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DESCRIPTION

Background

[0001] Optical networks use Wavelength Selective Switches (WSS) to dynamically route optical wavelength signals from a source to a destination. WSS devices often rely on wavelength manipulation elements such as liquid crystal on silicon (LCoS) devices or micro-electromechanical (MEMS) mirror arrays to perform the routing.

[0002] LCoS devices include a liquid crystal material sandwiched between a transparent glass layer having a transparent electrode, and a silicon substrate divided into a two-dimensional array of individually addressable pixels. Each pixel is individually drivable by a voltage signal to provide a local phase change to an optical signal, thereby providing a two-dimensional array of phase manipulating regions. Manipulation of individual spectral components is possible once an optical signal has been spatially separated by a diffractive element such as a diffraction grating. The spatial separation of spectral components is directed onto predetermined regions of the LCoS device, which can be independently manipulated by driving the corresponding pixels in a predetermined manner. EP-A- 1 176 451 discloses an isolated polarization beam splitter or combiner, for joining light from different inputs into one common port, and for dividing a beam of light into orthogonal polarizations. CA-A-2 445 327 discloses apparatus and a method for modifying two sub-sets of properties of optical signals independently of each other.

Summary

[0003] A method and device is provided for compensating for a difference in optical path length traversed by first and second optical portions of an optical beam which are in orthogonal polarization states. In accordance with the method, the optical beam is received at the input port and directed to a first walk-off crystal for spatially separating the optical beam into first and second optical portions that are in first and second polarization states, respectively. The first and second polarization states are orthogonal to one another. The first optical portion is walked-off by the walk-off crystal and the second optical portion passes therethrough without being walked-off. The polarization state of the first and second optical portions is rotated. After rotating the polarization state of the first and second optical portions, the first and second optical portions are directed to a second walk-off crystal that is oriented in an opposite direction from the first walk-off crystal so that the second optical component is walked-off by the walk-off crystal and the first optical component passes therethrough without being walked-off. Thicknesses of the first and second walk-off crystals are selected to adjust the optical path lengths traversed by each of the first and second optical portions.

[0004] In one particular implementation, an optical device includes an optical port array, a first walk-off crystal, a first half-wave plate, a second walk-off crystal and a segmented half-wave

plate. The optical port array has a first plurality of ports for receiving optical beams and a second plurality of ports for receiving optical beams. The first walk-off crystal spatially separates each of the optical beams into first and second optical portions that are in first and second polarization states, respectively. The first and second polarization states are orthogonal to one another. The first optical portions are walked-off by the first walk-off crystal and the second optical portions pass therethrough without being walked-off. The first half-wave plate rotates the polarization state of the first and second optical portions of the optical beams. The second walk-off crystal is oriented in an opposite direction from the first walk-off crystal such that the second optical portions are walked-off by the second walk-off crystal and the first portions pass therethrough without being walked-off. The segmented half-wave plate receives the second optical portions of the optical beams or the first optical portions of the optical beams.

Brief Description of the Drawings

[0005]

FIG. 1 shows a single input port to an optical arrangement such as a WSS that employs a LCoS device.

FIG. 2 shows one example of an optical path compensator.

FIGS. 3A and 3B are top and side views respectively of one example of a simplified optical arrangement such as a free-space that may employ the optical path compensator shown in FIG. 2.

Detailed Description

[0006] FIG. 1 shows a single input port 110 to an optical arrangement such as a WSS that employs a LCoS device. The input beam 115 to such a device can sometimes be highly astigmatic. In the representation shown in FIG. 1, the beam 115 has a small waist along the y-axis and a large waist along the z-axis. The beam 115, which is randomly polarized, first enters a walk-off crystal 120 to spatially separate the beam into two orthogonally polarized beams, a walked-off beam 150 and a pass-through beam 160. In FIG. 1 one polarization component (e.g., a vertical or v-component) is denoted by a vertical arrow, and the other polarization component (e.g., a horizontal or h-component) is denoted by a horizontal arrow. The walk-off direction of walk-off crystal 120 and the directions of rotation caused by the half-wave plate 130 will be described with respect to polarization components of light beams propagating in the forward or downstream direction, i.e., positive z-direction.

