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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 September 2018 (13.09.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/165031 A1

(51) International Patent Classification:
G02B 27/42 (2006.01) *G02B 5/18* (2006.01)
G02B 5/04 (2006.01)

(21) International Application Number:
PCT/US2018/020933

(22) International Filing Date:
05 March 2018 (05.03.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/469,887 10 March 2017 (10.03.2017) US

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(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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

(54) Title: WAVELENGTH SHIFT INVARIABLE PRISM AND GRATING SYSTEM

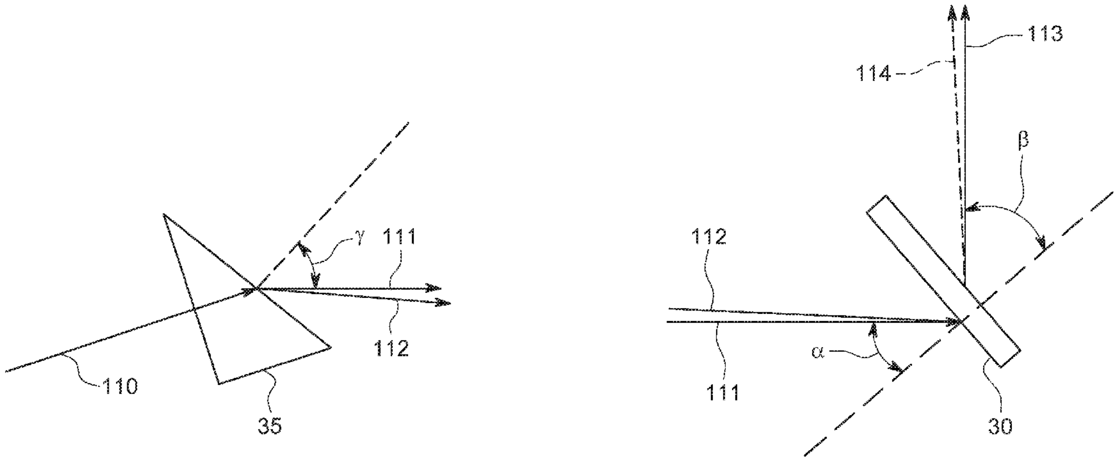

FIG. 6

(57) Abstract: An optical dispersion system through which optical signals pass in a medium includes a prism and a diffraction grating. The prism is formed of an optically transparent material and configured to refract a plurality of optical signals along a plurality of angles of refraction, with each optical signal being refracted along one of the angles of refraction. The diffraction grating is configured to receive the refracted plurality of optical signals at an angle of incidence and diffracts each optical signal into a plurality of sub-beams based upon a diffraction angle. The prism and diffraction grating are configured so that a change in each angle of refraction due to environmental changes in the medium compensates for a change in the angle of incidence due to the environmental changes in the medium to maintain the diffraction angle relatively constant.

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SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

WAVELENGTH SHIFT INVARIABLE PRISM AND GRATING SYSTEM

Related Applications

[0001] This application claims priority to U.S. Provisional Application No. 62/469,887, filed March 10, 2017, which is incorporated herein by reference in its entirety.

Technical Field

[0002] This patent disclosure relates generally to wavelength selective switch assemblies and, more particularly, to a wavelength shift invariable prism and grating system for use with a wavelength selective switch assembly.

Background

[0003] Optical switches are used in optical communication networks to provide high-speed, high data rate communication capabilities. The optical communication networks often use optical wavelength division multiplexing to maximize the use of the optical spectrum. Wavelength selective switch assemblies permit optical signals to be selectively switched between optical receivers to carry out the desired communications functionality. In a wavelength selective switch assembly, the distance between the optical receivers is extremely small so that necessary changes in the path of the optical signals used carry out the switching function are similarly small.

[0004] Wavelength selective switch assemblies may be configured to compensate for temperature changes in the components of the assembly in order to minimize the impact of changes on the performance of the switch assembly. However, changes in environmental conditions such as air pressure, air temperature, and off-gassing of components within the housing of a switch assembly may also impact the operation of a wavelength selective switch assembly. More specifically, changes in the environmental conditions within the housing of the switch assembly may cause a change in the refractive index of the air through which the optical signals are being transmitted and such changes in the refractive index may negatively impact the alignment of the optical signals. Accordingly, a wavelength selective switch assembly that compensates for changes in the refractive index of air is desirable.

[0005] The foregoing background discussion is intended solely to aid the reader. It is not intended to limit the innovations described herein, nor to limit or expand the prior art discussed. Thus, the foregoing discussion should not be taken to indicate that any particular element of a prior system is unsuitable for use with the innovations described herein, nor is it intended to indicate that any element is essential in implementing the innovations described herein. The implementations and application of the innovations described herein are defined by the appended claims.

Summary

[0006] In one aspect, an optical dispersion system through which optical signals pass in a medium includes a prism and a diffraction grating. The prism is formed of an optically transparent material and configured to refract a plurality of optical signals along a plurality of angles of refraction, with each optical signal being refracted along one of the angles of refraction. The diffraction grating is configured to receive the refracted plurality of optical signals at an angle of incidence and diffracts each optical signal into a plurality of sub-beams based upon a diffraction angle. The prism and diffraction grating are configured so that a change in each angle of refraction due to environmental changes in the medium compensates for a change in the angle of incidence due to the environmental changes in the medium to maintain the diffraction angle relatively constant.

[0007] In another aspect, an optical dispersion system through which optical signals pass in a medium includes a prism and a diffraction grating. The prism is formed of an optically transparent material and is configured to refract a plurality of optical signals along an angle of refraction. The diffraction grating has a plurality of grating elements for receiving the refracted plurality of optical signals at an angle of incidence and diffracting each optical signal into a plurality of sub-beams as a function of a diffraction angle. The prism and diffraction grating are configured so that a change in the angle of refraction due to environmental changes in the medium is approximately equal to a change in the angle of incidence due to the environmental changes in the medium.

[0008] In still another aspect, an optical dispersion system through which optical signals pass in a medium includes a prism and a diffraction grating. The prism is formed of an optically transparent material and is configured to refract a plurality of optical signals along an angle of refraction. The diffraction grating has a plurality of grating elements for receiving the refracted plurality of optical signals at an angle of incidence and diffracting each optical signal into a plurality of sub-beams as a function of a diffraction angle. A change in the angle of refraction $\Delta\gamma$ is approximated by:

$$\frac{\sin\gamma dn}{n\cos\gamma}$$

where γ is the angle of refraction, dn is the change of the refractive index of the medium, and n is the refractive index of the medium, a change in the angle of incidence $\Delta\alpha$ is approximated by:

$$m\lambda dn \frac{1}{\mathrm{d}n^2 cos\alpha}$$

where m is the diffraction order, λ is the wavelength of the optical signal, dn is the change of the refractive index of the medium, d is the grating constant, n is the refractive index of the medium, and α is the angle of incidence, and the change in the angle of refraction due to environmental changes in the medium is approximately equal to the change in the angle of incidence due to the environmental changes in the medium.

Brief Description of the Drawings

[0009] Fig. 1 is a schematic view of a wavelength selective switch assembly in which the principles of the present disclosure may be incorporated;

[0010] Fig. 2 is a graph showing the refractive index of air as a function of air pressure;

[0011] Fig. 3 is a graph showing the wavelength shift of light passing through air as a function of the air pressure;

[0012] Fig. 4 is a schematic view of a grating for use in accordance with the present disclosure;

[0013] Fig. 5 is a schematic view of a prism for use in accordance with the present disclosure;

[0014] Fig. 6 is a schematic view of a prism and grating system;

[0015] Fig. 7 is a schematic view of a prism and grating system configured in accordance with the principles of the present disclosure;

[0016] Fig. 8 is a schematic view of a second embodiment of prism and grating system configured in accordance with the principles of the present disclosure;

[0017] Fig. 9 is a graph showing the shift in the refractive angle of light exiting a prism is a function of air pressure; and

[0018] Fig. 10 is a graph of simulations of the frequency shift vs. air pressure for optical signals through a wavelength selective switch.

