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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 July 2008 (24.07.2008)

PCT

(10) International Publication Number
WO 2008/089342 A1

(51) International Patent Classification:
H01S 3/08 (2006.01) *H01S 3/1055* (2006.01)

(21) International Application Number:
PCT/US2008/051335

(22) International Filing Date: 17 January 2008 (17.01.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/885,660 19 January 2007 (19.01.2007) US

(71) Applicant *(for all designated States except US)*: **THE GENERAL HOSPITAL CORPORATION** [US/US]; 55 Fruit Street, Boston, MA 02114 (US).

(72) Inventors: BOUMA, Brett, Eugene; 12 Monmouth Street, Quincy, MA 02171 (US). **YUN, Seok-Hyun**; 30 Cambridge Park Drive, Apt. #4128, Cambridge, MA 02140 (US). **OH, Wang-Yuhl**; 700 Huron Avenue, Apt. #5110, Cambridge, MA 02138 (US). **VAKOC, Benjamin, J.**; 3 Sargent Street, Cambridge, MA 02140 (US). **TEARNY, Guillermo, J.**; 12 Fairmont Street, Cambridge, MA 02139 (US).

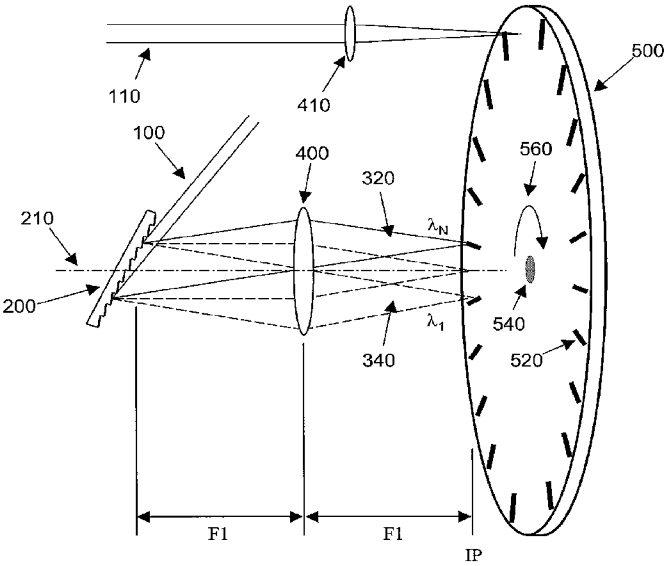
(74) Agents: ABELEV, Gary et al.; Dorsey & Whitney LLP, 250 Park Ave., New York, NY 10177 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
- — *with international search report*
- — *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(54) Title: ROTATING DISK REFLECTION FOR FAST WAVELENGTH SCANNING OF DISPERSED BROADBAND LIGHT



(57) Abstract: An apparatus and source arrangement for filtering an electromagnetic radiation can be provided which may include at least one spectral separating arrangement (200) configured to physically separate one or more components (320, 340) of the electromagnetic radiation based on a frequency of the electromagnetic radiation. The apparatus and source arrangement may also have at least one continuously rotating optical arrangement, e.g., a spinning reflector disk scanner (500), which is configured to receive at least one signal that is associated with the one or more components (320, 340). Further, the apparatus and source arrangement can include at least one beam selecting arrangement configured to receive the signal. Rotating disk (500) may comprise reflecting patterns (520) to generate a wavelength scan depending on the rotation frequency of the disk (500).

WO 2008/089342 A1

ROTATING DISK REFLECTION FOR FAST WAVELENGTH SCANNING OF DISPERSED BROADBAND LIGHT

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is based upon and claims the benefit of priority from U.S. Patent Application Serial No. 60/885,660, filed January 19, 2007, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates generally to optical systems, and more particularly to an optical wavelength filter system for wavelength tuning and a wavelength-swept laser using the optical wavelength filter system.

BACKGROUND INFORMATION

[0003] Considerable effort has been devoted for developing rapidly and widely tunable wavelength laser sources for optical reflectometry, biomedical imaging, sensor interrogation, and tests and measurements. A narrow line width, wide-range and rapid tuning have been obtained by the use of an intra-cavity narrow band wavelength scanning filter. Mode-hopping-free, single-frequency operation has been demonstrated in an extended-cavity semiconductor laser by using a diffraction grating filter design. Obtaining single-frequency laser operation and ensuring mode-hop-free tuning, however, may use a complicated mechanical apparatus and can limit the maximum tuning speed. One of the fastest tuning speeds demonstrated so far has been limited less than 100nm/s. In certain exemplary applications such as biomedical imaging, multiple-longitudinal mode operation, corresponding to an instantaneous line width as large or great than 10 GHz, may be sufficient. Such width may provide a ranging depth of a few millimeters in tissues in optical coherence tomography and a micrometer-level transverse resolution in spectrally-encoded confocal microscopy.

[0004] A line width on the order of 10 GHz can be achieved with the use of an intra-cavity tuning element (such as an acousto-optic filter, Fabry-Perot filter, and galvanometer-driven diffraction grating filter). However, the sweep frequency previously demonstrated has been less than 1 kHz limited by finite tuning speeds of the filters. Higher-speed tuning with a repetition rate greater than 15 kHz may be needed for video-rate (>30 frames/s), high-resolution optical imaging in biomedical applications.

[0005] Recent implementation of a wavelength-swept laser using polygon scanning filter has provided high-speed wavelength tuning up to 10,000 nm/ms. While the high-speed polygon based wavelength-swept light source enabled high-speed imaging as fast as 200 frames/s, wavelength tuning rate as fast as 10,000 nm/ms keeping an instantaneous linewidth narrower than 0.15 nm has already reached to the limit of the polygon based wavelength-swept laser.

[0006] Accordingly, there may be a need for new wavelength scanning filter and laser scheme for faster tuning and especially for wide wavelength tuning range and narrow instantaneous linewidth at fast tuning rate.

[0007] One of the objects of the present invention is to overcome the above-described deficiencies.

SUMMARY OF EXEMPLARY EMBODIMENTS OF PRESENT INVENTION

[0008] An exemplary embodiment of the present invention can be provided which may include apparatus and source arrangement for lightwave filtering that provides high-speed wavelength-swept light with broad spectral tuning range and narrow instantaneous linewidth. In exemplary variant of the exemplary embodiment of the present invention, the optical filter can include a diffraction grating, a focusing lens and a spinning disk. The spinning disk can have reflector patterns and/or transmission window patterns. Certain optical components and arrangement and a proper design of the disk enables high-speed wavelength sweeping over a broad tuning range with narrow instantaneous linewidth.

[0009] In another exemplary embodiment of present invention, the wavelength-swept filter is combined with a proper gain medium implementing a wavelength tunable light source. The filter and gain medium may further be incorporated into a laser cavity. For example, a laser can emit a narrow band spectrum with its center wavelength being rapidly swept over a broad wavelength range. The exemplary laser resonator may include a unidirectional fiber-optic ring and/or a full free space linear cavity with a specially designed semiconductor optical gain medium to minimize the cavity length of the laser.

[0010] According to one exemplary embodiment of the present invention, an apparatus can be provided which may include an arrangement that has at least one section thereon which is configured to receive a first electro-magnetic radiation. The section may be configured to transmit and/or reflect a second electro-magnetic radiation associated with the first electro-magnetic radiation. The section can be configured to modify the second electro-magnetic radiation to have (i) a particular wave number which varies linearly in time, and (ii) a mean frequency which changes over time at a rate that is greater than 100 terahertz per millisecond. The mean frequency may change repeatedly at a repetition rate that is greater than 5 kilohertz. The spectrum can have an instantaneous line width that is smaller than 100 gigahertz.

[0011] According to yet another exemplary embodiment of the present invention, the arrangement can include a continuously rotating disk which reflects and/or transmits through the section the second electro-magnetic radiation to a particular location. The rotating disk can include at least one portion which reflects and/or transmits the second electro-magnetic radiation and which has a curved shape. The arrangement may be provided in a laser cavity.

A control arrangement can also be provided which may allow a processing arrangement and/or a user to control the mean frequency.

