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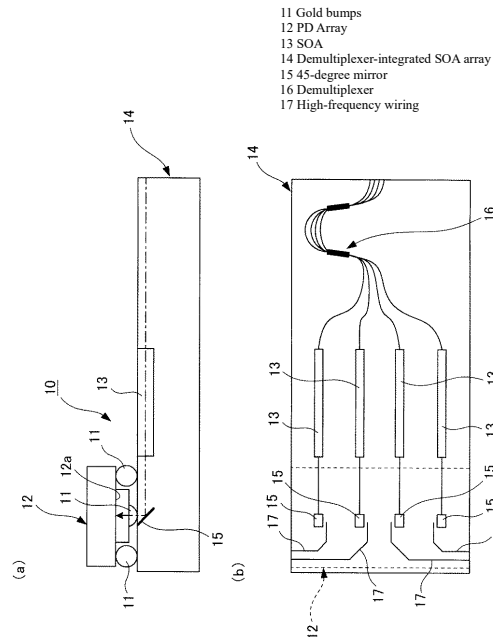
(54) [Title of Invention] Multi-channel Optical Receiver Device

(57) [Abstract]

[Problem to be solved by the invention] Disclosed is a multi-channel optical receiver device capable of compensating for received optical power and achieving miniaturization, even in long-distance systems.

[Means to solve the problem] The invention has: a demultiplexer (16) that splits incoming light into a number of channels; a corresponding number of semiconductor optical amplifiers (13) that individually amplify the light split by the demultiplexer (16); a corresponding number of mirrors (15) that reflect the light output from each of the semiconductor optical amplifiers (13), all integrated onto a substrate (14); and a photodetector array (12) that integrates a corresponding number of photodetectors to detect the light guided from each mirror (15), so that the light from the demultiplexer (16) enters each photodetector via the mirrors (15); the photodetector array (12) is mounted on the surface of the substrate (14) using flip-chip assembly.

[Selected figure(s)] Figure 1



(2)

[Claims]

[Claim 1]

A multi-channel optical receiver characterized in that it has a demultiplexer that splits incoming light into a number of channels, a corresponding number of semiconductor optical amplifiers that individually amplify the light split by the demultiplexer, a corresponding number of mirrors that reflect the light output from each of the semiconductor optical amplifiers, all integrated onto a substrate, and a corresponding number of photodetectors that detect the light guided from each mirror, so that the light from the demultiplexer enters each photodetector via the mirrors, and that the aforesaid photodetector is mounted on the surface of the substrate using flip-chip assembly.

[Claim 2]

A multi-channel optical receiver characterized in that it has a demultiplexer that splits incoming light into a number of channels, a corresponding number of semiconductor optical amplifiers that individually amplify the light split by the demultiplexer, a corresponding number of mirrors that reflect the light output from each of the semiconductor optical amplifiers, all integrated onto a substrate, and a photodetector array that integrates a corresponding number of photodetectors that detect the light guided from each mirror, so that the light from the demultiplexer enters each photodetector via the mirrors, and that the aforesaid photodetector array is mounted on the surface of the substrate using flip-chip assembly.

[Claim 3]

The multi-channel optical receiver as described in Claims 1 or 2, characterized in that the demultiplexer is integrated into a substrate.

[Claim 4]

The multi-channel optical receiver as described in any of Claims 1 through 3, characterized in that signal wiring of the photodetectors or photodetector array is provided for each corresponding channel on the surface of the substrate surrounding the mirrors, and that the photodetectors or photodetector array are mounted to this signal wiring using flip-chip assembly.

[Claim 5]

The multi-channel optical receiver as described in any of Claims 1 through 4, characterized in that the photodetectors have p-side and n-side electrodes positioned on the light-incident side of the photodetectors.

[Detailed description of the invention]

[Technical field]

[0001]

The present invention relates to a multi-channel optical receiver that is a component of a long-distance, high-capacity optical communication network.

[Prior art]

[0002]

The configuration diagram in Figure 4 shows the structure of a conventional 4-channel optical receiver.

Conventional multi-channel optical receivers have typically been structured as shown in the configuration diagram in Figure 4; instead of a photodetector (hereinafter, "PD") array, they consisted of optical receivers (51) corresponding to the number of channels (in this case, four) and a single optical demultiplexer (52).

However, the problem with this structure was that it resulted in larger sizes.

