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(71) Applicant *(for all designated States except US):* **GENIA PHOTONICS INC.** [CA/CA]; 1111, Lapierre St. Local 1.845, Lasalle, Quebec, H8N 2J4 (CA).

(72) Inventor; and
(75) Inventor/Applicant *(for US only):* **VILLENEUVE, Alain** [CA/CA]; 194, Brookfield, Mount-Royal, Quebec, H3P 3J8 (CA).

(74) Agent: **TESSIER, Louis;** P.O. Box 54029, Town Mount-Royal, Quebec, H3P 3H4 (CA).

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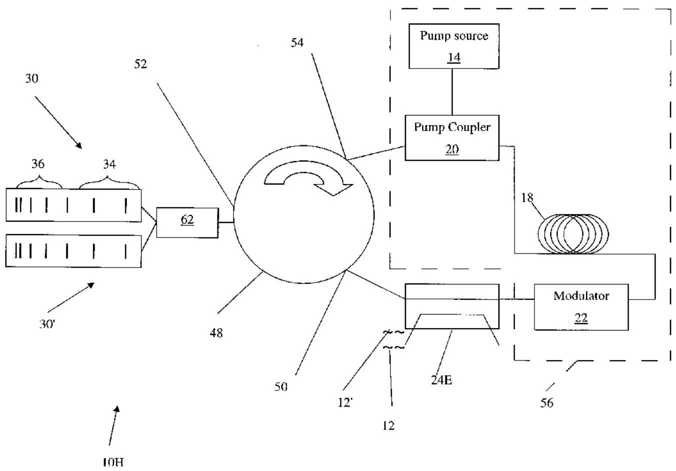

Figure 10

(57) Abstract: A laser for emitting simultaneously a first and second laser lights having respectively first and second wavelength differing from each other. The laser comprises: an optical resonator defining a first optical path and a second optical path, the first laser light travelling along the first optical path and the second laser light travelling along the second optical path; a modulated gain element inserted in the optical resonator for amplifying the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths, the modulated gain element having a variable gain modulated with a modulation period, round trip times of the first and second laser lights along respectively the first and second optical paths being respective integer multiples of the modulation period; and an output port for releasing the first and second laser lights from the optical resonator.

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TITLE OF THE INVENTION

TUNABLE MODE-LOCKED LASER

FIELD OF THE INVENTION

[0001] The present invention relates to the general field of optics, and is particularly concerned with a mode-locked laser.

BACKGROUND

[0002] Mode-locked lasers, for example, mode-locked fiber lasers, generate relatively short pulses of laser light. To achieve the generation of such pulses, many methods are used in the prior art. For example, pulses may be generated by inserting in the laser cavity a saturable absorber. The saturable absorber is a material that preferentially transmits light having high intensity. Therefore, in these embodiments, any random fluctuation in the intensity of the light propagating within the laser cavity is preferentially selected. Since these lasers include highly reflective mirrors at both ends thereof, even relatively inefficient intensity selection will result in the formation of pulses as light travels back and forth in the laser cavity. A disadvantage of these mode-locked lasers is that they are typically not tunable in wavelength.

[0003] In another type of mode-locked lasers, the saturable absorber is replaced by an optical component that periodically changes its absorption coefficient at the lasing frequency. For example, this may be achieved by using acousto-optic modulators, or electro-optic modulators. By selecting the frequency at which the absorption coefficient is modulated, it is possible to select for light traveling within the lasing cavity in pulses having a round trip time around the cavity that is a multiple of the frequency at which the absorption coefficient is modulated. Therefore, only a few or one pulse is selected within the cavity, which produces the pulsed output. Conventional mode-locked lasers using this technology are also typically not adjustable in wavelength.

[0004] To produce tunable mode-locked lasers, Sorin et al., in US Patent 6,091 ,744 issued on July 18, 2000, have proposed using a laser in which one end thereof includes a plurality of fiber Bragg gratings longitudinally spaced apart from each other, each fiber Bragg grating being reflective at a respective wavelength. A tunable filter is inserted in the laser cavity. By selecting a specific wavelength using the tunable filter, reflection occurs at a specific one of the fiber Bragg gratings, which provides selection of wavelength in discreet steps. Such lasers have been shown to be advantageous in telecommunication applications in which specific wavelengths are used to transmit information over different channels. However, these set-ups require the use of a tunable filter and are therefore relatively expensive. Furthermore, tunable filters are typically relatively fragile components and, therefore, the resulting lasers are not very robust. Yet, furthermore, this laser is not continuously adjustable in wavelength, which may prove a disadvantage in many applications.

[0005] PCT Publication Ser. No. WO 03/043149 published on May 22, 2003 by Duguay et al. describes an electronically tunable laser using wavelength selective reflectors. In this tunable laser, a gain fiber is coupled at both ends thereof to optical fibers in which paired sets of fiber Bragg gratings are formed, the fiber Bragg gratings being reflective at different wavelengths and each of the fiber Bragg grating in each pair being located in a respective one of the optical fibers. The fiber Bragg gratings in each pair are all distanced from each other by a substantially similar distance and are longitudinally offset from each other.

Therefore, a round trip time inside the cavity does not depend on the specific pair of fiber Bragg gratings that reflects each wavelength. An optical modulator is inserted between one of the optical fibers containing the fiber Bragg gratings and the gain medium so as to select times at which pulses are permitted to travel inside the laser. By properly selecting the delay between two successive moments at which pulses are allowed to pass through the modulator, pulses reflected by a specific pair of fiber Bragg gratings are preferentially selected in the tunable laser. Consequently, the wavelength of the laser light produced by the laser is selected using the optical modulator by selecting the pair of fiber Bragg gratings that is used to reflect the light. However, this arrangement is relatively complex and requires relatively precise timing of the modulator to operate properly.

[0006] Also, in some cases, it would be useful for a mode-locked laser to be able to emit simultaneously two or more wavelengths.

[0007] Against this background, there exists a need in the industry to provide an improved mode-locked laser. An object of the present invention is therefore to provide such a device.

SUMMARY OF THE INVENTION

[0008] In a broad aspect, the invention provides a laser cavity for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength using pump light emitted by a pump light source, the first and second wavelengths differing from each other, the laser cavity comprising: an optical resonator, the optical resonator defining a first optical path and a second optical path, the first laser light travelling along the first optical path and the second laser light travelling along the second optical path; a gain medium inserted in the optical resonator, the gain medium being responsive to the pump light for converting the pump light to the first and second laser lights; a pump light input port optically coupled to the gain medium for receiving the pump light and conveying the pump light to the gain medium; an optical intensity modulator inserted in the optical resonator for absorbing simultaneously a portion of both the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths, the optical intensity modulator having a light absorption coefficient that is modulated with a modulation period, round trip times of the first and second laser lights along respectively the first and second optical paths being respective integer multiples of the modulation period; and an output port for releasing the first and second laser lights from the optical resonator. When the gain medium is pumped with the pump light, modulating the optical intensity modulator with the modulation period produces simultaneously the first and second laser lights having respectively the first and second wavelengths.

[0009] The first and second optical paths represent the path along which the first and second laser lights propagate in the optical resonator. Typically, the first and second optical paths are physically superposed along a portion thereof, for example by including a common optical fiber, and are disjoint from each other along another portion thereof, for example by including separate optical fibers. However, in alternative embodiments of the invention, the first and second optical paths are not superposed at all or they are superposed along their entire length.

[0010] The pump light source can include one or more components. For example, the pump light source includes a single physical component producing the pump light. In another example, the pump light source includes at least two distinct physical components, such as laser diodes, among other possibilities, producing each part of pump light.

[001 1] In other words, in some embodiments of the invention, the first and second optical paths coincide with each other over at least a portion thereof and are, for example, disjoint from each other over another portion thereof.

[0012] In some embodiments of the invention, the optical resonator includes a first reflector provided in the first optical path for reflecting the first laser light in the optical resonator and a second reflector provided in the second optical path for reflecting the second laser light in the optical resonator. For example, the first reflector is a first fiber Bragg grating embodied in a first optical fiber and the second reflector is a second fiber Bragg grating embodied in second optical fiber. In a specific example the modulation period is selectively adjustable between a first modulation period value and a second modulation period value and the first and second fiber Bragg gratings are chirped fiber Bragg gratings.

[0013] For the purpose of this document, chirped gratings are to be understood as gratings that are reflective at different wavelengths therealong, the wavelength varying typically monotonously along the grating. While the reflected wavelength can be linearly related to position along the grating, this relationship can be non-linear. Also, in alternative embodimetns of the invention, the variation in reflected wavelength is not monotonous as a function of position along the optical fiber.

[0014] In some embodiments of the invention, the first reflector includes a first reflector first portion and a first reflector second portion for respectively reflecting the first laser light exclusively at two different values of the first wavelength, the first reflector first and second portions being respectively spaced apart from the optical intensity modulator by a first reflector first portion-to-modulator distance and a first reflector second portion-to-modulator distance, the first reflector first portion-to-modulator distance being smaller than the first reflector second portion-to-modulator distance.

[0015] In some embodiments of the invention, the first reflector is a first fiber Bragg grating and the second reflector is a second fiber Bragg grating, the first and second fiber Bragg grating being embodied in a common optical fiber. For example, the modulation period is selectively adjustable between a first modulation period value and a second modulation period value, which selects a location along the fiber Bragg grating at which light can be reflected, and therefore selects the first wavelength. In some specific embodiments of the invention, the first and second fiber Bragg gratings are chirped and are at least partially superposed.

[0016] In some embodiments of the invention, the gain medium includes a gain medium first portion provided in the first optical path and a gain medium second portion provided in the second optical path, the gain medium first and second portions being disjoint from each other, the gain medium first and second portions being provided in parallel in the optical resonator. For example, the gain medium first and second portions each include a respective doped gain fiber. In a specific example of implementation, the optical resonator includes a chirped fiber Bragg grating provided in both the first and second optical paths for reflecting the first and second laser lights and the gain medium first and second portions have different lengths.

[0017] In some embodiments of the invention, the first and second optical paths have respectively first and second optical paths lengths, the first and second optical path lengths being dependant respectively on values of the first and second wavelengths. For example, the modulation period is selectively adjustable between a first modulation period value and a second modulation period value and the optical resonator includes a first reflector provided in the first optical path for reflecting the first laser light in the optical resonator and a second reflector provided in the second optical path for reflecting the second laser light in the optical resonator, the first and second reflectors each including a respective chirped fiber Bragg grating.

[0018] In some embodiments of the invention, the gain medium defines a gain medium first end and a substantially opposed gain medium second end. The optical resonator includes a reflector and an optical circulator, the optical circulator including a circulator first port, a circulator second port and a circulator third port, the optical circulator being configured in a manner such that the first and second laser lights incoming at the circulator first port are emitted at the circulator second port, the the first and second laser lights incoming at the circulator second port are emitted at the circulator third port and the the first and second laser lights incoming at the circulator third port are emitted at the circulator first port, the circulator first port being optically coupled to the gain medium through the gain medium first end, the circulator second port being optically coupled to the reflector and the circulator third port being optically coupled to the gain medium through the gain medium second end.

[0019] In some embodiments of the invention, the optical intensity modulator includes an electro-optic modulator or a variable attenuation modulator.

[0020] In some embodiments of the invention, the gain medium includes a doped gain fiber.

[0021] In some embodiments of the invention, the output port includes an optical switch for alternatively and selectively releasing the laser light from the optical resonator and confining the laser light in the optical resonator.

[0022] In some embodiments of the invention, the first optical path includes a delay element for delaying propagation of the first laser light exclusively along the first optical path. For example, the delay element is a variable delay element for which a propagation delay is selectable.

[0023] In some embodiments of the invention, the first and second optical paths have substantially similar lengths. In other embodiments of the invention, the first and second optical paths have different lengths.

[0024] In another broad aspect, the invention provides a laser for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength, the first and second wavelengths differing from each other. The laser includes: a pump light source for emitting a pump light; an optical resonator, the optical resonator defining a first optical path and a second optical path, the first laser light travelling along the first optical path and the second laser light travelling along the second optical path; a gain medium inserted in the optical resonator and optically coupled to the pump light source, the gain medium being responsive to the pump light for converting the pump light to the first and second laser lights; an optical intensity modulator inserted in the optical resonator for absorbing a portion of both the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths, the optical intensity modulator having a light absorption coefficient that is modulated with a modulation period, round trip times of the first and second laser lights along respectively the first and second optical paths being respective integer multiples of the modulation period; and an output port for releasing the first and second laser lights from the optical resonator. When the gain medium is pumped with the pump light, modulating the optical intensity modulator with the modulation period produces simultaneously the first and second laser lights having respectively the first and second wavelengths.