Detailed Description

[0019] A block diagram of an exemplary dual 1 x N wavelength selective switch 10 with folding optics is depicted in Fig. 1. The dual wavelength selective switch 10 permits the operation of two independent wavelength selective switches using a common set of optical components.

[0020] The dual wavelength selective switch 10 includes, in sequence, common port and branch port collimators 12, polarization conditioning optics 13, a polarization beam splitter array 14, beam expansion optics 15, dispersion components 16, a first folding mirror 17, a second folding mirror 20, lenses 21, a third folding mirror 22, a fourth folding mirror 23, and a polarization modulator array 24. Each of the common port and branch port collimators 12 corresponds to a common port for a respective wavelength selective switch of the dual wavelength selective switch 10. When operating as a 1 x N demultiplexer, the respective common port collimators may each receive an optical input beam having multiple wavelengths that are routed to respective branch output port collimators. When operating as an N x 1 multiplexer, the respective common ports may receive a combined light beam for output, e.g., to an optical fiber. Input light beams may be received at the dual wavelength selective switch 10 from one or more branch collimators of a respective set of branch collimators associated with the corresponding common port collimator.

[0021] Polarization conditioning optics 13 includes a birefringent element and a half wave plate so that, in the multiplexing direction, light beams input at a common port undergo polarization conditioning. The output light beams having the same polarization direction pass through the polarization beam splitter array 14 and are expanded by beam expansion optics 15 and a dispersion system 16. The dispersion system 16 may include a pair of gratings and one or more prisms.

[0022] The expanded light beams are reflected by the first and second folding mirrors 17 and 20 and directed to the first and second lenses 21. The lenses 21 focus the expanded light beams on the third folding mirror 22, which reflects the light beams to the fourth folding mirror 23. The fourth folding mirror 23 directs the expanded light beams onto the polarization modulator array 24.

[0023] The polarization switched wavelengths from the polarization modulator array 24 follow a reverse path through the wavelength selective switch 10 wherein the reverse direction cancels the dispersion and expansion provided by the respective components. The polarization beam splitter array 14 routes particular polarization switched wavelengths toward particular branch port collimators associated with the corresponding common port of the particular wavelength selective switch of the dual wavelength selective switch 10.

[0024] In many instances, the wavelength selective switch 10 will be operating in a sealed enclosure (not show). However, in some instances, the seal may fail causing the wavelength selective switch 10 to be subject to environmental conditions that affect the air or medium through which the optical signals (e.g., light) of the wavelength selective switch are operating. These environmental conditions may include changes in air pressure, air temperature, as well as off-gassing of components within the enclosure. Such changes in the environmental conditions of the air within the enclosure containing the optics of the system may cause changes in the refractive index of the air n_{air} through which the optical signals are being transmitted.

[0025] The changes in the refractive index of the air n_{air} may cause changes that disrupt the performance of the system or switch 10. In particular, the changes in the refractive index of the air n_{air} may result in changes in the wavelength of the light being transmitted and changes in the performance the prisms of beam expansion optics 15. More specifically, the refractive index of the air n_{air} through which an optical signal such as light or an electromagnetic wave is traveling is a function of the temperature and pressure of the air and may be expressed as:

$$n_{air} = 1 + \frac{\left(n_{eff} - 1\right) * P}{1 + (T - 15) * 3.4785 * 10^{-3}} \tag{1}$$

where n_{air} is the refractive index of the air, P is the air pressure, T is the air temperature and n_{eff} is the effective refractive index.

[0026] The effective refractive index n_{eff} is a function of the wavelength of the light being transmitted and may be expressed as:

$$n_{eff} = 1 + \left[6432.8 + \frac{2949810\lambda^2}{146\lambda^2 - 1} + \frac{25540\lambda^2}{41\lambda^1 - 1}\right] * 1.0 * 10^{-8} \tag{2}$$

[0027] Fig. 2 depicts a graph of the refractive index as a function of air pressure (e.g., Equation (1)) at a constant temperature (20° C) and for a wavelength λ of 1550nm. From Fig. 2 it may be understood that the changes in the refractive index of air n_{air} due to the changes in pressure P of the air are very small, with the refractive index in a vacuum n_{vac} being 1.0 and the refractive index of n_{air} at 1 atm being 1.000269. The relationship between the wavelength of light traveling through air as compared to that traveling through a vacuum may be expressed as:

$$\lambda_{air} = \frac{\lambda_{vac}}{n_{air}} \tag{3}$$

where λ_{air} is the wavelength of the light in air and λ_{vac} is the wavelength of the light in a vacuum. Accordingly, a small change in refractive index of air n_{air}, as compared to the refractive index in a vacuum (i.e., $n = 1$), will result in a small decrease in the wavelength of the optical signal being transmitted.

[0028] While such a small change in wavelength may not be significant in some applications, when used in a system such as a wavelength selective switch 10 in which the differentiation between signals may only be 0.0004 μm, a small change in wavelength may significantly affect the performance of the system. As may be seen in Fig. 3, the shift in wavelength between a vacuum and a system operating at 1 atm may be approximately 0.0004 μm. Thus, if a system is sealed at specified environmental conditions and the seal is broken or compromised, the wavelength of the optical signals may change enough to affect the positions of the optical signals. While the change in the wavelength may be relatively small, the small differentiation between wavelengths in the wavelength selective switch 10 may significantly affect the operation of the system.

[0029] More specifically, referring to Fig. 4, an optical input signal 100 is received at diffraction grating 30 at an angle of incidence α and is dispersed into a plurality of sub-beams, with only a single sub-beam 101 depicted for clarity. Grating 30 includes a plurality of evenly spaced apart diffraction grating elements 31 that operate to diffract or disperse the optical signal 100 into a plurality of sub-beams at different wavelengths. Each sub-beam is diffracted by grating 30 at a diffraction angle β according to the following equation:

$$m\,\lambda/n_{air} = \mathrm{d}\,(\sin\alpha + \sin\beta) \qquad (4)$$

where m is the diffraction order, d is the grating constant, and α is the angle of incidence.

[0030] If the wavelength of the optical input signal changes based upon a change in environmental conditions, for a specified or constant angle of incidence α, the diffraction angle β will also change, which may result in misalignment of the diffracted sub-beams relative to their desired paths. As depicted in Fig. 4, a second optical signal 102 having a different wavelength is received at grating 30 at the same angle of incidence α and is dispersed as a plurality of sub-beams with only a single sub-beam 103 depicted at a second, modified diffraction angle β_{mod}.

[0031] To prevent such misalignment, it is desirable for the diffraction angle β to remain constant even with a change in wavelength λ. In order to do so, the change in wavelength λ must be compensated for by a like change in the angle of incidence α. Equation (4) may be re-written in terms of the angle of incidence α as follows:

$$m\lambda\frac{1}{\mathrm{d}n} - sin\beta = sin\alpha \qquad (5)$$

[0032] Since the diffraction angle β is constant, differentiation of Equation (5) results in the following equation:

$$cos\alpha d\alpha = m\lambda dn \frac{1}{\mathrm{d}n^2} \tag{6}$$

where $d\alpha$ is the change of the angle of incidence α and dn is the change of the refractive index of air n_{air}

[0033] Equation (6) may then be solved for the change in the angle of incidence $d\alpha$ which results in the following equation:

$$d\alpha = m\lambda dn \frac{1}{\mathrm{d}n^2 cos\alpha} \tag{7}$$

[0034] To improve the performance of the wavelength selective switch 10, the prisms of wavelength selective switch 10 may be configured to compensate for the change the angle of incidence $d\alpha$. As depicted in Fig. 5, prism 35 includes a first face 36 and a second face 37 disposed at an angle 38 to the first face. Prism 35 may be formed of any desired optically transparent material. Each optical input signal such as signal 105 entering prism 35 perpendicular to first face 36 and at an angle of incidence θ relative to second face 37 exits the prism at an angle of refraction γ relative to a line perpendicular to the second face based upon the following equation:

$$n_{glass} \sin\theta = n \sin\gamma \tag{8}$$

where n_{glass} is the refractive index of the material from which the prism is formed and n is the refractive index of the material or medium (e.g., air) from which the optical signal 106 exits the prism 35 at the second face 37.

