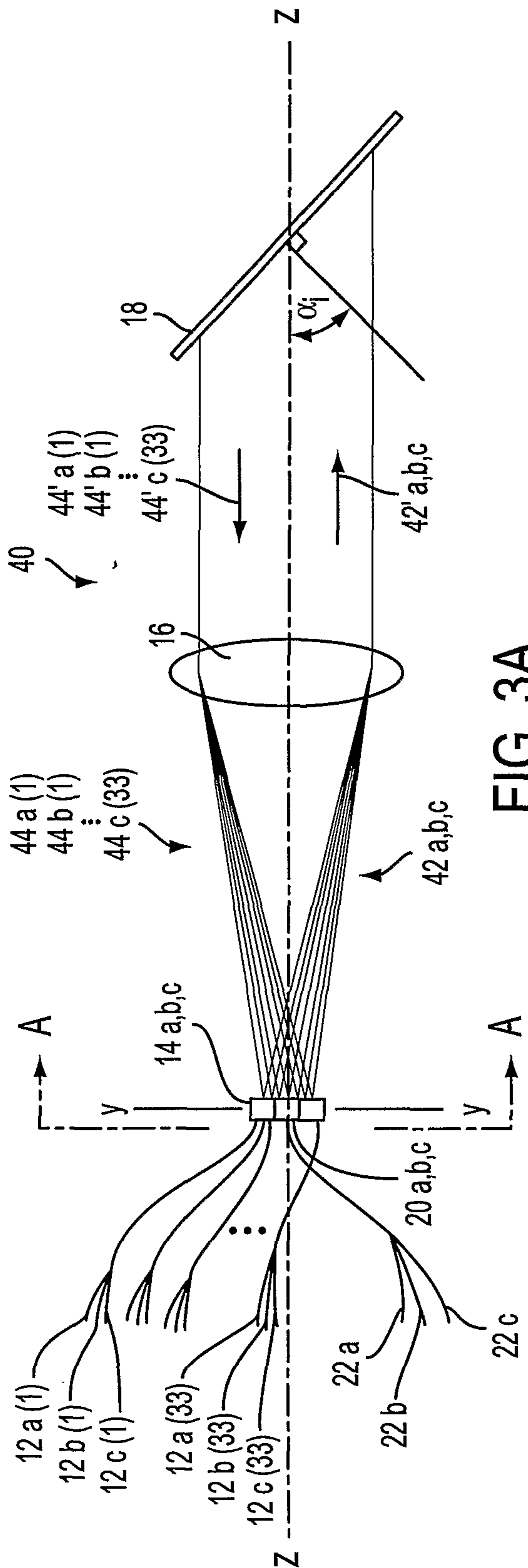


FIG. 3A

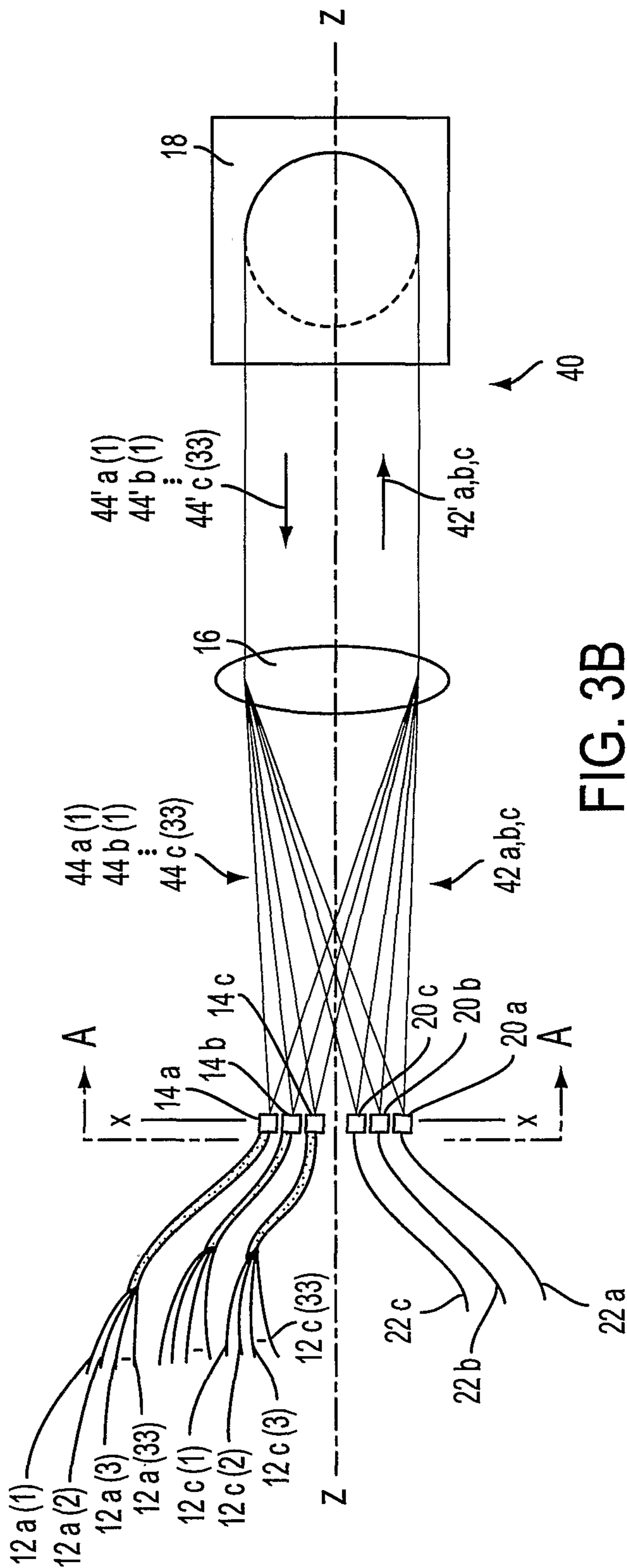