[0007] In order to place both the two spatially separated beams 150 and 160 exiting the walk-

off crystal 120 into the same polarization state the walked-off beam 150 passes through a half-wave plate 130 that rotates the walked-off beam from the h-polarization state to the v-polarization state. The v-polarized beam 160 does not pass through the half-wave plate 130. As a result the beams 150 and 160 are both in the same polarization state.

[0008] One problem with the arrangement shown in FIG. 1 is that the two beams 150 and 160 propagate over different optical path lengths because of the walk-off crystal 120 and the half-wave plate 130. This can be a problem if the incoming astigmatic beam has a small waist. For instance, if the beam waist is about 3.5 microns its Raleigh length or range is about 30 microns. The path length differential experienced by the two beams is generally desired to be less than this distance.

[0009] By way of illustration, in the example of FIG. 1 the walked-off beam 150 may travel an effective propagation distance of about 200 microns compared to the pass-through beam 160. Likewise, when traversing the half-wave plate 130 the walked-of beam 150 may travel an effective propagation distance of about -30 microns compared to the pass-through beam 160. Thus, the difference in the total effective propagation distance traveled by the two beams is about 170 microns. Clearly, this distance is large in comparison to the Rayleigh range of the beam.

[0010] One way to address this problem is to compensate for this difference in the total effective propagation distance by using two walk-off crystals that are oriented in opposite directions from one another. In this case a beam in one polarization state accumulates an effective propagation distance differential in the first walk-off crystal but not in the second walk-off crystal while the beam in the other polarization state accumulates an effective propagation distance differential in the second walk-off crystal but not the first walk-off crystal. FIG. 2 shows one example of an optical path compensator that is operable in this manner.

[0011] As shown in FIG. 2 the walked-off beam 235 undergoes an effective propagation distance differential of 90 microns in the first walk-off crystal 220 relative to the pass-through beam 225. A half-wave plate 250 rotates the polarization state of the beam 225 from the horizontal to the vertical so that it will be walked-off by the second walk-off crystal 240. Likewise, the half-wave plate 250 rotates the polarization state of the beam 235 from the vertical to the horizontal. As a consequence, the beam 225 undergoes an effective propagation distance differential of 120 microns in the second walk-off crystal 240 relative to the beam 235. Additionally, the beam 235 undergoes an additional effective propagation distance differential of 30 microns relative to the beam 225 since the beam 225 traverses the half-wave plate 230. Accordingly, the beam 225 undergoes a total effective propagation distance differential of 120 microns and the beam 235 also undergoes a total effective propagation distance differential of 120 microns (i.e., 90 + 30 microns). As a result both beams propagate over the same path length.

[0012] As the example of the optical path compensator shown in FIG. 2 illustrates, the thickness of the second walk-off crystal 240 is chosen to compensate for the effective

propagation distance differential of both the first walk-off crystal 220 and the half-wave plate 230 through which only one of the beams pass. The thicknesses of the two walk-off crystals 220 and 240, which determine the additional path lengths traversed by the walked-off beams that respectively pass therethrough, are therefore different from one another.

[0013] FIG. 2 shows a single optical input port of an optical arrangement. The optical beams received by devices employing multiple ports may be processed in a similar manner to ensure that the two orthogonally polarized, spatially separated beams into which each incoming beam is divided propagate over the same path length. In some cases these optical arrangements incorporate the functionality of multiple wavelength switches may share a common set of optical elements such as lenses, dispersion elements and a spatial light modulator. One example of such a wavelength selective switch that employs the methods and techniques herein will be presented below in connection with FIGs. 3A and 3B.