[0035] Neither the angle of incidence θ nor the refractive index of the glass n_{glass} from which the prism 35 is formed changes with the change in air pressure but, as stated above, the refractive index of air n_{air} will change with the change in pressure. Accordingly, differentiation of Equation (8) results in the following equation:

$$\sin\gamma dn + n\cos\gamma d\gamma = 0 \tag{9}$$

where $d\gamma$ is the change of the angle of refraction .

[0036] Solving Equation (9) for the change in the angle of refraction $d\gamma$ results in the following equation:

$$d\gamma = \frac{\sin\gamma dn}{n\cos\gamma} \tag{10}$$

[0037] Referring to Fig. 6, grating 30 and prism 35 are depicted with an optical input signal 110 entering the prism 35 through first face 36. At a first pressure, such as at one atm, an optical signal, depicted at 111, exits the second face 37 of prism 35 at a first angle of refraction γ. At a second pressure, such within a vacuum, an optical signal, depicted at 112, exits the second face 37 of prism 35 at a second angle of refraction γ that is different from the first angle of refraction. The difference between the angles of refraction $d\gamma$ of the two optical signals 111, 112 is caused by the change in pressure at the prism 35.

[0038] The change in the angle of refraction $d\gamma$ of the optical signal 111, 112 exiting the prism 35 will result in a change in the angle of incidence α of the optical signal at the grating 30. For purposes of illustration, the optical signals 111, 112 are depicted as being received at the grating 30 at the same location but are reversed in orientation as compared to the orientation upon exiting the prism to reflect the angular orientation of the signals. The different angles of incidence α of the optical signal at the grating 30 will result in a change in the diffraction angle β as the light exits the grating. For example, the optical signal 111 at 1 atm entering the grating 30 is depicted as exiting as optical signal 113 and the optical signal 112 within a vacuum entering the grating exits as optical signal 114.

[0039] By appropriately selecting components with the desired properties and/or dimensions, the changes in the angle of refraction $d\gamma$ may be used to compensate or offset the changes in the angle of incidence $d\alpha$ caused by the change in refractive index of air dn due to the change in pressure. By selecting the prism 35 with the desired properties, the angle of refraction γ of the optical signals exiting the prism is adjusted to adjust the angle of incidence α of the optical signals at the grating 30. The adjustment to the angle of incidence α is set to eliminate changes in the diffraction angle β.

[0040] In doing so, approximations may be made since the change in the angle of incidence $\Delta\alpha$ is very small. As a result, the derivative of the angle of incidence $d\alpha$ may be approximated as the change in the angle of incidence $\Delta\alpha$ as follows:

$$\Delta\alpha = m\lambda dn \frac{1}{\mathrm{d}n^2 cos\alpha} \tag{11}$$

[0041] Further, since the change in the angle of refraction $\Delta\gamma$ is very small, the derivative of the angle of refraction $d\gamma$ may be approximated as the change in the angle of refraction $\Delta\gamma$ as follows:

$$\Delta\gamma = \frac{\sin\gamma dn}{n\cos\gamma} \tag{12}$$

[0042] In the example depicted in Fig. 7, the characteristics and dimensions of the components of the grating 40 and prism 45 may be selected to offset or compensate for changes in the refractive index of air n_{air} caused by changes in the pressure P and other environmental factors with respect to the air of the system. In one example, a grating 40 may have angle of incidence α of 46.5°, a grating constant d of 1.0636 μm, and a diffraction order of -1. The wavelength λ may be 1.55 μm and the refractive index of the air n_{air} through which the optical signal is transmitted may be 1.00025. Based upon the refractive index of the air n_{air} of 1.00025, the change in the refractive index as compared to a vacuum may be observed to be 0.00025. Through the use of Equation (6), the change in angle of incidence $\Delta\alpha$ may be calculated to be 0.0303°.

[0043] The change of the angle of incidence $\Delta\alpha$ of 0.0303° represents the amount of change for which the prism 45 must compensate in order to create a wavelength shift invariable prism and grating system (i.e., a system that is not affected by changes in pressure and other environmental factors that affect the air of the system). If the refractive index of the glass n_{glass} of the prism 45 is 1.8, Equation (10) may be used to determine that the angle of refraction γ is 64.7°. Through the use of Equation (8), it may be determined that a wavelength shift invariable prism and grating system may be created using the characteristics and dimensions described above and an angle of incidence γ calculated to be 30.15°.

[0044] As depicted in Fig. 7, the prism 40 and grating 45 operate as a wavelength shift invariable prism and grating system 50. An optical signal 115 such as light enters the prism 40 through the first face 41 at an angle of incidence θ to a line normal to the second face 42. At 1 atm, the optical signal is refracted at the second face 42 at an angle of refraction γ as defined by Equation (8) and is depicted at 116. In a vacuum, the optical signal is refracted at the second face 42 at an angle of refraction γ as defined by Equation (8) and is depicted at 117.

[0045] The optical signal 116 is received at the grating 45 at an angle of incidence α and is dispersed into a plurality of sub-beams, with only a single sub-beam 118 depicted for clarity. Each sub-beam is diffracted by grating 45 at a diffraction angle β according to Equation (4). The optical signal 117 is received at the grating 45 at an angle of incidence α and is dispersed into a plurality of sub-beams that are aligned with the sub-beams from optical signal 116. Only a single sub-beam from optical signal 117 is depicted at 119, which is aligned with sub-beam 118. By configuring the wavelength shift invariable prism and grating system 50 so that the change of the angle of incidence $\Delta\alpha$ according to Equation (11) matches the change in the angle of refraction $\Delta\gamma$ according to Equation (12), the system 50 will operate as desired regardless of the changes in pressure, temperature, and other environmental factors that affect the refractive index of the air n of the wavelength selective switch 10.

[0046] If the wavelength shift invariable prism and grating system 50 were not used, changes in the refractive index of the air n caused by events such as a broken seal of the wavelength selective switch 10 may result in a switch or system whose performance varies with changes in the environmental conditions. As depicted in Fig. 6, if the grating 30 and prism 35 are not configured to compensate for the changes in the environmental conditions, the path of the optical signal changes as it leaves the prism and thus the optical signal does not impinge on the grating at the desired angle. The optical signal will then be dispersed by the grating 35 at an undesired angle which may negatively impact the performance of the entire wavelength selective switch 10.

[0047] Fig. 8 depicts an alternate embodiment of a wavelength shift invariable prism and grating system 55. Wavelength shift invariable prism and grating system 55 utilizes a double prism 60 and a pair of gratings 65, 70 to increase the finesse or separation between wavelengths passing through the system. The double prism 60 refracts the optical signal 120 a first time as it enters the prism at first face 61 and a second time as it exits the prism at second face 62. For example, at a first pressure such as 1atm, an optical signal, depicted at 121, exits the second face 62 at a first angle of refraction. At a second pressure, such within a vacuum, an optical signal, depicted at 122, exits the second face 62 of double prism 60 at a second angle of refraction γ that is different from the first angle of refraction. The difference between the angles of refraction $d\gamma$ of the two optical signals 121, 122 is caused by the change in pressure at the double prism 60.

[0048] As an example, Fig. 9 depicts a graph of the refractive angle shift for an optical signal exiting the double prism 60 as a function of air pressure at a constant temperature (20° C) and for a wavelength λ of 1545nm with the double prism configured to have an apex angle 63 of 62° and an angle of incidence of 61°.

