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(72) Inventor; and
(71) Applicant : **TISSOT, Yann** [CH/CH]; Av. Bethusy 8, CH-1005 Lausanne (CH).

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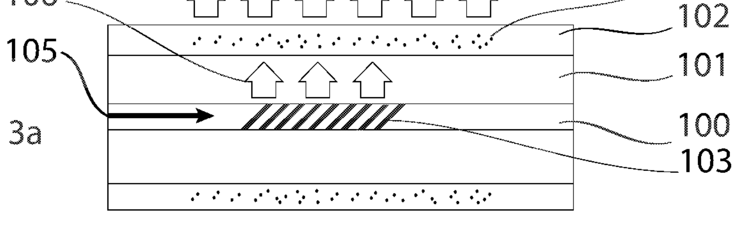

Fig. 3a

(57) Abstract: A waveguide in which coherent light is to propagate along its longitudinal axis has formed therein a first scattering zone (103) that runs along the longitudinal axis and that is to scatter the propagating coherent light (105) out of the waveguide at a non-zero angle relative to the longitudinal axis. Means for vibrating a light spot of the coherent light relative to the waveguide, or means for dynamically changing a focus of the light spot, is provided, so that light coupling of the coherent light into the waveguide changes over time thereby generating different speckle patterns in the waveguide that overlap with the first scattering zone. Other embodiments are also described and claimed including one where a functional or diffusing coating (102) is provided that in combination with the first scattering zone yields a reduced speckle pattern.

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COHERENT LIGHT WAVEGUIDE ILLUMINATION SYSTEM WITH SPECKLE NOISE REDUCER

This non-provisional application claims the benefit of the earlier filing date of U.S. provisional application no. 61/846,183, filed July 15, 2013, entitled "Coherent Light Waveguide Illumination System with Integrated Speckle Noise Reducer."

An embodiment of the invention relates to an illumination device that exhibits a reduced degree of coherence and thus a low speckle noise contrast. Other embodiments are also described.

BACKGROUND

It is known that shining coherent light upon an illumination surface generates a shimmering illumination pattern also known as speckles. A speckle pattern arises from the local interferences generated between the incoming wavefront from a coherent light source and the scattered wavefront from an illumination surface for example as illustrated in **Fig. 1**. More specifically, the speckle pattern may originate from the superposition of random discrete wavefronts arising from contributing points in the illumination surface.

In the specific case of a multimode waveguide, it is also known that the propagation of coherent light in the core of the waveguide generates a strong speckled distribution of the intensity. The speckle pattern at the waveguide end may be produced by random interference between the various propagation modes.

The resulting random intensity pattern of these illumination systems is a drawback in many applications, *e.g.* inspection lighting, where the projected speckles are transformed into imaging noise.

A technique for reducing the speckle noise on an illumination surface involves dynamically decorrelating the speckles of the coherent light source (see **Fig. 2A**), *i.e.* by time-varying one or all of the following parameters: the polarization, the phase, and the wavelength of the coherent light source.

Another method is to dynamically decorrelate the projected speckles generated by the illumination surface or by the optical projection system (**Fig. 2B**). Typically, a moving optical element (*e.g.*, a diffuser) is positioned within the optical path between the coherent light source and the illumination surface. The dynamic motion of this optical element in its entirety reduces the spatial coherence of the incident coherent light and thus a reduction of the overall speckle contrast is achieved. In this case, however, significant motion amplitudes are needed and are typically provided by, *e.g.* the mechanical rotation of a refractive element (U.S. Patent Application Publication No. 2007/0223091, PCT Patent Application Publication No. WO2009133111, and U.S. Patent No. 6,081,381), the mechanical vibration or displacement of a plane diffuser (U.S. Patent Application Publication No. 2007/0251916, and U.S. Patent Application Publication No. 2011/0267680), screen vibration (U.S. Patent Application Publication No. 2013/0010356 A1), or the use of segmented mirrors (U.S. Patent No. 7,502,160 B2).