[0012] According to a further exemplary embodiment of the present invention, an apparatus can provide an electromagnetic radiation, and may include a first continuously-rotating arrangement that has at least one section thereon which is configured to receive a first electro-magnetic radiation. The section may be configured to transmit and/or reflect a second electro-magnetic radiation associated with the first electro-magnetic radiation. A wavelength of the second electro-magnetic radiation may be scanned in a characteristic repetition time. A second arrangement can be provided which may include at least one laser cavity which may be configured to receive the second electro-magnetic radiation. A roundtrip travel time of the second electro-magnetic radiation in the laser cavity can be substantially equal to an integer multiple of the characteristic repetition time.

[0013] According a still further exemplary embodiment of the present invention, a third arrangement can be provided which is configured to control the roundtrip travel time and/or the characteristic repetition time. A fourth arrangement may be provided which is configured to determine a relationship between the roundtrip travel time and the characteristic repetition time, and control the third arrangement based on the relationship. In addition, a further arrangement may be provided which is configured to control the roundtrip travel time and/or the characteristic repetition time and determine a relationship between the roundtrip travel time and the characteristic repetition time. The further arrangement may be controlled based on the relationship. In another exemplary embodiment of the present invention, yet another arrangement can be provided internally or externally with respect to the second arrangement, and configured to amplify at least one of the first electro-magnetic radiation or the second electro-magnetic radiation based on at least one Raman amplification characteristic.

[0014] These and other objects, features and advantages of the present invention will become apparent upon reading the following detailed description of embodiments of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Further objects, features and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying figures showing illustrative embodiments of the invention, in which:

[0016] Fig. 1A is a first exemplary embodiment of a spinning disk-based wavelength tuning filter according to the present invention;

[0017] Fig. 1B is a second exemplary embodiment of the spinning disk-based wavelength tuning filter according to the present invention;

[0018] Fig. 2 is a third exemplary embodiment of a short linear cavity laser using a disk reflector-based wavelength tuning filter according to the present invention;

[0019] Fig. 3 is an exemplary embodiment of a fiber ring laser using the disk reflector-based wavelength tuning filter according to the present invention;

[0020] Fig. 4 is an exemplary embodiment of a resonant cavity fiber ring laser using the disk reflector-based wavelength tuning filter according to the present invention;

[0021] Fig. 5 is an exemplary embodiment of a resonant cavity fiber Raman ring laser using the disk reflector-based wavelength tuning filter according to the present invention;

[0022] Fig. 6A is a first exemplary embodiment of a disk reflector according to the present invention;

[0023] Fig. 6B is a second exemplary embodiment of the disk reflector according to the present invention; and

[0024] Fig. 6C is a third exemplary embodiment of the disk reflector according to the present invention.

[0025] Throughout the figures, the same reference numerals and characters, unless otherwise stated, are used to denote like features, elements, components or portions of the illustrated embodiments. Moreover, while the subject invention will now be described in detail with reference to the figures, it is done so in connection with the illustrative embodiments. It is intended that changes and modifications can be made to the described embodiments without departing from the true scope and spirit of the subject invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0026] Fig. 1A shows a schematic of a first exemplary embodiment of the disk reflector-based wavelength tuning filter in accordance with the present invention. For example, the optical wavelength filter can comprises of a collimated input/output beam 100, a diffraction grating 200, a focusing lens 400, and a spinning reflection disk 500. Light input to the optical wavelength filter is provided as a collimated input beam 100. Wavelength filtered output is retro-reflected as a collimated light output 100. The diffraction grating 200 is used as a wavelength dispersing element, which may include but is not limited to, a reflection grating, a transmission grating, a prism, a diffraction grating, an acousto-optic diffraction cell or combinations of one or more of these elements.

[0027] The diffraction grating 200 can have a concave curvature that has a focal length and thereby eliminates the need for the focusing lens 400. The focusing lens 400 is located approximately at the distance of its focal length F1 from the diffraction grating. The focusing lens 400 receives collimated wavelength components diffracted from the grating 200 and focuses them onto an image plane IP. At the image plane IP, a disk 500 with reflection patterns 520 is placed. As the reflection disk 500 spins 560 around its center 540, each wavelength component is selectively reflected from one of the reflector patterns 520 one by one providing a continuous wavelength sweep over time. After one reflector strip passes through the desired spectrum of wavelengths 340-320, the next reflector repeats the scan. Different types of materials can be used to make the disk 500, including light weight metals, a light weight plastic, and a substrate of different materials like glass substrate or silicon substrate. The focusing lens 400 can be also composed of different materials depending on applications, for example, a plastic molded aspheric lens can be used for low cost application.

[0028] The exemplary orientation of the incident beam 100 with respect to the optic axis 210 and a rotation direction 560 of the disk reflector 500 can be used to determine the direction of wavelength tuning, e.g., a wavelength up (positive) scan or a wavelength down (negative) scan. The spinning speed of the disk 500 may be monitored and controlled by using a feedback loop circuit. A monitoring beam 110 can be used to provide a feedback. The exemplary arrangement shown in Fig. 1A can generate a positive wavelength sweep. It should be understood that although the disk reflector arrangement 500 is shown in Fig. 1A as having, e.g., twenty reflector patterns 520, reflector pattern arrangements 520 which may have fewer than twenty reflector strips or greater than twenty reflector strips can also be used. While generally not considering practical mechanical limits, based upon conventional manufacturing techniques, a particular number of reflector strips 520 of the disk reflector arrangement 500 to use in any application may depend on a desired scanning rate and scanning range for a particular application.

[0029] Furthermore, the size of the disk 500 may be selected based on preferences of a particular application, and preferably taking into account certain factors including, but not limited to, manufacturability and weight of the disk 500.

[0030] In one exemplary embodiment according to the present invention, a Gaussian beam 100 can be utilized with a broad optical spectrum incident to the grating. A conventional grating equation can be expressed as $\lambda = p \cdot (\sin\alpha + \sin\beta)$ where λ is the optical wavelength, p is the grating pitch, and α and β are the incident and diffracted angles of the beam with respect to the normal axis of the grating, respectively. The center wavelength of tuning range of the filter may be defined by $\lambda_0 = p \cdot (\sin\alpha + \sin\beta_0)$ where β_0 is the angle between the optic axis 210 and the grating normal axis. FWHM bandwidth of the spectral resolution of the diffraction grating arrangement is defined by $(\delta\lambda)_{FWHM} / \lambda_0 = A \cdot (p/m)\cos\alpha / W$, where $A = \sqrt{4\ln 2}/\pi$ for double pass, m is the diffraction order, and W is $1/e^2$-width of the Gaussian beam at the fiber collimator.

[0031] The tuning range of the filter may be given by $\Delta\lambda = p\cos\beta_0 (L/F1)$, where $L = 2F1\tan(\Delta\beta/2)$ denotes the distance between the stripes. Since the beam spot size (measured at the $1/e^2$ intensity points) at the image plane can be given by $w_s = 4\lambda F1/\pi W'$, where $W' = W(\cos\beta/\cos\alpha)$ is $1/e^2$-width of the collimated beam of each wavelength components at the focusing lens 400, the effective finesse of the filter, which can be defined as *(Tuning range)/ (Linewidth)* of the filter, can be determined as $\Im = L/w_s = L\pi W'/4\lambda F1 = \dfrac{\pi}{2\lambda}\tan(\Delta\beta/2)W' \approx \dfrac{\pi\Delta\lambda W}{4\lambda p\cos\alpha}$.

[0032] As can be determined from this relation, large groove density of the grating and large beam incident angle are required for high finesse of the filter, assuming that the spectral resolution of the grating is sufficiently high. For example, with $W = 0.5\ mm$, $\lambda = 1.3\ \mu m$, $\Delta\lambda = 120\ nm$, and $p = 1/1200\ mm$, incident angle α should be $86.9°$ ($W = 0.5\ mm$ and $(\delta\lambda)_{FWHM} = 0.062\ nm$) to achieve a finesse of 800 ($\Delta\lambda = 120\ nm$ and $(\delta\lambda)_{filter} = 0.15\ nm$). Since shorter focal length (higher NA) provides smaller spacing between reflector strips (and smaller spot size), using short focal length lens 400 is better for having larger number of reflector strips, on the same size disk, therefore possibly higher wavelength sweep repetition rate, as long as the clear aperture of the lens 400 is large enough to prevent beam clipping. For example, with $F1 = 10\ mm$ and $D = 10\ mm$ ($NA{\sim}0.5$), where D is the clear aperture of the lens 400, $L = 1.74\ mm$ and $w_s = 2.16\ \mu m$.

