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Eye-safe lidar system based on mems

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[Continued on next page]

(54) **Title:** EYE-SAFE LIDAR SYSTEM BASED ON MEMS

(57) Abstract: The present disclosure relates to an eye-safe LIDAR system, more specifically a LIDAR system with a micro-electro-mechanical system used for spatially dithering laser beam.

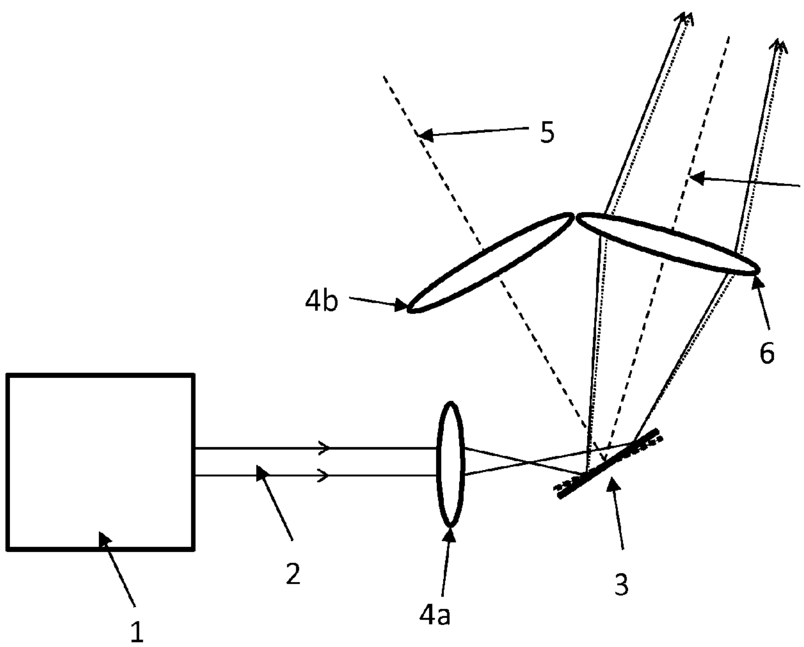

Fig. 2

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Eye-safe LIDAR system based on MEMS

Field of invention

The present invention relates to an eye-safe LIDAR system, more specifically a LIDAR system with a micro-electro-mechanical system (MEMS) used for spatially dithering an output beam.

Background of invention

Eye safety is an important aspect to consider when designing a light detection and ranging (LIDAR) system. A LIDAR system transmits at least one laser beam to a probed target. The probed target can either be a single solid object or an ensemble of minute objects or particulates in fluid suspension. The LIDAR also receives light emanating from the probed target (usually back-reflected light) which, in combination with particular optoelectronic detection and signal processing means, enables it to deduce some properties of the probed target such as position, speed, reflectance, absorption, concentration, temperature, etc. Depending on the application, the laser beam transmitted from the LIDAR can either be divergent, collimated, or convergent (that is, focused at a certain distance). For divergent and collimated cases, the optical power density (for CW lasers) or energy density (for pulsed lasers) is at maximum at the exit-pupil - hence, satisfying the eye safety requirement at the exit-pupil of the LIDAR may be considered sufficient. However, for the case of a focused transmitted beam, the power (or energy) density increases as we move away from the exit-pupil, reaching a maximum at the focal plane, and decreases again beyond the focal plane. It is therefore at the focal plane where the power (or energy) density of the laser beam has to be considered when satisfying the prescribed Maximum Permissible Exposure (MPE) for eye-safe operation. MPE is "the highest power (or energy) density in W/m^2 (or J/m^2) of a light source that is considered safe", i.e. that has a negligible probability for creating damage. It is usually about 10% of the dose that has a 50% chance of creating damage under worst-case conditions.

For a range-resolved wind-speed measuring LIDAR that relies on a CW laser, the transmitted beam is focused at a remote distance R such that the $1/e^2$ beam radius ω_{FP} at the focal plane is significantly smaller than the beam radius ω_{EA} at the plane of the exit-pupil. The back-reflection from the airborne particles that serve as tracers of the wind field being probed is very small. This means that a relatively high power laser beam in the order of few hundreds of milliwatts (the precise amount depends on the concentration of airborne particles) is typically required to detect the Doppler shift from a sufficient amount of back-reflected signal that overcomes the noise level and thereby deduce radial wind speed. Consequently, this may result in a relatively high power density at the focal plane exceeding the MPE - especially if particle concentration is low. Consequently, there is a need for reducing the mean power density from a LIDAR system.