[0025] In some embodiments of the invention, the optical intensity modulator absorbs light with two different discrete absorption coefficients. For example, when the optical intensity modulator is in a first state, substantially all the light incoming at the optical intensity modulator is let through the optical intensity modulator and, when the optical intensity modulator is in a second state, a predetermined percentage of the light incoming at the optical intensity modulator is absorbed. In other embodiments of the invention, the optical intensity modulator has an absorption coefficient that is continuously variable within a predetermined interval of absorption coefficients.

[0026] The reader skilled in the art will readily appreciate the the terminology "absorption coefficient" used herein does not imply that light is necessarily physically absorbed in the optical intensity modulator. Instead, this terminology only refers to the portion of the light incoming at the optical intensity modulator that is not transmitted to the remainder of the tunable laser. In some embodiments, the light is simply modulated in intensity through interference.

[0027] Advantageously, the proposed tunable laser cavity and the proposed laser are manufacturable using commonly available components and techniques. Therefore, a tunable laser emitting at least two wavelengths simultaneously and having a relatively wide tuning range may be manufactured at relatively low costs. In some embodiments of the invention, the tunable laser cavity and the tunable laser are manufactured using optical fibers, which produces relatively rugged lasers at relatively low costs.

[0028] In another broad aspect, the invention provides a laser for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength, the first and second wavelengths differing from each other. The laser comprises: an optical resonator, the optical resonator defining a first optical path and a second optical path, the first laser light travelling along the first optical path and the second laser light travelling along the second optical path; a modulated gain element inserted in the optical resonator for amplifying the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths, the modulated gain element having a variable gain modulated with a modulation period, round trip times of the first and second laser lights along respectively the first and second optical paths being respective integer multiples of the modulation period; and an output port for releasing the first and second laser lights from the optical resonator. Modulating the gain at the modulation period produces simultaneously the first and second laser lights having respectively the first and second wavelengths.

[0029] In a variant, the modulated gain element includes: a pump light source for emitting a pump light; a gain medium inserted in the optical resonator and optically coupled to the pump light source, the gain medium being responsive to the pump light for converting the pump light to the first and second laser lights; and an optical intensity modulator inserted in the optical resonator for absorbing a portion of both the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths, the optical intensity modulator having a light absorption coefficient that is modulated with the modulation period.

[0030] Other objects, advantages and features of the present invention will become more apparent upon reading of the following non-restrictive description of preferred embodiments thereof, given by way of example only with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] Figure 1, in a schematic view, illustrates a tunable laser in accordance with an embodiment of the present invention;

[0032] Figure 2, in a schematic view, illustrates a tunable laser in accordance with an alternative embodiment of the present invention;

[0033] Figure 3, in a schematic view, illustrates a tunable laser in accordance with another alternative embodiment of the present invention;

[0034] Figure 4, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention;

[0035] Figure 5, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention;

[0036] Figure 6, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention;

[0037] Figure 7, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention;

[0038] Figure 8, in a schematic view, illustrates an apparatus usable for arbitrarily shaping the spectrum of a pulse of light;

[0039] Figure 9, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention;

[0040] Figure 10, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention; and

[0041] Figure 11, in a schematic view, illustrates a tunable laser in accordance with yet another alternative embodiment of the present invention.

DETAILED DESCRIPTION

[0042] Referring to Fig. 1, there is shown a tunable laser 10 for selectively emitting laser light 12 having a first wavelength and a second wavelength. While in some embodiments of the invention the tunable laser 10 is able emit laser light 12 having two different, discretely spaced apart, wavelengths, it is also within the scope of the invention to have a tunable laser 10 that is able to emit laser light 12 having more than two different wavelengths and laser light having a wavelength contained within a substantially continuous spectrum of wavelengths included in a predetermined wavelength interval.

[0043] The tunable laser 10 includes a pump light source 14 for emitting a pump light (not shown in the drawings). The tunable laser 10 also includes an optical resonator 16. The optical resonator 16 has a configuration, optical properties and dimensions such that a first round trip time of the laser light 12 having the first wavelength in the optical resonator 16 differs from a second round trip time of the laser light 12 having the second wavelength in the optical resonator 16. A gain medium 18 is inserted in the optical resonator 16 and is optically coupled to the pump light source 14. The gain medium 18 defines a gain medium first end 26 and a substantially opposed gain medium second end 28. The reader skilled in the art will understand that the terminology "gain medium first and second ends 26 and 28" does not imply that the gain medium 18 is necessarily rectilinear. For example, the gain medium may be formed by a rolled optical fiber. The gain medium 18 is responsive to the pump light for converting the pump light into the laser light 12. For example, the tunable laser 10 includes a pump light input port 20, also referred to as a pump coupler, optically coupled to the gain medium 18 for receiving the pump light and conveying the pump light to the gain medium 18.

[0044] An optical intensity modulator 22 is inserted in the optical resonator 16 for selectively absorbing a portion of the laser light 12 as the laser light 12 propagates back and forth in the optical resonator 16. The optical intensity modulator 22 has a light absorption coefficient that is modulated with a modulation period. The modulation period is selectively adjustable between a first modulation period value and a second modulation period value. The first and second round trip times are substantially equal to a respective integer multiple of respectively the first and second modulation period values.

[0045] The tunable laser 10 further includes an output port 24 for releasing the laser light 12 from the optical resonator 16. In some embodiments of the invention, a tunable laser cavity is provided instead of a tunable laser 10. The tunable laser cavity is simply a tunable laser 10 from which the pump light source 14 has been removed. The tunable laser cavity is usable with the pump light source 14 to build the tunable laser 10.

[0046] When the gain medium 18 is pumped with the pump light, modulating the optical intensity modulator 22 with the first modulation period value produces laser light having the first wavelength. Also, modulating the optical intensity modulator 22 with the second modulation period value produces laser light having the second wavelength.

[0047] Indeed, when the optical intensity modulator 22 is modulated, there will be periodic time intervals during which the optical intensity modulator 22 absorbs more light than at subsequent or previous moments. Since the laser light 12 is preferentially transmitted through the optical intensity modulator 22 at predetermined periodic time intervals, there will be a preference for the tunable laser 10 to operate with laser light pulses circulating within the optical resonator 16 in a manner such that these laser light pulses have a round trip time that is equal to the modulation period with which the optical intensity modulator is modulated, or a multiple of this modulation period. The configuration of the optical resonator 16 will therefore favor laser light pulses within the optical resonator 16 that have a round trip time corresponding respectively to the first and second wavelengths when the optical intensity modulator 22 is respectively modulated with the first and second modulation period values. The pulse duration of the pulses is governed by many factors, among which are the power provided by the pump light source 14, the dispersion in the whole tunable laser 10 and the exact wave shape of the modulation provided by the optical intensity modulator 22.

[0048] It has been found particularly advantageous in some embodiments of the invention to change the modulation period in steps instead of continuously. Indeed, lasers have a tendency to be locked at a predetermined wavelength when operating. Changing the modulation period in a substantially continuous manner from the first to the second modulation period values may then cause instabilities and, in turn, promote difficult mode locking at the second wavelength. By changing the modulation periods in discreet steps, tuning occurs faster using commonly available components.

[0049] In some embodiments of the invention, modulating the absorption coefficient of the optical intensity modulator 22 with a signal that is the sum of many single-frequency signals helps in modulating the output laser light 12. For example, by modulating the absorption coefficient with a signal that is the sum of two sinusoidal signals having frequencies that are close to each other, the laser light 12 has an output that varies sinusoidally with a frequency that is equal to the beat frequency of the two sinusoidal signals.

[0050] In other embodiments, the optical intensity modulator has an absorption coefficient that is modulated temporally in any suitable manner to produce a corresponding temporal intensity profile of the pulses of laser light produced. The temporal modulation is periodic with a period corresponding to the round trip time in the optical resonator 16.

[0051] In yet other embodiments, multi-wavelength pulses can be produced. To that effect, the optical resonator 16 is such that the two or more wavelengths have the same round trip time in the optical resonator 16. In the specific case in which the optical resonator 16 includes a fiber Bragg grating, which are described in further details hereinbelow, the group delay as a function of wavelength in the Bragg grating must not increase of decrease monotonically. In a specific example of implementation, the number of wavelengths is equal to the number of zeros in the dispersion. Also, the derivative of variations in reflected wavelength with position along the Bragg grating determines the tuning rate of each of the wavelengths. However, there are other manners in which the optical resonator 16 can be configured to achieve the same results. It should be noted that due to the physical structure of these embodiments, laser light at all wavelengths are produced synchronously and are tuned at different, customizable rates.

[0052] In yet other embodiments of the invention, the optical resonator 16 is such that different wavelength light impulsions have different round trip times, as in the "base" embodiment first described hereinabove. In these embodiments, by modulating the optical intensity modulator 22 with a modulation that is a sum of modulation corresponding to many wavelengths produced in the case of single period modulation, pulse trains of laser light having impulsions of different wavelengths can be produced. In other words, the pulse trains produced are a linear superposition of individual pulse trains having different wavelengths, and therefore repetition rates. This increases the pulse repetition rate and scans many frequencies over relatively short amounts of time. As in the other embodiments of the invention, the optical modulation is either complete (complete absorption) or partial (partial absorption at maximal absorption), with a possibility of pulse shaping.

[0053] In the embodiment of the invention shown in Fig. 1, the optical resonator 16 includes a first reflector 30 and a second reflector 32. The first and second reflectors 30 and 32 are each reflective at about the first and second wavelengths. The first and second reflectors 30 and 32 are optically coupled to the gain medium 18 respectively through the gain medium first and second ends 26 and 28. It should be noted that, in some embodiments of the invention, other optical components are present between either of the reflectors 30 and 32 and the gain medium 18. Therefore, the first and second reflectors 30 and 32 need not be directly physically coupled to the gain medium 18.

[0054] The first reflector 30 includes a first reflector first portion 34 and a first reflector second portion 36 for reflecting respectively the laser light 12 having the first and second wavelengths. The first reflector first and second portions 34 and 36 are respectively spaced apart from the gain medium first end 26 by a first reflector first portion-to-gain medium distance and a first reflector second portion-to-gain medium distance. The first reflector first portion-to-gain medium distance is smaller than the first reflector second portion-to-gain medium distance. Therefore, the first reflector first portion 34 must be transmitting the second wavelength so that laser light having the second wavelength can reach the first reflector second portion 36. Also, in some embodiments of the invention, the distances are instead measured with respect to the distance from the optical intensity modulator 22.

[0055] Similarly, the second reflector 32 includes a second reflector first portion 38 and a second reflector second portion 40 for reflecting respectively the laser light 12 having the first and second wavelengths. The second reflector first and second portions 38 and 40 are respectively spaced apart from the gain medium second end 28 by a second reflector first portion-to-gain medium distance and a second reflector second portion-to-gain medium distance. The second reflector first portion-to-gain medium distance is smaller than the second reflector second portion-to-gain medium distance. Therefore, the second reflector first portion 38 must be transmitting the second wavelength so that laser light having the second wavelength can reach the second reflector second portion 40.

[0056] The first and second reflector first portions 34 and 38 are thus distanced from each other by a smaller distance than the first and second reflector second portions 36 and 40. This will cause the laser light 12 having the first wavelength to have a smaller first round trip time between the first and second reflector first portions 34 and 38 than the round trip time of the laser light 12 having the second wavelength between the first and second reflector second portions 36 and 40. In a specific embodiment of the invention, the first and second reflectors 30 and 32 each include a respective fiber Bragg grating. For example, the first reflector first and second portions 34 and 36 include respectively a first and a second fiber Bragg grating segment. In a specific embodiment of the invention, the first reflector first and second portions 34 and 36 each include a respective chirped fiber Bragg grating segment, which may be formed by having a single chirped fiber Bragg grating that defines both the first reflector first and second portions 34 and 36. In some specific embodiment of this latter construction, a tunable laser 10 having continuous wavelength selection is provided.

