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(54) **TUNABLE ADD/DROP OPTICAL FILTER**

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(52) **U.S. Cl.** **349/117**; 385/14; 385/31; 385/39

(58) **Field of Search** 349/117, 96; 385/24, 385/31, 39, 14; 359/114, 124, 117, 130, 122, 156

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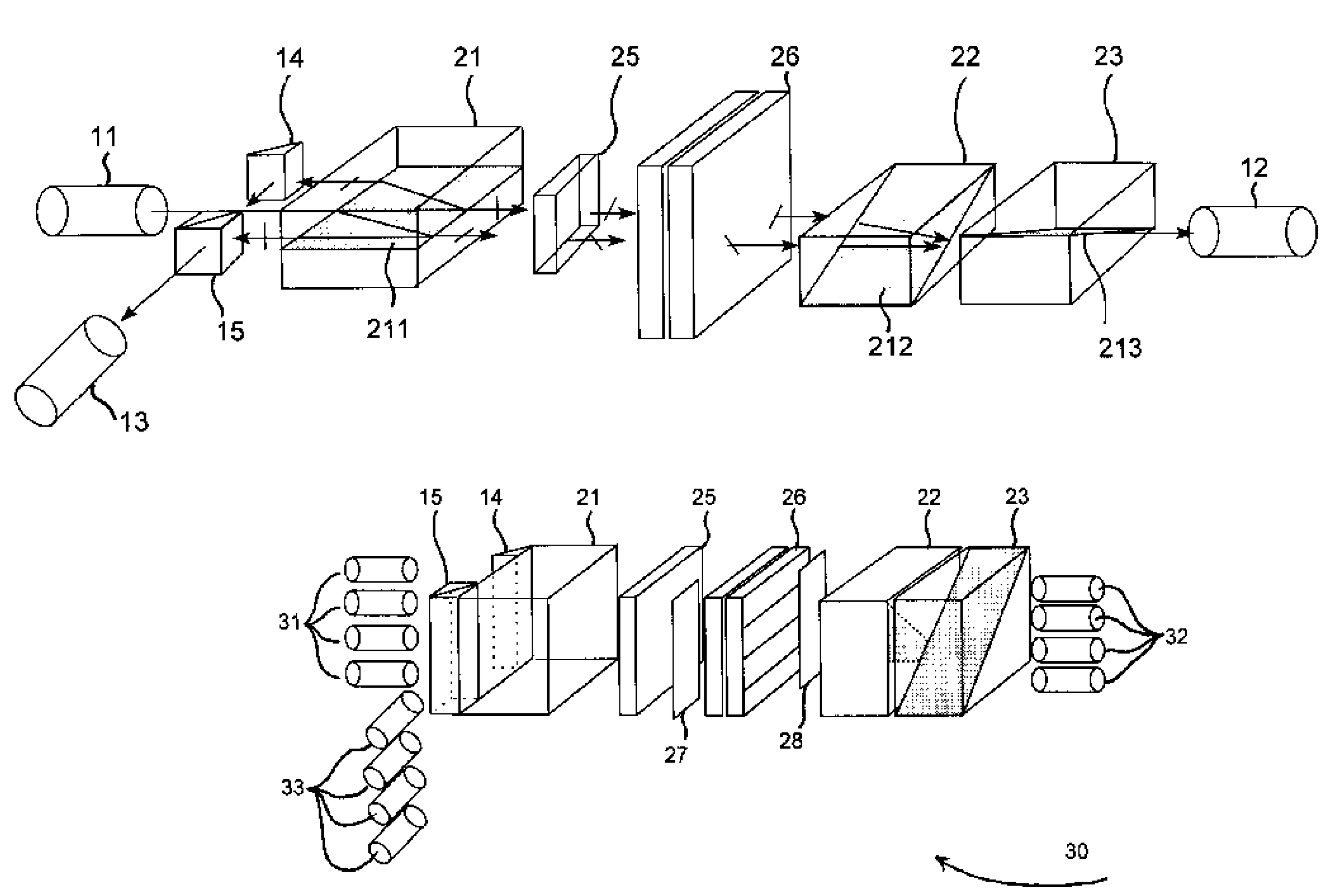
(57) **ABSTRACT**

In all-optical networks, optical switching and routing become the most important issues for interconnecting the transport network layers. This invention describes a novel tunable optical add/drop filter for the all-optical wavelength-division-multiplexing (WDM) network applications. This filter can add or drop part of the high transmission capacity signals of a WDM link. It can be used to decentralized access point in the access network or as small core network node to realizing branching points in the network topology. It works in both wavelength and space domains. It has the advantages of: 1) High throughput and low voltage operation; 2) Wide tuning range and therefore, high channel capacity; 3) High isolation and high directivity between input and output ports; 4) Compact device packaging is possible as compares to the conventional grating and mechanical switching type of add/drop filter; 5) Multiple ports add/drop tunable filters can be realized with this invention to interconnect multiple WDM networks. This novel add/drop filter can be used in various WDM topologies. It enhances the performance of the conventional tunable filter by re-routing the rejected wavelengths back to network, which not only save the precious optical energy, but also cut down the return loss of the device.

30 Claims, 6 Drawing Sheets



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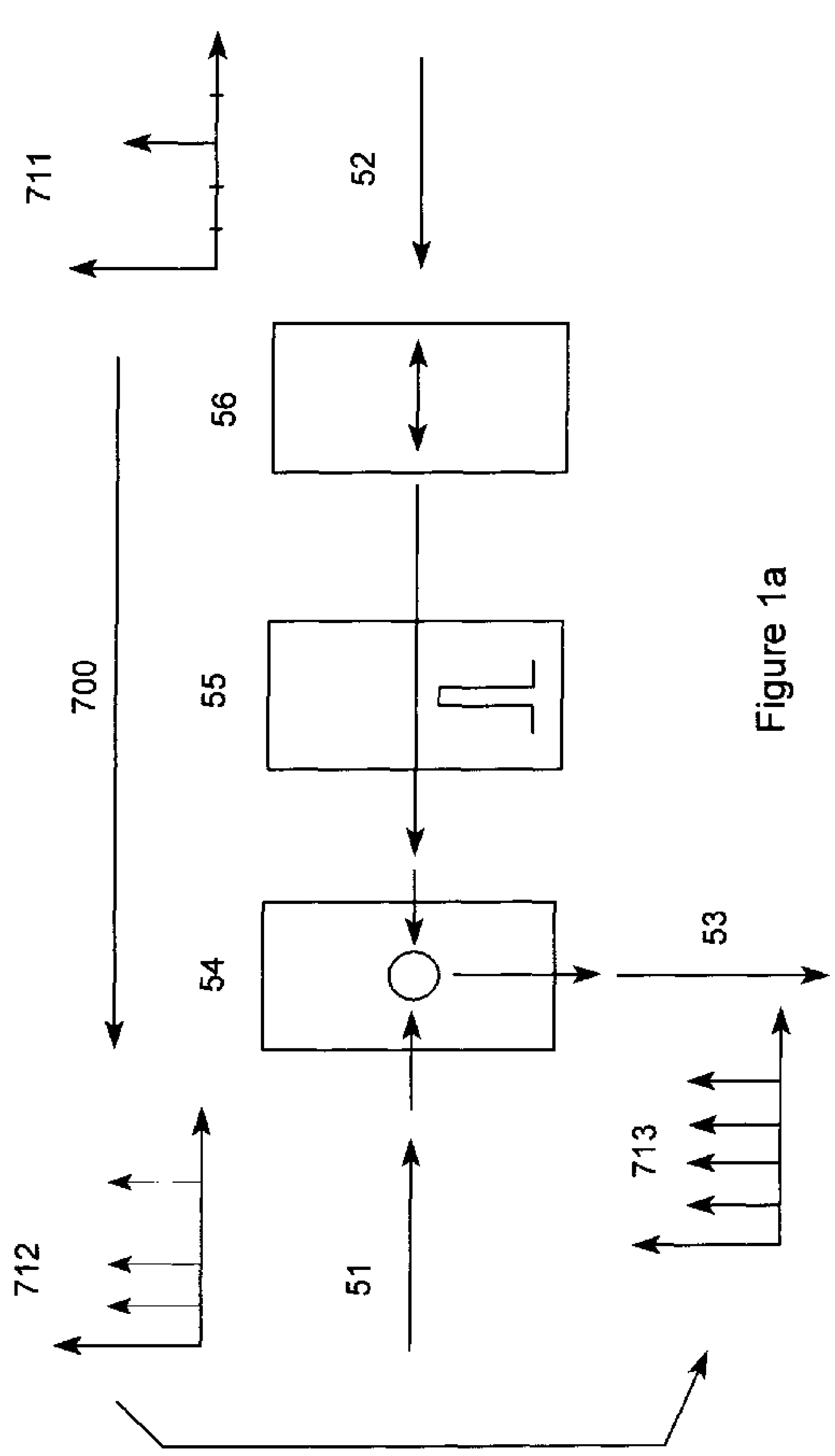