One way to reduce the mean power density for a given exposure time for the purpose of satisfying the eye safety requirement is to dither or scan the laser light that is emitted from a LIDAR system, for example by rotating a wedge or a mirror. In particular it has been suggested that the wedge or the mirror is set up to direct a beam into a telescope in different degrees of inclination to produce the spatial dither of the beam at the focal plane. Several problems are related to such solutions. First of all, rotating a wedge or a mirror requires a rather great power in particular because the wedge or mirror has a great mass that needs to be moved and/or rotated. Secondly, directing a beam into a telescope using a wedge or a mirror is rather inefficient in terms of how the scanning/dithering is facilitated by the moving/rotating wedge or mirror. In other words, inefficient scanning using a wedge or mirror is known.

Thus, there is a need for an efficient solution to spatially dither a beam from a LIDAR system at the focal plane, in particular to reduce the mean power density for a given exposure time and for the purpose of satisfying the eye safety requirement.

Summary of invention

In order to provide a LIDAR system to reduce the mean power density for a given exposure time and for the purpose of satisfying the eye safety requirement, and solve the above described shortcomings, the present invention provides an eye-safe LIDAR system, comprising: a beam-generating section adapted for generating an output beam; a beam-focusing optical unit, comprising an inner optical element configured for focusing the output beam to an inner point of focus, and one or more outer optical elements, each outer optical element configured for focusing the output beam to an outer point of focus, and a beam-steering element comprising a micro-electro-mechanical-system (MEMS) having at least one reflecting element and capable of switching the output beam from the inner optical element in a first movement pattern towards one of said outer optical elements such that the outer point of focus is spatially dithered, wherein the LIDAR system is configured such that the inner point of focus is located before or after the at least one reflecting element.

An advantage of the present invention over known LIDAR systems having reduced mean power is that it provides a LIDAR system where the at least one reflecting element is only required to move very little in comparison to systems where the scanning member, i.e. wedge mirror or, is placed outside the telescope. In other words, the present invention provides an efficient dithering of an output beam in a LIDAR setup.

By the present invention, it may be understood that the at least one reflecting element, is placed inside the telescope, i.e. inside the beam-focusing optical unit, i.e. on an optical path inside the beam-focusing optical unit, between the inner optical element and the one or more outer optical element. By this setup, it has been found, that very efficient dithering is achieved.

Furthermore, efficient dithering is also achieved by providing that that the inner point of focus is located before or after the at least one reflecting element. Typically, when using at least one reflecting element, it is common practice to place an inner point of focus directly on a MEMS mirror in order to be able to use a reflecting surface with a small as possible area. Thus, by having the inner point of focus located before or after the at least one reflecting element, the output beam is easily moved.

It can be found using geometrical optics, that the lateral displacement, r, is given by $r = 2\ R\ Af\text{-}iAQ/f_2$, where R is the outer point of focus distance from the lens plane of the one or more outer optical element, Δf_1 is the distance between the inner point of focus to a focus point that would have been the inner focus point on the at least one reflecting element, if the inner point of focus would lie on the plane of the at least one reflecting element. In other words, Δf_1 is the defocus from the at least one reflecting element. The angle, $\Delta\Theta$, is the deflection angle of the at least one reflecting element, and f_2 is the focal length of the one or more outer optical element. The present invention provides thus several advantages as can be seen directly from the formula, and as will be described in the following.

The lateral displacement, or dithering distance, is proportional to the distance by which the inner point of focus lies from the plane of the at least one reflecting element, more specifically to a point in the plane of the at least one reflecting element, wherein that point would have been the inner focus point on the at least one reflecting element if the inner point of focus would lie on the plane of the at least one reflecting element.

The lateral displacement, or dithering distance, is proportional to the deflection angle of the at least one reflecting element.