[0057] In some embodiments of the invention, the first wavelength is larger than the second wavelength and the chirped fiber Bragg gratings included in the first and second reflectors 30 and 32 also provides dispersion compensation. However, in alternative embodiments of the invention, the first wavelength is smaller than the second wavelength, which may be useful in embodiments in which other components of the proposed tunable laser 10 have anomalous dispersion properties.

[0058] In some embodiments of the invention, the first reflector 30 includes a relatively highly reflective chirped fiber Bragg grating. In these embodiments, substantially all the light incoming at the first reflector 30 is reflected back towards the gain medium 18. The second reflector 32 is an output chirped fiber Bragg grating and is not perfectly reflective so that some of the laser light 12 can be transmitted through the second reflector 32, which therefore provides the output port 24. Other manners of outputting the laser light 12 from the tunable laser 10 are within the scope of the invention and some of them are described in further details hereinbelow.

[0059] In some embodiments of the invention, the gain medium 18 has a first gain at the first wavelength and a second gain at the second wavelength. The first and second gains differ from each other. In these embodiments, to facilitate the production of laser light 12 having substantially similar powers at the two wavelengths, the first and second fiber Bragg grating segments included in the first reflector first and second portions 34 and 36 have respectively a first segment reflectivity and a second segment reflectivity. The first and second segment reflectivities are such that the tunable laser 10 has substantially constant gain at the first and second wavelengths. Therefore, it is possible to select the reflectivity of the first reflector first and second portions 34 and 36 so that the reflection of the laser light 12 at these first reflector first and second portions 34 and 36 compensates for the non-flat gain curve of the gain medium 18.

[0060] In some embodiments of the invention, one or both the first and second reflectors 30 and 32 are each made from a chirped fiber Bragg grating defining a variable group delay therealong. Therefore, the fiber Bragg grating segments included in different portions along the first and second reflectors 30 and 32 have different group delay characteristics, which affects the duration of laser light pulses produced using the tunable laser 10. Also, pulse characteristics other than the duration of the laser light pulses can be modified by selecting suitable group delays for fiber Bragg grating segments included in the first reflector first and second portions 34 and 36.

[0061] In yet other embodiments of the invention, the position of the second reflector first and second portions 38 and 40 is reversed with respect to the gain medium 18 while the first reflector first and second portions 34 and 36 remain in the same position. In these embodiments, wavelength selection of the laser light 12 is permitted by spacing apart the second reflector first and second portions 38 and 40 from each other by a greater distance than the distance by which the first reflector first and second portions 34 and 36 are spaced apart from each other. When chirped fiber Bragg gratings are used in the first and second reflectors 30 and 32, different group delay slopes are produced, and the laser operates with a group velocity dispersion that is the difference between the two group delay slopes. A mix between a soliton laser and a normal dispersion laser is thus formed that reduces or eliminates Kelly's side bends.

[0062] In some embodiments of the invention, the gain medium 18 includes a doped gain fiber. Such doped gain fibers are well known in the art and will therefore not be described in further details. It is also within the scope of the invention to manufacture tunable lasers 10 using any other suitable gain medium 18. Also, the pump light source 14 is any suitable pump light source 14 that can emit pump light that allows the gain medium 18 to produce the laser light 12 having both the first and second wavelengths. For example, the pump light source 14 includes a light emitting diode.

[0063] The pump light input port 20 is also any suitable pump light input port 20. For example, the pump light input port 20 includes a wave division multiplexer (WDM) that allows light having the first and second wavelengths to be freely transmitted, or substantially freely transmitted therethrough but which, through optical isolators or any other suitable means, substantially prevents light, and especially the laser light 12, from being transmitted back towards the pump light source 14. The WDM also allows for receiving pump light emitted by the pump light source 14 and transmitting this pump light into the optical resonator 16 and, more specifically, into the gain medium 18.

[0064] The optical intensity modulator 22 is any suitable component allowing variations in the transmission of the laser light 12 having the first and second wavelengths therethrough. Typically, the optical intensity modulator 22 takes the form of a component that is coupled to and inserted between the chirped fiber Bragg grating forming the first reflector 30 and the WDM multiplexer forming the pump light input port 20. However, any other physical configurations of the optical intensity modulator 22 are within the scope of the invention. In some embodiments of the invention, the optical intensity modulator 22 includes an electro-optic modulator.

[0065] In some embodiments of the invention, the optical intensity modulator 22 is a component that allows the laser light 12 to pass therethrough with two different absorption levels. For example, one level allows substantially all the light incoming at the optical intensity modulator 22 to pass therethrough. At a second level, a predetermined fraction of the light incoming at the optical intensity modulator 22 is not transmitted. In these embodiments, periodically changing the absorption coefficient of the optical intensity modulator 22 between the first level and the second level preferentially selects a laser light pulse that travels through the optical resonator 16 as described hereinabove.

[0066] The reader skilled in the art will readily appreciate that the optical intensity modulator 22 need not absorb all or a large fraction of the light circulating within the tunable laser 10 for the mode locking effect provided by the optical intensity modulator 22 to be provided. Indeed, only relatively small variations in the absorption coefficient are sufficient in some embodiments of the invention to produce the desired effect.

[0067] In some embodiments of the invention, the optical intensity modulator 22 includes a variable attenuation modulator. In opposition to the previously described optical intensity modulator, the variable attenuation modulator allows for a substantially continuous variation in the absorption coefficient of the optical intensity modulator 22 over a predetermined absorption range. In this embodiment, the power of the laser light 12 may therefore be regulated using the optical intensity modulator 22, in addition to being regulated using the power of the pump light source 14.

[0068] As illustrated in Fig. 1, in some embodiments of the invention, the tunable laser 10 includes a controller 42 for controlling the modulation period of the optical intensity modulator 22. Typically, fiber Bragg gratings, such as the fiber Bragg gratings usable in the first and second reflectors 30 and 32, do not have ideal, theoretically predictable, reflection spectra at different locations therealong due to manufacturing defects. However, once a fiber Bragg grating has been characterized, it is possible to map the distance from one end of the fiber Bragg grating to each location therealong and to associate with each of these locations a specific wavelength that is reflected. Therefore, by characterizing the first and second reflectors 30 and 32 in this manner, the controller 42 can be programmed to select precisely the wavelength at which the laser light 12 will be emitted for a specific tunable laser 10 as the modulation period can then be selected to achieve this wavelength.

[0069] Also, the group delay characteristics of chirped fiber Bragg gratings are not perfect. Imperfections create a group delay ripple which may cause unwanted effects in the pulsed laser light 12. A ratio between the group delay ripple and the group delay as a function of frequency is herein referred to as the ratio spectrum. The pulses of laser light 12 produced by the tunable laser 10 have a pulse spectrum. It is preferable to manufacture the chirped Bragg gratings with sufficient precision that the ratio spectrum is substantially disjoint from the pulse spectrum. In other words, regions of the ratio spectrum in which there is a significant power should be separate from regions of pulse spectrum at which there is a significant power.

[0070] Fig. 2 illustrates an alternative tunable laser 10A. The tunable laser 10A has many components that are substantially similar to those of the tunable laser 10. These components will therefore not be described in further details.

[0071] As seen from Fig. 2, the tunable laser 10A differs from the tunable laser 10 in that it includes two pump light sources 14, each coupled to the gain medium 18 through a respective pump light input port 20. Also, it is within the scope of the invention to have more than two pump light sources 14. In addition, a tap 44 is provided, for example at an end of the first reflector 30 opposed to the gain medium 18, so that a photodiode 46, or any other suitable light intensity measurement device, can be used to measure the taped light intensity and feed this light intensity to the controller 42. The controller 42 is therefore connected to the photodiode 46 so that light intensity measurements can be transmitted by the photodiode 46 to the controller 42. The controller 42 is also operatively coupled to the pump light source 14 for controlling the intensity of the pump light. The controller 42 is then used in a feedback loop to control the power provided by the pump light sources 14 in response to light intensity measurements to obtain a predetermined power for the laser light 12.

[0072] Figure 3 illustrates yet another tunable laser 10B. The tunable laser 10B being similar also to the tunable laser 10. A difference that occurs in the tunable laser 10B is that an alternative first reflector 30B is used. The alternative first reflector 30B is such that the first reflector 30B reflects the laser light 12 having both the first and second wavelengths at substantially similar first reflector-to-modulator distances from the optical resonator 16. For example, this is achieved by using a mirror instead of a fiber Bragg grating in the first reflector 30B. In yet other embodiments of the invention, the first reflector 30B is replaced by an optical circulator or a loop of optical fiber that returns all incoming light toward the second reflector 32.

[0073] Fig. 4 illustrates yet another tunable laser 10C in which the optical resonator 16, the gain medium 18 and optical intensity modulator 22 are all polarization maintaining, as illustrated by the dashed representation of these components. Therefore, the tunable laser 10C is able to produce polarized laser light 12. To select the polarization, a polarizer 47 is inserted in the optical resonator 16C for polarizing the laser light 12.

[0074] Fig. 5 illustrates yet another tunable laser 10D. The tunable laser 10D uses only a single reflector 30 instead of the first and second reflectors 30 and 32. The resonance in the optical resonator 16D is provided by using an optical circulator 48. The optical circulator 48 includes a circulator first port 50, a circulator second port 52 and a circulator third port 54. The optical circulator 48 is configured in a manner such that the laser light incoming at the circulator first port 50 is emitted at the circulator second port 52, laser light incoming at the circulator second port 52 is emitted at the circulator third port 54 and laser light incoming at the circulator third port 54 is emitted at the circulator first port 50. The circulator first port 50 is optically coupled to the gain medium 18 through the gain medium first end 26 with the optical intensity modulator 22 inserted between the gain medium first end 26 and the circulator first port 50. The circulator second port 52 is optically coupled to the reflector 30 and the circulator third port 54 is optically coupled to the gain medium 18 through the gain medium second end 28 with the pump light input port 20 inserted between the gain medium second end 28 and the circulator third port 54. The reflector 30 is a reflector similar to the first and second reflectors 30 and 32 and has a structure and a function substantially similar to that of the first and second reflectors 30 and 32. In this embodiment, the reflector 30 allows for the emission of the laser light 12 by the laser 10D by letting a portion of the laser light 12 to be transmitted through the reflector 30. In this embodiment of the invention, a unidirectional loop is created, which reduces losses in the tunable laser 10D caused by the optical intensity modulator 22.

[0075] In yet another embodiment of the invention, a tunable laser 10E shown in Fig. 6 is provided. The tunable laser 10E includes an alternative output port 24E inserted between the optical intensity modulator 22 and the circulator first port 50. The tunable laser 10E has a configuration substantially similar to the configuration of the tunable laser 10D, with the exception that the reflector 30 is highly reflective and, therefore, does not allow for laser light 12 to be transmitted therethrough.

Instead, an output port 24E in the form of a fiber coupler or, in other words, a tap, is provided for tapping into the tunable laser 10E and therefore releasing the tunable laser light 12.

[0076] Fig. 7 illustrates yet another geometry for a tunable laser 10F in which the second reflector 32F includes an optical circulator 48 for receiving the laser light 12 from the gain medium 18 and returning the laser light back 12 to the gain medium 18. In this embodiment, the circulator first port 50 is optically coupled to the circulator third port 54 with an optical switch 51 and the optical intensity modulator 22 inserted therebetween. The circulator second port 52 is optically coupled to the first reflector 30 with the gain medium 18 and the pump light input port 20 inserted therebetween. Advantageously, various optical components can be inserted in the loop formed between the circulator first and third ports 50 and 54 to allow emission of the laser light 12, modulation of the intensity of the laser light 12 and any other conditioning or characterization of the laser light 12.

[0077] The optical switch 51 defines the output port 24F and is usable for selectively releasing the laser light 12 from the optical resonator 16F and confining the laser light 12 in the optical resonator 16F. More specifically, in one state of the optical switch 51, all the light incoming at the optical switch 51 is fed back into the optical resonator 16F. This allows for build up of laser light power inside the optical resonator 16F. When a pulse is to be let out of the optical resonator 16F, the optical switch 51 is switched to the other state in which a part or all of the light incoming at the optical switch 51 is output at another port that forms the output port 24F.

[0078] The reader skilled in the art will readily appreciate that in alternative embodiments of the invention, the tunable lasers 10D, 10E and 10F have an optical intensity modulator 22 that is located at any suitable location between the circulator first and third ports 50 and 54. In other words, the exact position of the optical intensity modulator 22 in the loop formed between the circulator first and third ports 50 and 54 can be varied along this loop while achieving tunable lasers that perform satisfactorily. In yet other embodiments of the invention, the various components of the tunable lasers 10D, 10E and 10F are configured in any suitable order as long as an optical resonator is formed. Also, the pump light can travel either in the direction of the laser light or in the opposite direction.