[0033] The width of the strip, w, can preferably be substantially equal to the beam spot size, w_s, at the surface of the disk. For $w > w_s$, the filter bandwidth may become greater, and for $w < w_s$, the filter bandwidth may become narrower but the efficiency (reflectivity) of the filter can be decreased by beam clipping.

[0034] A second exemplary embodiment of the optical wavelength filter is shown in Fig. 1B. In this exemplary filter arrangement, strips of transmission windows may be placed on the spinning disk. Only wavelength components that pass through the transmission window are relayed to the reflection mirror 600 via a telescope arrangement 420 and 440 and then retro-reflected to the input port 100.

[0035] Fig. 2 shows an exemplary embodiment of the wavelength-swept laser using a spinning reflector disk. Collimated light output 100 from a semiconductor optical amplifier (SOA) 700 is directly coupled into the spinning disk wavelength filter. A small portion of the light from the reflection facet side of the SOA 710 can be coupled into the single mode fiber 720 providing output of the laser 740.

[0036] A frequency downshift in the optical spectrum of the intra-cavity laser light may arise as the light passes through the SOA gain medium, as a result of an intraband four-wave mixing phenomenon. In the presence of the frequency downshift, greater output power can be generated by operating the wavelength scanning filter in the positive wavelength sweep direction. Since the combined action of self-frequency shift and positive tuning allows higher output to be obtained and enables the laser to be operated at higher tuning speed, the positive wavelength scan may be the preferable operation. The output power can be decreased and the instantaneous linewidth can be broadened with an increasing tuning speed. A short cavity length may be desired to reduce the sensitivity of the output power and instantaneous linewidth to the tuning speed.

[0037] With a short length wavelength scanning filter based on the disk reflector and direct free-space coupling between the gain medium and the optical wavelength filter, the total cavity round trip length can be shorter than 20 cm, which is advantageous for reducing the sensitivity of the output power and instantaneous linewidth to the tuning speed. Transmission type spinning disk filter can also be used, but reflection type may be preferred due to the shorter cavity length.

[0038] Fig. 3 shows another exemplary embodiment of the wavelength-swept laser using spinning reflector disk. A fiber ring cavity 702 can be coupled to the disk scanning filter via collimating lens 750. For the applications where the high speed tuning is not essential so that the relatively long cavity length can be allowed, fiber ring cavity with a conventional dual port SOA 712 can be an optional exemplary configuration.

[0039] Fig. 4 shows an exemplary embodiment of the disk-based fiber ring wavelength swept-laser with long cavity length. Increasing the cavity length so that the laser light becomes resonant after a round trip of the cavity is another way to reduce the sensitivity of the output power and instantaneous linewidth to the tuning speed. Additional length of fiber 760, whose length depends on the tuning repetition rate, in the ring cavity 702 enables resonant tuning. Cavity length variation of the laser cavity with disk scanner may be smaller than that of the polygon scanner based laser, therefore better resonant may be obtainable. A further preferable cavity resonant may be obtained by using transmission type disk scanning filter, because the cavity mirror position is fixed and the cavity length for each wavelength is not changing as the disk spins. The spinning speed of the disk 500 can be maintained constant by using a feedback loop maybe with a monitoring beam 110 for measuring the rotational speed. Active phase tuning with an electro-optic phase modulator or a piezo modulator can be also utilized to remove the phase variation due to non-uniformities in disk thickness and flatness. The monitoring beam 110 can also be used to provide a cavity length change feedback to the phase modulator.

[0040] Fig. 5 shows an exemplary embodiment of the resonant cavity fiber Raman ring laser using the disk scanning filter. Since long length of optical fiber 760 is used for resonant wavelength tuning, Raman gain can be induced in the long length of fiber 760 with proper pump light 770 supplied through a WDM coupler 780. Special type of fiber can be used as a long length fiber 760 in the cavity to enhance the Raman gain efficiency. Since the Raman gain wavelength band is determined by the wavelength band of the pump light, wavelength swept-laser with arbitrary wavelength tuning band may be obtained as far as the pump light with proper wavelength band is available. Also, depending on the pump light power and the Raman gain efficiency in the fiber, high power wavelength-swept laser may be implemented. Pump light for the Raman gain can be also provided in backward direction to the laser light and both forward and backward pumps can be used simultaneously to obtain higher gain. The pump light is not limited to the light with a single wavelength component. To obtain a broad bandwidth Raman gain, a multiple wavelength pump light can be preferably utilized. This exemplary configuration can be further expanded to achieve a laser tuning range beyond the filter free spectral range by using multiple Raman pump light staggered in wavelength, whose gain bandwidth is broader than the free spectral range of the filter, that are progressively cycled on and off.

[0041] Fig. 6A shows an exemplary embodiment of the scanning disk reflector (or transmission window) pattern 520 configuration. For example, more than a hundred reflector strips 520 can be written on the spinning disk 500. Spatially dispersed line of wavelength components 580 is incident on the disk preferably with 90 degree orientation to the reflector strip. The thickness and the spacing between the reflector strips can be determined based on the consideration explained above. The region where there is no reflector (or transmission window) may be anti-reflection coated. The bigger (larger diameter) disk may be preferred as far as it's spinning speed is not significantly slower than that of the smaller disk, because larger number of reflector strip elements can be written on the disk providing faster tuning repetition rate with the same spinning speed. If the disk is spun 560 at 1000 rotations/s, with more than a hundred reflector strips, faster than 100 kHz tuning repetition rate can be obtained.

[0042] Fig. 6B shows another exemplary embodiment of the scanning disk reflector (or transmission window) pattern 520 configuration. In this exemplary embodiment the reflector strip is not a straight line but a curved line. The curvature of the reflector strip is carefully designed so that any arbitrary desired wavelength tuning slope can be obtained with the disk scanner spinning at constant speed. The angle f between the reflector strip element and the line of wavelength components 580 should be accurately aligned to the pre-designed value to have desired wavelength tuning slope. One exemplary tuning slope may be desired for OFDI (optical frequency domain imaging) is that the wavenumber of the filtered light is linearly swept over time as the disk spins at constant speed.

[0043] Fig. 6C shows another exemplary embodiment of the scanning disk reflector (or transmission window) pattern 520 configuration. In this exemplary configuration, multiple rings of the reflector strips 522 may be written on the disk. Each reflector strip ring corresponds to specific wavelength filtering condition (e.g., tuning range, linewidth), and multiple rings can provide various options for different wavelength sweep requirements.

[0044] The foregoing merely illustrates the principles of the invention. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. Indeed, the arrangements, systems and methods according to the exemplary embodiments of the present invention can be used with any OCT system, OFDI system, spectral domain OCT (SD-OCT) system or other imaging systems, and for example with those described in International Patent Application PCT/US2004/029148, filed September 8, 2004, U.S. Patent Application No. 11/266,779, filed November 2, 2005, and U.S. Patent Application No. 10/501,276, filed July 9, 2004, the disclosures of which are incorporated by reference herein in their entireties. It will thus be appreciated that those skilled in the art will be able to devise numerous systems, arrangements and methods which, although not explicitly shown or described herein, embody the principles of the invention and are thus within the spirit and scope of the present invention. In addition, to the extent that the prior art knowledge has not been explicitly incorporated by reference herein above, it is explicitly being incorporated herein in its entirety. All publications referenced herein above are incorporated herein by reference in their entireties.

What Is Claimed Is:

1. An apparatus comprising:

an arrangement including at least one section thereon which is configured to receive a first electro-magnetic radiation,

wherein the at least one section is configured to at least one of transmit or reflect a second electro-magnetic radiation associated with the first electro-magnetic radiation, and

wherein the at least one section is configured to modify the second electro-magnetic radiation to have:

a. a particular wave number which varies linearly in time, and

b. a mean frequency which changes over time at a rate that is greater than 100 terahertz per millisecond.