[0014] FIGS. 3A and 3B are top and side views respectively of one example of a simplified optical arrangement such as a free-space WSS 100 that may be used in conjunction with embodiments of the present invention. Light is input and output to the WSS 100 through optical waveguides such as optical fibers which serve as input and output ports. A fiber collimator array 101 includes a first series of fibers 120, which are associated with a first WSS, and a second series of fibers 130, which are associated with a second WSS. Each individual fiber is associated with a collimator 102, which converts the light from each fiber to a free-space beam.

[0015] As best seen in FIG. 3B, the fibers 320₁, 320₂, 320₃ and 320₄ in the first fiber series 320 are interleaved with the fibers 330₁, 330₂ and 330₃ in the second fiber series 330. Moreover, as also seen in FIG. 3B, the fibers in the fiber series 320 are angularly offset from fibers in the second fiber series 330. This angular offset causes the wavelengths associated with the two different WSSs to be spatially offset from one another on the LCoS device 21 in the y-direction (the port axis), as shown in FIG. 2.

[0016] An optical path compensator of the type shown in FIG. 2 receives the optical beams from each fiber/collimator pair. In FIGs. 2 and 3 like elements are denoted by like reference numerals. Two representative beams are illustrated in FIG. 3B, a first beam that is received by fiber 320₁ (associated with the first WSS) and a second beam that is received by adjacent fiber 330₁ (associated with the second WSS). As shown, after exiting the first walk-off crystal 220 the optical beam received by fiber 320₁ is divided into two beams 323 and 325 which are in orthogonal polarization states with respect to one another. Likewise, after exiting the second walk-off crystal 240 the optical beam received by fiber 330₁ is divided into two beams 333 and 335 which are also in orthogonal polarization states with respect to one another.

[0017] The beams from the two different WSSs are angled so that they cross in the plane of the patterned half-wave plate 260 having half-wave plate segment 230. Accordingly, the location of the patterned half-wave plate determines the angle at which the beams need to be

launched from the optical ports. In the example of FIG. 3B, the beam 323 from the port 320₁ associated with the first WSS and the beam 333 from the port 130₁ associated with the second WSS cross at the half-wave plate segment 230. Likewise, beam 325 from the port 320₁ associated with the first WSS and the beam 335 from the port 330₁ associated with the second WSS cross in the plane of the half-wave plate segment 230. In one alternative implementation, the beams 325 and 335 may be directed to the half-wave plate 230 and not the beams 323 and 333.

[0018] Following the optical path compensator, a pair of telescopes or optical beam expanders magnifies the free space light beams from the port array 101. A first telescope or beam expander is formed from optical elements 106 and 107 and a second telescope or beam expander is formed from optical elements 104 and 105.

[0019] In FIGs. 3A and 3B, optical elements which affect the light in two axes are illustrated with solid lines as bi-convex optics in both views. On the other hand, optical elements which only affect the light in one axis are illustrated with solid lines as plano-convex lenses in the axis that is affected. The optical elements which only affect light in one axis are also illustrated by dashed lines in the axis which they do not affect. For instance, in FIGs. 3A and 3B the optical elements 102, 108, 109 and 110 are depicted with solid lines in both figures. On the other hand, optical elements 106 and 107 are depicted with solid lines in FIG. 3A (since they have focusing power along the y-axis) and with dashed lines in FIG. 3B (since they leave the beams unaffected along the x-axis). Optical elements 104 and 105 are depicted with solid lines in FIG. 3B (since they have focusing power along the x-axis) and with dashed lines in FIG. 3A (since they leave the beams unaffected in the y-axis).

[0020] Each telescope may be created with different magnification factors for the x and y directions. For instance, the magnification of the telescope formed from optical elements 104 and 105, which magnifies the light in the x-direction, may be less than the magnification of the telescope formed from optical elements 106 and 107, which magnifies the light in the y-direction.