[0003]

Therefore, a method has been proposed by which a PD array capable of miniaturization is coupled to a 4-channel fiber using a 45-degree mirror (see "Non-patent literature 1"). This method allows for greater miniaturization than conventional techniques and allows for reduced assembly time through the use of flip-chip mounting.

However, when this method is applied to medium- or long-distance systems of 10 km or more, it is necessary to attach external optical amplifiers to compensate for the received optical power, therefore rendering dramatic miniaturization impossible.

(3)

[Citations of the prior art]

[Non-patent literature]

[0004]

[Non-patent literature 1] Masataka Itoh et al., "Use of AuSn Solder Bumps in Three-dimensional Passive Aligned Packaging of LD/PD Arrays on Si Optical Benches," ECTC1996

[Summary of invention]

[Problem to be solved by the invention]

[0005]

Based on the above, the present invention was created to solve the aforementioned problem, and aims to provide a multi-channel optical receiver capable of compensating for received optical power and achieving miniaturization, even in long-distance systems.

[Means to solve the problem]

[0006]

A multi-channel optical receiver of the first invention to solve the aforementioned problem, characterized in that it has an optical demultiplexer that splits incoming light into a number of channels, a corresponding number of semiconductor optical amplifiers that individually amplify the light split by the optical demultiplexer, a corresponding number of mirrors that reflect the light output from each of the semiconductor optical amplifiers, all integrated onto a substrate, and a corresponding number of photodetectors that detect the light guided from each mirror, so that the light from the optical demultiplexer enters each photodetector via the mirrors, and that the aforesaid photodetector is mounted on the surface of the substrate using flip-chip assembly.

[0007]

A multi-channel optical receiver of the second invention to solve the aforementioned problem, characterized in that it has an optical demultiplexer that splits incoming light into a number of channels, a corresponding number of semiconductor optical amplifiers that individually amplify the light split by the optical demultiplexer, a corresponding number of mirrors that reflect the light output from each of the semiconductor optical amplifiers, all integrated onto a substrate, and a photodetector array that integrates a corresponding number of photodetectors that detect the light guided from each mirror, so that the light from the optical demultiplexer enters each photodetector via the mirrors, and that the aforesaid photodetector array is mounted on the surface of the substrate using flip-chip assembly.

[0008]

A multi-channel optical receiver of the third invention to solve the aforementioned problem, characterized in that the multi-channel optical receiver pertaining to the first or second inventions integrates the optical demultiplexer into the substrate.

[0009]

A multi-channel optical receiver of the fourth invention to solve the aforementioned problem, characterized in that the multi-channel optical receiver as described in any of Claims 1 through 3 provides signal wiring of the photodetectors or photodetector array for each corresponding channel on the surface of the substrate surrounding the mirrors, and that the photodetectors or photodetector array are mounted to this signal wiring using flip-chip assembly.

[0010]

A multi-channel optical receiver of the fifth invention to solve the aforementioned problem, characterized in that the multi-channel optical receiver as described in any of Claims 1 through 4 has photodetectors with p-side and n-side electrodes positioned on the light-incident side of the photodetectors.

(4)

[Effect of the invention]

[0011]

With the multi-channel optical receiver of the present invention, it is possible to compensate for received optical power even in long-distance systems. As a result, the need for external optical amplifiers is eliminated, allowing for greater miniaturization compared to conventional multi-channel optical receivers.

[Brief description of drawings]

[0012]

[FIG. 1] Figure 1 shows the configuration of the multi-channel optical receiver in Embodiment 1 of the present invention, Figure 1(a) shows a side view thereof, and Figure 1(b) shows a top view of the structure excluding the photodetector array.

[FIG. 2] Figure 2 is a configuration diagram showing the measurement setup for measuring the eye pattern of the multi-channel optical receiver shown in Figure 1.

[FIG. 3] Figure 3 shows the configuration of the multi-channel optical receiver in Embodiment 2 of the present invention, Figure 3(a) shows a side view thereof, and Figure 3(b) shows a top view of the structure excluding the photodetector array

[FIG. 4] Figure 4 is a configuration diagram showing the structure of a conventional multi-channel optical receiver.

[Description of embodiments]

[0013]

The following sections describe the multi-channel optical receiver of the present invention with reference to specific embodiments. These embodiments are provided as examples of the multi-channel optical receiver of the present invention, and may be modified insofar as they do not deviate from the goal of the present invention.

[Embodiment 1]

[0014]

The multi-channel optical receiver in the first embodiment of the present invention is described specifically, with reference to Figure 1.