The lateral displacement, or dithering distance, is proportional to outer point of focus distance from the lens plane of the one or more outer optical elements.

The lateral displacement, or dithering distance, is inverse proportional to the focal length of the one or more outer optical elements.

When spatially dithering the outer point of focus, the lateral displacement, or dithering distance, is the lateral distance from the outer point of focus.

Most preferably, the eye-safe LIDAR system according to the present invention may be mounted on a wind turbine.

Description of drawings

Fig. 1 shows one embodiment of an eye-safe LIDAR according to the present invention.

Fig. 2 shows a second embodiment of an eye-safe LIDAR according to the present invention.

Fig. 3 shows a third embodiment of an eye-safe LIDAR according to the present invention.

Detailed description of the invention

The present disclosure relates to a LIDAR system to reduce the mean power density for a given exposure time and for the purpose of satisfying the eye safety requirement.

The LIDAR system as disclosed herein may be a coherent Doppler LIDAR system. In such a system, the system transmits a light beam and receives a part of backscattered light from a target, such that the backscattered light is coherently superpositioned with a reference beam generated by a local oscillator. Thus the LIDAR system may comprise a local oscillator. The local oscillator may be comprised of optical elements, such as a reference wedge, for example responsible for generating a reflected signal.

Accordingly, the backscattered light may be received with the reference beam on a detector, from where the line-of-sight or radial speed of the target may be deduced. Thus, the backscattered light may be a Doppler-shifted target signal and an unshifted reference signal, i.e. the detector may receive a Doppler spectrum from which an analysis, such as a frequency analysis, can be performed, for example in a signal processor. By having more outer optical elements, it may be possible to resolve a plurality of velocity vectors for the target and/or for several targets.

In one embodiment, the LIDAR system further comprising an optical circulator comprising at least two ports configured to be in optical connection with at least the beam-generating section and the beam-steering element. Thus, a first port is connected to the beam generating section, and a second port is where the output beam is transmitted from and further into the MEMS via the inner optical element. Prior the MEMS, the beam may have passed through a local oscillator generating optics, such as a reference wedge, when setup as a coherent LIDAR Doppler LIDAR.

Preferably, the optical circulator comprises three ports, such that a third port is in optical connection with a detector. Thus, the third port may be where the Doppler-shifted target signal and the reference signal is transmitted to the detector.

The optical elements may represent a group of elements. For example the inner optical element and/or the outer optical elements may be two or several optical lenses, for example in order to properly focus the beam, either on the target plane and/or the detector.

Reflective element

According to the present invention, the eye-safe LIDAR system comprises a beam-steering element comprising a micro-electro-mechanical-system (MEMS) having at least one reflecting element. In some embodiments, the at least one reflective element is a single reflecting element. Thus, the single reflecting element may comprise a single reflective surface. In some embodiments, the at least one reflective element, such as two or more reflective elements, form a single reflective surface, for example in embodiments, where the two or more reflective elements are placed side by side. In embodiments, where the micro-electro-mechanical-system (MEMS) has a single reflecting element, the micro-electro-mechanical-system (MEMS) may be referred to as a MEMS reflecting element. The MEMS reflecting element bay thus be referred to such as a MEMS mirror or a MEMS grating. Examples of an eye-safe LIDAR system comprising a beam-steering element comprising a single MEMS reflecting elements are shown in Figures 1-3.

Inner point of focus

As previously described, the inner point of focus is located before or after the at least one reflecting element. In other words, the inner point of focus does not lie on a plane of the at least one reflecting element. In fact, as has also been shown analytically, lateral dithering converges to zero as the defocus approaches zero. In other words, a very inefficient dithering system would be provided if the defocus was zero. Due to a point source having a diffraction-limited size, it would be possible to move the output beam when the inner point of focus does lie on a plane of the at least one reflecting element, i.e. when the focus spot is diffraction limited. However, since the lateral displacement, or dithering distance, increases proportional to the defocus, the efficiency of scanning also increases proportional to the defocus.