[0079] Referring to Figure 8, there is shown an apparatus 100 for arbitrarily shaping the spectrum of a pulse of light. In some embodiments of the invention, the apparatus 100 is inserted at a suitable location in the tunable lasers 10 to 10F to provide laser light pulses having an arbitrary spectrum.

[0080] The apparatus 100 includes an optical circulator 48. The optical circulator 48 includes a circulator first port 50, a circulator second port 52 and a circulator third port 54. The optical circulator 48 is configured in a manner such that light incoming at the circulator first port 50 is emitted at the circulator second port 52, and light incoming at the circulator second port 52 is emitted at the circulator third port 54. The circulator first port 50 is optically coupled to an input port 102 used for receiving laser light. The circulator second port 52 is optically coupled to a reflector 30, such as a chirped Bragg grating, that reflects light having different wavelengths at different locations therealong, and the circulator third port 54 is optically coupled to an optical modulator 22. The optical modulator 22 is optically coupled to an output port 24 usable for releasing the light modulated by the optical modulator 22.

[0081] The reflector 30 spreads temporally the different frequencies comprised in the light incoming at the input port 102. Therefore, by suitable modulation of the absorbance of the optical modulator 22 as a function of time, light having any desired spectrum is achievable. Also, each successive pulse of light incoming at the input port 102 can be shaped differently. In some embodiments of the invention, the output port 24 is optically coupled to an optical component having a dispersion inverse that of the reflector 30, thereby temporally compressing the spectrally shaped pulse.

[0082] It should be noted that in alternative embodiments of the invention, any component that spreads temporally light having different frequencies is usable instead of the reflector 30.

[0083] In yet another embodiment of the invention, a tunable laser 10G shown in Fig. 9 is provided. The tunable laser 10G is similar to the tunable laser 10E shown in Fig. 6. However, a delay element 60 is inserted at any suitable location in the resonator of the laser 10G for delaying, or changing the phase, of the light that passes through the delay element 60. For example, the delay element 60 is inserted between the pump light input port 20 and the gain medium 18. The delay element 60 changes the pulse frequency/light wavelength relationship of the tunable laser 10G. If the delay element 60 is a variable delay element, this relationship can be adjusted to any needed relationship. For example, the delay could be selected so that all wavelengths emitted by the tunable laser 10 G have the same pulse frequency.

[0084] In yet another embodiment of the invention, a tunable laser 10H shown in Fig. 10 is provided. The tunable laser 10H is similar to the tunable laser 10E shown in Fig. 6. However, many reflectors 30 and 30' are used in parallel, instead of a single one. Each of the reflectors 30 and 30' reflects a different wavelength for a given resonating cavity length. This creates a laser in which pulses of laser light including many different wavelengths are created, all the wavelengths being emitted in a synchronized manner. While two reflectors 30 and 30' are shown in the drawings, any suitable number of reflectors is usable. The reflectors 30 and 30' are coupled to the remainder of the tunable laser 10H using any suitable coupler 62, such as, for example, a wavelength division multiplexer. In other similar embodiments of the invention, the reflectors 30 and 30' reflecting different wavelengths are embodied in a single component, for example as superposed Bragg gratings in a single optical fiber.

[0085] In yet another example of a multi-wavelength laser, a laser having a structure similar to the one of the lasers 10 or 10A to 10F produces pulses including many wavelengths by having their reflectors (reflecting exclusively each light having a respective wavelength) create cavities of different lengths for different wavelengths, the lengths being such that round-trip travel times for all wavelengths are all integer multiples of a base period. By suitably selecting the frequency at which the optical intensity modulator 22 is modulated, with the base period, simultaneous production of light pulses at all the wavelengths is possible. For example, if a cavity of a base length is created for a first wavelength and a cavity of double the base length is created for a second wavelength, modulating the optical intensity modulator at a speed required to create pulses at the first wavelength automatically allows creation of pulses at the second wavelength.

[0086] By selecting appropriate wavelengths for pulses circulating in the optical resonator and the delays (or phase difference) between them, it is possible to synthesise resulting total pulses having arbitrary shapes. In some embodiments of the invention, the resulting pulse is reflected by a chirped fiber Bragg grating prior to use to compress the resulting total pulse.

[0087] In other words, in the laser 10H, two optical paths are created in the optical resonator of the laser 10H, each carrying a respective laser light 12 and 12'. The first optical path includes the reflector 30, the coupler 62, the optical circulator 48, the pump light input port 20, the gain medium 18, the output port 24E and the optical intensity modulator 22. The second optical path includes the reflector 30', the coupler 62, the optical circulator 48, the pump light input port 20, the gain medium 18, the output port 24E and the optical intensity modulator 22.

[0088] The optical intensity modulator 22 is therefore inserted in both the first and second optical paths for absorbing simultaneously a portion of both the first and second laser lights 12 and 12' as the first and second laser lights 12 and 12' propagate respectively along the first and second optical paths. It should be noted here that with reference to Figs 10 and 11, the first and second laser lights 12 and 12' are simultaneously emitted by the lasers 10H and 101 described therein, as opposed to the laser lights having two different wavelengths mentioned in the description of Figs. 1 to 9. The optical intensity modulator 22 has a light absorption coefficient that is modulated with a modulation period, round trip times of the first and second laser lights 12 and 12' along respectively the first and second optical paths being respective integer multiples of the modulation period. When the gain medium 18 is pumped with the pump light, modulating the optical intensity modulator 22 with the modulation period produces simultaneously the first and second laser lights 12 and 12' having respectively the first and second wavelengths. The laser lights 12 and 12' are pulsed and the pulses are synchronized.

[0089] The first and second optical paths thus coincide with each other over at least a portion thereof and the first and second optical paths are disjoint from each other over another portion thereof. The reflectors 30 and 30' are typically chirped fiber Bragg gratings. However, any other suitable reflectors 30 and 30' are usable. In some embodiments of the invention, the reflectors 30 and 30' each reflect only a single wavelength of light and the laser 10H is then not tunable. In some embodiments of the invention, the two reflectors 30 and 30' are fiber Bragg gratings embodied in a common optical fiber. For example, the fiber Bragg gratings are chirped and are at least partially superposed.

[0090] More generally speaking, the optical intensity modulator 22, gain medium 18, pump light input port 20 and pump light source 14 form a modulated gain element 56 inserted in the optical resonator for amplifying the first and second laser lights as the first and second laser lights propagate in the optical resonator respectively along the first and second optical paths. The modulated gain element 56 has a variable gain modulated with a modulation period, round trip times of the first and second laser lights along respectively the first and second optical paths being respective integer multiples of the modulation period.

[0091] The reader skilled in the art will readily appreciate that while a specific modulated gain element 56 is illustrated in Fig. 10, any other suitable modulated gain element is usable in alternative embodiments of the invention. Such modulated gain elements provide the amplification required to achieve the laser effect and are such that the gain of the amplification can be varied in time with the modulation period in a manner suitable for achieving the mode locking effect for both the first and second laser lights 12 and 12'. In addition to the laser variants 10 , 10A-10G and 10I shown in the other Figures, in yet other variants, the modulated gain element 56 can include embodiments in which there is no optical intensity modulators 22. Instead, a variable gain component, such as a semiconductor light amplifier, among other possibilities, is usable. The variable gain of the modulated gain element 56 is thus achieved by either an absorptive component that absorbs light in a selected manner, or an active component with larger than 1 gain with a time varying gain.

[0092] In alternative embodiments of the invention, the first and second laser lights are produced using any suitable optical phenomenon, such as four wave mixing (FWM), second harmonic generation (SHG) or using any suitable optical parametric oscillator (OPO).

[0093] Fig. 11 illustrates another laser 101 that provides a functionality similar to that of the laser 10H. Instead of having two reflectors 30 and 30', the laser 101 includes a single reflector 30. Also, the laser 101 includes a gain medium first portion 18A provided in a first optical path and a gain medium second portion 18B provided in a second optical path, the gain medium first and second portions 18A and 18B being disjoint from each other. The two optical paths are otherwise superposed in space.

[0094] In alternative embodiments of the invention, not shown in the drawings, the first optical path includes a delay element 60, such as the one described with respect to Fig. 9, for delaying propagation exclusively of the first laser light 12 along the first optical path. For example, the delay element 60 is a variable delay element for which a propagation delay is selectable. The delay element 60 allows then selection of a relationship between the wavelengths of the first and second laser lights 12 and 12'.

[0095] The propagation delay along each of the optical paths is different in the gain medium first portion 18A and in the gain medium second portion 18B. For example, the gain medium first and second portions 18 A and 18B each include a respective doped gain fiber, the doped gain fibers being provided in parallel in the laser 101. The difference in propagation delay is provided for example by having the gain medium first and second portions having different lengths. Also, if the reflector 30 is a fiber Bragg grating, the two optical paths have optical path lengths that dependant respectively on values of the first and second wavelengths as the location at which the light is reflected in the fiber Bragg grating is wavelength dependent.

[0096] In the above-described tunable lasers 10 to 101, using suitable components allows for variations in the duration of the laser light pulses by varying the intensity of these laser light pulses. In turn, this intensity is adjustable by varying many controllable variables, such as the duration and time evolution profile of the optical intensity modulation provided by the optical intensity modulator 22 and the power provided by the pump light source 14. In some embodiments, the first reflector 30, the second reflector 32 or both the first and second reflectors 30 and 32 have an adjustable dispersion, which is then also usable to change the laser light pulses shape and duration. It should be noted that the variations in the pulse duration is achievable without changing the pulse repetition frequency.

[0097] While some embodiments of a tunable laser have been described hereinabove, it is within the scope of the invention to have many other variants, for example obtained by mixing structures exemplified in the above-described lasers 10 and 10A to 101. Also, it is within the scope of the invention to use many concepts associated with lasers to operate the proposed tunable lasers in different operation ranges. For example, the proposed laser may be Q switched and, as described hereinabove in a specific embodiment, cavity dumping may be used.

[0098] Although the present invention has been described hereinabove by way of preferred embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A laser cavity for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength using pump light emitted by a pump light source, said first and second wavelengths differing from each other, said laser cavity comprising:
   - an optical resonator, said optical resonator defining a first optical path and a second optical path, said first laser light travelling along said first optical path and said second laser light travelling along said second optical path;
   - a gain medium inserted in said optical resonator, said gain medium being responsive to said pump light for converting said pump light to said first and second laser lights;
   - a pump light input port optically coupled to said gain medium for receiving said pump light and conveying said pump light to said gain medium;
   - an optical intensity modulator inserted in said optical resonator for absorbing simultaneously a portion of both said first and second laser lights as said first and second laser lights propagate in said optical resonator respectively along said first and second optical paths, said optical intensity modulator having a light absorption coefficient that is modulated with a modulation period, round trip times of said first and second laser lights along respectively said first and second optical paths being respective integer multiples of said modulation period; and
   - an output port for releasing said first and second laser lights from said optical resonator;
   - whereby, when said gain medium is pumped with said pump light, modulating said optical intensity modulator with said modulation period

produces simultaneously said first and second laser lights having respectively said first and second wavelengths.

2. A laser cavity as defined in claim 1, wherein said first and second optical paths coincide with each other over at least a portion thereof.

3. A laser cavity as defined in claim 2, wherein said first and second optical paths are disjoint from each other over another portion thereof.

4. A laser cavity as defined in claim 1, wherein said optical resonator includes a first reflector provided in said first optical path for reflecting said first laser light in said optical resonator and a second reflector provided in said second optical path for reflecting said second laser light in said optical resonator.

5. A laser cavity as defined in claim 4, wherein said first reflector is a first fiber Bragg grating embodied in a first optical fiber and said second reflector is a second fiber Bragg grating embodied in second optical fiber.

6. A laser cavity as defined in claim 5, wherein said modulation period is selectively adjustable between a first modulation period value and a second modulation period value and said first and second fiber Bragg gratings are chirped fiber Bragg gratings.