[0015]

This embodiment depicts a 4-channel optical receiver as an example of a multi-channel optical receiver, and its structure contains four integrated photodetectors (hereinafter, “PD”) integrated into a 4-channel PD array (12), and a 4-channel demultiplexer-integrated SOA array (14) that integrates a semiconductor optical amplifier (hereinafter, “SOA”), a demultiplexer, and an optical waveguide structure.

[0016]

The demultiplexer-integrated SOA array (14) is formed on an InP or other such semiconductor substrate. Specifically, as shown in Figure 1(b), the demultiplexer-integrated SOA array (14) integrates a demultiplexer (16), an SOA (13), and a 45-degree mirror (15), in order from the direction of light incidence. The demultiplexer (16) is a single device that splits the input light into the corresponding number of channels (four in this case). The optical waveguides connected to the output side of the demultiplexer (16) are connected to the input side of each of the corresponding SOA (13). A 45-degree mirror (15) and SOA (13) are formed for each of the four channels, and the optical waveguides connected to the output sides of each SOA (13) are each connected to the corresponding 45-degree mirror (15). An input optical waveguide, not shown in the figure, is connected to the input side of the demultiplexer (16). In Figure 1(b), the position of the PD array (12) is indicated by a dotted line for reference.

[0017]

The PD array (12) is also formed on an InP or other such semiconductor substrate and has electrode pads (not shown) that are connected to the high-frequency wiring (17) described later. In this way, the PD array (12) is formed on the InP substrate, and both p and n electrodes (electrode pads) for each channel are provided on the light-incident side (12a), so that the electrodes can be removed from the light-incident side.

[0018]

Therefore, the light guided from the input optical waveguide (not shown in the figure) through the demultiplexer (16) is amplified by each SOA (13), and the light amplified by each SOA (13) is reflected by the 45-degree mirror (15) and input to each PD in the PD array (12). An array waveguide grating (hereafter “AWG”) is used as a demultiplexer (16).

(5)

[0019]

On the surface of the demultiplexer-integrated SOA array (14) around the mirror (15), the high-frequency wiring (signal wiring) (17) for supplying high-frequency signals to the PD array (12) are formed for four channels through patterning. The high-frequency wiring (17) is connected to the electrode pads of the PD array (12) (not shown in the figure) via the gold bumps (11), and the PD array (12) is flip-chip mounted on the surface of the demultiplexer-integrated SOA array (14). In this process, the PD array (12) is flip-chip mounted so that light enters each PD in the PD array (12) via the mirror (15).

[0020]

This flip-chip mounting combines the PD array (12) with the demultiplexer-integrated SOA array (14) to form a PD array-integrated SOA array (10). Furthermore, this flip-chip mounting allows for the signal wiring to be connected in a batch, which achieves reductions in mounting time and thus lowers costs; furthermore, it renders wire mounting unnecessary and allows for improvement of high-frequency characteristics.

[0021]

The channel spacing was set at 250  $\mu\text{m}$ , and the incident wavelengths were 1,295 nm, 1,300 nm, 1,305 nm, and 1,310 nm.

[0022]

### 1. Operating Principle

This embodiment explains how a wave is split from a single optical waveguide and the split optical signal is converted into a high-speed electrical signal. First, the optical signal is split into channels by the demultiplexer (AWG) (16) on the demultiplexer-integrated SOA array (14), and the optical power is amplified by being input to the SOA (13) in each channel. The optical signal amplified by the SOA (13) then enters each PD in the PD array (12) via the 45-degree mirror (15) and is converted into an electrical signal (see the single-dotted line in Figure 1(a)).

[0023]

### 2. Assembly Process

The following is a description of the procedure for fabricating a multi-channel optical receiver (device) with the configuration described above. In other words, it is a description of the procedure for actually fabricating a PD array-integrated SOA array (10) by assembling a PD array (12) and a demultiplexer-integrated SOA array (14). First, gold bumps (11) are formed on the electrode pads of the p and n electrodes of the PD using a ball bonder. At this time, the bump diameter was set to 60  $\mu\text{m}$ . Next, the PD array (12) is mounted using a flip-chip mounting device so that the gold bumps (11) connect to the high-frequency wiring (17) of the demultiplexer-integrated SOA array (14). This completes the PD array-integrated SOA array (10).