2. The apparatus according to claim 1, wherein the mean frequency changes repeatedly at a repetition rate that is greater than 5 kilohertz.

3. The apparatus according to claim 1, wherein the spectrum has an instantaneous line width that is smaller than 100 gigahertz.

4. The apparatus according to claim 1, wherein the arrangement includes a continuously rotating disk which at least one of reflects or transmits through the at least one section the second electro-magnetic radiation to a particular location.

5. The apparatus according to claim 4, wherein the rotating disk includes at least one portion which at least one of reflects or transmits the second electro-magnetic radiation and which has a curved shape.

6. The apparatus according to claim 1, wherein the at least one section has a curved shape.

7. The apparatus according to claim 1, wherein the arrangement is provided in a laser cavity.

8. The apparatus according to claim 1, further comprising a control arrangement which allows at least one of a processing arrangement or a user to control the mean frequency.

9. An apparatus for providing an electromagnetic radiation, comprising:

a first continuously-rotating arrangement including at least one section thereon which is configured to receive a first electro-magnetic radiation, wherein the at least one section is configured to at least one of transmit or reflect a second electro-magnetic radiation associated with the first electro-magnetic radiation, and wherein a wavelength of the second electro-magnetic radiation is scanned in a characteristic repetition time; and

a second arrangement including at least one laser cavity which is configured to receive the second electro-magnetic radiation, wherein a roundtrip travel time of the second electro-magnetic radiation in the laser cavity is substantially equal to an integer multiple of the characteristic repetition time.

10. The apparatus according to claim 9, further comprising a third arrangement configured to control at least one of the roundtrip travel time or the characteristic repetition time.

11. The apparatus according to claim 10, further comprising a fourth arrangement configured to determine a relationship between the roundtrip travel time and the characteristic repetition time, and control the third arrangement based on the relationship.

12. The apparatus according to claim 9, further comprising a further arrangement configured to control at least one of the roundtrip travel time or the characteristic repetition time and determine a relationship between the roundtrip travel time and the characteristic repetition time, wherein the further arrangement is controlled based on the relationship.

13. An apparatus for providing an electromagnetic radiation, comprising:

a first arrangement including at least one section thereon which is configured to receive a first electro-magnetic radiation, wherein the at least one section is configured to at least one of transmit or reflect a second electro-magnetic radiation associated with the first electro-magnetic radiation, and wherein a wavelength of the second electro-magnetic radiation is scanned in a characteristic repetition time;

a second arrangement including at least one laser cavity which is configured to receive the second electro-magnetic radiation, wherein a roundtrip travel time of the second electro-magnetic radiation in the laser cavity is substantially equal to an integer multiple of the characteristic repetition time; and

a third arrangement provided internally or externally with respect to the second arrangement, and configured to amplify at least one of the first electro-magnetic radiation or the second electro-magnetic radiation based on at least one Raman amplification characteristic.

14. The apparatus according to claim 13, further comprising a fourth arrangement configured to control at least one of the roundtrip travel time or the characteristic repetition time.

15. The apparatus according to claim 14, further comprising a fifth arrangement configured to determine a relationship between the roundtrip travel time and the characteristic repetition time, and control the fourth arrangement based on the relationship.

16. The apparatus according to claim 13, further comprising a further arrangement configured to control at least one of the roundtrip travel time or the characteristic repetition time and determine a relationship between the roundtrip travel time and the characteristic repetition time, wherein the further arrangement is controlled based on the relationship.