In relation to efficiency of scanning, the LIDAR system is in preferred embodiments configured such that the inner point of focus is selected to be placed at a first distance from the at least one reflecting element and the first distance is selected to reduce differences between angular positions in the first movement pattern. The difference between angular positions in the first movement pattern can be seen in comparison to an eye-safe LIDAR system providing the same lateral displacement, wherein the inner point of focus is at a second distance from the at least one reflecting element, and wherein the first distance is greater than the second distance. It is thus clear that the first position provides the most efficient scanning in comparison to the second position, since the defocus at the first position is greater than the defocus at the second position.

In a preferred embodiment of the present invention, the inner point of focus is located at a focal plane such that the output beam from the inner optical element is at least partly truncated by an exit-pupil of the beam-focusing optical unit. In this embodiment, an exit-pupil of the beam focusing optical unit may be the one or more outer optical elements, for example the clear aperture of the one or more outer optical elements, or a circular exit-pupil defined elsewhere in the beam-focusing optical unit. The truncation by the exit-pupil of the beam-focusing optical unit may be the dominant truncation.

In another preferred embodiment of the present invention, the inner point of focus is located at a focal plane such that the output beam from the inner optical element is at least partly truncated by the at least one reflecting element. For example, due to the beam being Gaussian, the tails of the beam may be truncated by the at least one reflecting element.

Beam generating section and output beam

In a most preferred embodiment of the present invention, the beam generating section is adapted for generating a collimated output beam toward the inner optical element. In other words, this may facilitate that the inner optical element is focusing the collimated beam towards the beam-steering element, however without focusing the output beam on the beam-steering element, or on the at least one reflecting element. In some embodiments of the present invention, it follows that the inner optical element is configured with a positive focal length.

In one embodiment, the output beam is redirected to the one or more outer optical elements such that output beam, as defined by a measure of radius, is at least equal to 80% of a radius of the one or more outer optical elements or a radius of the exit-pupil of the beam-focusing optical unit. The measure of radius may be defined in many ways, but in common practice, a typical measure of radius is the $1/e^2$ beam radius. By this embodiment, the output beam significantly fills the exit lens, i.e. the one or more outer optical elements, to achieve tight focusing at remote distance R. Under this condition, there is provided a specific optimal LIDAR condition, called optimal heterodyne efficiency.

Dithering

In most embodiments of the present invention, the first movement pattern corresponds to the at least one reflecting element being switched with at least angular positions, whereby said outer point of focus is at least laterally shifted by a lateral displacement.

In one embodiment of the present invention, the first movement pattern corresponds to the at least one reflecting element being switched with angular positions differing by less than 1 degree. As previously described, such an embodiment may be achieved by properly choosing the defocus, the focal length of the one or more outer optical element, and the distance to the outer focus point from the one or more outer optical elements. As also previously described, it is possible to use so small angular positions changes because the LIDAR system according to the present invention has the at least one reflecting element on an optical path between the inner optical element and the one or more outer optical element.

In order to realize the embodiment as just described, i.e. making sure, that eye-safe operation is corresponding to the small angular movement, the defocus may be between 1 mm and 20 mm, such as between 2 mm and 10 mm, such as between 4 mm and 5 mm. As the lateral displacement depends on three factors, the defocus, the focal length of the one or more outer optical elements, and the distance to the outer focus point from the one or more outer optical elements, also called the far focus, all of the three factors can contribute to the realization of the embodiment. Accordingly, the far focus may be between 30 m and 200 m, such as between 50 m and 100 m, such as 60 m, 70 m, 80 m, or 90 m, preferably around 60 m.

In embodiments of the present invention, the one or more outer optical elements are configured with a positive focal length. The focal length of the one or more outer optical elements may be between 100 mm and 500 mm, such as between 150 mm, and 250 mm, such as between 200 mm and 220 mm.

Using a far focus of for example 60 m, one outer optical element with a focal length of 216 mm, and a defocus of 4.78 mm, provides a lateral displacement of r = 2.7

mm/mrad. Thus, by way of example, there is provided a lateral displacement of 7 mm, using only 0.1 5 degrees angular deflection of the at least one reflecting element. The angular deflection is a difference in angular positions.