Figure 1a

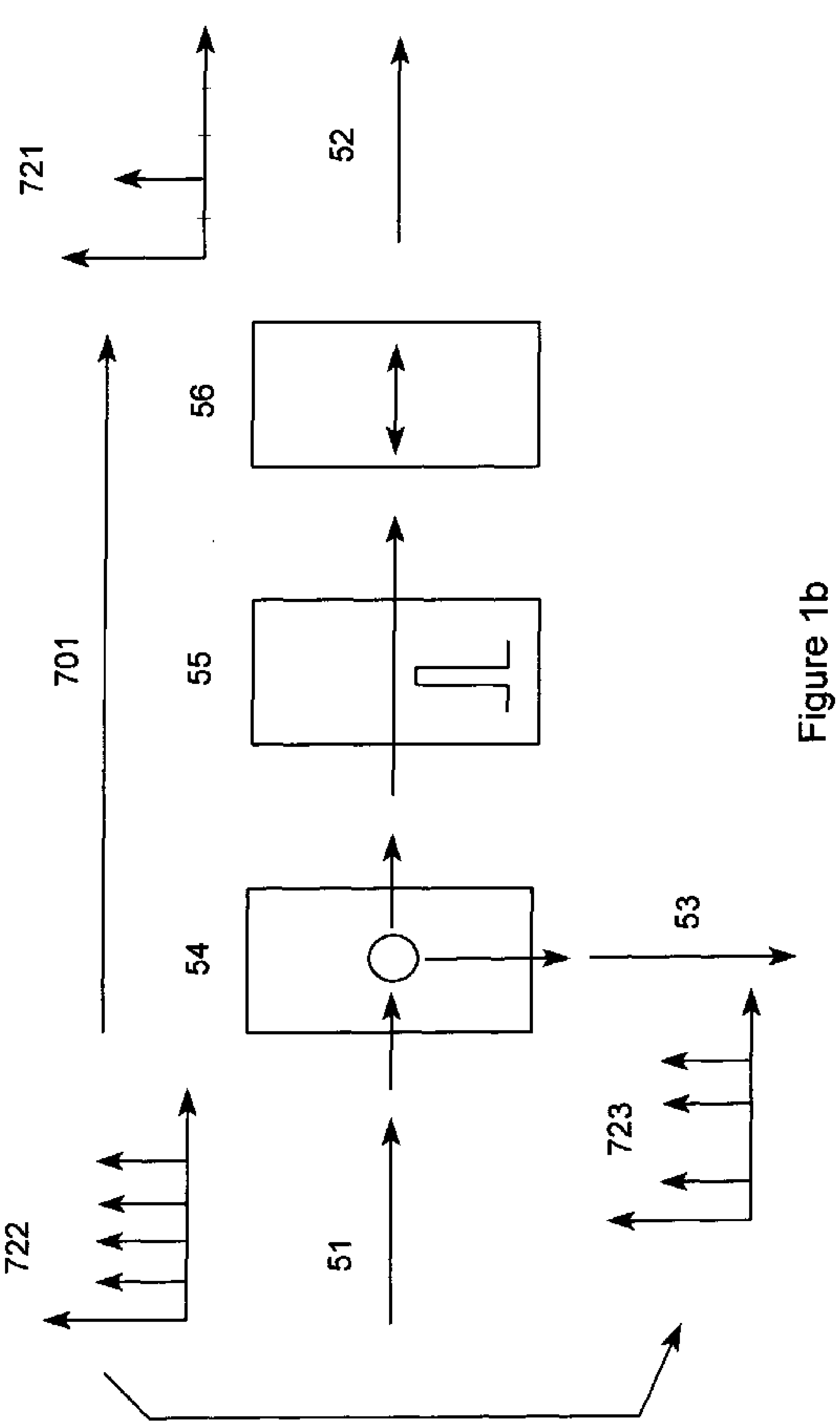


Figure 1b

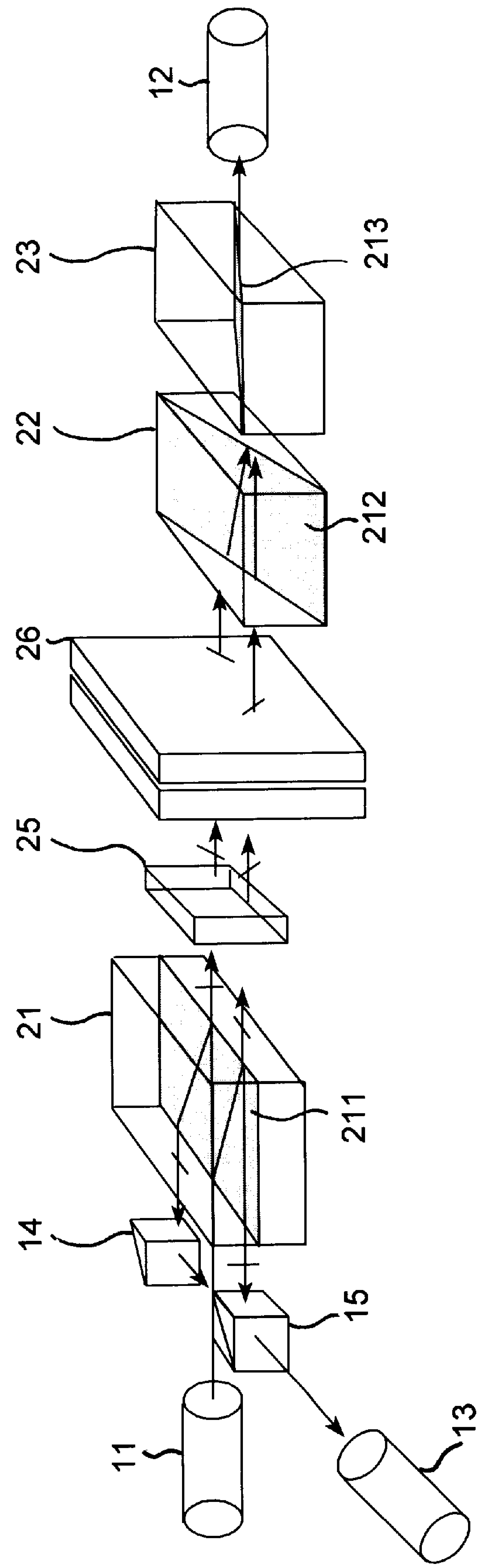
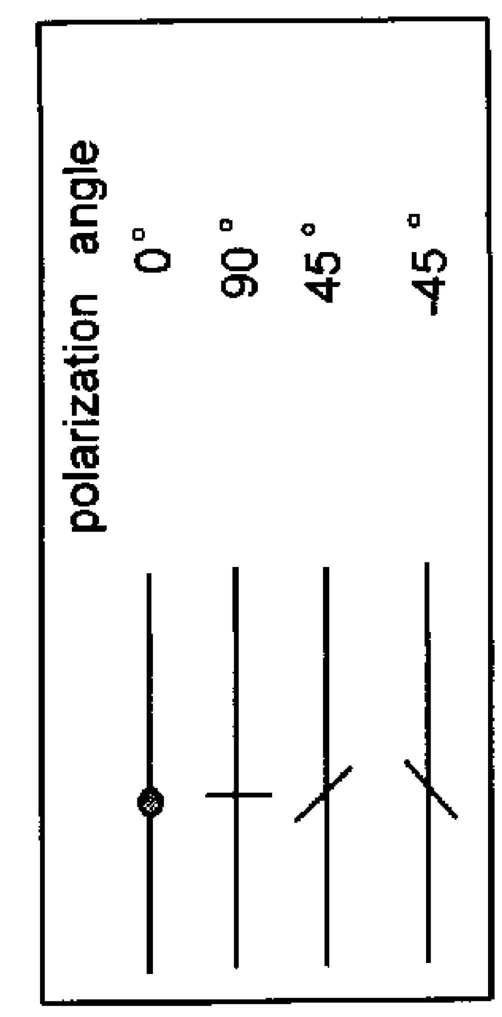