[0021] The pair of telescopes magnifies the light beams from the port array 101 and optically couples them to a wavelength dispersion element 108 (e.g., a diffraction grating or prism), which separates the free space light beams into their constituent wavelengths or channels. The wavelength dispersion element 108 acts to disperse light in different directions on an x-y plane according to its wavelength. The light from the dispersion element is directed to beam focusing optics 109.

[0022] Beam focusing optics 109 couple the wavelength components from the wavelength dispersion element 108 to a programmable optical phase modulator, which may be, for example, a liquid crystal-based phase modulator such as a LCoS device 110. The programmable optical phase modulator produces a phase shift at each of its pixels which gives rise to a phase shift profile across its surface. As shown in FIG. 3, the wavelength components are dispersed along the x-axis. Accordingly, each wavelength component of a given

wavelength is focused on an array of pixels 19 extending in the y-direction. By way of example, and not by way of limitation, three such wavelength components having center wavelengths denoted λ_1 , λ_2 and λ_3 are shown in FIG. 3A being focused on the LCoS device 110 along the wavelength dispersion axis (x-axis).

[0023] As best seen in FIG. 3B, after reflection from the LCoS device 110, each wavelength component can be coupled back through the beam focusing optics 109, wavelength dispersion element 108 and optical elements 106 and 107 to a selected fiber in the port array 101. Accordingly, appropriate manipulation of the pixels 19 in the y-axis allows selective independent steering of each wavelength component to a selected output fiber.

[0024] Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above.

REFERENCES CITED IN THE DESCRIPTION

Cited references

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Patentkrav

1. Fremgangsmåde til at kompensere for en forskel i en optisk banelængde, som krydses af en første og anden optisk del af en optisk stråle, som er i ortogonale polarisationstilstande, omfattende:

- 5 at modtage den optiske stråle ved en indgangsport;
 at lede den optiske stråle til en første walk-off-krystal (220) for rumligt at adskille den optiske stråle i en først og anden optisk del, der er i henholdsvis en første og en anden polarisationstilstand, idet den første og anden polarisationstilstand er ortogonale i forhold til hinanden, idet den
- 10 første optiske del bliver afbøjet af walk-off-krystallen, og den anden optiske del passerer derigennem uden at blive afbøjet;
 at rotere polarisationstilstanden af den første og anden optiske del;
 efter rotation af polarisationstilstanden af den første og anden optiske del,
 at lede den første og anden optiske del til en anden walk-off-krystal (240),
- 15 der er orienteret i en modsat retning af den første walk-off-krystal (220), således at den anden optiske del afbøjes af walk-off-krystallen, og den første optiske del passerer derigennem uden at blive afbøjet, idet en tykkelse af den første og anden walk-off-krystal (220, 240) er valgt til at justere de optiske banelængder, der krydses af hver af den første og anden
- 20 optiske del,
 hvor tykkelsen af den første og anden walk-off-krystal (220, 240) yderligere er valgt til at kompensere for en optisk baneforskel, der opstår fra et eller flere optiske nedstrømselementer, som krydses af en af den første og anden optiske del og ikke den anden af den første og anden
- 25 optiske del, hvor tykkelsen af den første og anden walk-off-krystal (220, 240), som bestemmer en yderligere banelængde krydset af den første og anden optiske del, der passerer derigennem, er forskellige fra hinanden.

2. Fremgangsmåde ifølge krav 1, hvor fremgangsmåden til at lede

- 30 bølgelængdedele af en optisk stråle fra en indgangsport af et portarray (101) til mindst en udgangsport på portarrayet omfatter:
 at modtage en første optisk stråle ved en første indgangsport af portarrayet (101) associeret med en første bølgelængdeselektiv omskifter;