7. A laser cavity as defined in claim 4, wherein said first reflector includes a first reflector first portion and a first reflector second portion for respectively reflecting said first laser light exclusively at two different values of said first wavelength, said first reflector first and second portions being respectively

spaced apart from said optical intensity modulator by a first reflector first portion-to-modulator distance and a first reflector second portion-to-modulator distance, said first reflector first portion-to-modulator distance being smaller than said first reflector second portion-to-modulator distance.

8. A laser cavity as defined in claim 4, wherein said first reflector is a first fiber Bragg grating and said second reflector is a second fiber Bragg grating, said first and second fiber Bragg gratings being embodied in a common optical fiber.

9. A laser cavity as defined in claim 8, wherein said modulation period is selectively adjustable between a first modulation period value and a second modulation period value.

10. A laser cavity as defined in claim 9, wherein said first and second fiber Bragg gratings are chirped and are at least partially superposed.

11. A laser cavity as defined in claim 1, wherein said gain medium includes a gain medium first portion provided in said first optical path and a gain medium second portion provided in said second optical path, said gain medium first and second portions being disjoint from each other.

12. A laser cavity as defined in claim 11, wherein said gain medium first and second portions each include a respective doped gain fiber, said gain medium first and second portions being provided in parallel in said optical resonator.

13. A laser cavity as defined in claim 11, wherein

- said optical resonator includes a chirped fiber Bragg grating provided in both said first and second optical paths for reflecting said first and second laser lights; and
- said gain medium first and second portions have different lengths.

14. A laser cavity as defined in claim 1, wherein said first and second optical paths have respectively first and second optical paths lengths, said first and second optical path lengths being dependant respectively on values of said first and second wavelengths.

15. A laser cavity as defined in claim 14, wherein said modulation period is selectively adjustable between a first modulation period value and a second modulation period value.

16. A laser cavity as defined in claim 15, wherein said optical resonator includes a first reflector provided in said first optical path for reflecting said first laser light in said optical resonator and a second reflector provided in said second optical path for reflecting said second laser light in said optical resonator, said first and second reflectors each including a respective chirped fiber Bragg grating.

17. A laser cavity as defined in claim 1, wherein

- said gain medium defines a gain medium first end and a substantially opposed gain medium second end;
- said optical resonator includes a reflector and an optical circulator, said optical circulator including a circulator first port, a circulator second port and a circulator third port, said optical circulator being configured in a manner such that said first and second laser lights incoming at said

circulator first port are emitted at said circulator second port, said said first and second laser lights incoming at said circulator second port are emitted at said circulator third port and said said first and second laser lights incoming at said circulator third port are emitted at said circulator first port, said circulator first port being optically coupled to said gain medium through said gain medium first end, said circulator second port being optically coupled to said reflector and said circulator third port being optically coupled to said gain medium through said gain medium second end.

18. A laser cavity as defined in claim 1, wherein said optical intensity modulator includes an electro-optic modulator.

19. A laser cavity as defined in claim 1, wherein said optical intensity modulator includes a variable attenuation modulator.

20. A laser cavity as defined in claim 1, wherein said gain medium includes a doped gain fiber.

21. A laser cavity as defined in claim 1, wherein said output port includes an optical switch for alternatively and selectively releasing said laser light from said optical resonator and confining said laser light in said optical resonator.

22. A laser cavity as defined in claim 1, wherein said first optical path includes a delay element for delaying propagation of said first laser light exclusively along said first optical path.

23. A laser cavity as defined in claim 22, wherein said delay element is a variable delay element for which a propagation delay is selectable.

24. A laser cavity as defined in claim 1, wherein said first and second optical paths have substantially similar lengths.

25. A laser cavity as defined in claim 1, wherein said first and second optical paths have different lengths.

26. A laser for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength, said first and second wavelengths differing from each other, said laser comprising:

- a pump light source for emitting a pump light;
- an optical resonator, said optical resonator defining a first optical path and a second optical path, said first laser light travelling along said first optical path and said second laser light travelling along said second optical path;
- a gain medium inserted in said optical resonator and optically coupled to said pump light source, said gain medium being responsive to said pump light for converting said pump light to said first and second laser lights;
- an optical intensity modulator inserted in said optical resonator for absorbing a portion of both said first and second laser lights as said first and second laser lights propagate in said optical resonator respectively along said first and second optical paths, said optical intensity modulator having a light absorption coefficient that is modulated with a modulation period, round trip times of said first and second laser lights along respectively said first and second optical paths being respective integer

multiples of said modulation period; and

- an output port for releasing said first and second laser lights from said optical resonator;
- whereby, when said gain medium is pumped with said pump light, modulating said optical intensity modulator with said modulation period produces simultaneously said first and second laser lights having respectively said first and second wavelengths.

27. A laser for emitting simultaneously a first laser light having a first wavelength and a second laser light having a second wavelength, said first and second wavelengths differing from each other, said laser comprising:

- an optical resonator, said optical resonator defining a first optical path and a second optical path, said first laser light travelling along said first optical path and said second laser light travelling along said second optical path;
- a modulated gain element inserted in said optical resonator for amplifying said first and second laser lights as said first and second laser lights propagate in said optical resonator respectively along said first and second optical paths, said modulated gain element having a variable gain modulated with a modulation period, round trip times of said first and second laser lights along respectively said first and second optical paths being respective integer multiples of said modulation period; and
- an output port for releasing said first and second laser lights from said optical resonator;
- whereby modulating said gain at said modulation period produces simultaneously said first and second laser lights having respectively said first and second wavelengths.

28. A laser as defined in claim 27, wherein said modulated gain element includes:

- a pump light source for emitting a pump light;
- a gain medium inserted in said optical resonator and optically coupled to said pump light source, said gain medium being responsive to said pump light for converting said pump light to said first and second laser lights; and
- an optical intensity modulator inserted in said optical resonator for absorbing a portion of both said first and second laser lights as said first and second laser lights propagate in said optical resonator respectively along said first and second optical paths, said optical intensity modulator having a light absorption coefficient that is modulated with said modulation period.

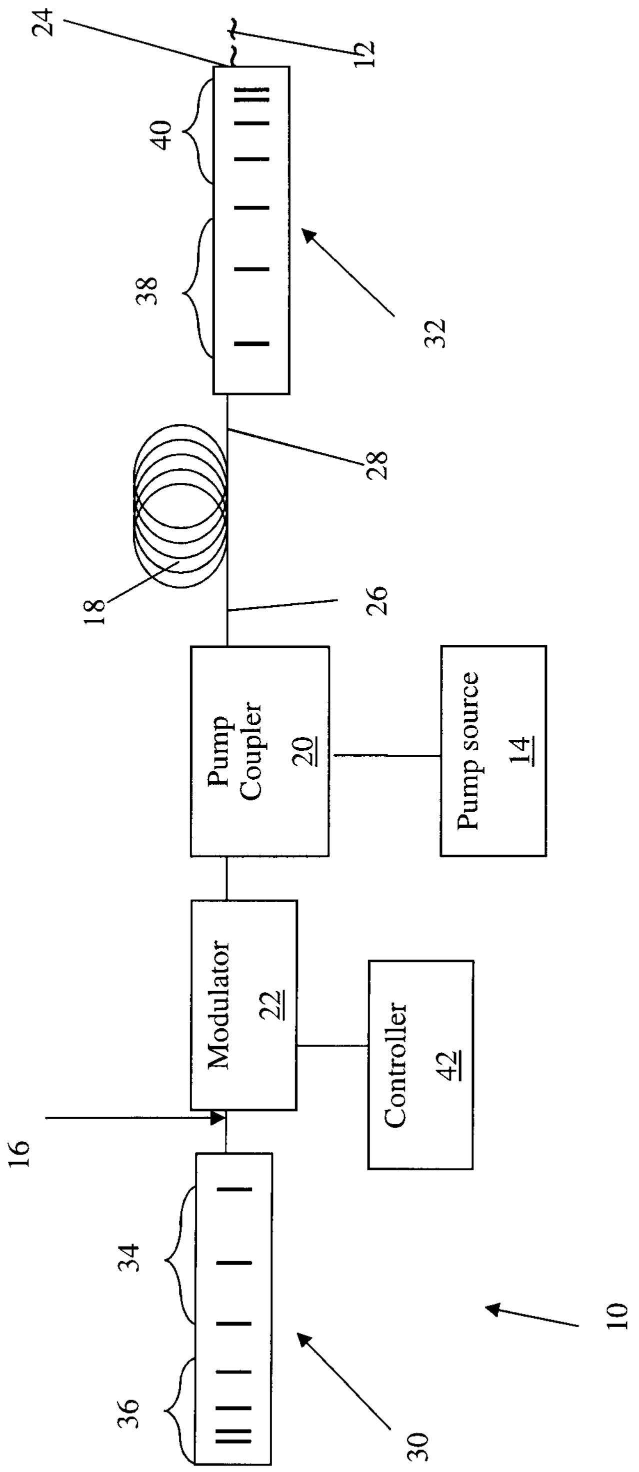
24
12
40
38
32
28
18
26
Pump Coupler 20
Pump source 14
Modulator 22
Controller 42
16
34
36
30
10

Figure 1

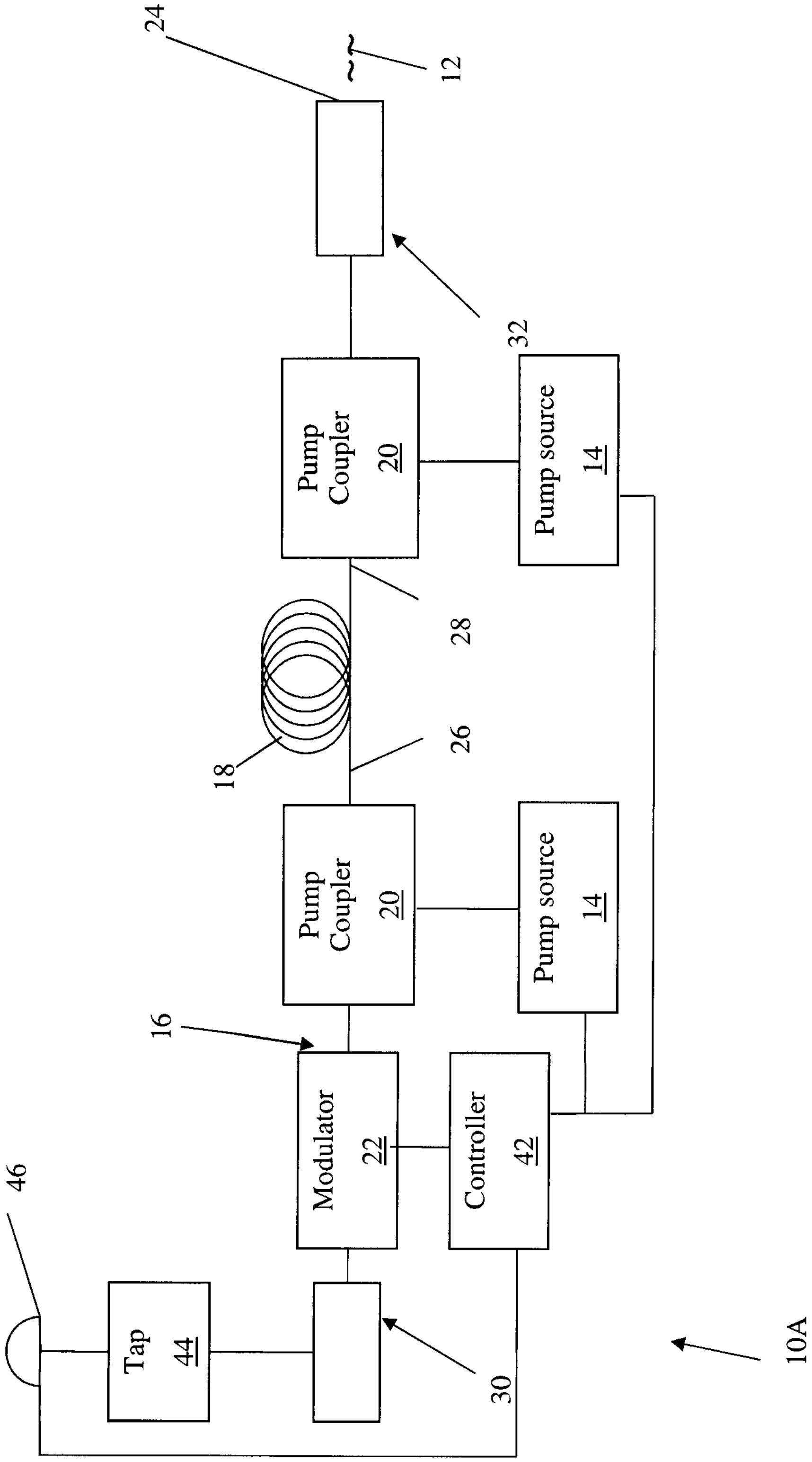
24
12
32
Pump Coupler 20
Pump source 14
28
26
18
Pump Coupler 20
Pump source 14
16
Modulator 22
Controller 42
46
Tap 44
30
10A