[0049] Referring back to Fig. 8, the optical signal 121 exiting the double prism 60 is received at a first grating 65 and diffracted a first time and received at a second grating 70 and diffracted a second time in order to increase the finesse of the wavelength selective switch in which the system 55 is operating. For purposes of illustration, the optical signals 121, 122 are depicted as being received at the first grating 65 at the same location but are reversed in orientation as compared to the orientation upon exiting the prism to reflect the angular orientation of the signals.

[0050] The double prism 60 and the first and second gratings 65, 70 are configured as described above to eliminate the impact of changes in the refractive index of air such as those caused by changes in pressure, temperature, and other environmental conditions impacting the air. In other words, the double prism 60 and the first and second gratings 65, 70 are appropriately configured with the desired properties and/or dimensions so that the changes in the angle of refraction $d\gamma$ may be used to compensate or offset the changes in the angle of incidence $d\alpha$ caused by the change in refractive index of air dn due to the change in pressure. Accordingly, the optical signals 121,122 exit the first grating 65 as a plurality of sub-beams with only a single sub-beam of optical signal 121 depicted at 124 and only a single sub-beam of optical signal 122 depicted at 125 . The sub-beams of the optical signals 121, 122 exit the second grating 70 as a plurality of aligned sub-beams, with each sub-beam depicted at 127, 128, respectively, and are parallel to each other. Without the wavelength shift invariable prism and grating system 55, the alignment of the sub-beams would not be appropriately modified, as indicated, for example at 123, 126.

[0051] Referring to Fig. 10, the results of a simulation of the operation of the wavelength selective switch 10 with and without the wavelength shift invariable prism and grating system 55 are depicted. In each instance, the simulation was conducted at a constant temperature of 20 ° C. A wavelength of 1.52838 µm is depicted by line 130 and wavelength of 1.56631 µm is depicted by line 131 when the wavelength selective switch 10 is used with the wavelength shift invariable prism and grating system 55. A wavelength of 1.52838 µm is depicted by line 132 and wavelength of 1.56631 µm is depicted by line 133 when the wavelength selective switch 10 is used without the wavelength shift invariable prism and grating system 55.

[0052] It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. For example, although the embodiments are depicted with a plurality of optical fibers and other optical components, the concepts described herein are applicable to embodiments including only a single optical fiber or optical component at each face of the optical coupling member. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

[0053] Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

[0054] Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context. Still further, the advantages described herein may not be applicable to all embodiments encompassed by the claims.

CLAIMS:

1. An optical dispersion system through which optical signals pass in a medium, comprising:

a prism formed of an optically transparent material configured to refract a plurality of optical signals along a plurality of angles of refraction, each optical signal being refracted along one of the angles of refraction; and

a diffraction grating for receiving the refracted plurality of optical signals at an angle of incidence and diffracting each optical signal into a plurality of sub-beams based upon a diffraction angle;

wherein a change in each angle of refraction due to environmental changes in the medium compensates for a change in the angle of incidence due to the environmental changes in the medium to maintain the diffraction angle relatively constant.

2. The system of claim 1, wherein the prism is a right angle prism with the plurality of optical signals entering the prism generally perpendicular to a wall of the prism.

3. The system of claim 1, wherein the prism is a double prism.

4. The system of claim 3, wherein the plurality of optical signals enter the prism at an acute angle relative to a wall of the prism.

5. The system of claim 4, wherein the diffraction grating is a first diffraction grating and further including a second diffraction grating adjacent the first diffraction grating.

6. The system of claim 5, wherein the change in the angle of refraction $\Delta\gamma$ is approximated by:

$$\frac{\sin\gamma dn}{n\cos\gamma}$$

where γ is the angle of refraction, dn is the change in the refractive index of the medium, and n is the refractive index of the medium.

7. The system of claim 6, wherein the change in the angle of incidence $d\alpha$ is approximated by:

$$m\lambda dn\frac{1}{\mathrm{d}n^2 cos\alpha}$$

where m is the diffraction order, λ is the wavelength of the optical signal, dn is the change in the refractive index of the medium, d is the grating constant, n is the refractive index of the medium, and α is the angle of incidence.

8. The system of claim 1, wherein the diffraction grating is a first diffraction grating and further including a second diffraction grating adjacent the first diffraction grating.

9. The system of claim 1, wherein the diffraction grating includes a plurality of grating elements

10. The system of claim 9, wherein the grating elements are evenly spaced apart along the grating.

11. The system of claim 1, wherein the change in the angle of refraction $d\gamma$ is approximated by:

$$\frac{\sin\gamma dn}{n\cos\gamma}$$

where γ is the angle of refraction, dn is the change in the refractive index of the medium, and n is the refractive index of the medium.

12. The system of claim 11, wherein the change in the angle of incidence $\Delta\alpha$ is approximated by:

$$m\lambda dn\frac{1}{\mathrm{d}n^2 cos\alpha}$$

where m is the diffraction order, λ is the wavelength of the optical signal, dn is the change in the refractive index of the medium, d is the grating constant, n is the refractive index of the medium, and α is the angle of incidence.

13. An optical dispersion system through which optical signals pass in a medium, comprising:

a prism formed of an optically transparent material configured to refract a plurality of optical signals along an angle of refraction; and

a diffraction grating having a plurality of grating elements for receiving the refracted plurality of optical signals at an angle of incidence and diffracting each optical signal into a plurality of sub-beams as a function of a diffraction angle;

wherein a change in the angle of refraction due to environmental changes in the medium is approximately equal to a change in the angle of incidence due to the environmental changes in the medium.

14. The system of claim 13, wherein the prism is a double prism and the plurality of optical signals enter the prism at an acute angle relative to a wall of the prism.

15. The system of claim 14, wherein the diffraction grating is a first diffraction grating and further including a second diffraction grating adjacent the first diffraction grating.

16. The system of claim 13, wherein the change in the angle of refraction $\Delta\gamma$ is approximated by:

$$\frac{\sin\gamma dn}{n\cos\gamma}$$

where γ is the angle of refraction, dn is the change in the refractive index of the medium, and n is the refractive index of the medium and the change in the angle of incidence $\Delta\alpha$ is approximated by:

$$m\lambda dn\frac{1}{\mathrm{d}n^2 cos\alpha}$$

where m is the diffraction order, λ is the wavelength of the optical signal, dn is the change in the refractive index of the medium, d is the grating constant, n is the refractive index of the medium, and α is the angle of incidence.

17. The system of claim 13, wherein the prism is a right angle prism with the plurality of optical signals entering the prism generally perpendicular to a wall of the prism.

18. The system of claim 13, wherein the diffraction grating is a first diffraction grating and further including a second diffraction grating adjacent the first diffraction grating.

19. An optical dispersion system through which optical signals pass in a medium, comprising:

a prism formed of an optically transparent material configured to refract a plurality of optical signals along an angle of refraction; and

a diffraction grating having a plurality of grating elements for receiving the refracted plurality of optical signals at an angle of incidence and diffracting each optical signal into a plurality of sub-beams as a function of a diffraction angle;

wherein a change in the angle of refraction $\Delta\gamma$ is approximated by:

$$\frac{\sin\gamma dn}{n\cos\gamma}$$

where γ is the angle of refraction, dn is the change in the refractive index of the medium, and n is the refractive index of the medium;

wherein a change in the angle of incidence $\Delta\alpha$ is approximated by:

$$m\lambda dn\frac{1}{\mathrm{d}n^2 cos\alpha}$$

where m is the diffraction order, λ is the wavelength of the optical signal, dn is the change in the refractive index of the medium, d is the grating constant, n is the refractive index of the medium, and α is the angle of incidence; and

wherein the change in the angle of refraction due to environmental changes in the medium is approximately equal to the change in the angle of incidence due to the environmental changes in the medium.