at modtage en anden optisk stråle ved en anden indgangsport af portarrayet (101) associeret med en anden bølgelængdeselektiv omskifter; at lede den første optiske stråle til den første walk-off-krystal (220) for rumligt at adskille den første optiske stråle i en første og anden optisk del, 5 som er i henholdsvis den første og anden polarisationstilstand, idet den første og anden polarisationstilstand er ortogonale i forhold til hinanden, idet den første optiske del afbøjes af walk-off-krystallen, og den anden optiske del passerer derigennem uden at blive afbøjet; at lede den anden optiske stråle til den første walk-off-krystal (220) for 10 rumligt at adskille den anden optiske stråle i en tredje og fjerde optisk del, der er i henholdsvis den første og anden polarisationstilstand, idet den tredje optiske del afbøjes af den første walk-off-krystal (220), og den fjerde optiske del passerer derigennem uden at blive afbøjet; at rotere polarisationstilstanden af den første, anden, tredje og fjerde 15 optiske del; efter rotation af polarisationstilstanden af den første, anden, tredje og fjerde optiske del, at lede den første, anden, tredje og fjerde optiske del til en anden walk-off-krystal, der er orienteret i en modsat retning af den første walk-off-krystal (220), således at den anden og fjerde optiske del 20 afbøjes af den anden walk-off-krystal (240), og den første og tredje optiske komponent passerer derigennem uden at blive afbøjet, idet en tykkelse af walk-off-krystallerne (220, 240) er valgt til at justere de optiske banelængder, der krydses af hver af den første, anden, tredje og fjerde optiske del; 25 hvor tykkelsen af den første og anden walk-off-krystal (220, 240) yderligere er valgt til at kompensere for en optisk baneforskel, der opstår fra et eller flere optiske nedstrømskomponenter, som krydses af en af den første og anden optiske del og ikke den anden af den første og anden optiske del, og som krydses af en af den tredje og fjerde optiske del og 30 ikke den anden af den tredje og fjerde optiske del; rumligt at adskille bølgelængdekomponenterne af den første, anden, tredje og fjerde optiske del; at fokusere de rumligt adskilte bølgelængdekomponenter på en programmerbar optisk fasemodulator (110), således at 35 bølgelængdekomponenterne af den første og anden optiske stråle er

rumligt adskilt langs en bølglængdespredningsakse af modulatoren (110);
 og
 at justere en faseforskydningsprofil af modulatoren (110) langs en anden
 retning for selektivt at lede individuelle bølglængdekomponenter af
 5 bølglængdekomponenterne til en udgangsport.

3. Fremgangsmåden ifølge et hvilket som helst af de foregående krav, hvor det
 optiske element er en halvbølgeplade (260) placeret nedstrøms for den første og
 anden walk-off-krystal.

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4. Fremgangsmåden ifølge krav 2 eller krav 3, hvor den første indgangsport er
 vinkelforskydning i forhold til den anden indgangsport omkring en akse parallel med
 bølglængdespredningsaksen.

15 **5.** Optisk indretning, omfattende:

et optisk portarray (101) med en første flerhed af porte til at modtage
 optiske stråler og en anden flerhed af porte til at modtage optiske stråler;
 en første walk-off-krystal (220) til rumligt at adskille hver af de optiske
 stråler i en første og anden optisk del, der er i henholdsvis en første og
 20 anden polarisationstilstand, idet den første og anden polarisationstilstand
 er ortogonale i forhold til hinanden, idet de første optiske dele afbøjes af
 den første walk-off-krystal (220), og de anden optiske dele passerer
 derigennem uden at blive afbøjet;
 en første halvbølgeplade (250) til at rotere polarisationstilstanden af den
 25 første og anden optiske del af de optiske stråler;
 en anden walk-off-krystal (240), der er orienteret i en modsat retning af
 den første walk-off-krystal (220), således at de anden optiske dele afbøjes
 af den anden walk-off-krystal (240), og de første dele passerer derigennem
 uden at blive afbøjet; og
 30 et optisk nedstrømselement (260) til at modtage de anden optiske dele af
 de optiske stråler eller de første optiske dele af de optiske stråler;
 hvor en tykkelse af den første og anden walk-off-krystal (220, 240) er
 valgt til at justere de optiske banelængder, der krydses af hver af den
 første og anden optiske del for at kompensere for en optisk banelængdeforskel,
 35 der opstår fra de første optiske dele eller de anden optiske dele, der