Figure 2

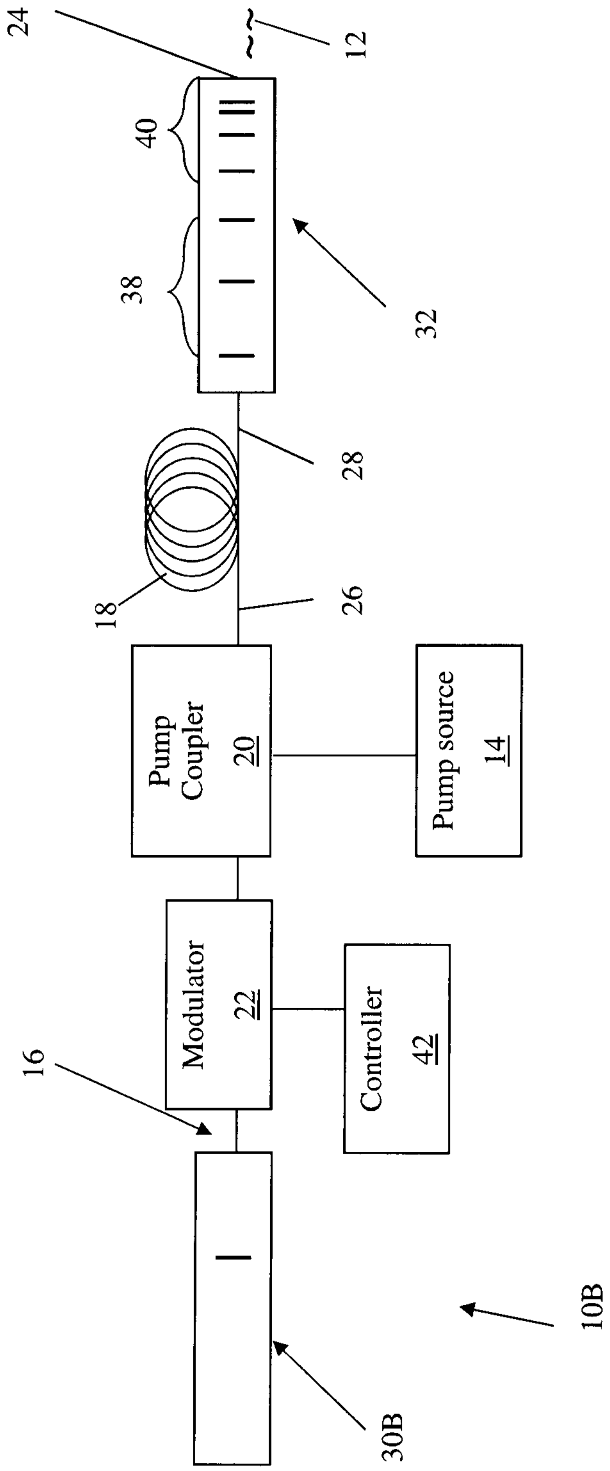
24
12
40
38
32
28
18
26
Pump Coupler
20
Pump source
14
Modulator
22
Controller
42
16
10B
30B

Figure 3

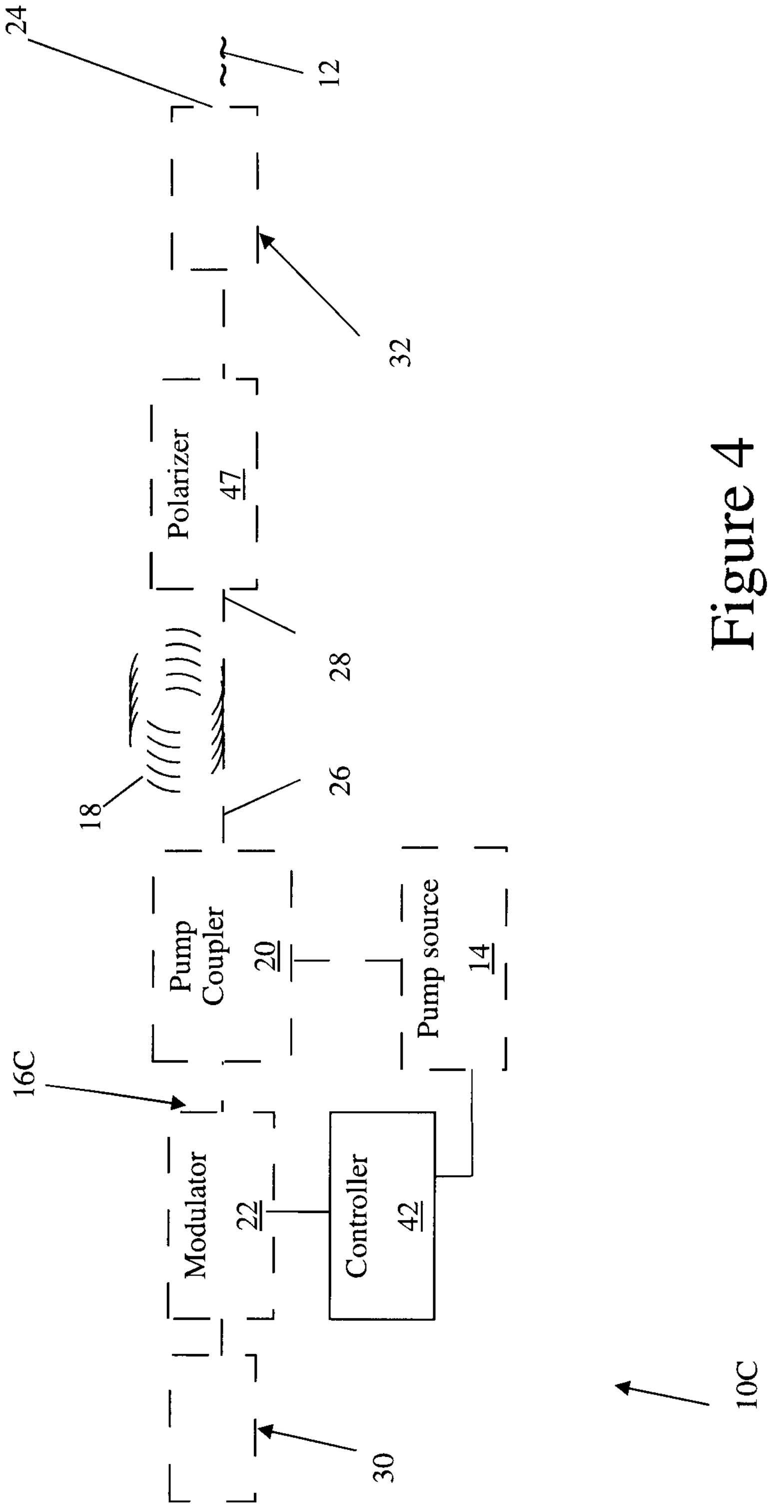
24
12
32
Polarizer
47
28
26
18
Pump
Coupler
20
Pump source
14
16C
Modulator
22
Controller
42
30
10C

Figure 4

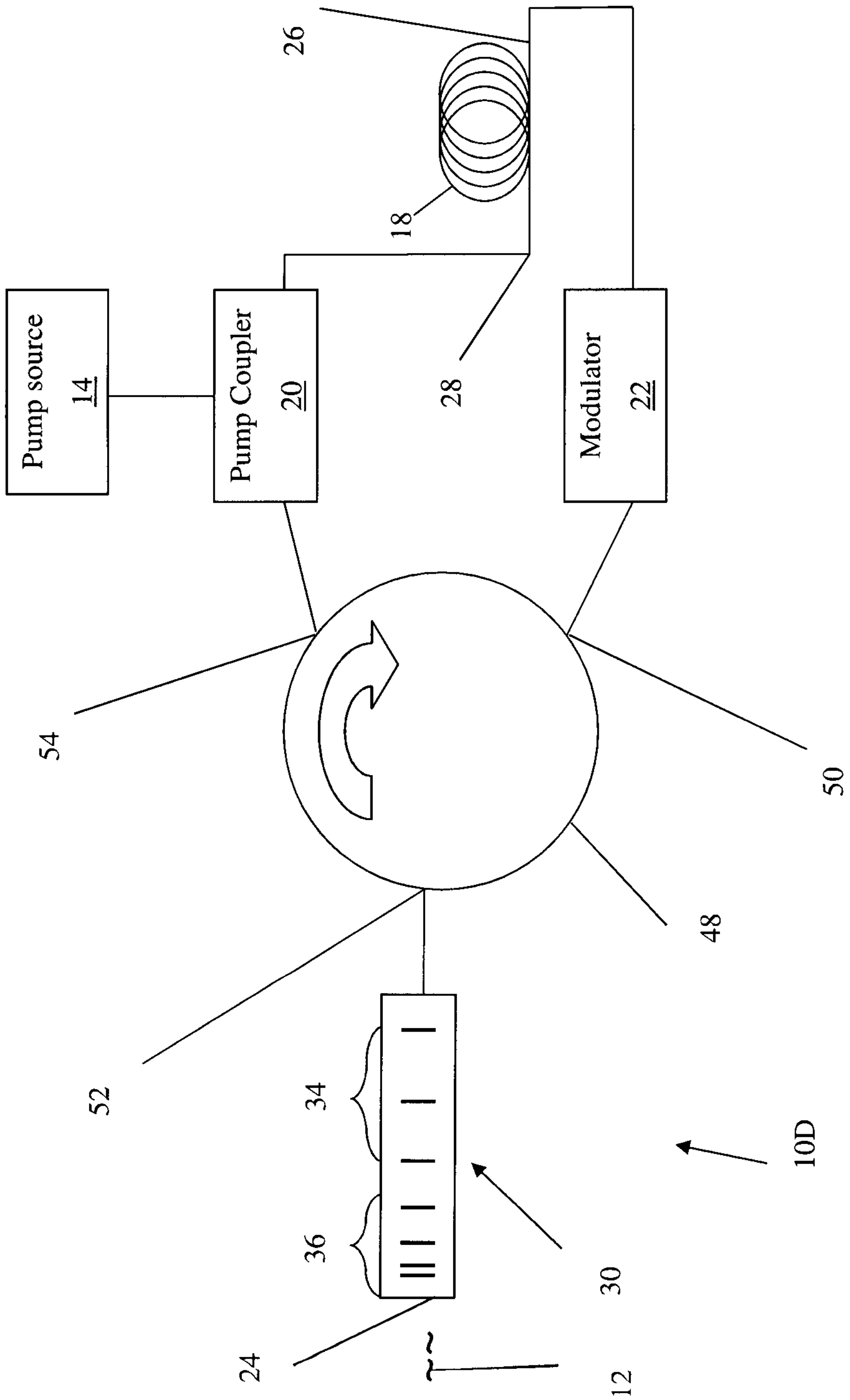
Pump source 14
Pump Coupler 20
Modulator 22
26
18
28
54
50
48
52
34
36
30
10D
24
12