Figure 2



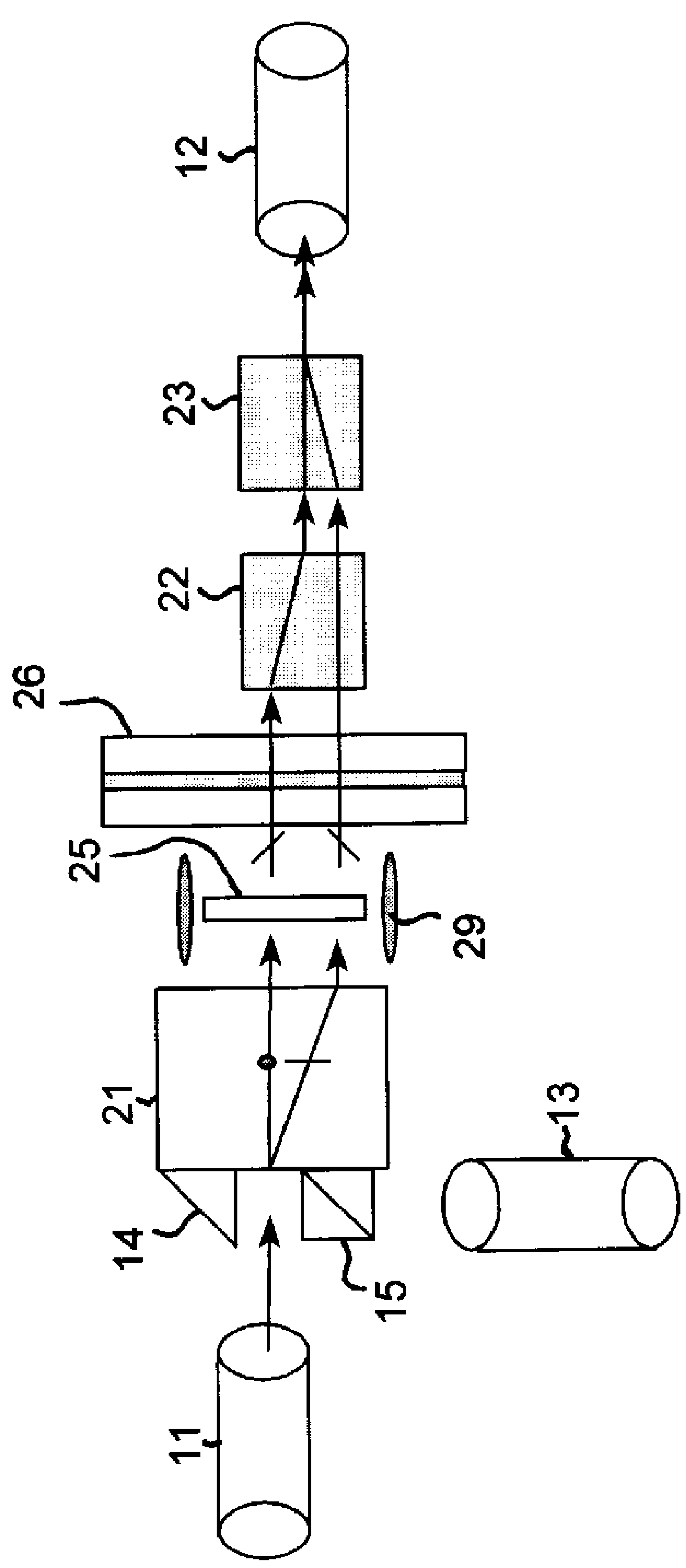


Figure 3a

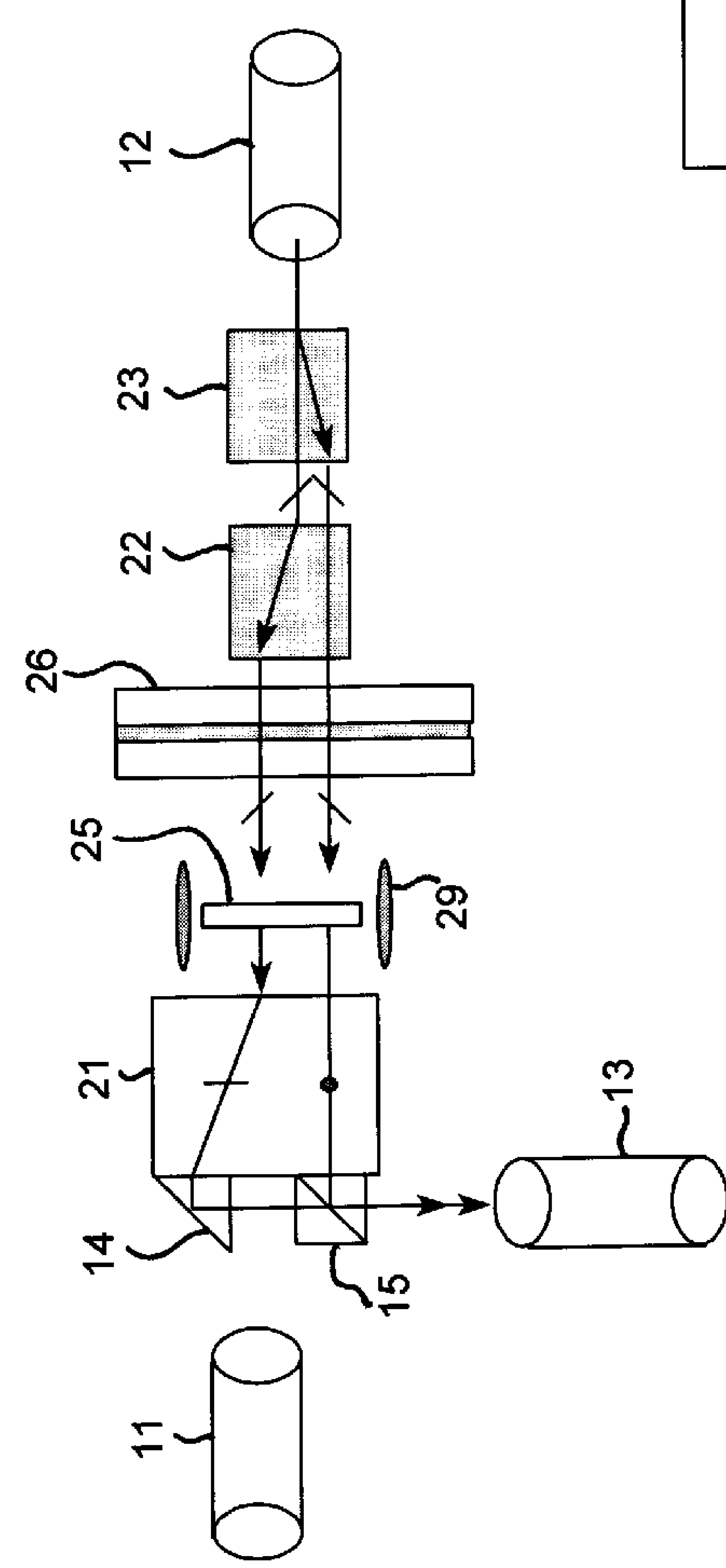


Figure 3b

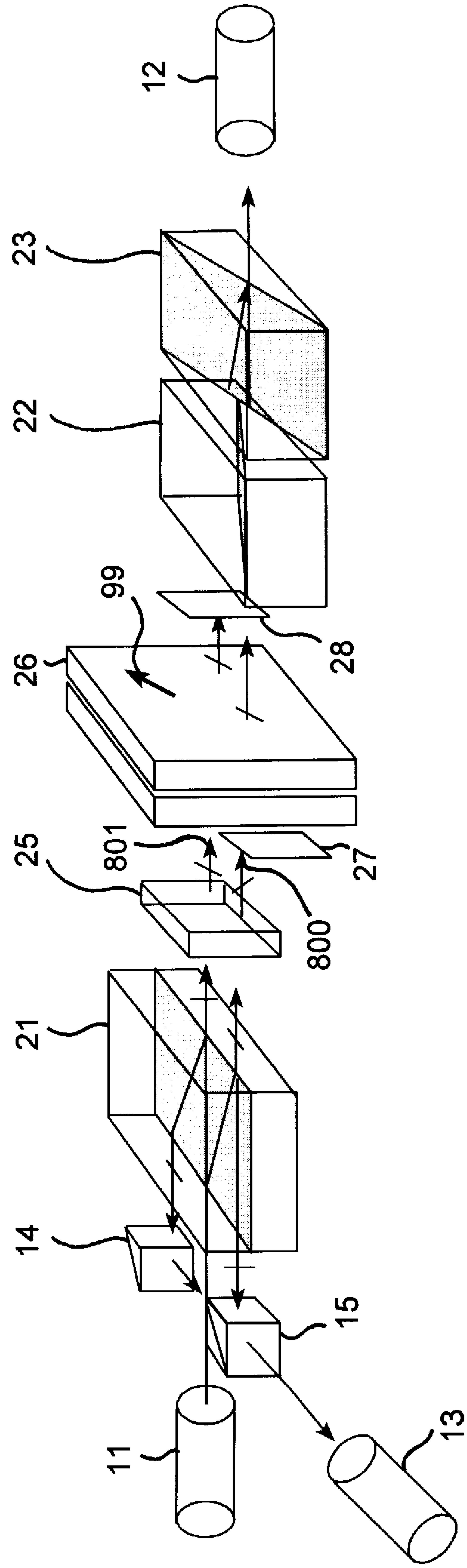


Figure 4

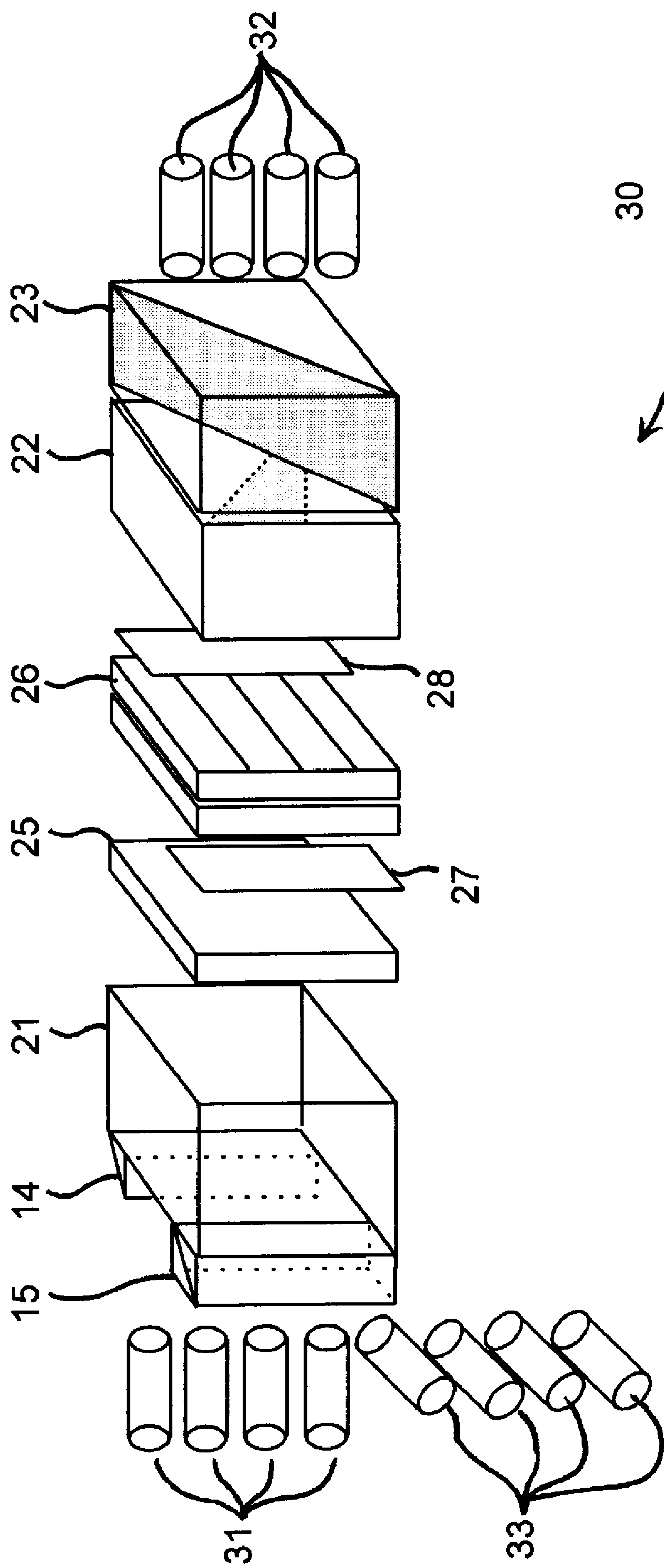


Figure 5

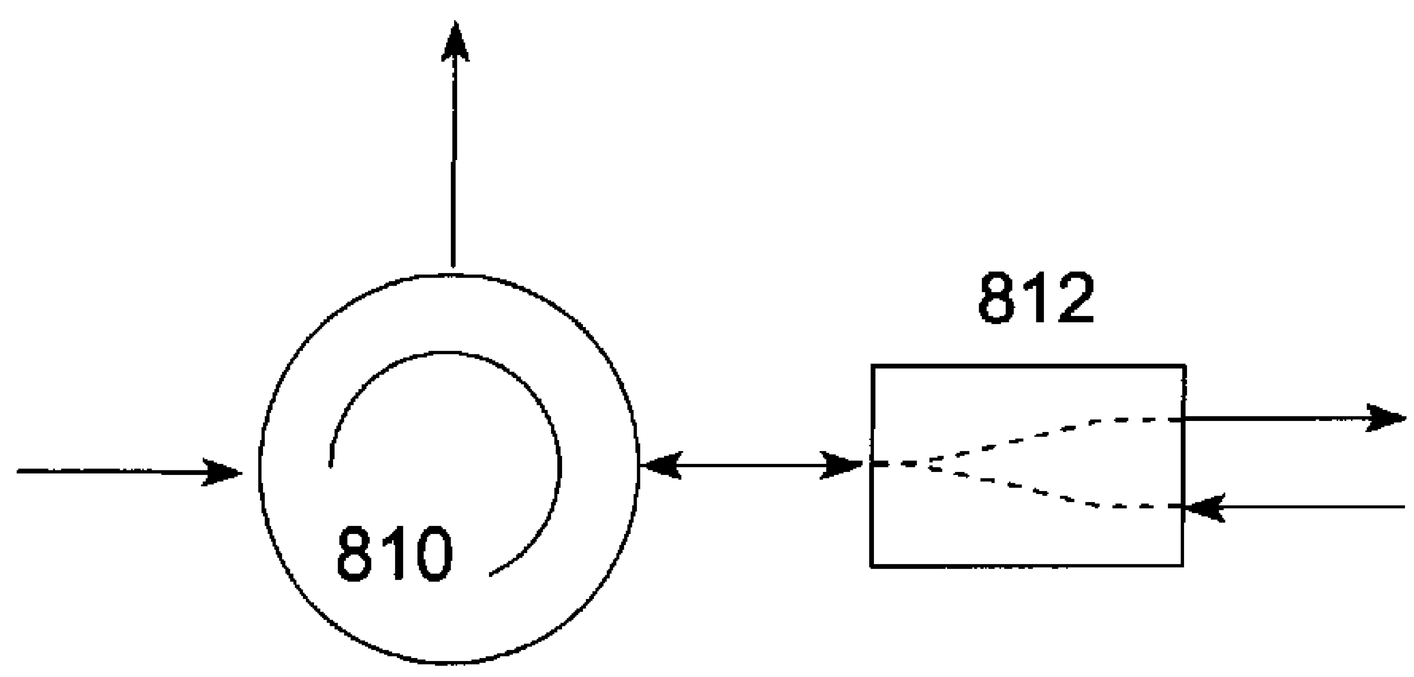


Figure 6a

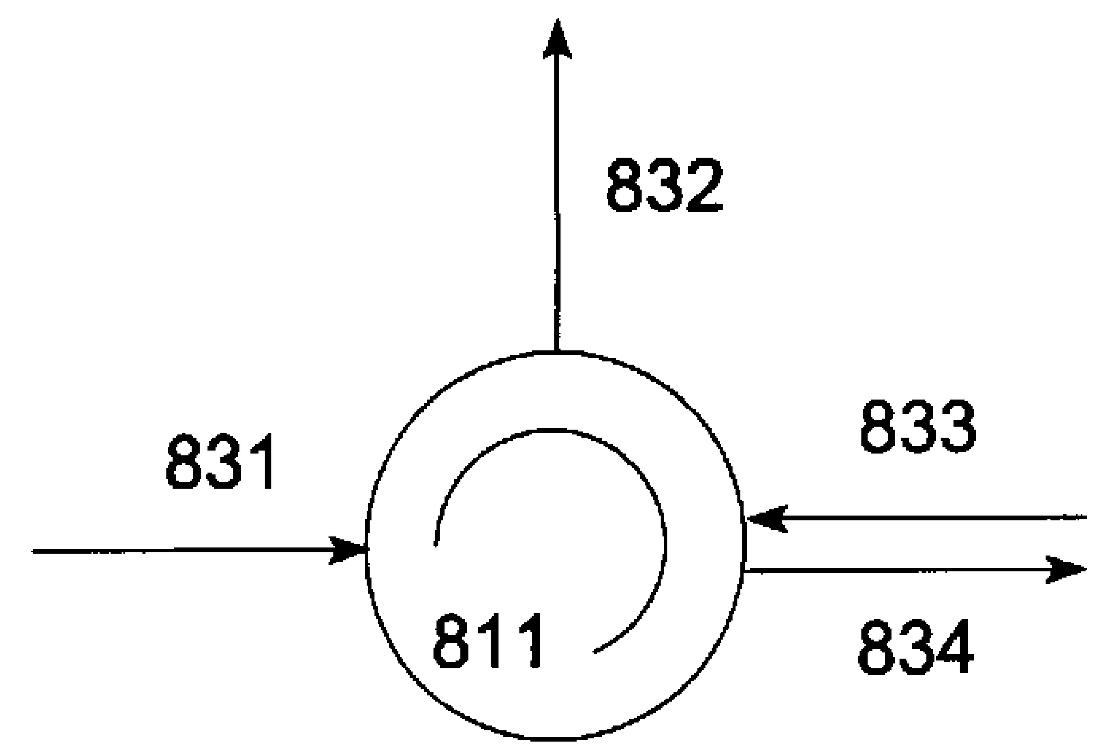


Figure 6b

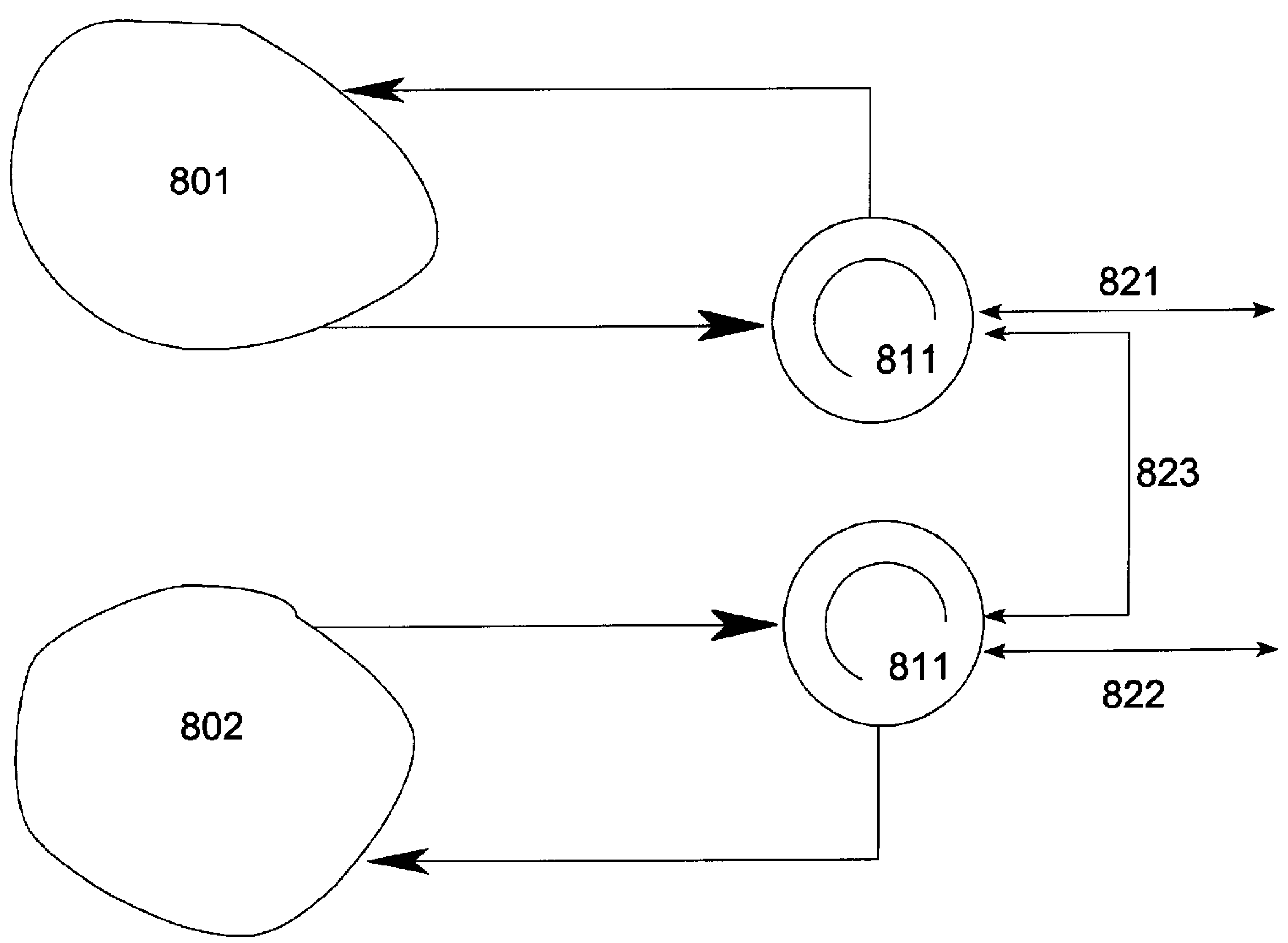


Figure 6c

TUNABLE ADD/DROP OPTICAL FILTER

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

FIELD OF THE INVENTION

In this invention, a tunable add/drop filter for the wavelength-division-multiplexing (WDM) network applications is described. This filter can add or drop part of the high transmission capacity signals of a WDM link.

BACKGROUND OF THE INVENTION

The communication environment is evolving towards increasingly heterogeneous but interconnected networks. The growth of demand for existing services and the introduction of new advanced services is expected to create a large increase of traffic flow in the near future. The current evolution of telecommunication network is led by asynchronous and synchronous transfer modes (Asynchronous Transfer Mode(ATM), Synchronous Optical Network (SONET), Synchronous Digital Hierarchy (SDH)), which require primarily electronic technologies for processing and switching. Although the necessary hardware building blocks are available to design wide area networks, complex [issue arises with] *issues arise with* the management of network resources. In order to simplify the transfer task, the layer structure of the transport network and the use of optical means are preferred.

In all-optical networks, optical switching and routing become the most important issues for interconnecting the transport network layers. This invention describes a tunable optical add/drop filter for the optical WDM network application. This filter can add or drop part of the high transmission capacity signals of a WDM link. It can be used to [decentralized access point] *decentralize access points* in the access network or as a small core network node [to] *in* realizing branching points in the network topology. It works in both wavelength and space domains.