FIG. 3B

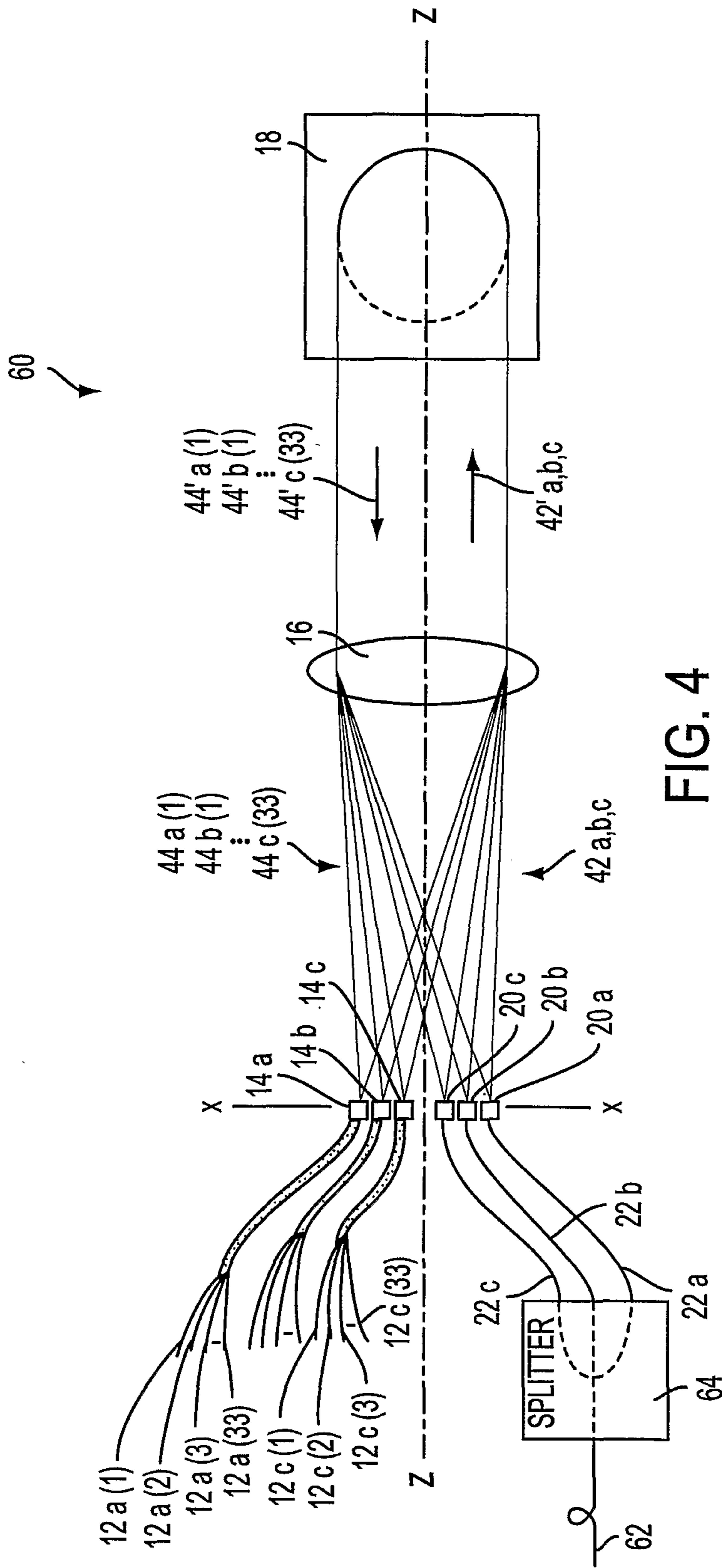


FIG. 4