Another method is to dynamically decorrelate the projection speckles by using at least two successive optical elements within the optical path and to move one of these elements in its entirety with respect to the other (**Fig. 2C**). In this case, much smaller motion amplitudes are needed to achieve the same reduction of the overall speckle contrast on the final illumination surface ("Speckle Removal by a Slowly Moving Diffuser associated with a motionless diffuser, J. Opt. Soc. Am., 61, pp. 847-851, 1971). The two optical elements may be, *e.g.* a refractive, diffractive or diffusing optical element.

Some of these methods need bulky, distinct optical elements or involve movement of an optical element in its entirety, which may be hard to integrate directly into a laser waveguide illumination system, such as, *e.g.* (U.S. Patent No. 7,437,035 and PCT Patent Application Publication No. WO2012146960 A1) where the speckle pattern may be spread over an elongated surface. Others solutions including decorrelation of the coherent light source may not be suitable for certain applications.

SUMMARY

An embodiment of the invention is an illumination device or system with low speckle noise. The device employs a waveguide that transports coherent light (*e.g.*, a laser light), with scattering structures inside the waveguide that re-distribute the coherent light outside the waveguide. A second scattering structure inside a coating of the waveguide scatters the light that is primarily out-coupled from the core of the waveguide, outside the waveguide. Each of these elements, *i.e.* the waveguide, the first scattering structures inside the waveguide and the second scattering structures inside the coating of the waveguide, defines a distinct speckle pattern. In one embodiment, the static superposition of these distinct speckle patterns advantageously allows for an overall reduction of the spatial coherence of the "final" illumination light produced by the device. In another embodiment, causing motion of one of these speckle patterns with respect to another (vibration) enables a significant reduction in the overall speckle noise produced by the illumination device. Several integrated mechanisms for obtaining motions inside the waveguide illumination system are also described.

In one embodiment, the static or dynamic superposition of the successive speckle patterns occurs within the context of a single waveguide. Individual speckle sources may be one or more of the following: the waveguide itself (*e.g.*, a multimode waveguide), a scattering structure integrated in the waveguide, and a scattering structure integrated in the coating of the waveguide. Methods for obtaining motion between one of these speckle sources with respect to another or with respect to a group of other speckle sources are described that may be able to reduce the speckle noise of the final illumination scheme. Examples for obtaining such motion include deformation of an optical element and changing the light coupling of a coherent light source to the waveguide.

The above summary does not include an exhaustive list of all aspects of the present invention. It is contemplated that the invention includes all systems and methods that can be practiced from all suitable combinations of the various aspects summarized above, as well as those disclosed in the Detailed Description below and particularly pointed out in the claims filed with the application. Such combinations have particular advantages not specifically recited in the above summary.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment of the invention in this disclosure are not necessarily to the same embodiment, and they mean at least one. Also, in the interest of conciseness, a given figure may be used to illustrate the features of more than one embodiment of the invention, or more than one species of the invention, and not all elements in the figure may be required for a given embodiment species.

Fig. 1 illustrates the formation of speckles.

Fig. 2A depicts the use of time varying parameters in the generation of the light source, to alleviate speckle.

Fig. 2B illustrates an example of how moving an optical element can alleviate speckle.

Fig. 2C shows another example of small motion of an optical element with respect to another to alleviate speckle.

Fig. 3A is a section view of a coherent light waveguide device having a speckle reducer in accordance with an embodiment of the invention.

Fig. 3B shows an example speckle reducer in accordance with another embodiment of the invention, which relies on relative motion between the light source and the waveguide.

Fig. 4A and **Fig. 4B** are section views of a coherent light waveguide device with a speckle reducer in accordance with yet another embodiment of the invention.

Fig. 5A and **Fig. 5B** are section views of another coherent light waveguide device with speckle reduction.

Fig. 6A and **6B** are section views of the coherent light waveguide device whose waveguide coating has large size and small size scattering centers, respectively.