[0024]

### 3. Characteristics of the Variable Optical Attenuator

The experimental system shown in Figure 2 was fabricated for the multi-channel optical receiver with the configuration described above, and the eye pattern was measured using this experimental system. A multi-channel transmitting light source (31) is connected to the input side of the demultiplexer (16) of the PD array-integrated SOA array (10) via the optical fiber (32). A pulse pattern generator (35) supplying high-frequency signals is connected to the multi-channel transmitting light source (31). In addition, an optical sampling oscilloscope (36) is connected to the PD array-integrated SOA array (10). During measurement, the optical fiber (32) was set to a length of 40 km, with the bias current of the semiconductor optical amplifier (SOA 13) at 100 mA, the data rate was configured at 27.7 Gbps, using Non-Return-to-Zero (hereinafter, "NRZ") format, and a pseudo-random bit sequence (hereinafter, "PRBS") signal with a length of  $2^{31}-1$  was input as the optical signal across four channels. At this time, the extinction ratio observed by the optical sampling oscilloscope (36) was 5 dB.

[0025]

Additionally, in the experimental system shown in Figure 2, the optical sampling oscilloscope (36) was changed to an error detector, and a variable optical attenuator was inserted between the optical fiber (32) shown in Figure 2 and the PD array-integrated SOA array (10) to measure the bit error rate characteristics (hereinafter, "BER characteristics"). At this time, error-free operation was confirmed for each channel. When only the 1,295 nm wavelength channel was operated, error-free operation was observed up to -10 dBm of the optical power input to the PD array-integrated SOA array (10).

(6)

[0026]

Therefore, it was made clear that the multi-channel optical receiver in this embodiment is feasible as a multi-channel optical receiver for long-distance applications that is compact and can be manufactured at low cost.

[Embodiment 2]

[0027]

The multi-channel optical receiver pertaining to the second embodiment of the present invention will be described specifically with reference to Figure 3.

[0028]

This embodiment also depicts a 4-channel optical receiver as an example of a multi-channel optical receiver, but it is a structure with a 4-channel SOA array (24) that integrates a 4-channel PD (22), SOA and optical waveguide structure, etc.

[0029]

The SOA array (24) is formed on an InP or other such semiconductor substrate. Specifically, as shown in Figure 3(b), the SOA array (24) integrates an SOA (23) and a 45-degree mirror (25), in order from the direction of light incidence. A 45-degree mirror (25) and SOA (23) are formed for each of the four channels, and the optical waveguides connected to the output sides of each SOA (23) are each connected to the corresponding 45-degree mirror (25). In Figure 3(b), the position of each PD (22) is indicated by a dotted line for reference.

[0030]

On the other hand, independent of the SOA array (24), a microlens array (28) is provided on the input port of the SOA array (24) (the input port of each SOA (23)). In addition, several demultiplexers (26) are provided to divide the four channels of multiplexed light into four beams. In this embodiment, the demultiplexers (26) are dielectric mirrors, and one beam of light is split by transmitting and reflecting one beam of light with one set of two dielectric mirrors. Therefore, to divide one beam of light into four waves, a total of three sets of dielectric mirrors (six mirrors in total) are arranged, and the light is finally input as four beams of light.

[0031]

Although the PD (22) is not arrayed like the 4-channel PD array (12) shown in Embodiment 1, its structure may be equivalent to the PD of the PD array (12) shown in Embodiment 1. Therefore, a description of the PD's structure is omitted here.

[0032]

Therefore, the light input to the demultiplexers (26) is split into four waves by the six demultiplexers, and the light amplified by each SOA (23) is reflected by the 45-degree mirror (15) and input to each PD (22).

[0033]

On the surface of the SOA array (24) around the mirror (25), the high-frequency wiring (signal wiring) (27) for supplying high-frequency signals to the PD array (22) are formed for four channels through patterning. The high-frequency wiring (27) is connected to the electrode pads of the PD array (22) (not shown in the figure) via the gold bumps (21), and the PD (22) is flip-chip mounted on the surface of the SOA array (24). In this process, the PD (22) is flip-chip mounted so that light enters each PD (22) through the mirror (25).

[0034]

This flip-chip mounting of the PD (22) and the SOA array (24) is combined to form a PD-integrated SOA array (20). Furthermore, this flip-chip mounting allows for the signal wiring to be connected in a batch, which achieves reductions in mounting time and thus lowers costs; furthermore, it renders wire mounting unnecessary and allows for improvement of high-frequency characteristics.

(7)

[0035]

The channel spacing was set at 500  $\mu\text{m}$ , and the incident wavelengths were 1,295 nm, 1,300 nm, 1,305 nm, and 1,310 nm.