The following describes various device structures that have been used for the add/drop filter design. The first structure [Cheung, "Acoustoopic Tunable Filters in Narrowband WDM networks: System Issues and Network Applications," IEEE J. Sele. Area Comm. 8(6), 1015, 1990.] uses four 1×N demultiplexers and N's 2×2 optical switches. The structure is complicated and the interconnections are difficult.

The second tunable add/drop filter, similar to the first geometry, has recently been proposed and demonstrated by Glance at AT&T. [Glance, "Tunable add/drop optical filter providing arbitrary channel arrangement", IEEE Photon. Lett., 7(11), 1303, 1995 and U.S. Pat. No. 5,488,500.] This filter provides the advantage of arbitrary channel arrangement, but still suffers a costly 6 dB optical coupling loss, because of the two array waveguide grating demultiplexers used in the structure.

The third type of wavelength-space switch [Dono et al, "A wavelength division multiple access network for computer communication", IEEE J. Sol. Area Comm., 8(6), 983, 1990.] has been widely used in various WDM networks, for example the IBM Rainbow Network. This structure uses a passive star-coupler that combines and splits the incoming light signals into N receivers. The receivers built with a tunable filter then select the desired channels. It has [the] broadcast capability and the control structure of this implementation is very simple. However, [the undesirable feature of the broadcast star, the splitting loss can be very high when the users number is large.] *an undesirable feature of the broadcast star is that splitting losses can be very high when the number of users is large.*

The add/drop filter presented in this invention can re-route the unused channels, which are rejected by the tunable filter, back to the network and save the precious optical energy in the network. It includes the design of an optical isolator, that also dramatically cuts down the return loss of the device, another important performance requirement for high-speed WDM devices. It operates in both wavelength and space domains that provides hybrid functionality with a relatively simple structure. It is ideal for the WDM applications.

DESCRIPTION OF THE DRAWINGS

FIGS. **1***a,* **1***b* are the building blocks of a tunable add/drop optical filter of this invention. It consists of three primary parts of non-reciprocal optical setup, tunable filter, and reciprocal optical setup.

FIG. **2** is a schematic representation of an exemplary tunable add/drop filter of this invention.

FIGS. **3***a,* **3***b* are schemes illustrating the operation of a tunable add/drop filter of this invention. The polarization states progressing through the optical elements is indicated and the definition of the signs are shown in the insert.

FIG. **4** is a structure representation of an exemplary tunable add/drop filter of this invention which incorporates a liquid crystal Fabry-Perot tunable filter. A pair of half waveplates are added into the two light paths, respectively, to rotate the polarizations match to the optical axis to the liquid crystal Fabry-Perot tunable filter.

FIG. **5** is a schematic representation of a multi-port add/drop tunable filter. The input/output ports have multiple fibers that carry the optical signals from multiple WDM networks. Each add/drop layer can independently drop or add a desired optical frequency through the sectioned tunable filter.

FIGS. **6***a,* **6***b,* **6***c* show optical switches combined with tunable add/drop filters to form tunable multiple-port add/drop filters.

SUMMARY DESCRIPTION OF THE INVENTION

The present invention includes a tunable add/drop filter that utilizes the unique operational characteristics of a non-reciprocal optical setup and a reciprocal optical setup for wavelength re-routing, and a tunable filter for wavelength selection. The non-reciprocal optical setup provides the functionality for optical channels to go in and out of the filter with high isolation. The reciprocal optical setup is used to keep the light were paths [stay] the same during the add/drop operations. In between the two optical setups, a filter is inserted to select the desired channels that pass through the add/drop filter.

In exemplary embodiments of the present invention, Fabry-Perot type filters and polarization interference filters are used. The non-reciprocal optical setup may comprise [of] a Faraday Rotator, a birefringent element, a polarizing beam combiner, and a right angle prism. The reciprocal optical setup may [comprises of] *comprise* a pair of birefringent elements with their polarization eigen [plane] *planes* orthogonal to each other and [are] ±45° to that of the birefringent element in the non-reciprocal setup, respectively. To properly recombine the two orthogonally polarized light waves at the add/drop port the thickness of *each of* the two birefringent elements in the reciprocal setup is 1/√2 *times the thickness* of the birefringent element in the non-reciprocal setup.

Other features and embodiments of the present invention will become clear to those of ordinary skill in the art by reference to the drawings and accompanying detailed description.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The core of this tunable add/drop filter [composes of a] *comprises a* tunable filter **55**, a non-reciprocal optical return setup **54**, and a reciprocal optical setup **56**, as shown in FIG. **1**. The spectra changed in the filter can be understood from **700** and **701** for the adding and dropping operations, respectively. In **700** adding operation (FIG. **1***a*), the channel (wavelength) to be added into the WDM network is in **711** and enters from **52**. It combines with the spectrum **712**, which already exists in the network, and [exit] *exits* at **53** with a combined spectrum **713**. In dropping operation **701** (FIG. **1***b*), the network spectrum is **722**. It drops part of the spectrum **721** to **52**. The rest of the returned channels then [re-routes] *re-route* through **53** and go back to the network with a spectrum **723**.

The light wave [propagates] *propagation* within the add/drop filter can be further explained as [follow] *follows*. In the dropping operation, the incoming network signals [carry] *carrying* multiple wavelengths enter from port **51**. The non-reciprocal optical setup **54** passes spectrum **722** to the tunable filter **55**. The selected channel **721** passes through the filter and the reciprocal setup **56**, and [exit] *exits* at port **52**. The rejected channels by the tunable filter, on the other hand, [reflects] *reflect* back to the non-reciprocal setup **54**. Because of the non-reciprocal property of **54**, light propagates backward in a different path [as in] *from* the forward propagating [direction] *path*. Therefore, it exits at port **53** and completes the dropping operation.

For the added operation, optical signal **711** to be added into the network enters from port **52**. Because *of* the reciprocal setup of **56**, light traveling in the reverse direction follows exactly the same path as it did in the forward direction. Therefore, spectrum **711** passes through the filter **55** that has been tuned to the channel and enters the non-reciprocal setup **54**. Because of the non-reciprocal optical path arrangement, this added channel joins the rest of the [rejected] channels *rejected* by the filter in the backward propagating direction and exits at port **53**. This completes the adding operations.

A preferred structure of this invention is shown in FIG. **2**. The non-reciprocal setup is built by a combination of a Faraday rotator **25**, a birefringent element **21**, a polarization beam combiner **15**, and a right angle prism **14**. The optical reciprocal setup is comprised of a pair of birefringent elements **22**/**23** with their polarization eigen planes **212**/**213** perpendicular to each other, and [are] ±45° relative to the polarization eigen plane **211** of the birefringent element in the non-reciprocal setup. The polarization eigen plane is defined by the plane that contains the optical axis of the birefringent element and also is the plane *that* contains the two orthogonal polarization states, when an unpolarized light is incident onto the element. The add/drop channel is selected by the tunable filter **26**. The add/drop port is designated by **12**. The input and output ports to the WDM network are **11** and **13**.

The detailed operations of the add/drop tunable filter are shown in FIG. **3**, which is the top view of the device. The

polarization progression within the filter is also indicated. In FIG. **3***a,* the forward dropping operation is realized by splitting the input polarization into two eigen orthogonal polarizations using the birefringent element **21**. These two light beams with polarization at (0°, 90°) are then rotated another 45° by the Faraday Rotator **25** *which* sits inside a magnet **29** and incident onto the filter **26**. The dropping channel passes through tunable filter **26** where it has been tuned to the desired resonant condition. The two spatially separated signals are recombined by the second and third birefringent [element] *elements* **22** and **23** oriented at ±45° and collected by the output lens **12**. Since the thickness of *each of* **22** and **23** is chosen to be only 1/√2 of the first birefringent element **21**, the two polarizations can be combined into a single beam by orientating **23** at 90° with respect to **22**. This arrangement of beam displacement allows any incoming state of polarization to be efficiently transmitted through the add/drop filter in the forward direction.

For the channels (wavelengths) that are rejected by the tunable filter **26**, they backward propagate to **25** and are rotated another 45°. Because this is a non-reciprocal effect, the returned polarizations are in (90°, 0°) states and are orthogonal to their original input states. Hence, they travel at different paths when passing through **21**, as shown in FIG. **3***b*. These two light beams are recombined by the right angle prism **14** and the polarization beam combiner **15** and send back to the WDM network.