krydser det optiske nedstrømsselement (260), og den anden af den første og anden optiske del, der ikke krydser det optiske nedstrømsselement (260), hvor tykkelsen af den første og anden walk-off-krystal (220, 240), som bestemmer en yderligere banelængde, der krydses af henholdsvis den første og anden optiske del, som passerer derigennem, er forskellige fra hinanden.

6. Optisk indretning ifølge krav 5, hvor det optiske nedstrømsselement omfatter en segmenteret halvbølgeplade (260).

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7. Den optiske indretning ifølge krav 5 eller krav 6, yderligere omfattende:
et spredningselement (108), der modtager den første og anden optiske del af de optiske stråler og rumligt adskiller den første og anden optiske del i en flerhed af bølglængdekomponenter langs en
bølglængdespredningsakse, idet en portakse er ortogonal på
bølglængdespredningsaksen, idet den første flerhed af porte strækker sig i et første plan, der inkluderer portaksen, og idet den anden flerhed af porte strækker sig i et andet plan, der inkluderer portaksen, idet det første og andet plan er parallelle med hinanden og forskudt fra hinanden langs
bølglængdespredningsaksen, idet den første flerhed af porte er vinkelforskudt i forhold til den anden flerhed af porte omkring en akse parallel med bølglængdespredningsaksen;
et fokuseringselement (109) til at fokusere flerheden af
bølglængdekomponenter; og
en programmerbar optisk fasemodulator (110) til at modtage den fokuserede flerhed af bølglængdekomponenter, idet modulatoren (110) er konfigureret til at styre bølglængdekomponenterne modtaget fra en hvilken som helst af den første flerhed af porte til en valgt port af den første flerhed af porte og er yderligere konfigureret til at styre
bølglængdekomponenterne modtaget fra en hvilken som helst af den anden flerhed af porte til en valgt port af den anden flerhed af porte.

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8. Den optiske indretning ifølge krav 7, hvor den første flerhed af porte er sammenflettet med den anden flerhed af porte langs portaksen.

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9. Den optiske indretning ifølge krav 7 eller krav 8, hvor den programmerbare optiske fasemodulator (110) inkluderer en flydende krystal-baseret fasemodulator (110).

5 **10.** Den optiske indretning ifølge et hvilket som helst af kravene 7 til 9, hvor det dispersive element er valgt fra gruppen bestående af et diffraktionsgitter og et prisme.

11. Den optiske indretning ifølge krav 7, yderligere omfattende et optisk system
10 (104) til at forstørre den optiske stråle modtaget fra det optiske portarray (101) og lede den forstørrede optiske stråle til spredningselementet (108).

12. Den optiske indretning ifølge krav 11, hvor det optiske system (104) har en første forstørrelsesfaktor i en første retning og en anden forstørrelsesfaktor i en
15 anden retning vinkelret på den første retning, idet den første forstørrelsesfaktor er forskellig fra den anden forstørrelsesfaktor.

13. Den optiske indretning ifølge krav 12, hvor den første retning er parallel med en bølglængdespredningsakse, langs hvilken de optiske stråler er rumligt adskilt,
20 idet den første forstørrelsesfaktor er mindre end den anden forstørrelsesfaktor.