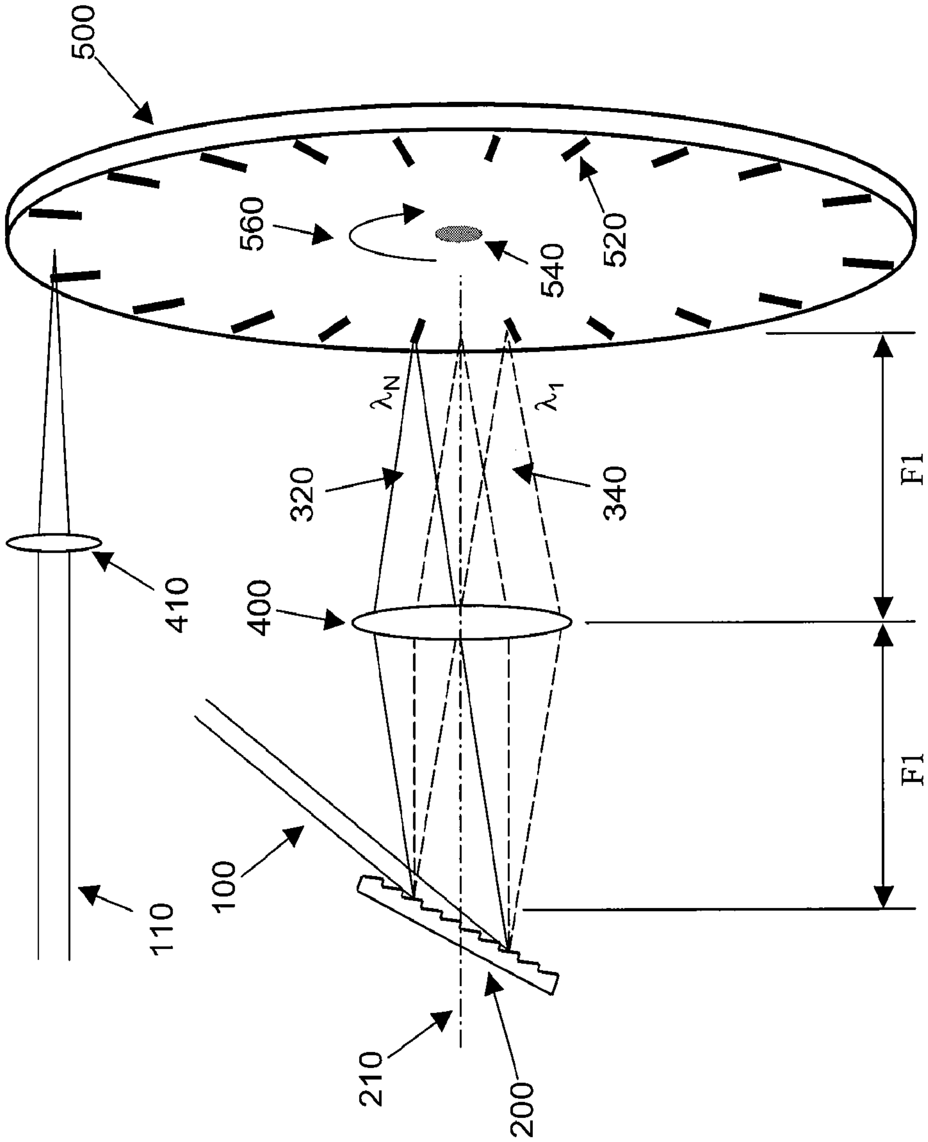

500
560
540
520
IP
λ_N
λ_1
320
340
F1
F1
410
400
100
110
210
200

Fig. 1A

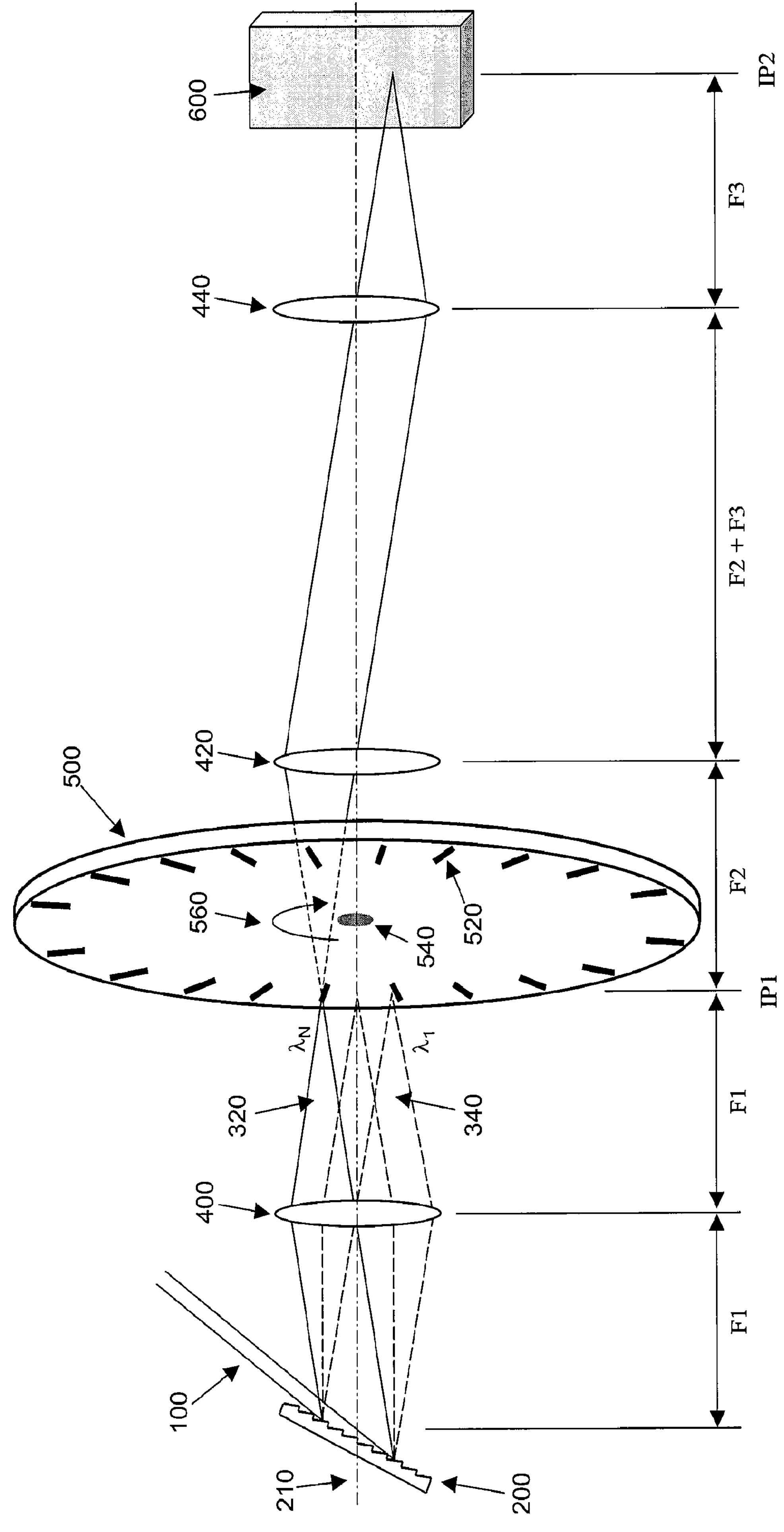

600
IP2
F3
440
F2 + F3
500
420
560