As is evident from the just described exampled embodiment, in a preferred embodiment, the first movement pattern corresponds to the at least one reflecting element being switched with angular positions differing such that a ratio between a lateral displacement of the outer point of focus and the difference in angular positions is more than 1 mm/mrad, such as more than 2 mm/mrad, such as more than 2.5 mm/mrad, such as 2.7 mm/mrad, or such as more than 3.0 mm/mrad.

In some embodiments of the present invention, the first movement pattern corresponds to laterally shifting said outer point of focus by less than 5 cm, such as less than 4 cm, such as less than 3 cm, such as less than 2 cm, such as less than 1 cm, such as 9 mm, such as 8 mm, such as 7 mm, such as 6 mm, such as 5 mm, or such as less than 5 mm.

Since the lateral beam displacement caused by the spatial dither at the focal plane is much smaller than measurement distance, or the far focus, R, the effect of spatial dithering on radial wind speed measurements are negligible.

In one embodiment of the present invention, the spatially dithering is applied for a period of time, wherein the period of time corresponds to a spatial dithering pattern.

The spatial dithering pattern may be a pattern that reduces the overall radiation exposure, such as spiral or a set of concentric rings or a random pattern.

<u>Two or more outer optical element(s)</u>

In one embodiment of the present invention, the eye-safe LIDAR system further comprises two or more outer optical elements and wherein the MEMS and the at least one reflecting element is further capable of switching the output beam from the inner optical element in a second movement pattern interchangeably between said two or more outer optical elements.

In this embodiment it may be stated that there are a plurality of telescopes, or a plurality beam-focusing optical units. It may also be stated that there is a telescope or a beam-focusing optical unit, having more outer optical elements to generate more output beams.

Further, in this embodiment, the power from the output beam may be reduced simply by moving the beam to different locations. This particular embodiment enables the use of the inner focusing optical element as a common component to a plurality of telescopes, i.e. a plurality of beam-focusing optical units. Time-sharing of the output beam reduces the average power density by a factor of N at the distant focal plane of each telescope (N is the total number of telescopes or outer optical elements that are exit lenses).

In preferred embodiment of the present invention, the first movement pattern is different from said second movement pattern.

Most preferably, when switching the output beam from the inner optical element in a second movement pattern interchangeably between said two or more outer optical elements, the at least one reflecting element may be switched with angular positions differing by more than 1 degree.

In some embodiments of the present invention, the first movement pattern corresponds to the outer point of focus being spatially dithered in a pattern such as a spiral pattern or a pattern with a set of concentric rings or a random pattern.

According to one or more of the above described embodiments, there is provided an eye-safe LIDAR system, where it is possible to move or scan at least one reflecting element in a fine way, i.e. positioning it with angular positions that differ less than 1 degree, and additionally in a coarse way, i.e. positioning it with angular positions that differ more than 1 degree. Such an eye-safe LIDAR system provides a very efficient way of providing eye-safe operation, whilst also providing the ability measure several wind velocity components that fully resolves not only the wind velocity magnitude but also the vector's direction.

Example 1 - An eye-safe LIDAR according to the present invention

Fig. 1 shows a beam-generating section **1,** (e.g. laser + optical circulator + detector); an output beam **2**; a MEMS scanning mirror (SM) **3** (two angular positions are shown); a beam-focusing optical unit **4**, comprising an inner optical element (positive lens) **4a;** and an outer optical element (positive lens) **4b;** an optical axis **5** defined by the two optical elements **4a** and **4b** or just the line normal to exit lens **4b.** The inner point of focus formed by the inner optical element **4a** occurs before reflection of the output beam by the MEMS-(SM).

Example 2 - An eye-safe LIDAR according to the present invention

Fig. 2 shows a beam-generating section **1,** (e.g. laser + optical circulator + detector); an output beam **2**; a MEMS scanning mirror (SM) **3** (two angular positions are shown); a beam-focusing optical unit **4**, comprising an inner optical element (positive lens) **4a;** and an outer optical element (positive lens) **4b;** an optical axis **5** defined by the two optical elements **4a** and **4b** or just the line normal to exit lens **4b.** An additional outer optical element **6** is further shown. A new optical axis **7** defined by the line normal to the additional optical element **6**. The combination of the inner optical element **4a** and the additional outer optical element **6** form a beam-focusing optical unit through which the beam is steered by sufficiently large deflection of the MEMS-SM and spatially dithered by appropriately small deflection of the MEMS-SM.