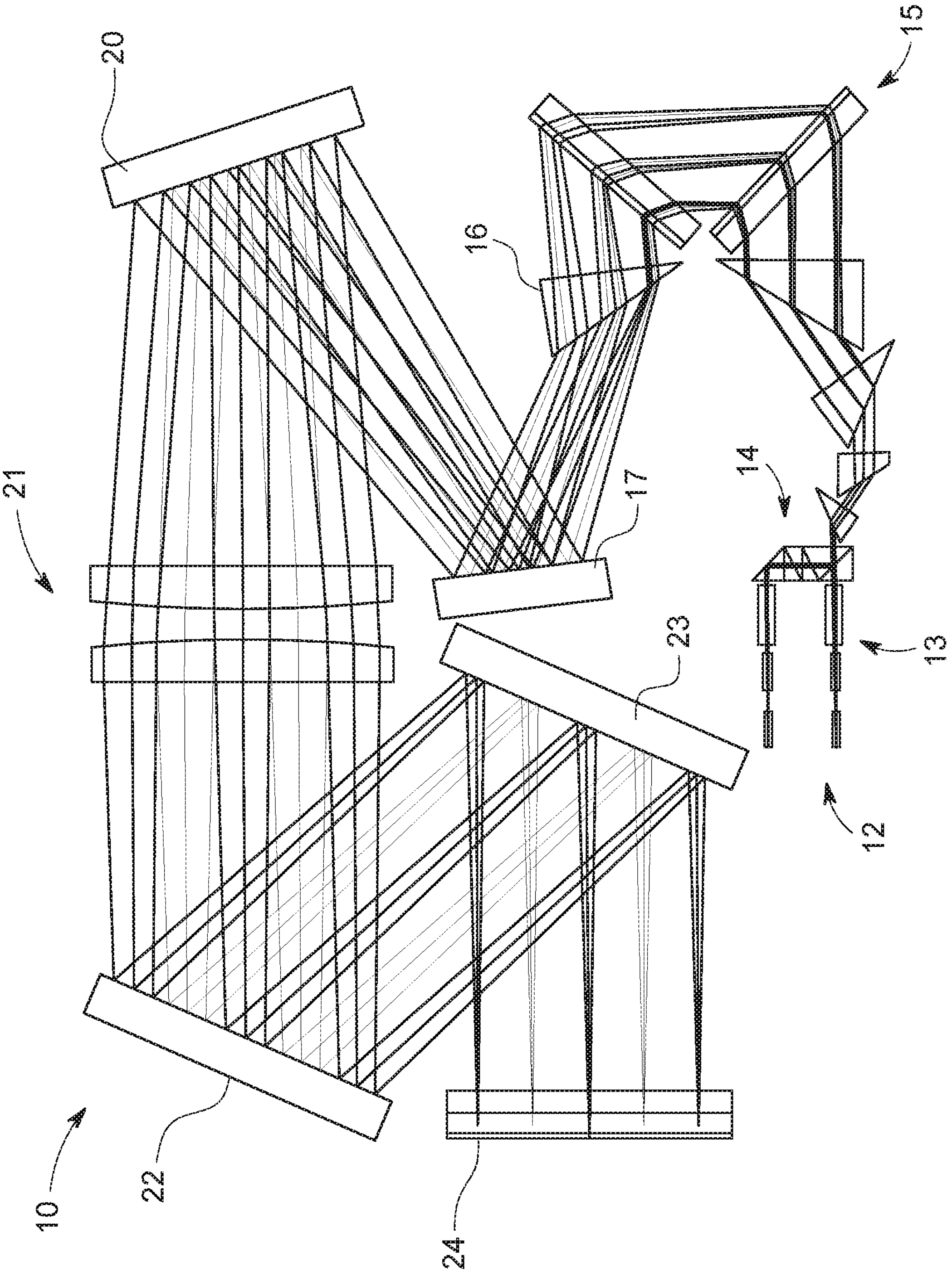

FIG. 1

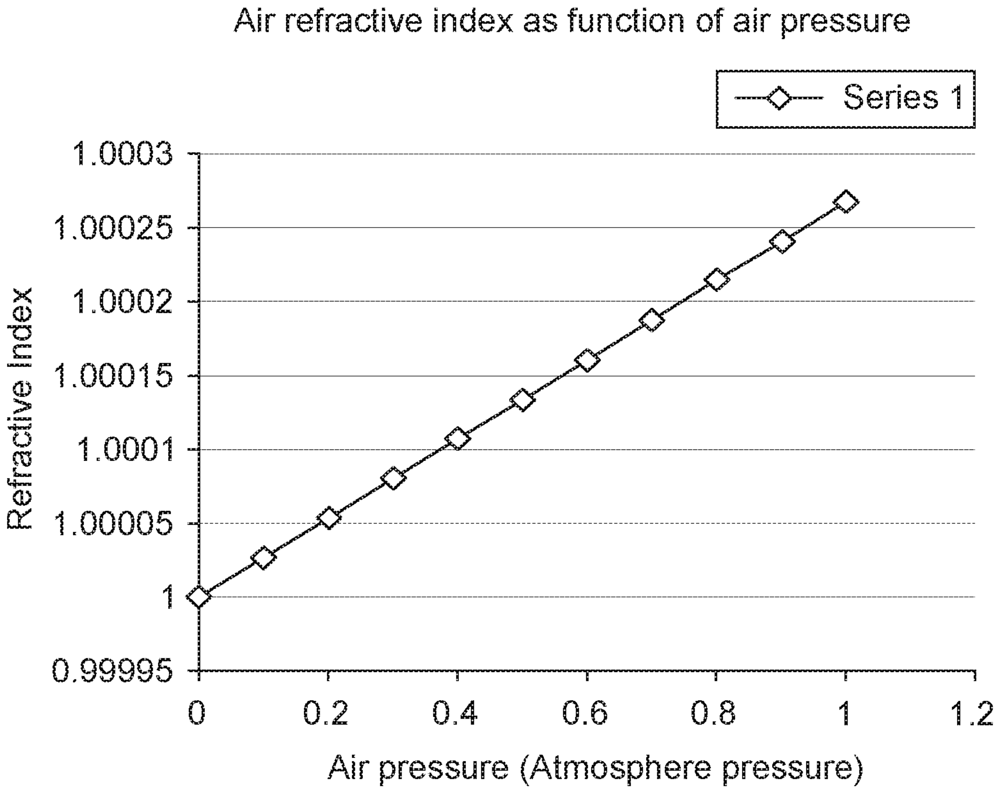
Air refractive index as function of air pressure
Series 1
Refractive Index
1.0003
1.00025
1.0002
1.00015
1.0001
1.00005
1
0.99995
0
0.2
0.4
0.6
0.8
1
1.2
Air pressure (Atmosphere pressure)