540
520
F2
IP1
λ_N
λ_1
320
340
F1
400
F1
100
210
200

Fig. 1B

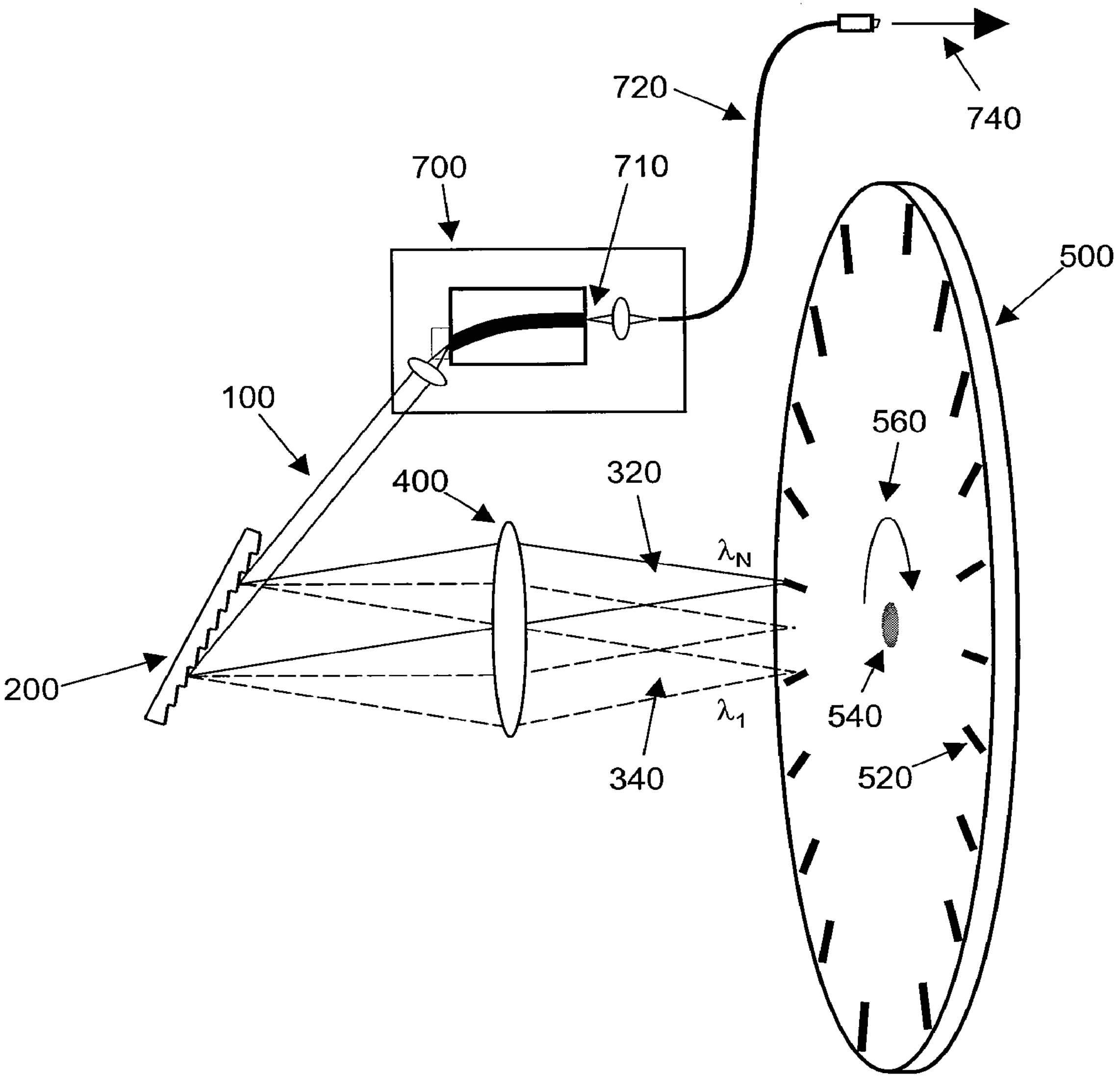

720
740
700
710
500
100
560
400
320
λ_N
200
540
λ_1
340
520

Fig. 2