[0036]

### 1. Operating Principle

This embodiment explains how a wave is split from a single optical waveguide and the split optical signal is converted into a high-speed electrical signal. First, the optical signal is split into individual channels by a dielectric mirror (26)-based demultiplexer, and the optical power is amplified by being input to the SOA (23) in each channel. The optical signal amplified by the SOA (23) then enters the PD (22) through the 45-degree mirror (25) and is converted into an electrical signal (see the single-dotted line in Figure 3 (a)).

[0037]

### 2. Assembly Process

The following is a description of the procedure for fabricating a multi-channel optical receiver (device) with the configuration described above. In other words, the procedure for actually fabricating a PD-integrated SOA array (20) by assembling a PD (22), a SOA array (24), a microlens array (28), and a dielectric mirror (26) is described. First, cast a collimated beam of light across four channels onto the 45-degree mirror (25). In this state, the microlens array (28) is secured at the position where the collimated light will be.

[0038]

After securing the array, secure the dielectric mirror (26c) at an angle of 45 degrees to the beam of light so that the light will travel in a straight line when the light enters from the upper portion of the third mirror (25) from the top in Figure 3(b), and place an optical power meter detector on the beam of light. Next, secure the dielectric mirror (26d) at the position where the optical power meter reaches its maximum value when the light enters from the upper portion of the fourth (lowest) mirror (25) from the top. Using the same procedure, secure the dielectric mirrors (26a and 26b) on the first (topmost) and second optical paths from the top. Next, secure the dielectric mirror (26f) at an angle of 45 degrees to the beam of light so that the light will travel in a straight line when the light enters from the upper portion of the third or fourth (lowest) mirror (25) from the top, and place an optical power meter detector on the beam of light. Next, secure the dielectric mirror (26e) at the position where the optical power meter reaches its maximum value when the light enters from the upper portion of the first (highest) mirror or second mirror (25) from the top.

[0039]

Gold bumps (21) are also formed on the electrode pads of the PD (22) using ball bonders. At this time, the bump diameter was set to 60  $\mu\text{m}$ . Finally, mount the PDs one by one using a flip-chip mounting device so that the gold bumps (21) connect to the high-frequency wiring (27) of the SOA array (24). This completes the PD-integrated SOA array (20).

[0040]

### 3. Characteristics of the Variable Optical Attenuator

The experimental system shown in Figure 2 was fabricated for the multi-channel optical receiver with the configuration described above, and the eye pattern was measured using this experimental system. In other words, a PD-integrated SOA array (20) is used instead of a PD array-integrated SOA array (10), a multi-channel transmitting light source (31) is connected to the input side of the demultiplexer (26) of this PD array-integrated SOA array (20) via the optical fiber (32). In addition, an optical sampling oscilloscope (36) is connected to the PD-integrated SOA array (20). During measurement, the optical fiber (32) was set to a length of 40 km, with the bias current of the semiconductor optical amplifier (SOA 23) at 100 mA, the data rate was configured at 27.7 Gbps, using Non-Return-to-Zero (hereinafter, "NRZ") format, and a pseudo-random bit sequence (hereinafter, "PRBS") signal with a length of  $2^{31}-1$  was input as the optical signal across four channels. At this time, the extinction ratio observed by the optical sampling oscilloscope (36) was 5 dB.

[0041]

Additionally, in the experimental system described above, the optical sampling oscilloscope (36) was changed to an error detector, and a variable optical attenuator was inserted between the optical fiber (32) and the PD-integrated SOA array (20) to measure the bit error rate characteristics (hereinafter, "BER characteristics"). At this time, error-free operation was confirmed for each channel. When only the 1,295 nm wavelength channel was operated, error-free operation was observed up to -20 dBm of the optical power input to the PD-integrated SOA array (20).

[0042]

Therefore, it was made clear that the multi-channel optical receiver in this embodiment is feasible as a multi-channel optical receiver for long-distance applications that is compact and can be manufactured at low cost.

[0043]

In the above steps, ruthenium and iron-doped InP can be used for the insulating parts of the PD and SOA.

[0044]

In Embodiment 1 described above, a PD-array-integrated SOA array (10) provided with a PD array (12) and a demultiplexer-integrated SOA array (14) is described, but this can also be described as a PD-integrated SOA array provided with PD- and demultiplexer-integrated SOA arrays corresponding to the number of channels.