Example 3 - An eye-safe LIDAR according to the present invention

Fig. 3 shows a beam-generating section **1,** (e.g. laser + optical circulator + detector); an output beam **2**; a MEMS scanning mirror (SM) **3** (two angular positions are shown); a beam-focusing optical unit **4**, comprising an inner optical element (positive lens) **4a;** and an outer optical element (positive lens) **4b;** an optical axis **5** defined by the two optical elements **4a** and **4b** or just the line normal to exit lens **4b.** This is a variant of the example in **Fig. 1.** Here, the inner point of focus formed by the inner optical element **4a** occurs after reflection of the output beam by the MEMS-SM.

Claims

1. An eye-safe LIDAR system, comprising:
   - a beam-generating section adapted for generating an output beam;
   - a beam-focusing optical unit, comprising
     - an inner optical element configured for focusing the output beam to an inner point of focus, and
     - one or more outer optical elements, each outer optical element configured for focusing the output beam to an outer point of focus, and
   - a beam-steering element comprising a micro-electro-mechanical-system (MEMS) having at least one reflecting element and capable of switching the output beam from the inner optical element in a first movement pattern of said reflecting element(s) towards one of said outer optical elements such that the outer point of focus is spatially dithered,

   wherein the LIDAR system is configured such that the inner point of focus is located before or after the at least one reflecting element.

2. The eye-safe LIDAR system according to claim 1, further comprising two or more outer optical elements and wherein the MEMS and the at least one reflecting element is further capable of switching the output beam from the inner optical element in a second movement pattern of said reflecting element(s) interchangeably between said two or more outer optical elements.

3. The eye-safe LIDAR system according to claim 2, wherein said first movement pattern is different from said second movement pattern.

4. The eye-safe LIDAR system according to any of the claims 2-3, wherein when switching the output beam from the inner optical element in a second movement pattern interchangeably between said two or more outer optical elements, the at least one reflecting element is switched with angular positions differing by more than 1 degree.

5. The eye-safe LIDAR system according to any of the preceding claims, wherein the first movement pattern corresponds to the outer point of focus being spatially dithered in a pattern such as a spiral pattern or a pattern with a set of concentric

rings or a random pattern.

6. The eye-safe LIDAR system according to any of the preceding claims, wherein the first movement pattern corresponds to the at least one reflecting element being switched with angular positions differing by less than 1 degree.

7. The eye-safe LIDAR system according to any of the preceding claims, wherein the first movement pattern corresponds to laterally shifting said outer point of focus by less than 5 cm, such as less than 4 cm, such as less than 3 cm, such as less than 2 cm, such as less than 1 cm, such as 9 mm, such as 8 mm, such as 7 mm, such as 6 mm, such as 5 mm, or such as less than 5 mm.

8. The eye-safe LIDAR system according to any of the preceding claims, wherein the first movement pattern corresponds to the at least one reflecting element being switched with angular positions differing such that a ratio between a lateral displacement of the outer point of focus and the difference in angular positions is more than 1 mm/mrad, such as more than 2 mm/mrad, such as more than 2.5 mm/mrad, such as 2.7 mm/mrad, or such as more than 3.0 mm/mrad.

9. The eye-safe LIDAR system according to any of the preceding claims, wherein the inner optical element is configured with a positive focal length.

10. The eye safe LIDAR system according to any of the previous claims, wherein the one or more outer optical elements is configured with a positive focal length.

11. The eye-safe LIDAR system according to any of the preceding claims, wherein the beam generating section is adapted for generating a collimated output beam toward the inner optical element.

12. The eye-safe LIDAR system according to any of the preceding claims, wherein the inner point of focus is located at a focal plane such that the output beam from the inner optical element is at least partly truncated by an exit-pupil of the beam-focusing optical unit.

13. The eye-safe LIDAR system according to any of the preceding claims, wherein the inner point of focus is located at a focal plane such that the output beam from the

inner optical element is at least partly truncated by the at least one reflecting element.