DETAILED DESCRIPTION

Several embodiments of the invention with reference to the appended drawings are now explained. Whenever the shapes, relative positions and other aspects of the parts described in the embodiments are not clearly defined, the scope of the invention is not limited only to the parts shown, which are meant merely for the purpose of illustration. Also, while numerous details are set forth, it is understood that some embodiments of the invention may be practiced without these details. In other instances, well-known circuits, structures, and techniques have not been shown in detail so as not to obscure the understanding of this description.

Referring to **Figs. 3A**, **3B**, **4A**, **4B**, **5A**, **5B**, **6A** and **6B**, several embodiments of the illumination device are illustrated, where each uses a coherent light source that is coupled to a waveguide which has a core 100 and a cladding 101, resulting in a primary light 105 that propagates along the waveguide until it is out-coupled by a first scattering structure or scattering zone 103 inside the waveguide. The out-coupled light is then diffused out of the waveguide by a coating 102 via an integrated scattering center or zone 104 therein. Light that is scattered by a particular scattering zone (103 or 104) exhibits a distinct speckle pattern. Therefore, illumination light 107 that is scattered outside the waveguide exhibits a speckle pattern that is the superposition of a first speckle pattern arising from the first scattering zone 103 and a second speckle pattern arising from the second scattering zone 104.

The light source that produces the primary light 105 may be a coherent or partially coherent light source such as a laser or a super-luminescent light source. The invention is not limited to a specific wavelength or spectrum width and for instance can be located from the deep UV to far IR wavelength range. The coherent light source may be composed of multiple single wavelength coherent sources, *e.g.* lasers emitting red, green and blue light (R, G, B).

The primary light 105 is coupled into and guided by a waveguide. The waveguide may be a light pipe. Alternatively, the waveguide may be composed of a core or core layer 100 covered with a cladding or cladding layer 101 as shown in the figures here. The core medium is in contact with the cladding medium, and these are designed such that the primary light 105 can propagate in the core in the direction shown and along the longitudinal axis of the waveguide, for example via total internal reflection, as for example in a multi-mode optical fiber. The waveguide may be any suitable waveguide, such as an optical fiber, and may be a single clad fiber, a multi-clad fiber, or a photonic-crystal or micro-structured waveguide.

The waveguide has one or more scattering structures 103 formed therein as shown, which serve to re-direct the propagating primary light 105 out of a side surface of the waveguide, resulting in so-called scattered or out-coupled light 106. In other words, the propagating light is redirected to a desired non-zero angle (*e.g.*, transverse or about 90 degrees) relative to the longitudinal or optical propagation axis of the waveguide, referenced here as scattered or out-coupled light 106.

The scattering structures may be particles or impurities directly integrated during fabrication of the waveguide (*e.g.*, during the drawing of an optical fiber).

The scattering structures may be laser-induced structures; these may be formed through the application of external intense laser light to selected locations in the waveguide. The location, the shape, the size, the scattering strength, the tilt or orientation, and periodicity of the scattering structures, along and across (transverse to) the light propagation direction (longitudinal axis) in the waveguide can be selected, by adapting the focus, intensity and position of the external processing laser. Specifically, these parameters may be adapted, in accordance with an embodiment of the invention, to obtain a desired first speckle pattern in the out-coupled light 106.

Still referring to **Fig. 3A**, the waveguide device has a coating 102 in which one or more light scattering zones 104 are formed. The coating 102 may be made of a mixture of silicone or other suitable material such as epoxy, or a polymer matrix, mixed with light diffusing particles that are designed to interact with the out-coupled light 106. In accordance with an embodiment of the invention, the particles may be transparent, semi-transparent or/ and may exhibit photo-luminescence. The refractive index, the size and the shape of the diffusing particles as well as their density and dispersion inside a medium such as an epoxy matrix, may be adapted to obtain a desired second speckle pattern, so as to reduce the overall speckle contrast upon final illumination outside the device, and perhaps to also obtain a desired illumination angle α (alpha) in the illumination light 107 - see the section views in **Fig. 6A** and **6B** where a directional radiation pattern having a radial spread angle alpha, at a radial position of “12 o’clock”, is shown. Other radial spread angles and radial positions are of course possible.