[0045]

In Embodiment 2 described above, a multi-channel optical receiver equipped with a PD-integrated SOA array (20) provided with PD (22) and SOA arrays (24) corresponding to the number of channels as well as several demultiplexers (26) is described, but this can also be described as a multi-channel optical multi-channel optical receiver equipped with a PD array-integrated SOA array provided with PD-integrated PD arrays and SOA arrays corresponding to the number of channels as well as several demultiplexers.

[Industrial applicability]

[0046]

The multi-channel optical receiver of the present invention is compact, can be manufactured at low cost, and is feasible as a multi-channel optical receiver for long distance applications, making it highly beneficial for the optical communication industry.

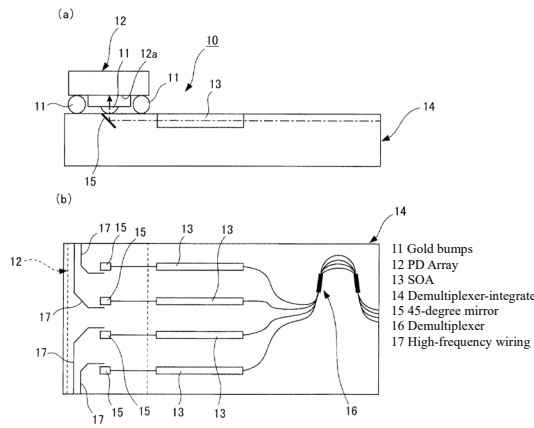
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[0047]

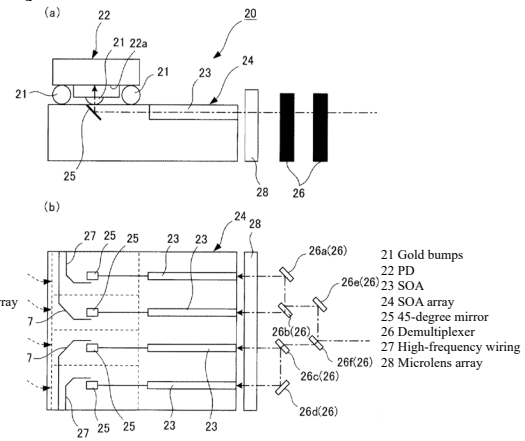
|    |                                         |
|----|-----------------------------------------|
| 10 | Multi-channel optical receiver          |
| 11 | Gold bumps                              |
| 12 | PD Array                                |
| 13 | SOA                                     |
| 14 | Demultiplexer-integrated SOA array      |
| 15 | 45-degree mirror                        |
| 16 | Demultiplexer                           |
| 17 | High-frequency wiring                   |
| 20 | Multi-channel optical receiver          |
| 21 | Gold bumps                              |
| 22 | PD                                      |
| 23 | SOA                                     |
| 24 | SOA array                               |
| 25 | 45-degree mirror                        |
| 26 | Demultiplexer                           |
| 27 | High-frequency wiring                   |
| 28 | Microlens array                         |
| 31 | Multi-channel transmitting light source |
| 32 | Optical fiber                           |
| 35 | Pulse pattern generator                 |
| 36 | Optical sampling oscilloscope           |
| 51 | Single-channel optical receiver         |
| 52 | Optical demultiplexer                   |

(9)

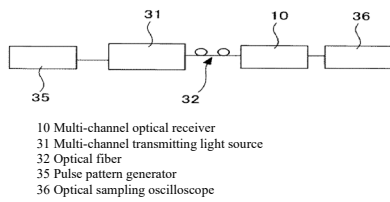
[FIG. 1]



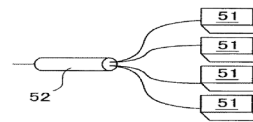
[FIG. 3]



[FIG. 2]



[FIG. 4]



(Continued from front page)

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5K102, AA15, AA52, AD01, PH15, PH32, PH38, PH45

# TRANSLATION CERTIFICATION

Date: January 9, 2025

To whom it may concern:

This is to certify that the attached translation is an accurate representation of the documents received by this office. The translation was completed from:

- Japanese

To:

- English (USA)

The documents are designated as:

- JP 2012034314A - Optical Demux

Emily Paras, Project Manager in this company, attests to the following:

“To the best of my knowledge, all statements contained in the translation are true and correct and the aforementioned documents are a true, full and accurate translation of the specified documents. I acknowledge that these statements are subject to the penalties for perjury.”

A handwritten signature in black ink, appearing to read "Emily Paras", written in a cursive style.

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Signature of Emily Paras