Similarly, the added operation can be traced as shown in FIG. **3***b*. The light signal to be added into the WDM network first splits its polarization by **22** and **23** combination with polarization angles of (+45°, −45°). This is based on the fact that the input and output of the combined elements (**22** and **23**) are reciprocal. This means that light traveling in the reverse direction (i.e. the adding operation) must follow exactly the same path as it does in the forward direction. Therefore, at the exit of [this] *the* combined birefringent element (**22**/**23**), the spatial walk-off and the polarizations are identical for both forward and backward traveling light waves. With filter **26** tuned to the added wavelength, light signal passes the filter and enters **25**. By adding another 45° polarization to its original state, the output polarizations become (90°, 0°), which are the same as the rejected wavelengths. They are then collected by the prism **14** and polarization combiner **15** and go into the WDM network as was explained above. This completes the add/drop operations.

The elements used in this invention are listed below for illustration. These shall not limit [to] the application*, but are for illustration purposes only*. The Faraday rotator can be those based on magneto-optic materials, for examples, yttrium iron garnet (YIG), bismuth-substituted rare earth iron garnet (RBiIG), and holmium and terbium doped garnet crystals (HoTbBi)IG. The filter in this invention can be, piezo-tuned Fabry-Perot optical filters, liquid-crystal based Fabry-Perot tunable filters (U.S. Pat. No. 5,111,321, by Patel), tunable polarization interference filters (A. Title, Tunable birefringent filters, Optical Engineering, Vol. 20, pp. 815, 1981.), and acoustooptical tunable filters (X. Wang, Acousto-optic tunable filters spectrally modulate light, Laser Focus World, May [1993] *1992*.). When fixed filters, for example the interference filters, are used in the invention, they result in fixed add/drop filters. The polarizing materials used for the reciprocal operation can be materials with optical anisotropy, for examples calcite, rutile, lithium niobate ($LiNbO_3$), and yttrium orthovanadate YVO_4. All these Faraday rotators, filters, and polarizing crystals are commercially available.

EXAMPLE 1

An example of the tunable add/drop filter can be realized by using a liquid-crystal Fabry-Perot tunable filter as shown in FIG. **4**. A pair of halfwave plates are inserted in front of and behind of the liquid crystal filter. A halfwave plate satisfies the equation $\Delta nd=\lambda/2$, where Δn and d are the birefringence and thickness of the wave plate, and λ is the light wavelength. The first wave plate **27** is added into the light path **800** to change the polarization of the decomposed input light to match the 45° optic axis of the filter **99**. The second halfwave plate **28**, which is placed on the opposite side of the filter, rotates the extra-ordinary light wave into ordinary in light paths **801**. The two then [recombines] *recombine* by the birefringent elements **22** and **23**. The rest of the operations are explained in the previous embodiment.

Due to the spatial-light-modulation capability (2-Dimensional) of a liquid-crystal Fabry-Perot filter, a multiple-port add/drop tunable filter can be realized based on the current structure. As shown in FIG. **5**, this multi-port add/drop tunable filter can be easily fabricated by patterning a liquid-crystal Fabry-Perot filter into sections, and spatially aligning a series of inputs and outputs ports together. Remember, this multi-port tunable add/drop filter has exactly the same number of birefringent elements, Faraday rotator, and filter as in the single-port design. The patterning of the liquid-crystal Fabry-Perot can also be achieved photolithographically on the controlling transparent indium-tin-oxide (ITO) electrodes. Therefore, costs saving on materials and a compact packaging are possible for this multi-port filter. Potential applications include, but [not limit to,] *are not limited to* multiple WDM networks interconnections where [simultaneously] *simultaneous performances of* add/drop channels at this filter node can be achieved.

It can also combine with a N×N optical switch at the add/drop ports. In this case, multiple WDM networks are interconnected to each other and exchange information on this optical node. It operates in wavelength-space domain and is transparent to users and operators. This versatile filter will release the complex design of the high-capacity WDM network and [decentralized access point] *decentralize access points* in the access network[or as] . *It may also be used as a* small core network node [to] *in* realizing branching points in the network topology.

EXAMPLE 2

When a fixed filter, for example the interference filter, is used in this invention a high throughput passive add/drop filter is realized. Here, the add/drop channel is pre-defined by the interference filter. However, only such a wavelength can go in and out of the ports.

EXAMPLE 3

When an 1×2 optical switch is added onto the add/drop port, as shown in FIG. **6***a,* the three-port add/drop filter becomes a four-port add/drop filter with it's input- and output-port separated.(See FIG. **6***b*) Two of [this] *these* add/drop filters **811** can be further interconnected to form a wavelength-space switching node for multi-layered WDM systems. In FIG. **6***c,* one of the add/drop [port] *ports* **823** of [the] *each of the* add/drop [filter **811** is linked to the each other] *filters 811 are linked together*. The channels between the two WDM systems **801** and **802** can then be shared through this interconnected optical node. Furthermore, because of the reciprocal nature of this add/drop filter at the add/drop [port] *ports* **821** and **822**, optical channels can still

be loaded up and down from the its WDM network **801** and **802**, respectively. This greatly [increase] *increases* the flexibility design from the system's perspective.

THE ADVANTAGES OF THIS INVENTION

This tunable add/drop filter can be regarded as a combination of a tunable filter and an optical circulator. It has the merits of:

1. High throughput because all of the optical energies are preserved by the re-routing characteristics of the add/drop operations.
2. Wide tuning range when liquid-crystal Fabry-Perot, piezoelectric Fabry-Perot, or acoustooptic tunable filter are used. Therefore, high channel capacity is obtainable.
3. High isolation and high directivity between input and output ports because of the use of Faraday rotator and birefringent materials.
4. Compact device packaging is possible, as [compares] *compared* to the conventional grating and mechanical switching type of add/drop filter.
5. When the tunable filter is a liquid-crystal Fabry-Perot type, multiple-port add/drop tunable filters can be realized by patterning the liquid-crystal Fabry-Perot filter into sections and spatially aligning an array of input and output fibers together. With the output ports connected to an N×N switch, a space-separated, wavelength-division demultiplexer can be realized. This multiple-port add/drop tunable filter can potentially be used to link multi-WDM networks without complicated electrooptic conversion at each networking node.

I claim:

1. A tunable add/drop filter [which comprises] *comprising*:

a nonreciprocal setup for optical channels return to WDM network, a tunable filter for predetermined optical channel selection, and a reciprocal optical add/drop setup for add/drop operations, [where, the non-reciprocal optical setup is a combination of an optical birefringent element which has a thickness of d, a Faraday rotator that rotates eigen polarization of input light beam by 45°, a polarization beam combiner and a right angle prism placed at an entrance side of the birefringent element to recombine returned optical signals; the tunable filter for selectively dropping or adding the optical channels; and the reciprocal optical add/drop setup comprises two optical birefringent elements with thickness of $(1/\sqrt{2})d$, and with their polarization eigen planes oriented at 45° and −45° relatively to a polarization eigen plane of the birefringent element in the non-reciprocal setup, respectively.]

wherein said non-reciprocal optical setup comprises a combination of an optical birefringent element, which has a thickness of d, and a Faraday rotator that rotates eigen polarization of input light beams by 45°, and

wherein said non-reciprocal optical setup further comprises a polarization beam combiner and a right angle prism placed at an entrance side of said birefringent element to recombine returned optical signals.

2. The tunable add/drop filter of claim **1**, wherein said tunable filter [is] *comprises* a liquid crystal based, birefringent filter[, a pair of halfwave plates are added to the front and back facets of the filter; said two halfwave plates are placed to intersect two orthogonally polarized incident light paths, respectively; a first one of the halfwave plates is placed on a first light path that rotates an ordinary light wave into extraordinary light wave that aligns a polarization of the light wave to an optical axis of the liquid crystal film; a second one of the halfwave plates is placed on a second light path that rotates the extra-ordinary light wave into ordinary light wave**]**.

3. The tunable add/drop filter of claim **2**, wherein said tunable birefringent filter is a patterned liquid crystal based filter with a plurality of sections; each filter section can selectively filter through optical channel and said tunable add/drop filter forms a tunable multiple-port add/drop filter.