In the embodiments of **Fig. 3A**, **6A** and **6B**, the coating 102 is shown as being formed on the outer surface of the waveguide, and in particular the outer surface of the cladding 101. There may be one or more intermediate material layers that are sandwiched between the coating 102 and the outer surface of the waveguide. In another embodiment, the coating 102 is formed in such a way that one or more of its sections are spaced apart from, and thus not in contact with, the outer surface of the waveguide, *e.g.* by an air gap.

In one embodiment, the coating 102 and the scattering zone 104 therein may be made of a mixture of material that exhibits electro-active properties and contains diffusing particles. Electro-active materials are materials that exhibit deformations or shape changes through the application of an electrical field. In this case, and referring now to **Fig. 5A** and **Fig. 5B**, intermediate electrodes 113-114 may be implemented in the inner surface and in the outer surface of a layer of electro-active material 115, that form part of the coating 102. This embodiment will be further described below, in connection with dynamic reduction techniques.

In another embodiment, the coating 102 may be made of a plain coating (not electro-active) and where its outer surface or inner surface is structured or textured (*e.g.*, surface relief). In that case, no diffusing particles may be needed inside the coating. The size and periodicity of the structure at the surface of such a coating may be adapted to obtain the desired second speckle pattern. The surface relief may be formed by *e.g.*, chemical etching or *e.g.*, by laser ablation.

In order to reduce speckle noise in the illumination light 107, dynamic and static methods may be used, as described below (where such techniques may also be combined with the textured coating 102).

Dynamic Reduction

With dynamic reduction, a small amount of motion is imparted between one of the speckle sources with respect to the others, and which may be obtained by different methods that are described hereunder. The motion is "small" in that its amplitude and frequency need only be enough to result in the desired reduction in overall speckle contrast when the illumination light 107 that emerges from the device illuminates a nearby surface. In one embodiment, the minimum motion magnitude should be of the order of the particle size and/or of the order of the nanostructures pattern of the scattering zone. Therefore, a motion of a few microns to a few hundreds of microns may be sufficient in some cases. Note however that smaller motion amplitudes could also be sufficient, if very small particles are used. As to the frequency of the motion, this may depend on the inspection means. For example, if the observer is a human eye, then about 60Hz may be sufficient. However if the observer is machine vision (camera), the frequency may be higher and may depend on the exposure integration time used.

a) Optically Changing the Mode Conditioning Inside the Waveguide (**Fig. 3B**)

Light coupling of the primary light 105 at one end of the waveguide is a function of position and tilt f(x,y,z, theta or q) of the coherent light source relative to the waveguide, and may be dynamically changed, *i.e.* as a function of time, $(x+dx(t), y+dy(t), z+dz(t), \theta+d\theta\,(t))$. In accordance with this embodiment of the invention, referring now to **Fig. 3B**, the light spot coupled to the waveguide is laterally (in the (x) or (y) direction), longitudinally in the (z) direction, or angularly (θ) shifted or tilted over time (or vibrated) relative to the waveguide. In another embodiment, the focus of the light spot may be dynamically changed, where the dynamically changing means may include, for example, a) a moveable focus lens through which the primary light 105 passes into the waveguide to produce the light spot, and b) an electro-mechanical actuator coupled to move the lens back and forth to dynamically change the focus of the resulting light spot.

Dynamically changing the light coupling of the primary light 105 (including the amplitude of the vibration and its frequency) may lead to excitation of propagation modes with different spatial distributions thereby generating different speckle patterns inside the waveguide core 100, and thus outside the waveguide core. The amplitude and frequency of vibration may be tuned to suit the particular observer, *e.g.* the human eye, a camera. This moving speckle pattern overlaps with the scattering zone 103 thereby providing a strong reduction of the first speckle pattern outside the waveguide core. The second scattering structures 104 inside the coating 102 may therefore be absent in this case, or they may be present in order to further increase the overall speckle reduction in the illumination light 107.