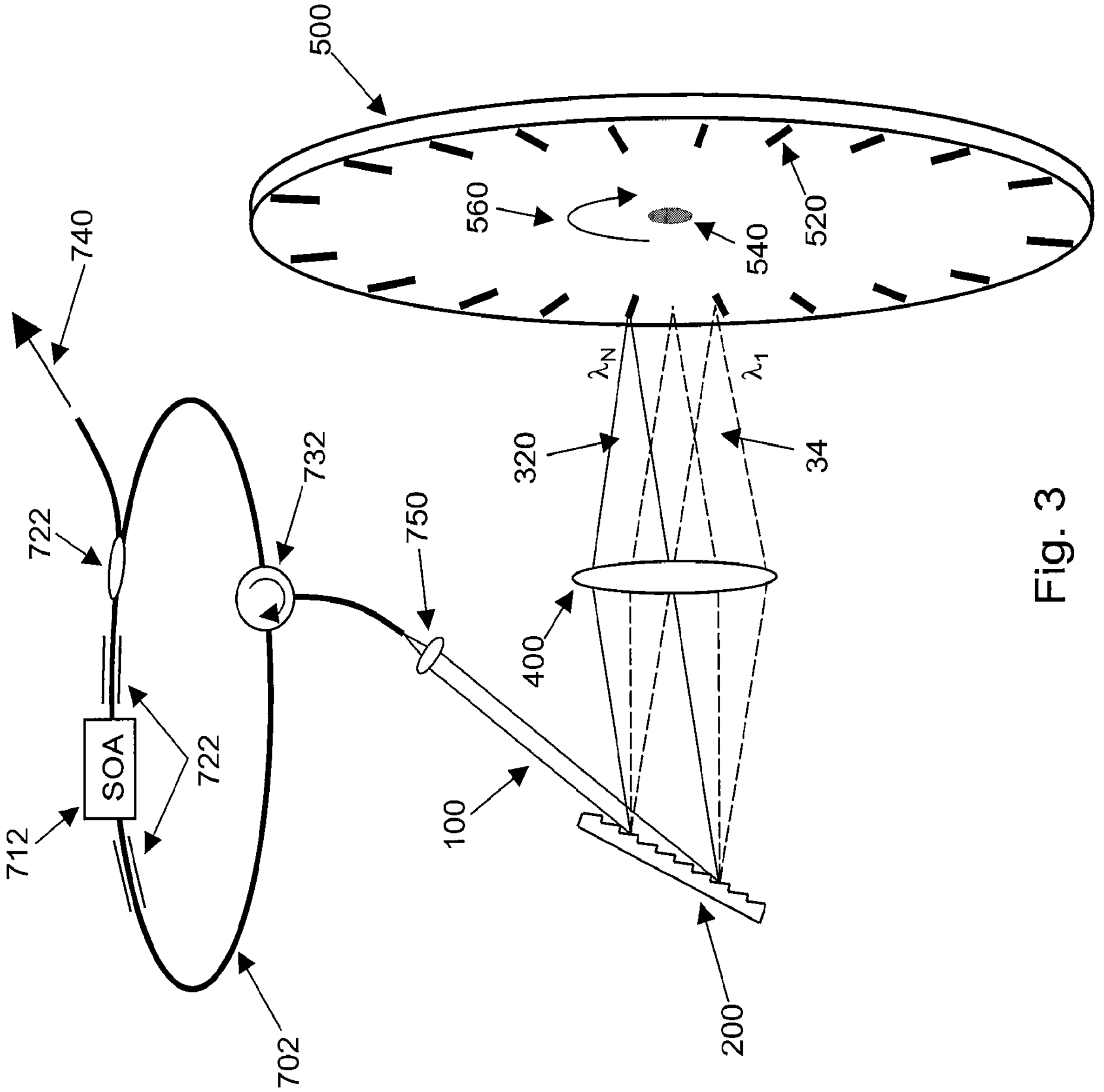

500
560
540
520
740
722
732
750
320
34
λ_N
λ_1
400
SOA
712
722
100
200
702

Fig. 3

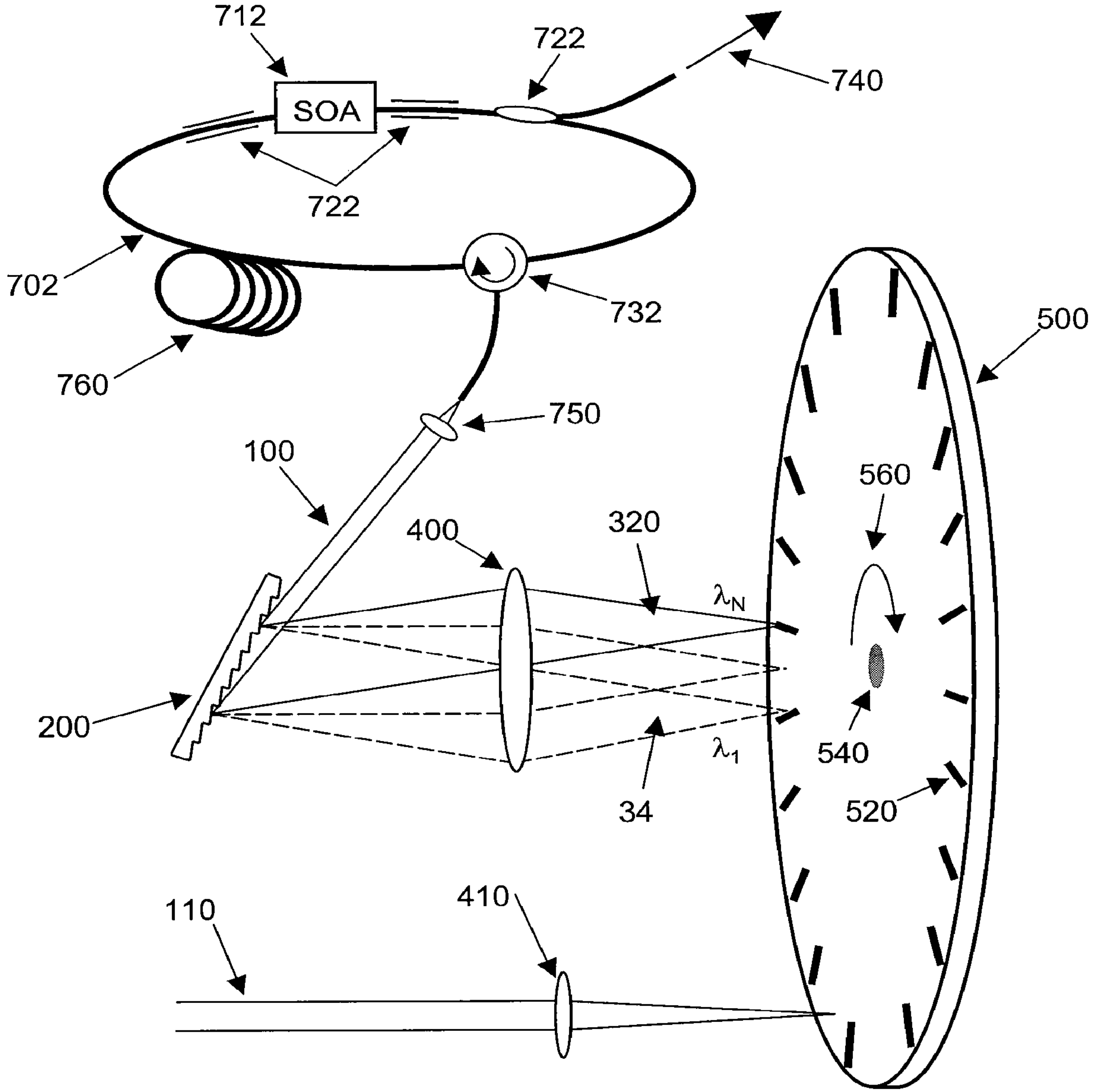
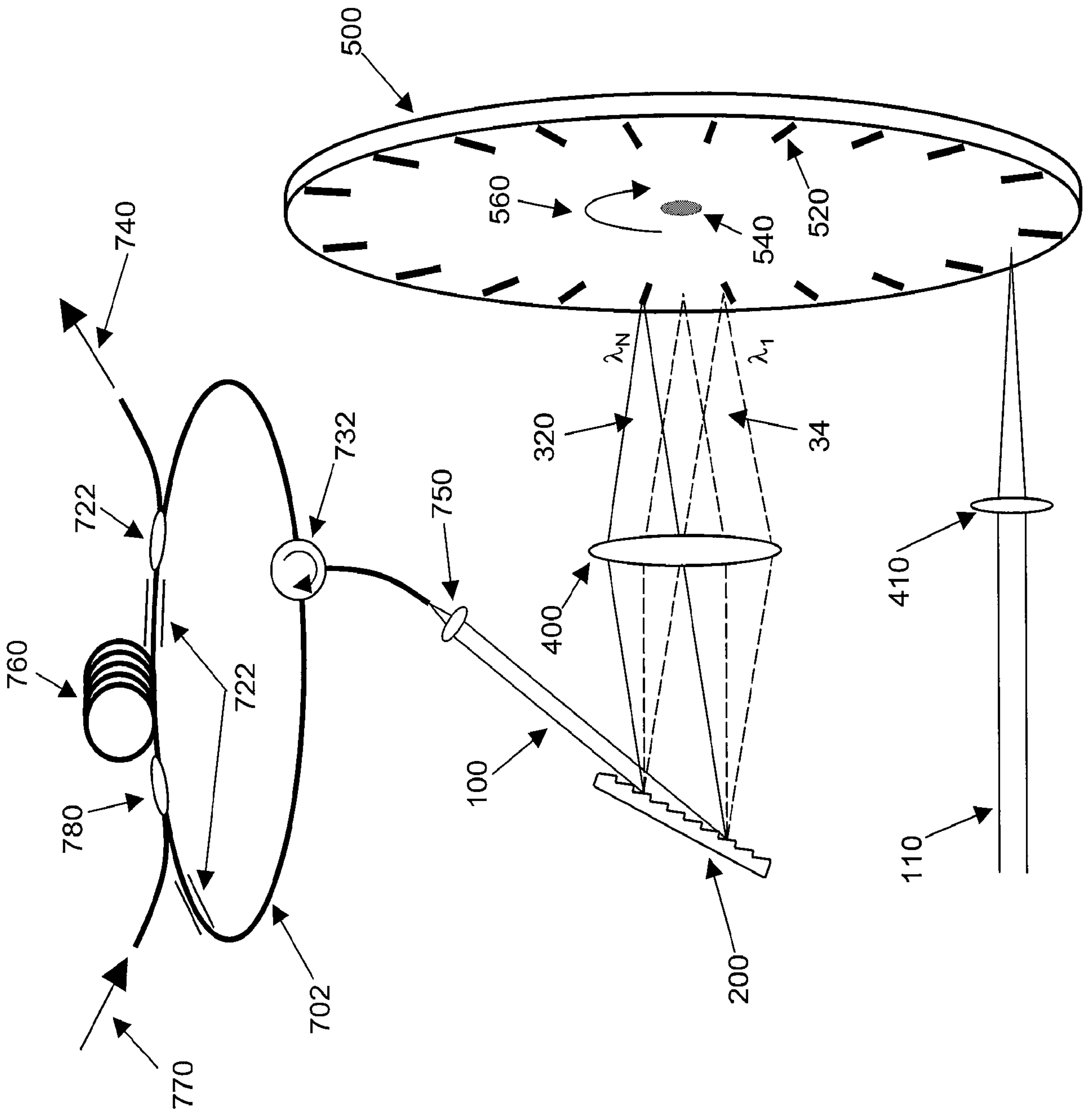