Figure 5

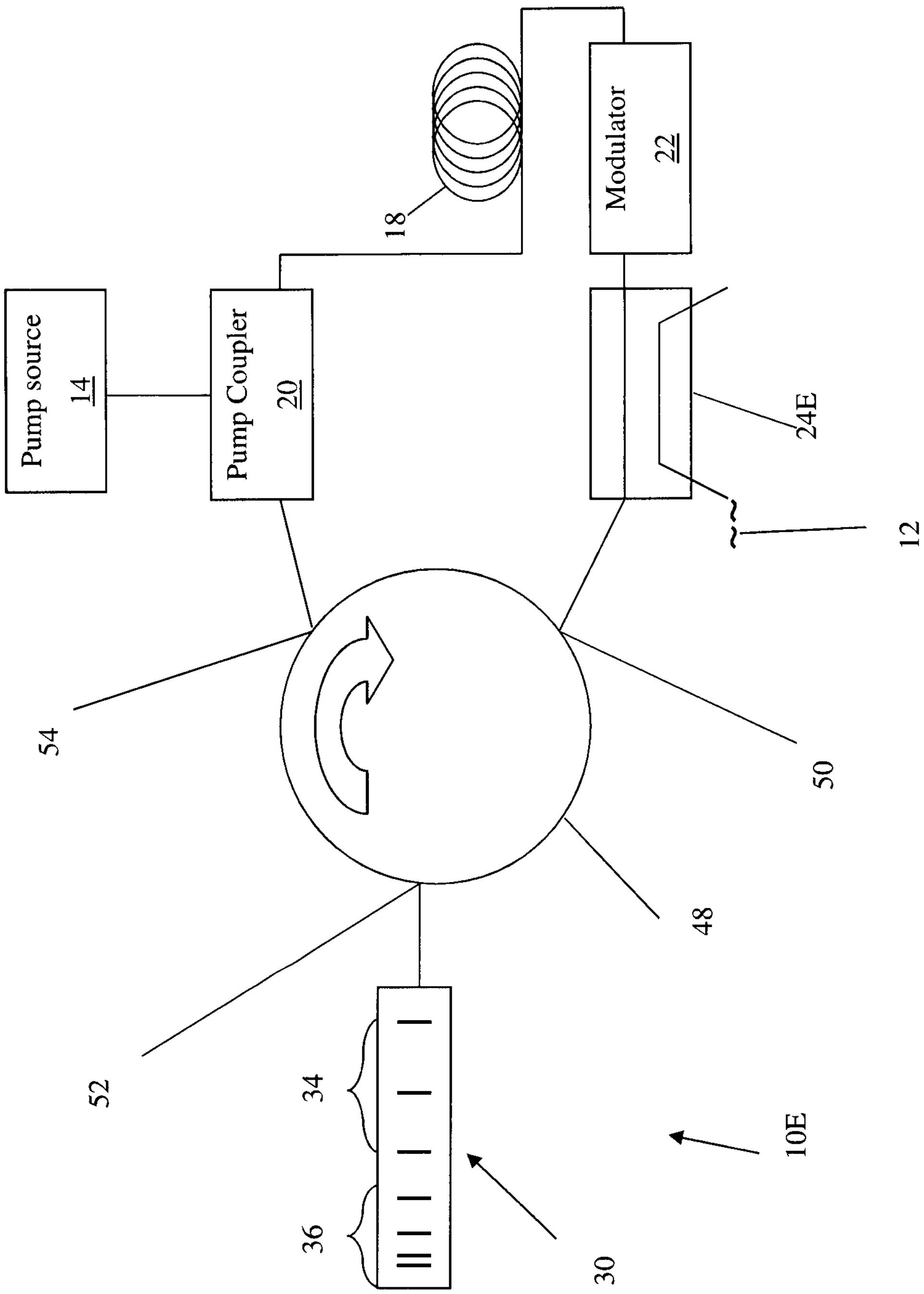
Pump source
14
Pump Coupler
20
18
Modulator
22
24E
12
54
50
48
52
34
36
30
10E

Figure 6

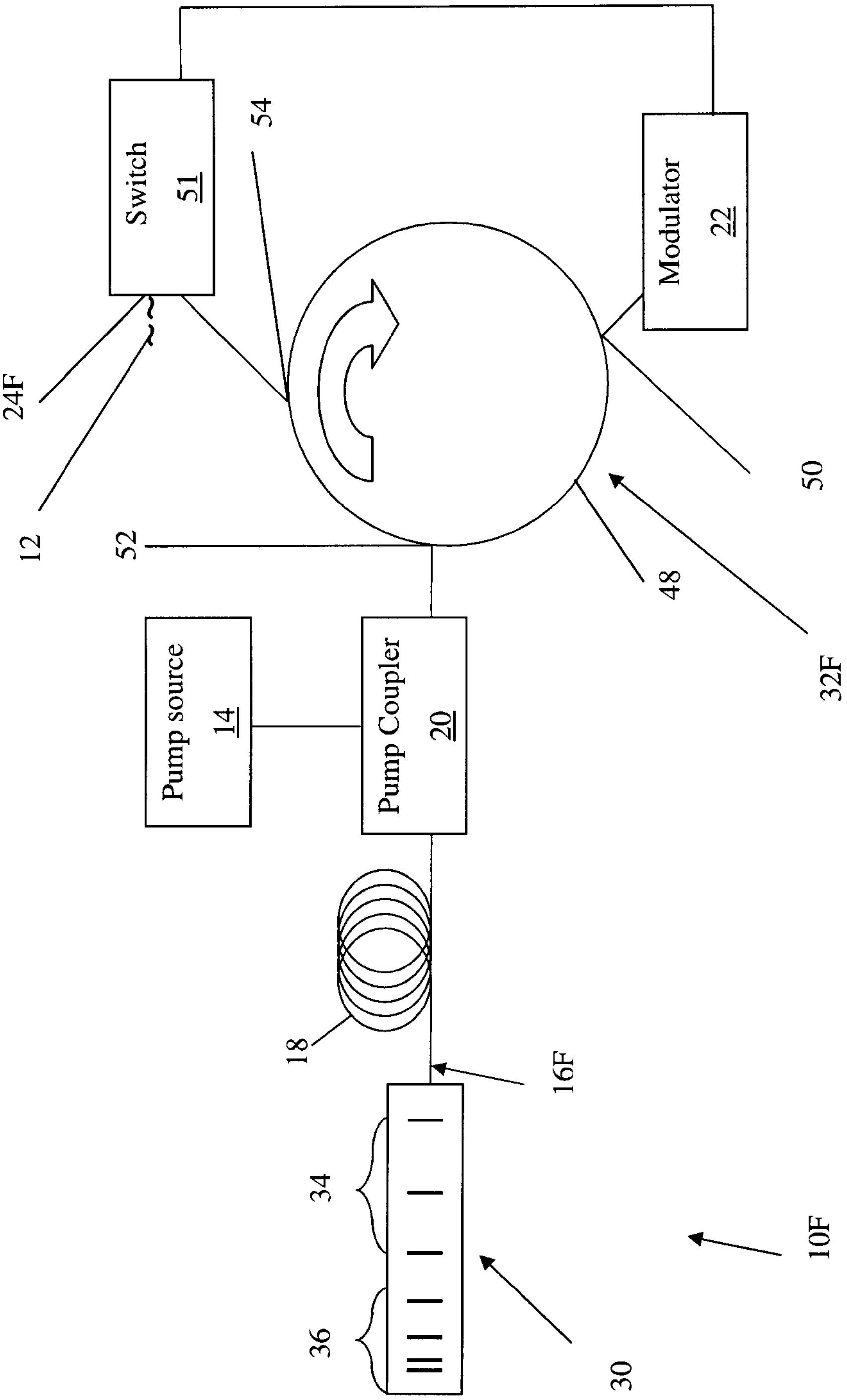
Switch
51
54
Modulator
22
24F
12
52
50
48
32F
Pump source
14
Pump Coupler
20
18
16F
34
36
30
10F