DRAWINGS

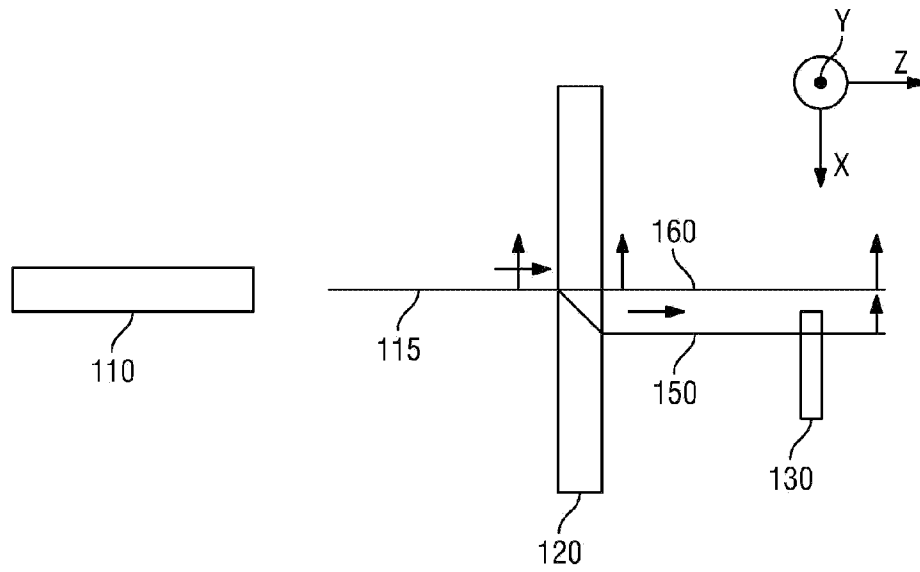


FIG. 1

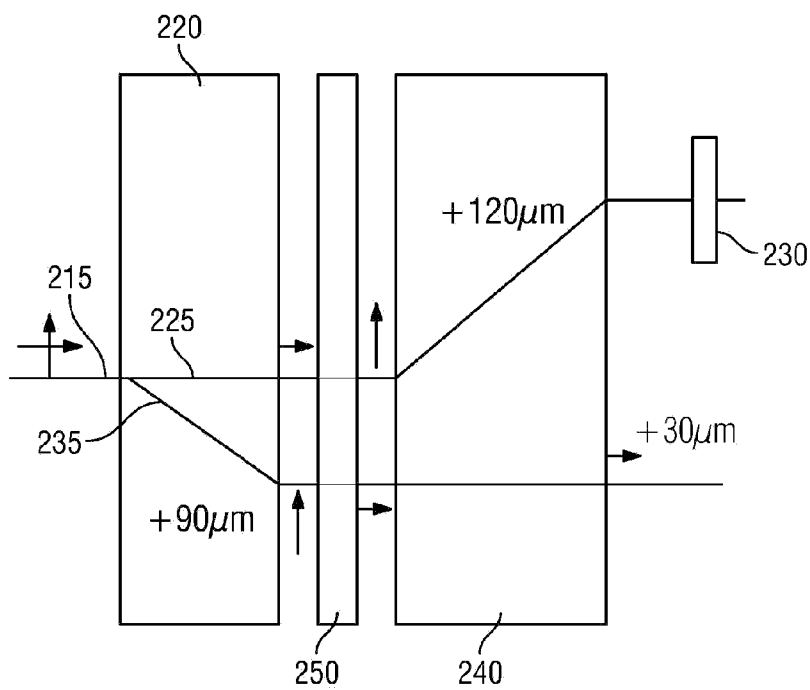