FIG. 2

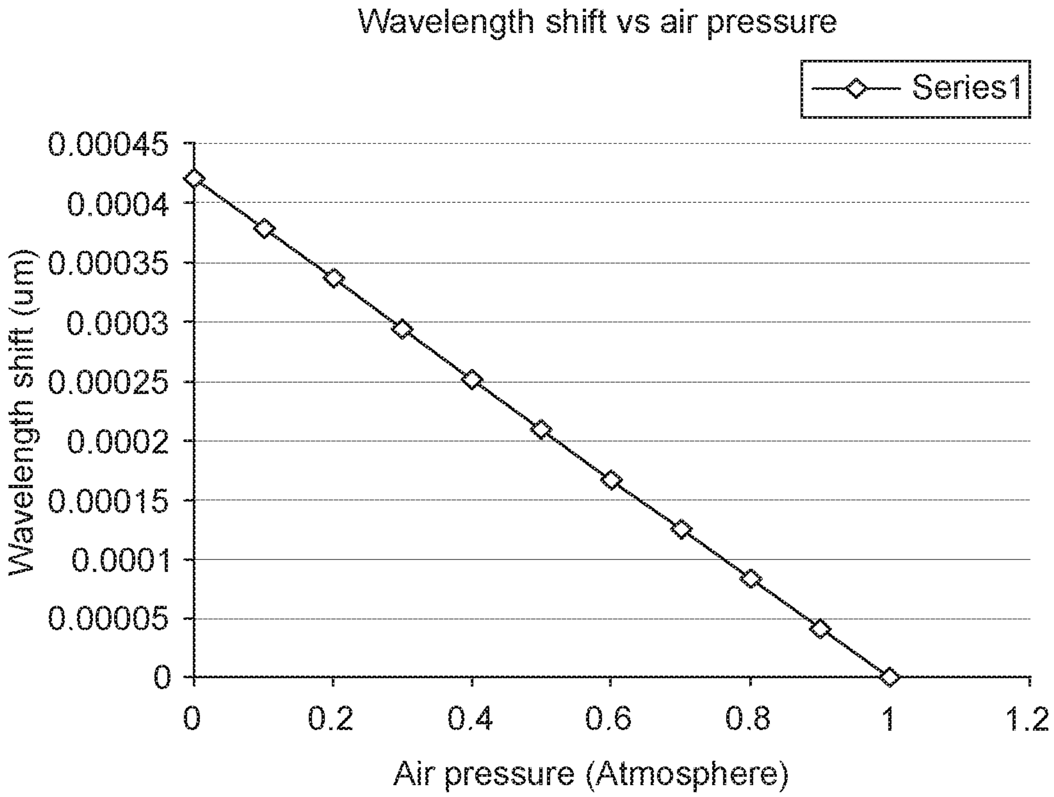
Wavelength shift vs air pressure
Series1
0.00045
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
Wavelength shift (um)
0
0.2
0.4
0.6
0.8
1
1.2
Air pressure (Atmosphere)