14. The eye-safe LIDAR system according to any of the preceding claims, whereby the output beam is redirected to the one or more outer optical elements such that output beam, as defined by a measure of radius, is at least equal to 80% of a radius of the one or more outer optical elements.

15. The eye-safe LIDAR system according to any of the preceding claims, whereby the output beam is redirected to the one or more outer optical elements such that output beam, as defined by a measure of radius, is at least equal to 80% of a radius of an exit-pupil of the beam-focusing optical unit.

16. The eye-safe LIDAR system according to any of the preceding claims, wherein the first movement pattern corresponds to the at least one reflecting element being switched with at least angular positions, whereby said outer point of focus is at least laterally shifted by a lateral displacement.

17. The eye-safe LIDAR system according to any of the preceding claims, wherein the LIDAR system is configured such that the inner point of focus is selected to be placed at a first distance from the at least one reflecting element and the first distance is selected to reduce the difference between angular positions in the first movement pattern.

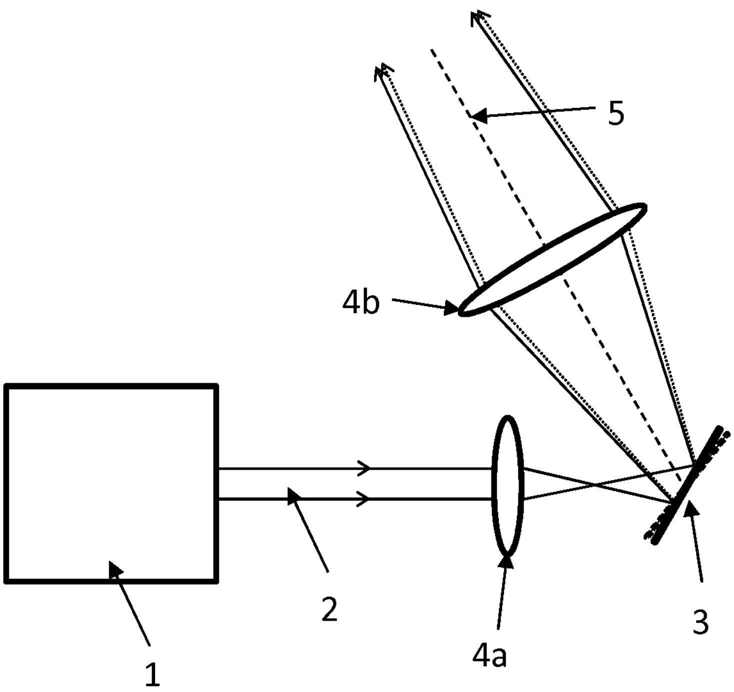

Fig. 1

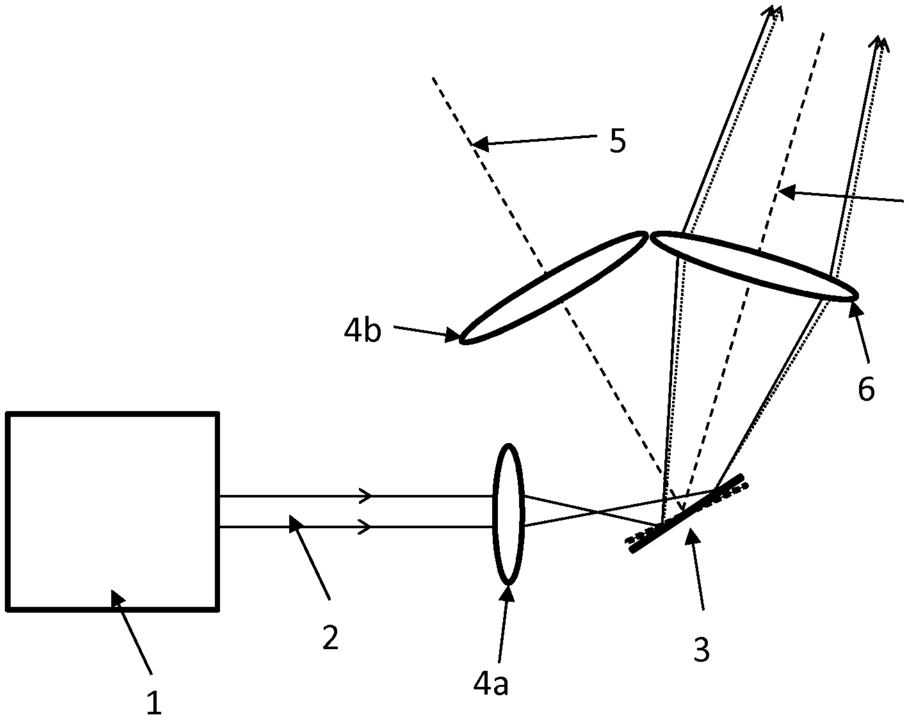

Fig. 2

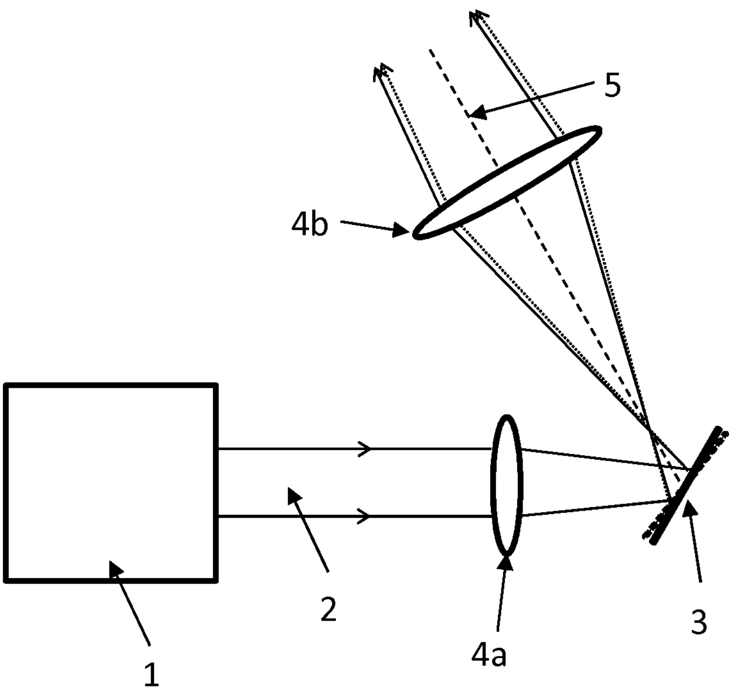

Fig. 3

INTERNATIONAL SEARCH REPORT

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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 G01S