FIG. 2

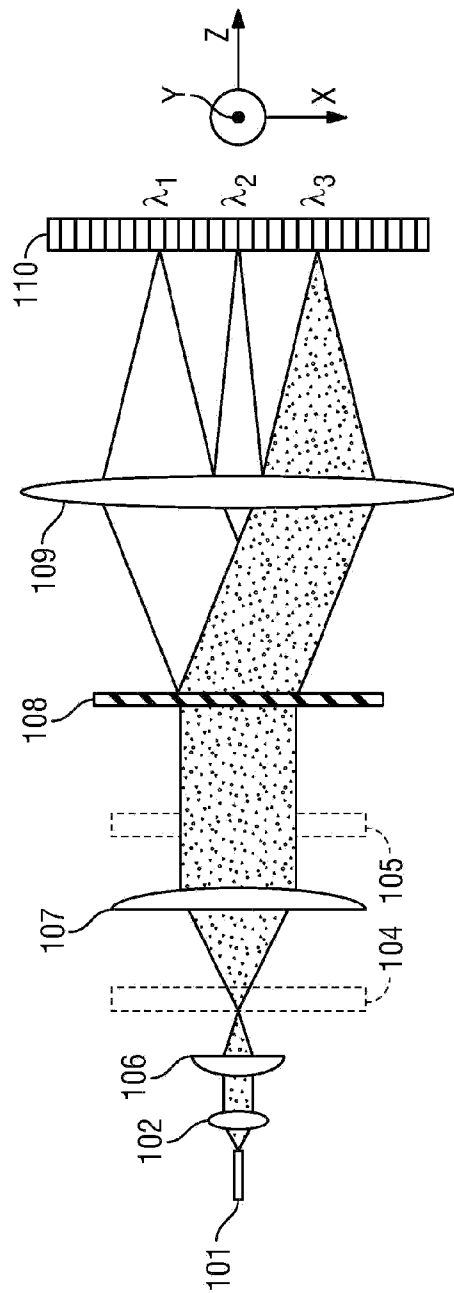


FIG. 3A

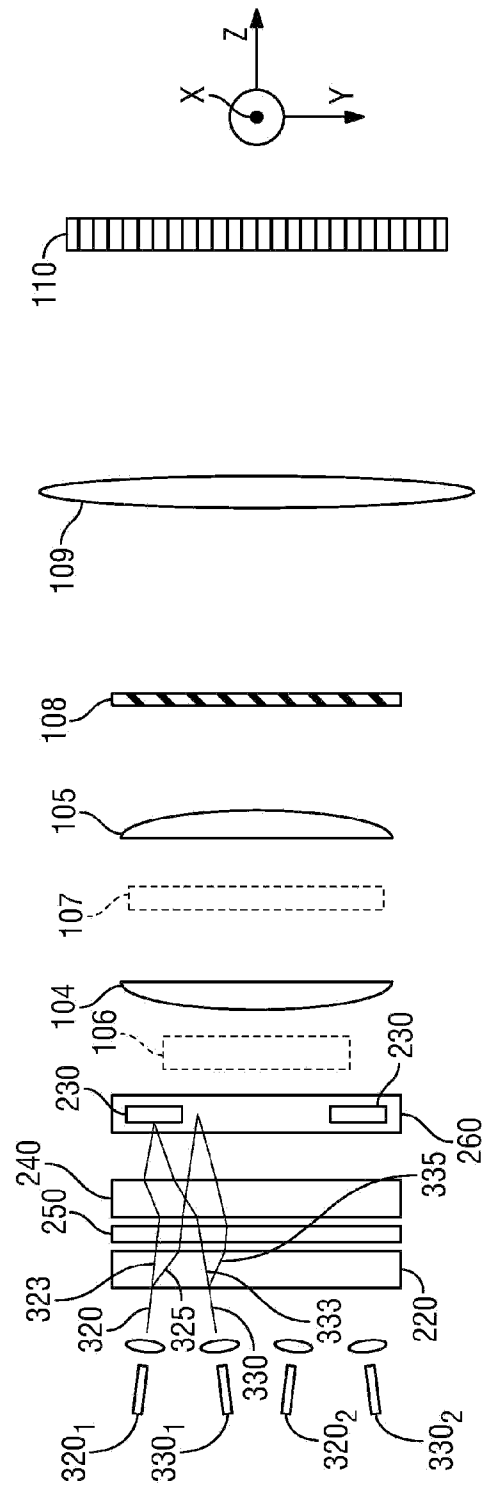


FIG. 3B