712
SOA
722
740
722
702
732
760
500
750
100
560
400
320
λ_N
200
540
λ_1
34
520
110
410

Fig. 4

Fig. 5


500
560
540
520
740
722
732
750
760
722
780
702
770
320
34
λ_N
λ_1
400
410
100
200
110

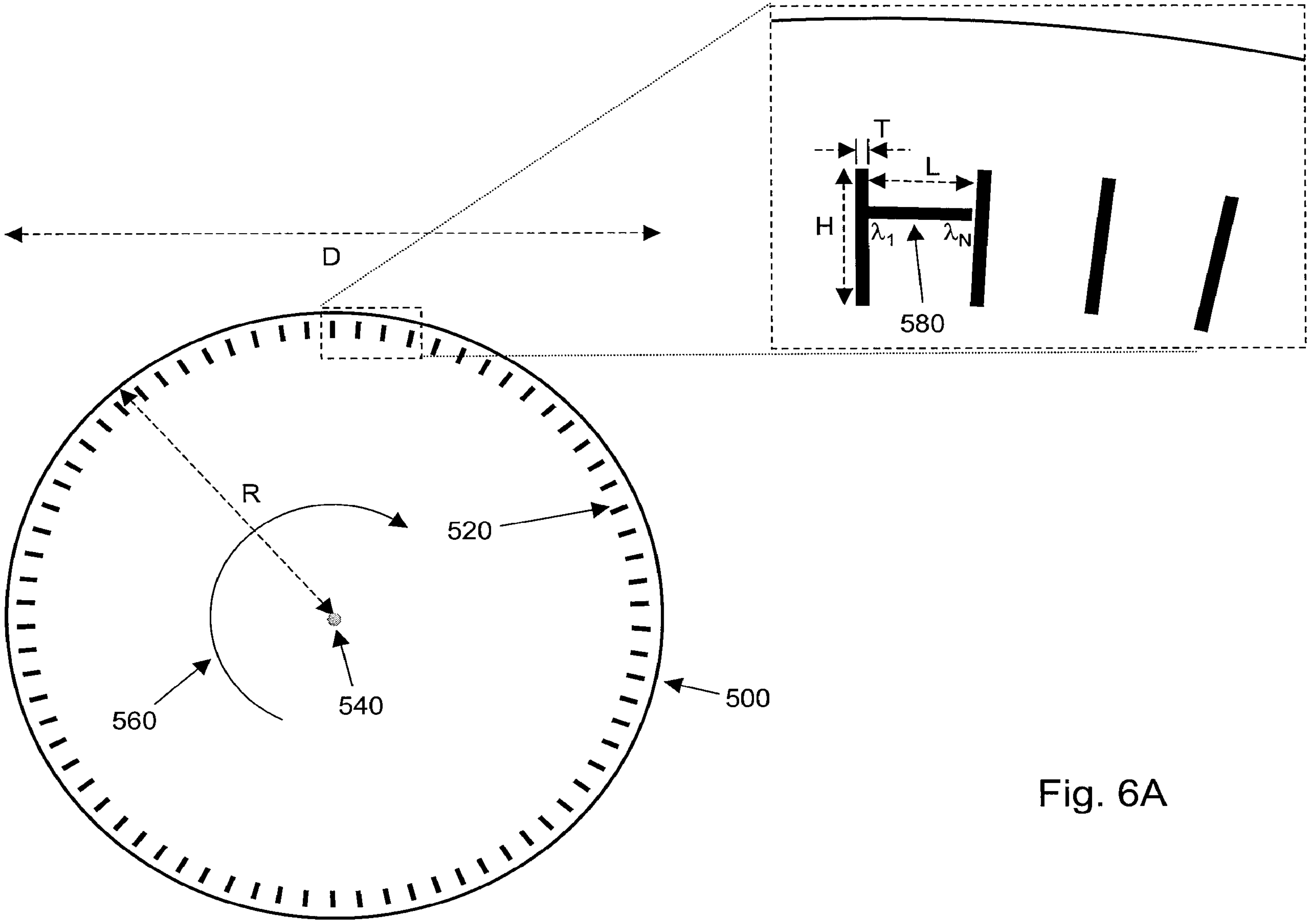


Fig. 6A

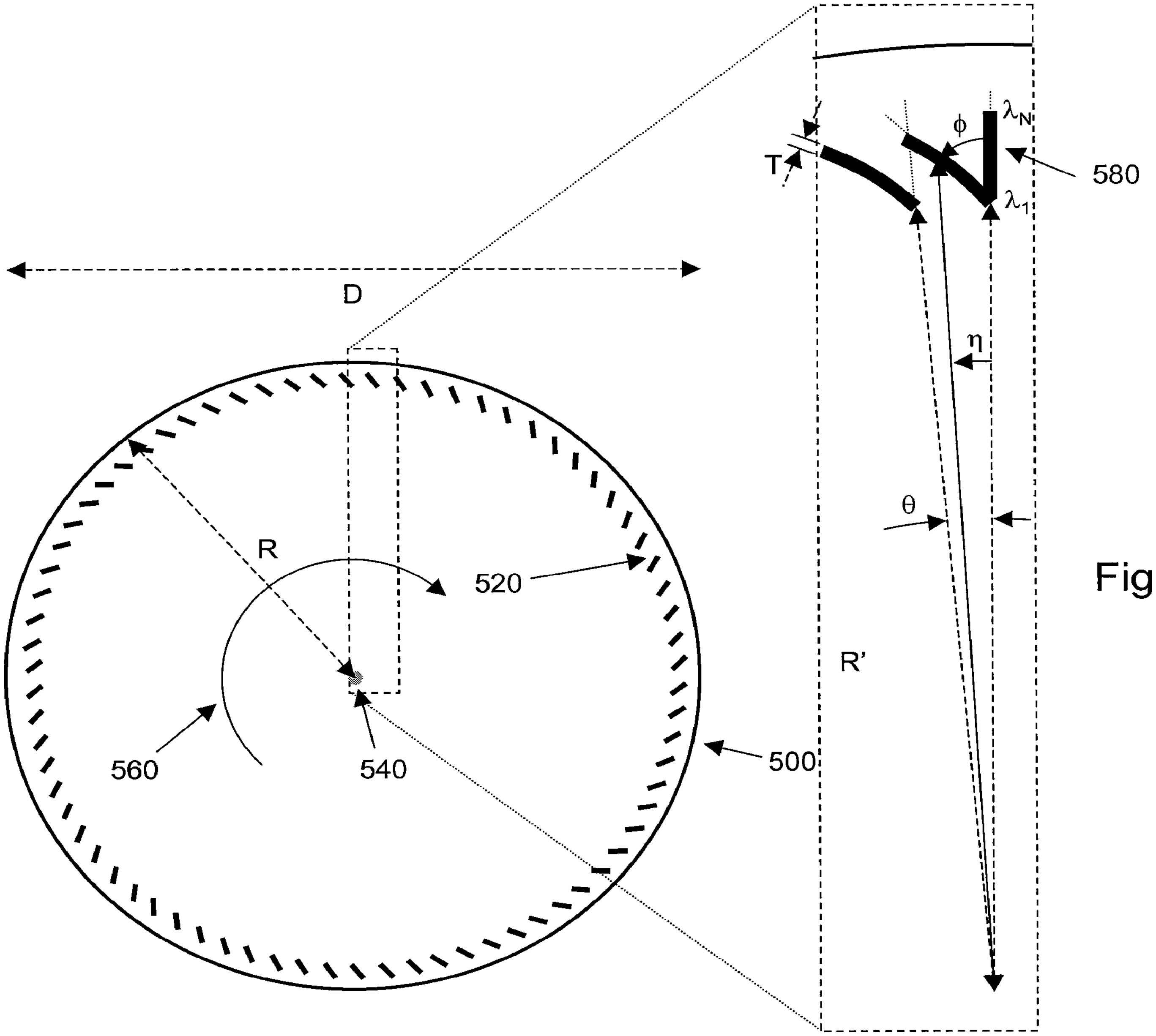


Fig. 6B

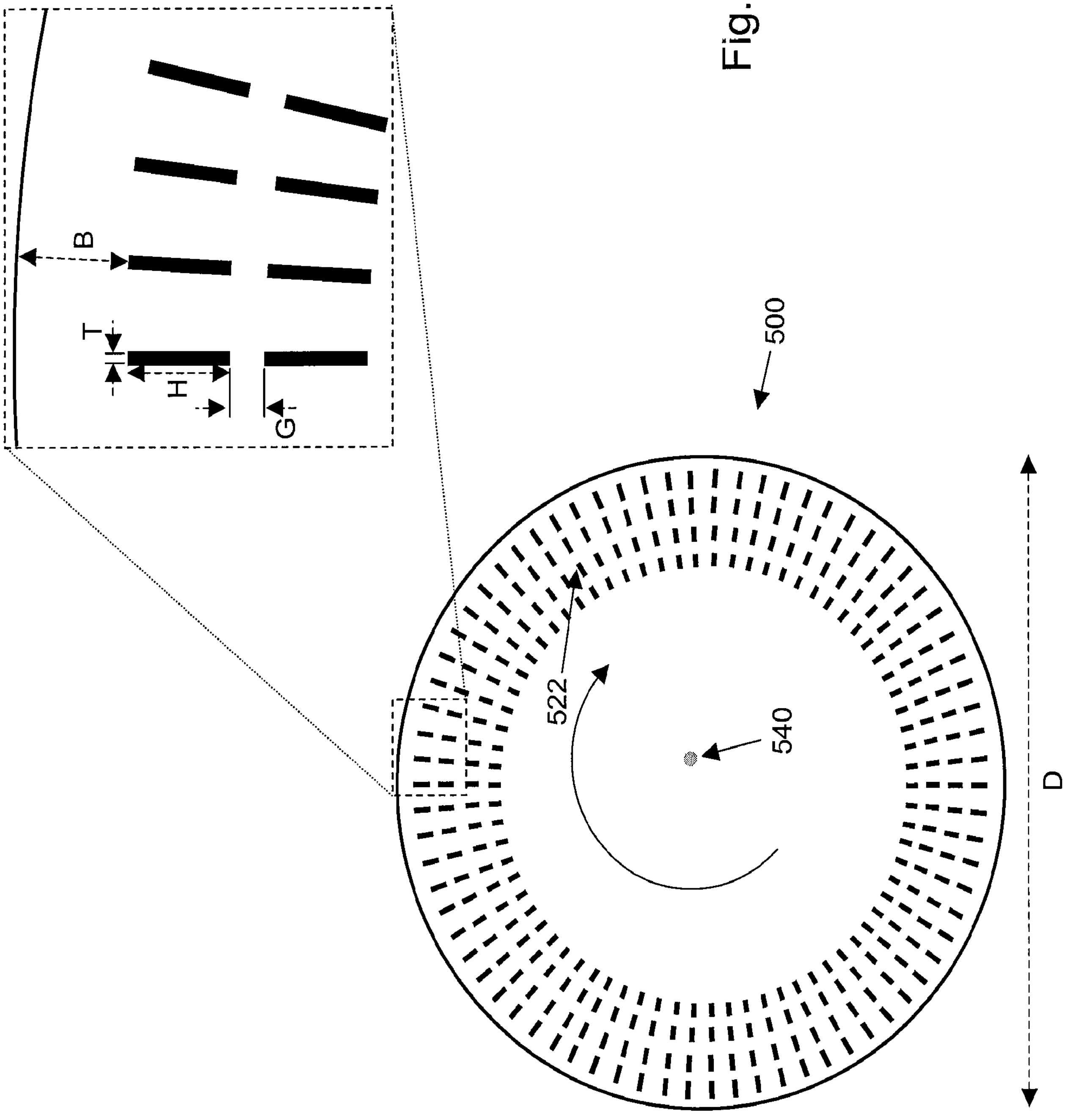


Fig. 6C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/051335

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01S3/08 H01S3/1055

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)
H01S G02B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/035295 A1 (BOUMA BRETT [US] ET AL) 17 February 2005 (2005-02-17)	1-8
Y	paragraphs [0006] - [0010], [0036] - [0050], [0058], [0061] - [0065]; figures 1,3,6-8	9-16
X	OH W ET AL: "Ultrahigh-speed optical frequency domain imaging and application to laser ablation monitoring" APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, vol. 88, no. 10, 10 March 2006 (2006-03-10), pages 103902-103902, XP012080529 ISSN: 0003-6951	1-3,6-8
Y	pages 103902-2, column 1 - pages 103902-2; figures 1-3	9-16

-/--

☒ Further documents are listed in the continuation of Box C.

☒ 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 document 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 28 May 2008	Date of mailing of the international search report 10/06/2008
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Laenen, Robert

International application No
PCT/US2008/051335

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	TELLE J M ET AL: "Very rapid tuning of CW dye laser" APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, vol. 26, no. 10, 15 May 1975 (1975-05-15), pages 572-574, XP002389841 ISSN: 0003-6951 page 572 - page 573; figure 1	9-16
X	US 3 872 407 A (HUGHES RICHARD SWART) 18 March 1975 (1975-03-18) column 2, line 34 - column 4, line 68; figures 2,3,5	1,7
A	US 4 751 706 A (ROHDE ROBERT S [US] ET AL) 14 June 1988 (1988-06-14) column 1, line 47 - column 2, line 16; figure 1	1,4,7

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2008/051335

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005035295 A1	17-02-2005	NONE	
US 3872407 A	18-03-1975	NONE	
US 4751706 A	14-06-1988	NONE	