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 practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2003/043363 A1 (JAMIESON JAMES R [US] ET AL) 6 March 2003 (2003-03-06) abstract; figures 1,7a, 7b, 8a, 8b, 15,32-36 paragraphs [0010] - [0012], [0052], [0054], [0056], [0072] - [0076], [0090] - [0093], [0126], [0127]	1-17
Y	US 2004/073200 A1 (CAUDLE GEORGE [US] ET AL) 15 April 2004 (2004-04-15) paragraphs [0002] , [0004] , [0006] , [0007], [0026], [0032]; figures 2-4	1-17
Y	CN 104 142 497 A (BEIJING INST TECHNOLOGY) 12 November 2014 (2014-11-12) the whole document	2-4,6
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 February 2017	13/02/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Blau, Gerd

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	J.H KIM ET AL: "Electromagnetically actuated 2-axis scanning micromirror with large aperture and tilting angle for lidar applications", 2015 TRANSDUCERS - 2015 18TH INTERNATIONAL CONFERENCE ON SOLID-STATE SENSORS, ACTUATORS AND MICROSYSTEMS (TRANSDUCERS), 25 June 2015 (2015-06-25), pages 839-842, XP55341756, DOI: 10.1109/TRANSDUCERS.2015.7181054 abstract * page 842, left hand column * -----	1-17
A	US 2011/149363 A1 (HARRIS MICHAEL [GB] ET AL) 23 June 2011 (2011-06-23) abstract; figures 3,4a paragraphs [0001], [0002], [0014] - [0016], [0022], [0033], [0034], [0038], [0045] -----	1-17

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/080416

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