FIG. 3

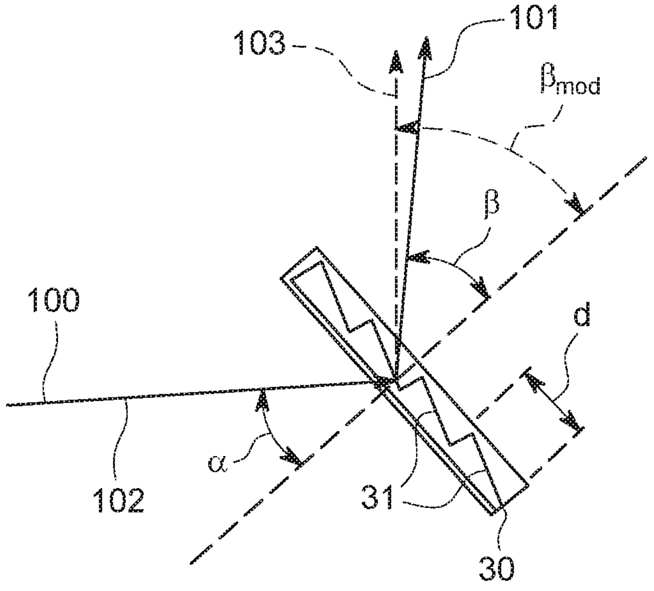

FIG. 4

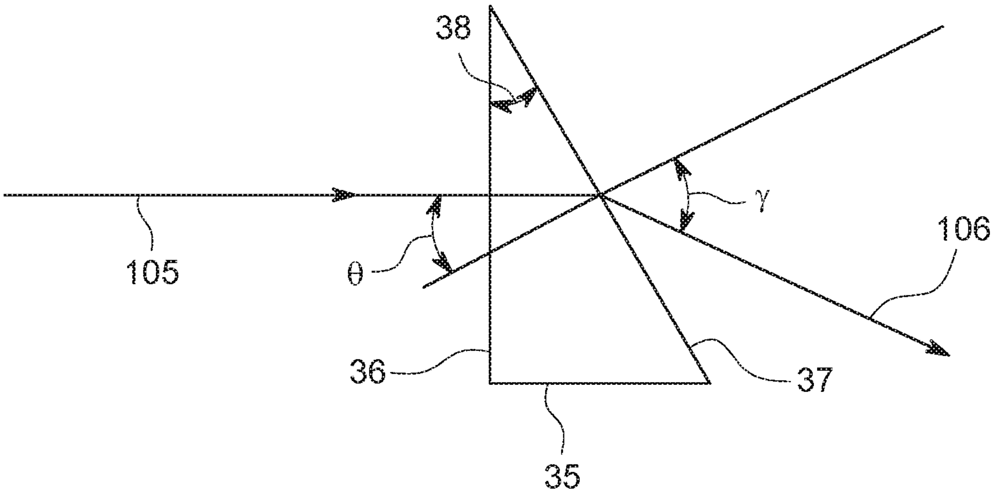

FIG. 5

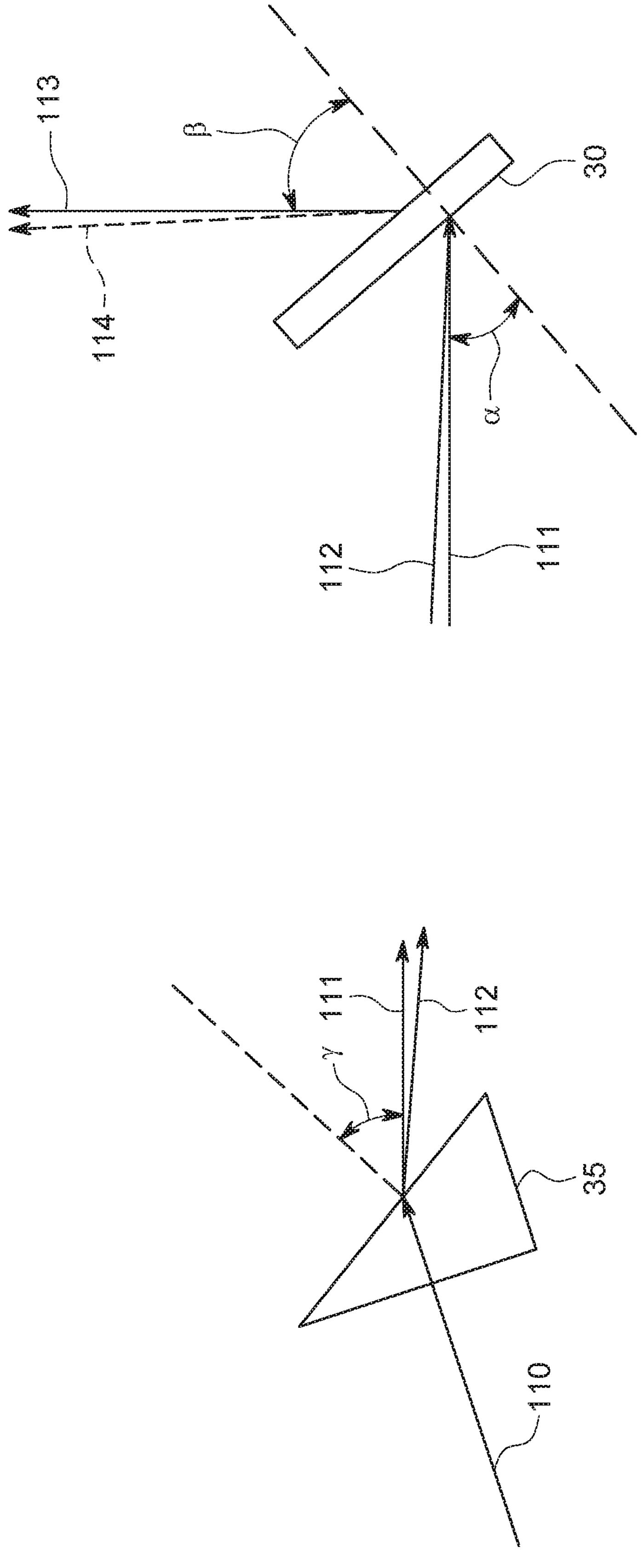

FIG. 6

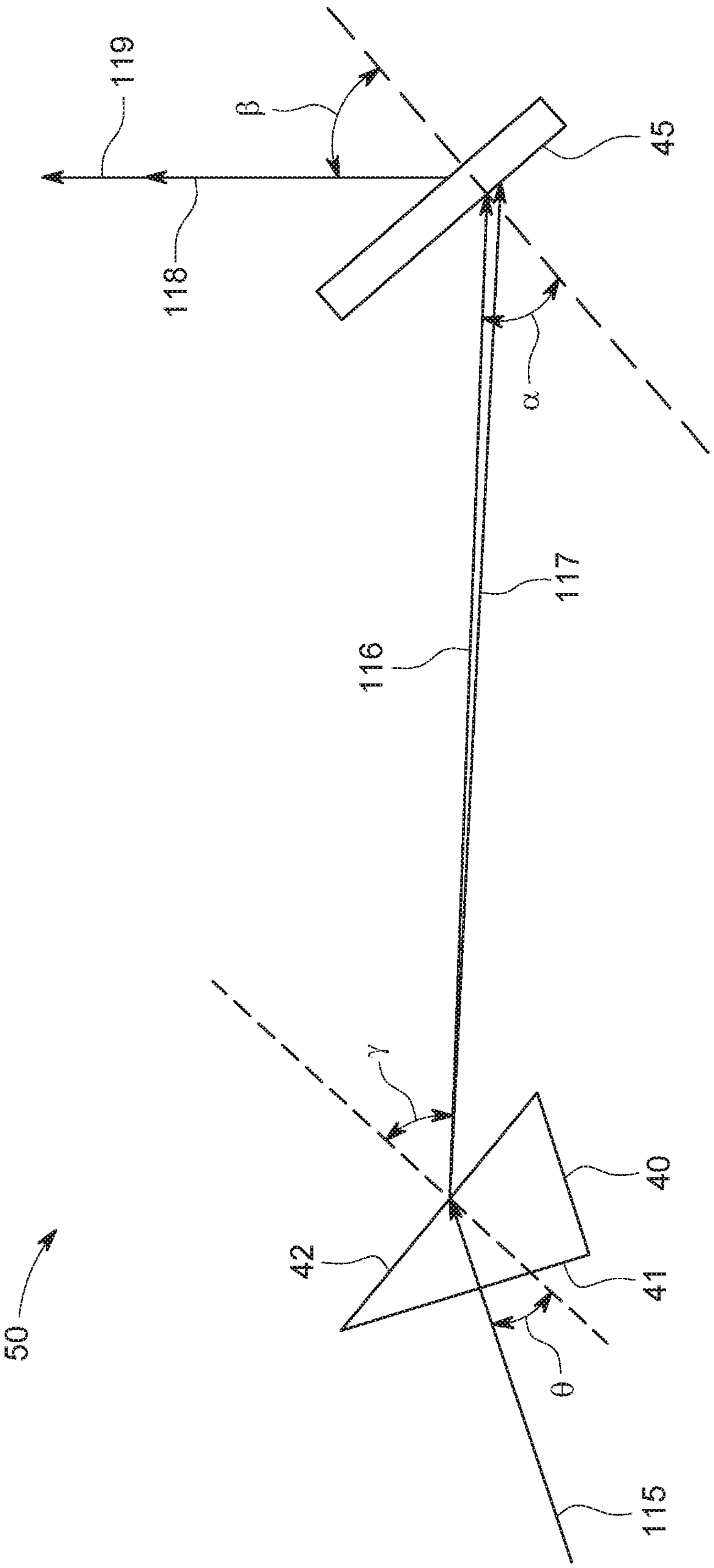

FIG. 7

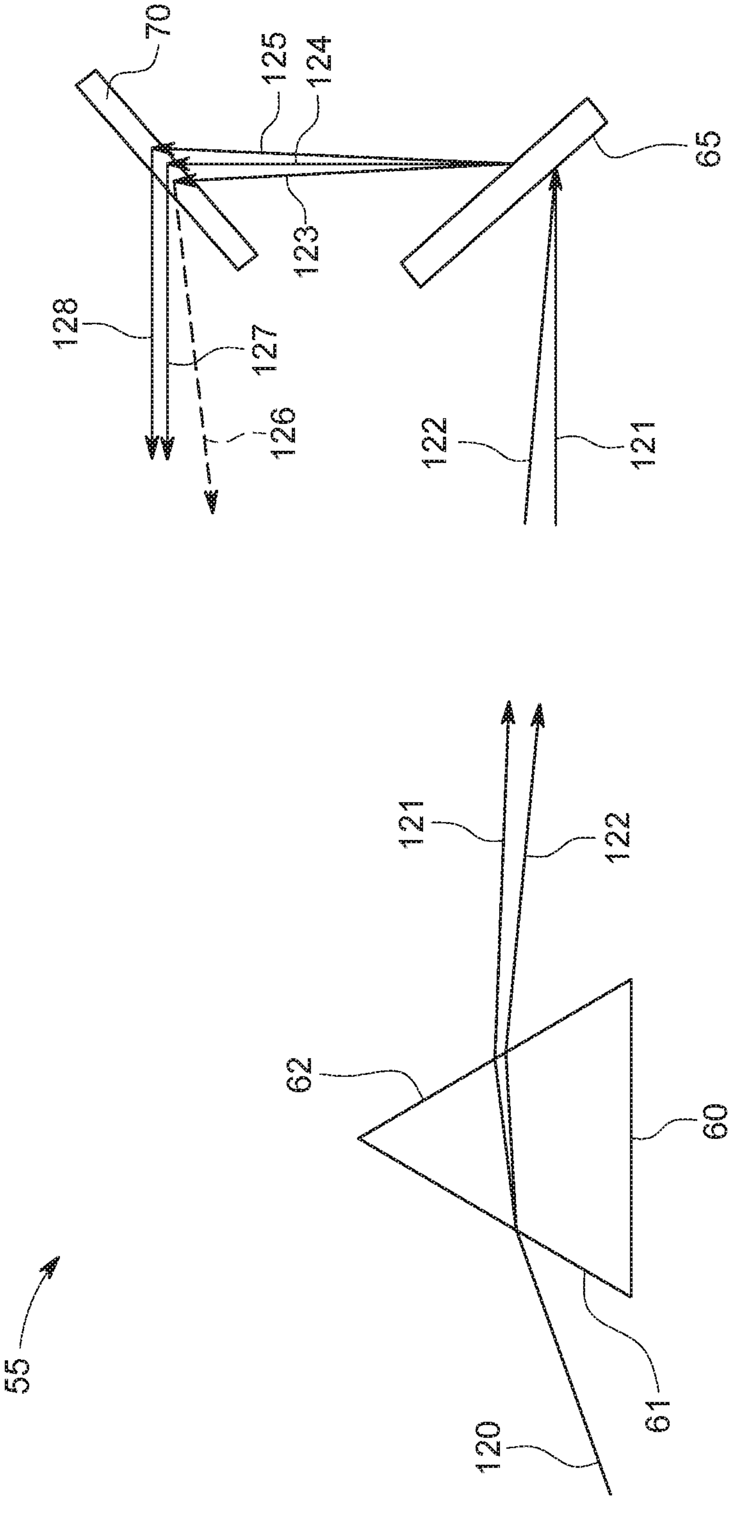

FIG. 8

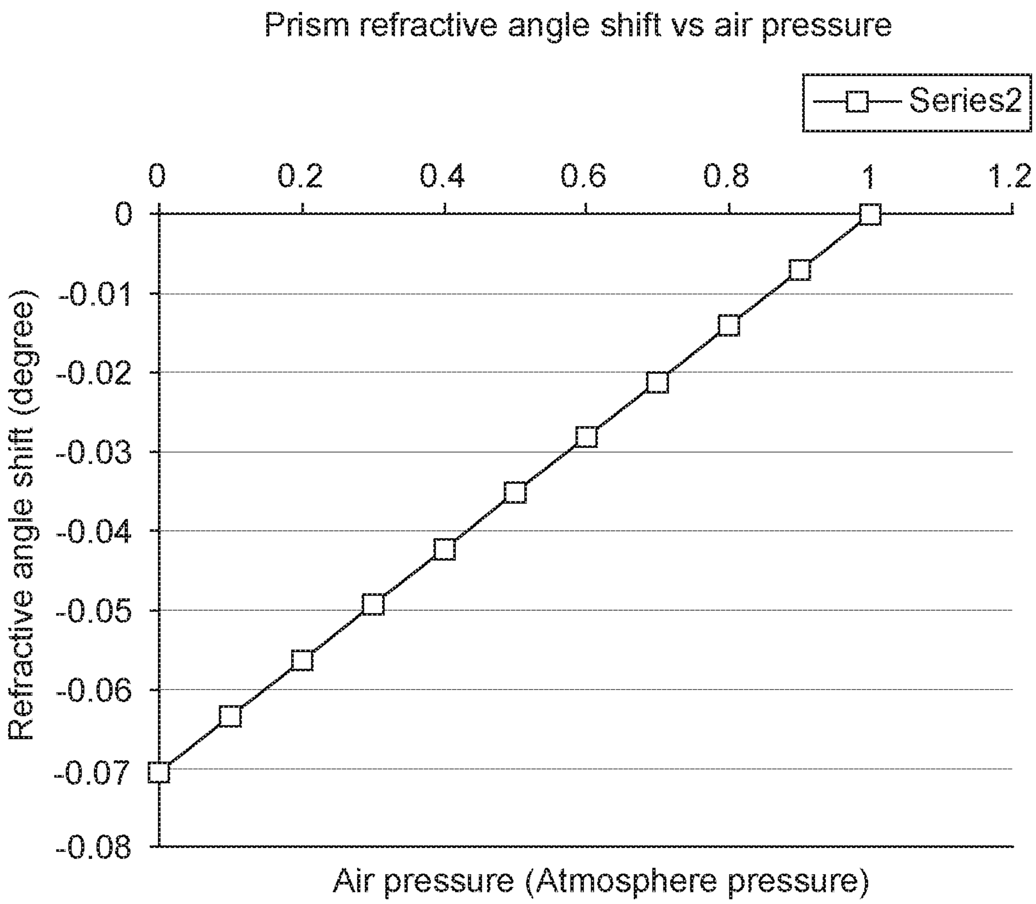
Prism refractive angle shift vs air pressure
Series2
0
0.2
0.4
0.6
0.8
1
1.2
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
Refractive angle shift (degree)
Air pressure (Atmosphere pressure)

FIG. 9

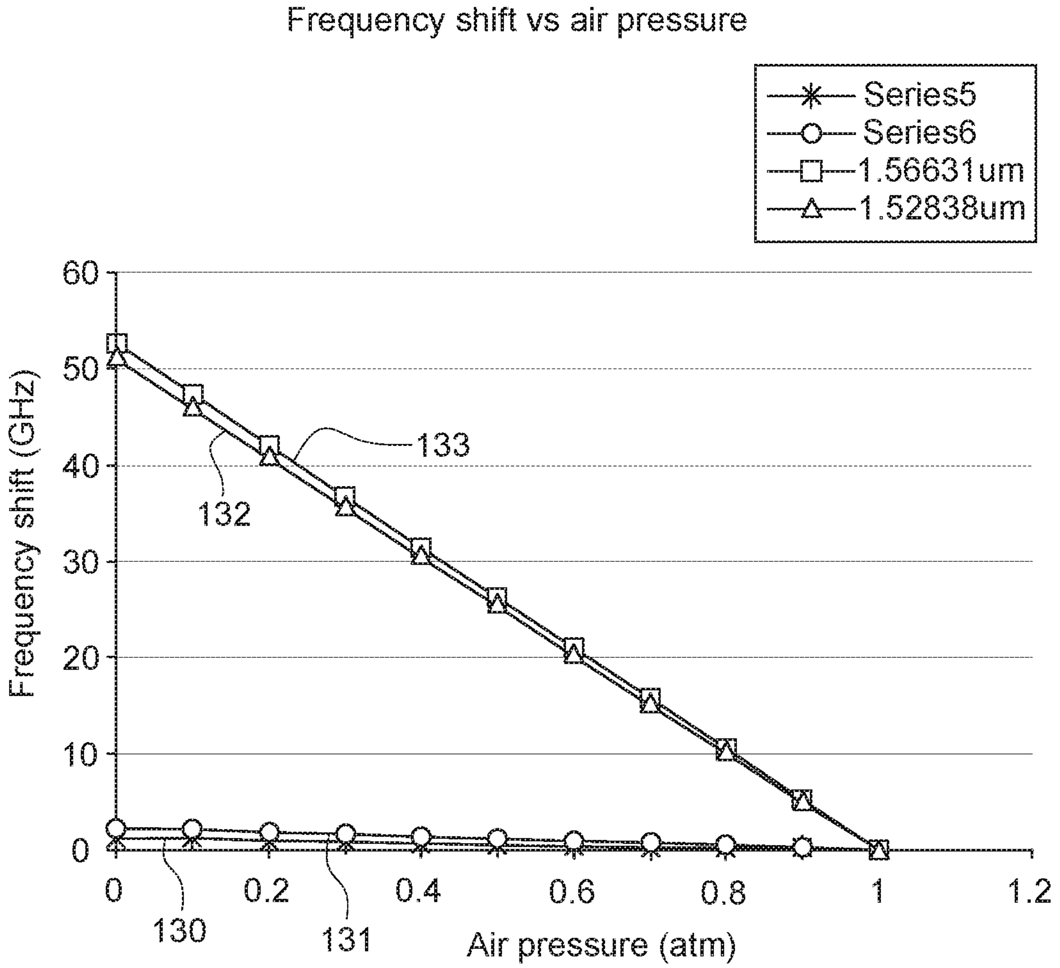
Frequency shift vs air pressure
Series5
Series6
1.56631um
1.52838um
Frequency shift (GHz)
60
50
40
30
20
10
0
133
132
0
0.2
0.4
0.6
0.8
1
1.2
130
131
Air pressure (atm)

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/020933

A. CLASSIFICATION OF SUBJECT MATTER

G02B 27/42(2006.01)i, G02B 5/04(2006.01)i, G02B 5/18(2006.01)i

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)
G02B 27/42; G02B 21/00; G02B 27/10; H04Q 11/00; G02B 27/00; G02B 6/34; G02B 27/09; G02B 27/28; G02B 5/04; G02B 5/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: dispersion, prism, diffraction grating, refraction, angle, incidence, compensate, change, wavelength

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0313315 A1 (TECHNION RESEARCH & DEVELOPMENT FOUNDATION LIMITED) 23 October 2014 See paragraphs [0085]-[0087]; claim 1; and figure 3.	1-19
Y	US 2011-0069388 A1 (HET HOOFT et al.) 24 March 2011 See paragraph [0026]; claim 1; and figure 2.	1-19
A	US 2015-0358699 A1 (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 10 December 2015 See figures 1, 2A, 4B.	1-19
A	CN 102375233 A (SHANGHAI INSTITUTE OF TECHNICAL PHYSICS et al.) 14 March 2012 See figures 2-3.	1-19
A	US 6421481 B1 (SAPPEY) 16 July 2002 See figures 1-2, 8.	1-19

☐ 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 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
27 June 2018 (27.06.2018)

Date of mailing of the international search report
27 June 2018 (27.06.2018)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/020933

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		WO 01-18577 A1	15/03/2001
		WO 01-81964 A2	01/11/2001
		WO 01-81964 A3	06/06/2002
		WO 02-071119A1	12/09/2002