Figure 7

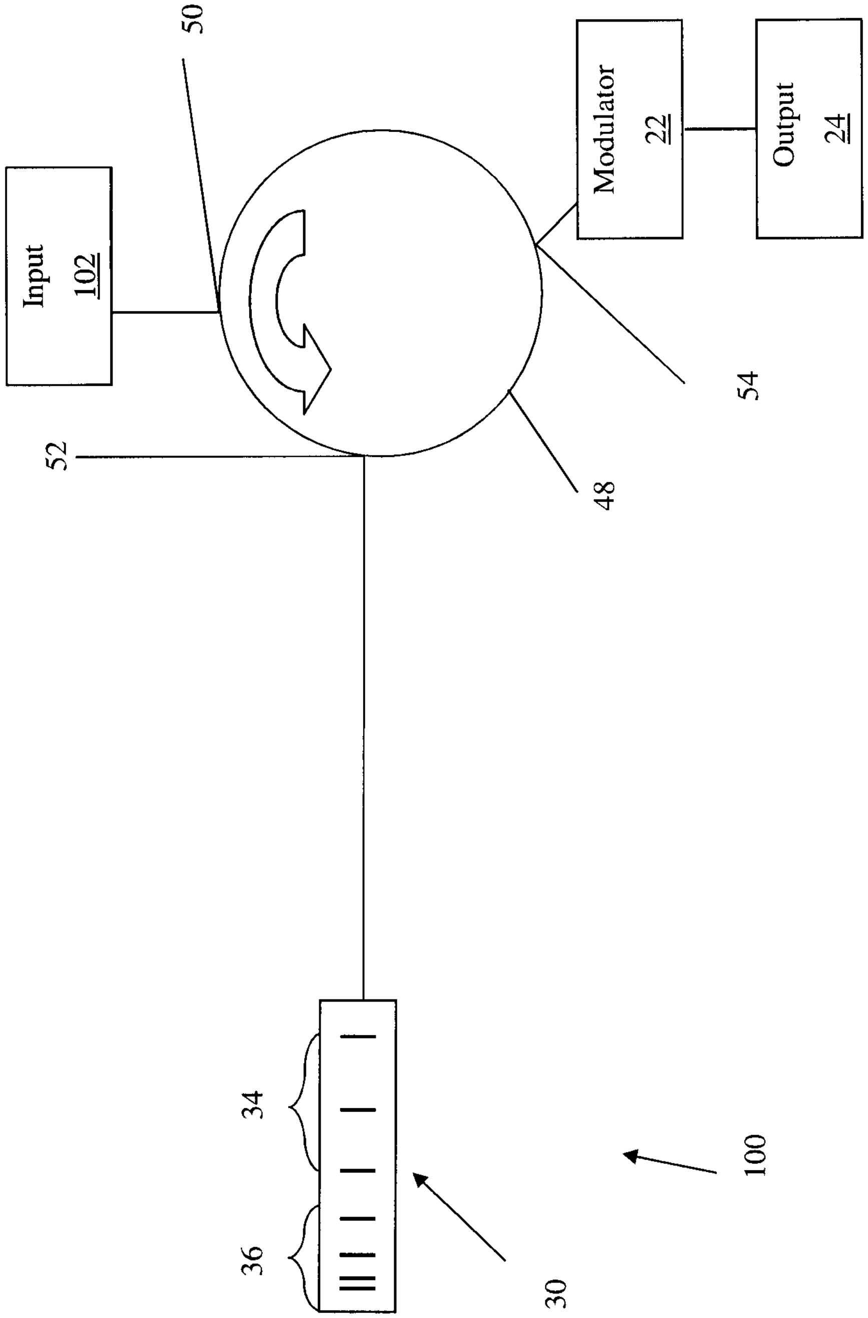

Figure 8

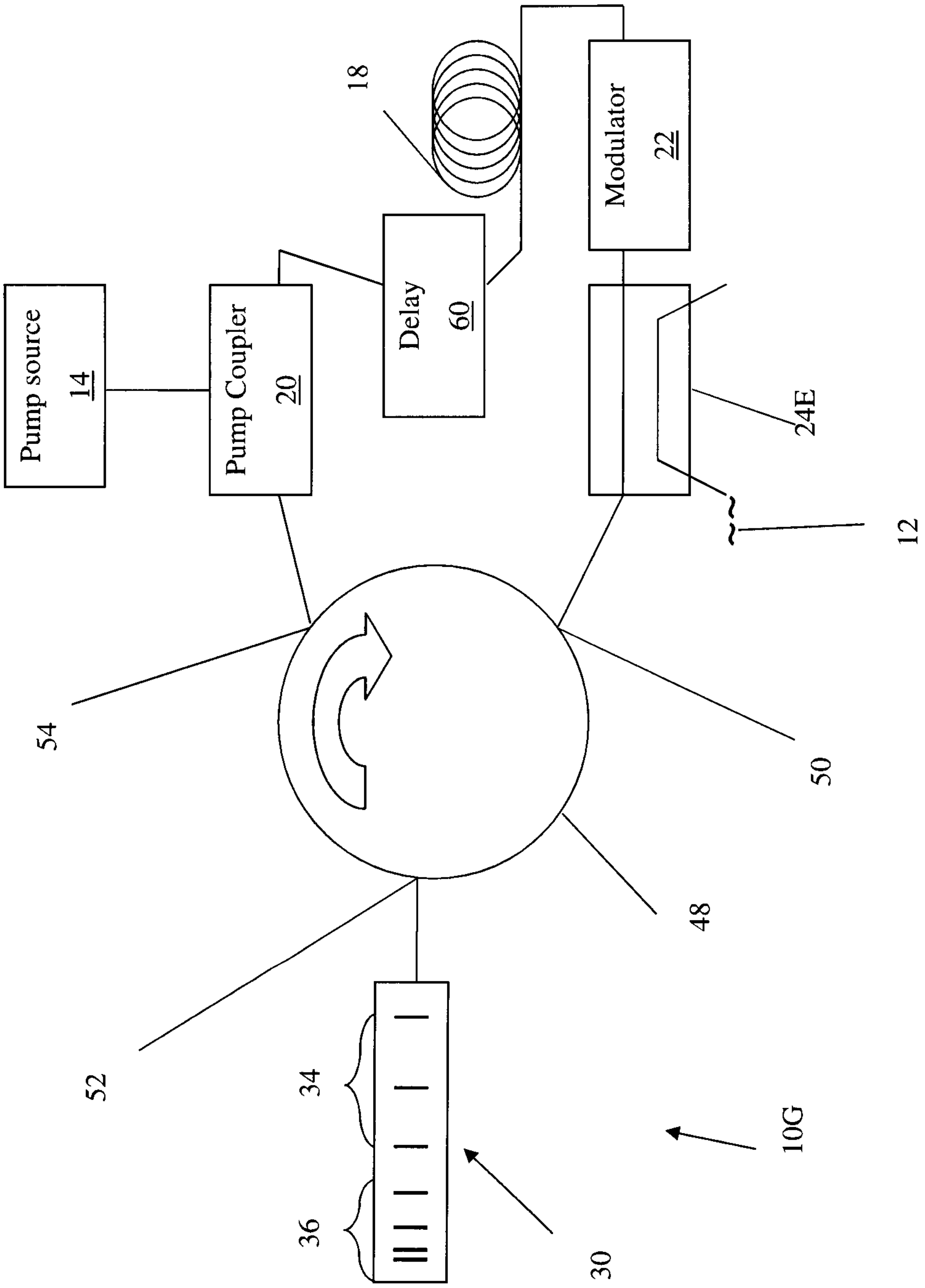
Pump source
14
Pump Coupler
20
Delay
60
Modulator
22
18
24E
12
54
50
48
52
34
36
30
10G

Figure 9

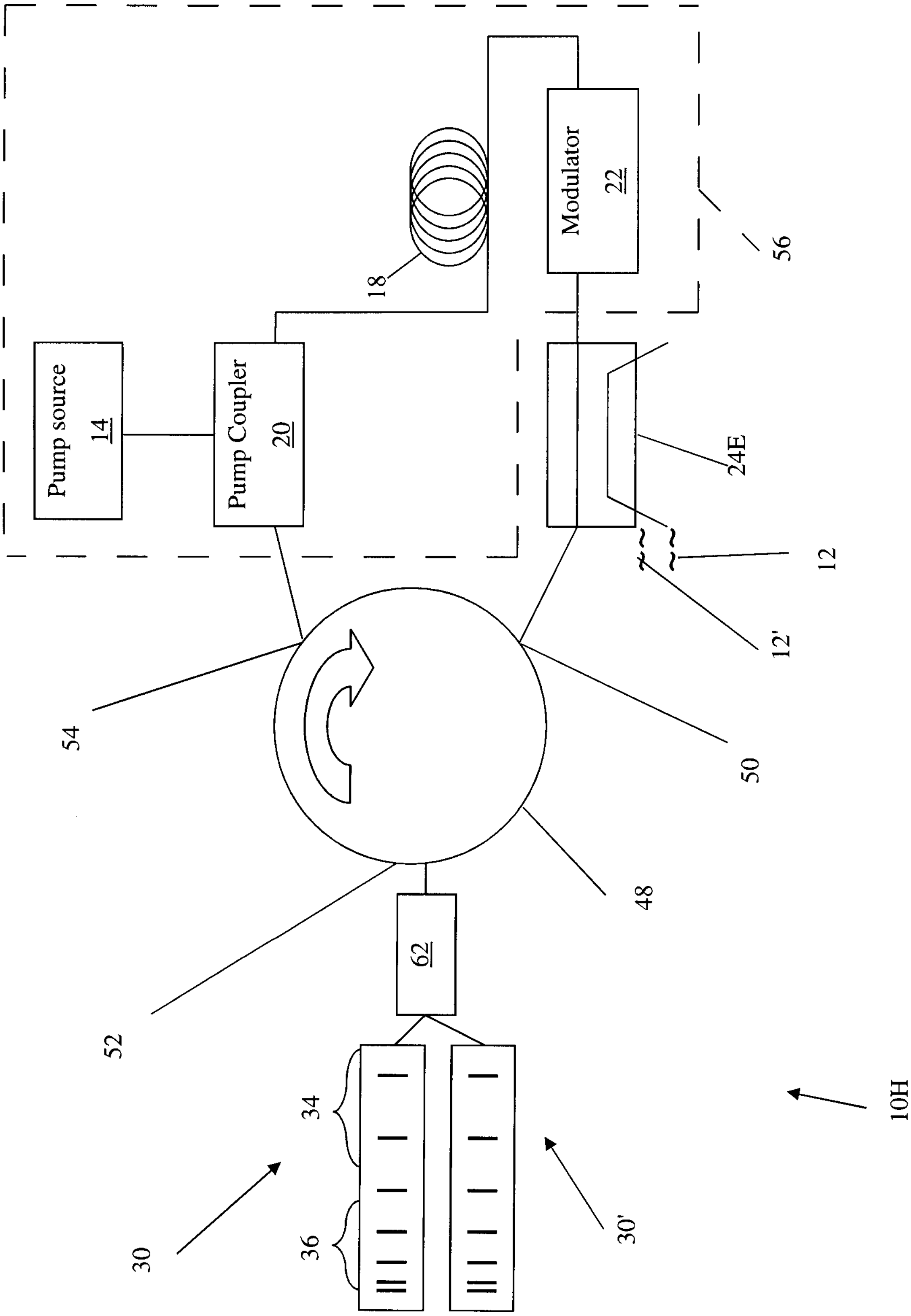
Pump source
14
Pump Coupler
20
Modulator
22
18
56
24E
12
12'
54
50
48
52
62
34
36
30
30'
10H

Figure 10

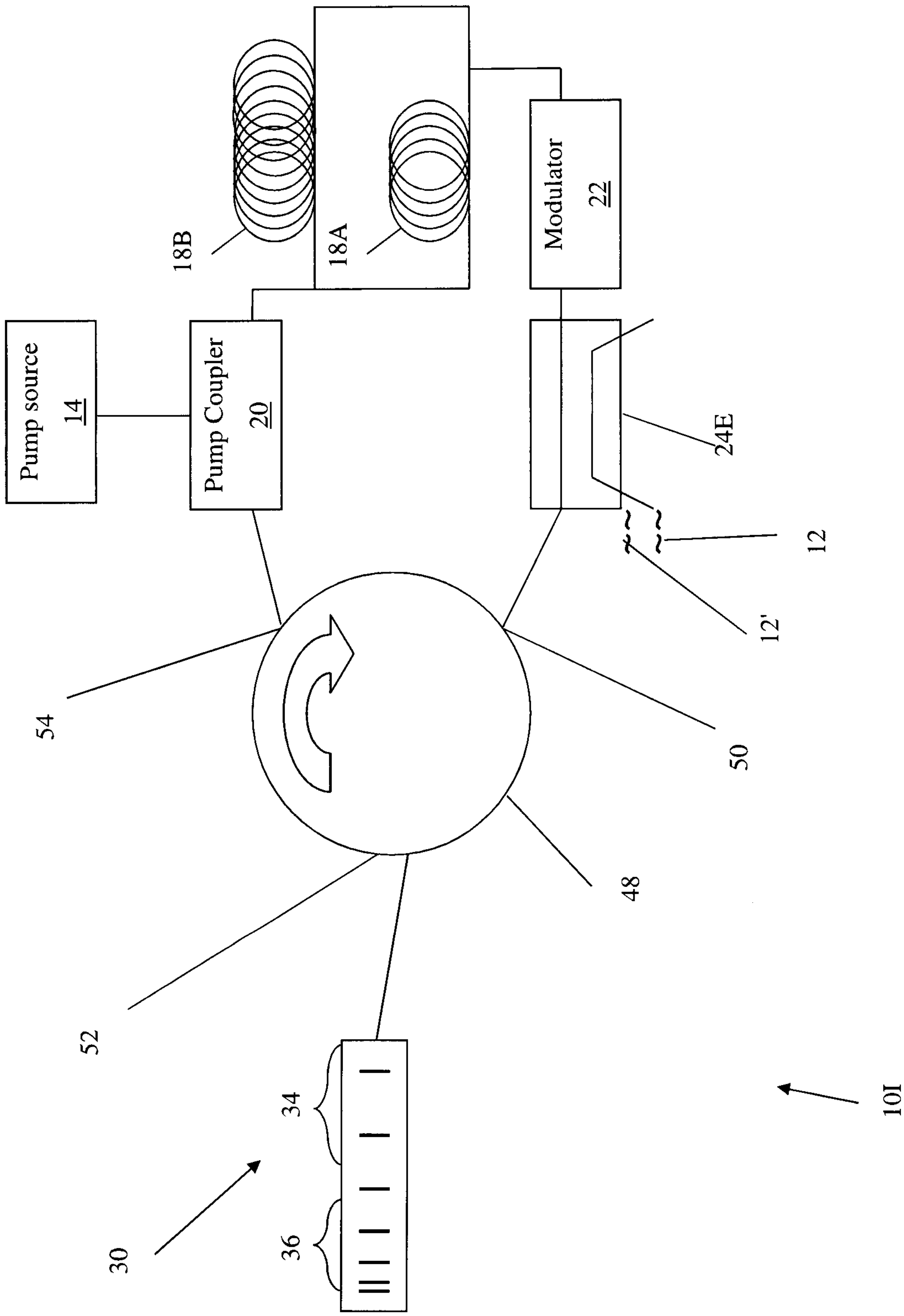
Pump source
14
Pump Coupler
20
18B
18A
Modulator
22
24E
12
12'
54
50
48
52
34
36
30
10I

Figure 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2011/000917

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***HOIS 3/10*** (2006.01) , ***H01S 3/091*** (2006.01) , ***H01S 3/098*** (2006.01) , ***H01S 3/1055*** (2006.01) , ***H01S 3/16*** (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***H01S 3/10*** (2006.01) , ***H01S 3/091*** (2006.01) , ***H01S 3/098*** (2006.01) , ***H01S 3/1055*** (2006.01) , ***H01S 3/16*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
TotalPatent, IEEE, Google.com: pulsed, gain, loop, chirped, grating, different cavity, period, reflector, doped, fiber, multi wavelength, absorber, saturable, modulation, mode locked, tunable, circulator and reflector.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant	Relevant to claim No.
Y	US 2009/0067456A1 (Villeneuve et al.) 12 March 2009 (12-03-2009) *the whole document*	1-28
Y	Pudo et al., "Actively Mode-Locked Tunable Dual-Wavelength Erbium-Doped Fiber Laser", IEEE Photonics Technology letters, Vol. 14, No. 2, February 2002 *the whole document*	1-28
A	WO 2004/073123 A1 (Larochelle et al.) 26 August 2004 (26-08-2004)	
A	US 7,613,214 B2 (Sanders) 3 November 2009 (03-11-2009)	
A	US 5,450,427 (Fermann et al.) 12 September 1995 (12-09-1995)	

[ ] Further documents are listed in the continuation of Box [X] See patent family annex.

* Special categories of cited documents :
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2011 (26-09-2011)	13 October 2011 (13-10-2011)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Wei Wang (819) 994-1711

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2011/000917

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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		CN101803132A	11 August 2010 (11-08-2010)
		EP2183829A2	12 May 2010 (12-05-2010)
		JP2010536164A	25 November 2010 (25-11-2010)
		US2009067456A1	12 March 2009 (12-03-2009)
		WO2009018664A3	26 March 2009 (26-03-2009)
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		WO2008144407A1	27 November 2008 (27-11-2008)
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		JP3781206B2	31 May 2006 (31-05-2006)
		JP2005268819A	29 September 2005 (29-09-2005)
		JP2009188432A	20 August 2009 (20-08-2009)