4. The tunable add/drop filter of claim 1, wherein said reciprocal optical add/drop setup comprises two optical birefringent elements.

5. The tunable add/drop filter of claim 1, wherein said tunable filter comprises a filter selected from the group consisting of: piezo-tuned, Fabry-Perot tunable filters; liquid crystal based Fabry-Perot tunable filters; tunable polarization interference filters; and acoustooptic tunable filters.

6. The tunable add/drop filter of claim 1, wherein said tunable filter further comprises a pair of halfwave plates, each of said pair located on opposite sides of said filter, respectively.

7. A tunable add/drop filter comprising:

a tunable filter which is selectively adjustable to pass only desired frequencies of light waves;

means for splitting an optical input polarization into two eigen orthogonal polarizations;

means for rotating said two orthogonal eigen polarizations by 45° and passing the rotated orthogonal eigen polarizations to a first side of said tunable filter;

means for spatially combining an optical output from a second side of said tunable filter;

means for spatially combining undesired frequencies of said two orthogonal eigen polarizations which are rejected by said tunable filter; and

means for outputting a combination of said undesired frequencies.

8. The tunable add/drop filter of claim 7, further comprising means for inputting an optical signal to said second side of said tunable filter; and

means for splitting said optical signal into two eigen orthogonal polarizations and passing the split optical signal to said second side of said tunable filter; and

means for spatially combining desired frequencies of said split optical signal which are outputted from said first side of said tunable filter with said undesired of frequencies of said two orthogonal eigen polarizations which are rejected by said tunable filter and outputting a combined signal through said means for outputting.

9. A tunable add/drop filter comprising:

selectively adjustable means for passing only desired frequencies of light waves;

means for splitting an optical input signal into two eigen orthogonal polarizations;

means for rotating said two orthogonal eigen polarizations by 45° and passing the rotated orthogonal eigen polarizations to a first side of said selectively adjustable means;

means for spatially combining an optical output from a second side of said selectively adjustable means;

means for redirecting frequencies of said two orthogonal polarizations, which are rejected by said selectively adjustable means, through said means for splitting such that said rejected frequencies follow different paths than the split optical input signal; and

means for spatially combining said rejected frequencies of said two orthogonal eigen polarizations.

10. The tunable add/drop filter of claim 9, further comprising means for outputting the combination of said rejected frequencies.

11. The tunable add/drop filter of claim 9, further comprising:

means for splitting a second optical input signal into two eigen orthogonal polarizations and passing the split second optical signal to said second side of said selectively adjustable means;

means for directing frequencies of said split optical signal, which pass through said selectively adjustable means, along said different paths and with the same polarizations as said rejected frequencies of said first optical signal; and

means for spatially combining said rejected frequencies of said first optical signal and the passed frequencies of said second optical signal.

12. The tunable add/drop filter of claim 11, further comprising means for outputting the combination of said rejected frequencies of said first optical signal and the passed frequencies of said second optical signal.

13. A tunable add/drop filter comprising:

at least two input ports for inputting optical signals;

selectively adjustable means for passing only desired frequencies of light waves;

means for splitting an optical input signal from each said input port into two eigen orthogonal polarizations;

means for rotating each pair of said two orthogonal eigen polarizations by 45° and passing the rotated orthogonal eigen polarizations to a first side of said selectively adjustable means;

means for spatially combining outputs received from a second side of said selectively adjustable means to form optical outputs, wherein each optical output corresponds to a respective pair of said two orthogonal eigen polarization inputted to said first side of said selectively adjustable means;

means for redirecting frequencies of each of said pairs of said two orthogonal polarizations, which are rejected by said selectively adjustable means, through said means for splitting such that said rejected frequencies follow different paths than the split optical input signals; and

means for spatially combining said rejected frequencies, wherein each spatial combination of rejected frequencies corresponds to a respective pair of said two orthogonal eigen polarizations rejected from said first side of said selectively adjustable means.

14. The tunable add/drop filter of claim 13, further comprising at least two output ports for outputting said spatial combinations of rejected frequencies.

15. The tunable add/drop filter of claim 14, wherein a number of said input ports equals a number of said output ports.

16. The tunable add/drop filter of claim 13, further comprising:

at least two input ports for inputting optical add signals;

means for splitting said optical add input signal into two eigen orthogonal polarizations each, and passing the split optical add signals to said second side of said selectively adjustable means;

means for directing frequencies of said split optical add signals, which pass through said selectively adjustable means, along said different paths and with the same polarizations as said rejected frequencies of said optical input signals; and

means for spatially combining said rejected frequencies of said optical input signal and the passed frequencies of said optical add signals, wherein each spatial combination of rejected frequencies and passed frequencies corresponds to a respective pair of said input ports for inputting optical signals and said input ports for inputting optical add signals.

17. The tunable add/drop filter of claim 16, further comprising means for outputting said spatial combinations of said rejected frequencies and said passed frequencies.

18. The tunable add/drop filter of claim 17, wherein said means for outputting comprises at least two output ports.

19. The tunable add/drop filter of claim 18, wherein a number of said input ports for inputting optical signals, said input ports for inputting optical add signals, and said output ports are all the same.

20. A tunable add/drop filter comprising

a nonreciprocal setup for optical channels return to WDM network, a tunable filter for predetermined optical channel selection, and a reciprocal optical add/drop setup for add/drop operations,

wherein said reciprocal optical add/drop setup comprises two optical birefringent elements, and wherein said two optical birefringent elements of said reciprocal optical add/drop setup have polarization eigen planes oriented at 45° and −45° relative to a polarization eigen plane of said birefringent element in said non-reciprocal setup, respectively.

21. The tunable add/drop filter of claim 20, wherein said non-reciprocal optical setup comprises a combination of an optical birefringent element, which has a thickness of d, and a Faraday rotator that rotates eigen polarization of input light beams by 45°.

22. The tunable add/drop filter of claim 21, wherein said non-reciprocal optical setup further comprises a polarization beam combiner and a right angle prism placed at an entrance side of said birefringent element to recombine returned optical signals.

23. The tunable add/drop filter of claim 21, wherein said reciprocal optical add/drop setup comprises two optical birefringent elements, each having a thickness of (1/√2)d, and with their polarization eigen planes oriented at 45° and −45° relative to a polarization eigen plane of said birefringent element in said non-reciprocal setup, respectively.

24. The tunable add/drop filter of claim 23, wherein said tunable filter further comprises a pair of halfwave plates, each of said pair located on opposite sides of said liquid crystal based, birefringent filter, respectively.

25. The tunable add/drop filter of claim 20, wherein said tunable filter comprises a liquid crystal based, birefringent filter.

26. The tunable add/drop filter of claim 25, wherein said tunable filter comprises a patterned liquid crystal based, birefringent filter with a plurality of sections.

27. The tunable add/drop filter of claim 20, wherein said tunable filter comprises a filter selected from the group consisting of: piezo-tuned, Fabry-Perot tunable filters; liquid crystal based Fabry-Perot tunable filters; tunable polarization interference filters; and acoustooptic tunable filters.

28. A tunable add/drop filter comprising

a nonreciprocal setup for optical channels return to WDM network,

a tunable filter for predetermined optical channel selection, and a reciprocal optical add/drop setup for add/drop operations,

wherein said non-reciprocal optical setup comprises a combination of an optical birefringent element, which has a thickness of d, and a Faraday rotator that rotates eigen polarization of input light beams by 45°, and

wherein said reciprocal optical add/drop setup comprises two optical birefringent elements, each having a thickness of (1/√2)d, and with their polarization eigen planes oriented at 45° and −45° relative to a polarization eigen plane of said birefringent element in said non-reciprocal setup, respectively.

29. The tunable add/drop filter of claim 28, wherein said tunable filter further comprises a pair of halfwave plates, each of said pair located on opposite sides of said liquid crystal based, birefringent filter, respectively.

30. The tunable add/drop filter of claim 28, wherein said tunable filter comprises a filter selected from the group consisting of: piezo-tuned, Fabry-Perot tunable filters; liquid crystal based Fabry-Perot tunable filters; tunable polarization interference filters; and acoustooptic tunable filters.

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