The dynamic changing of the light spot or light coupling of the primary light 105 may be achieved by vibrating a mechanical coupling of the coherent light source or the light source itself, relative to the waveguide. Alternatively, a section of the waveguide that is spaced apart from a section in which the scattering structures 103 are located can be vibrated. In this case the waveguide section that is in motion may be positioned "upstream" from the scattering structure 103 (in relation to the direction of propagation of primary light from the source 105). The vibrating means may be, for example, any suitable electro-mechanical actuator that is driven by an electronic circuit.

<u>b) Axial Stretching and/or Compressing of the Waveguide</u>

A dynamic axial strain may be applied to the waveguide. Generating a push/pull dynamic strain in the propagating direction (z) may change the first speckle pattern (generated by the scattering zone 103 inside the waveguide) and also the second speckle pattern (generated by the scattering zone 104 inside the coating 102), thus reducing the overall speckle contrast in the illumination light 107.

The strain may be generated by different kinds of actuators such as a stepper motor, a magnetic actuator, or a piezo-electric actuator. **Figs. 4A** and **4B** show an embodiment that integrates a piezo-electric actuator. In this case, the waveguide may be coated or surrounded by one or more piezo-electric ceramic disks or rings 109 that are sandwiched by two or more metallic electrodes 110-111 and positioned remote from the scattering structures 103 and 104. The ceramic disks may be substituted by any continuous or discontinuous parts of ceramic as long as it exhibits at least one contact with (or touches) the waveguide (*e.g.*, optical fiber) and at least one contact with (or touches) a holder 112. For instance it can be a half or a quarter of a disk, or one or more single ceramic sticks or rods positioned next to the fiber.

The fiber is positioned between one or more holders (*e.g.*, ferrules or posts) 108 and 112. The fiber may be clamped to at least one of the holders, which can be fixed, and be freely moving through at least another one of the holders. The fiber could be fixed at both of its ends so that both stretching and compression forces may be imparted upon it by the actuator.

When a varying voltage (*e.g.*, switching between V=O and V‡O) is applied to the electrodes 110-111, it may lead to a dynamic axial deformation of the piezo-electric material, in the disk or ring 109 – see **Fig. 4B**. The piezo-electric material may be a ceramic (*e.g.*, ZnO) or any other suitable material exhibiting piezo-electric properties. In one instance, axial motion is blocked on one end by the holder 112 and therefore the force created in the disk 109 may be transferred as a dynamic stretch or compression of the waveguide.

This stretch or compression results in a dynamic superposition of the first speckle pattern that arises from the first scattering structure 103 and that is changing due to the axial stretch and/or compression of the waveguide core 100 along the structure 103 (depicted within the out-coupled light 106 ad dotted lines in **Fig. 4B**) and a second speckle pattern that arises from the second scattering structure 104, thereby achieving an overall speckle contrast reduction of the final illumination light 107.

c) Transverse Stretching and/or Compression of the Coating

In yet another embodiment, a dynamic transverse strain may be applied to the coating 102 of the waveguide. Generating a push/pull motion, *e.g.* in the transverse direction (y) as seen in **Figs. 5A** and **5B**, may change the speckle pattern that is generated by the scattering zone 104 inside the coating 102 thus reducing the overall speckle contrast of the illumination light 107.

The strain may be generated by the use of an electro-active material as part of the coating 102. The electro-active material may be *e.g.*, a polymer or a dielectric elastomer. As seen for example in **Fig. 5A**, the waveguide may be coated with one or several layers of electro-active material 115 that are sandwiched by a pair (or more than one pair) of electrodes 113, 114 stacked on the outer and inner surfaces of part of the electro-active material layers 115 to be actuated. The waveguide (*e.g.*, optical fiber) is positioned between one or more holders (such as ferrules or posts) 108 and 112. The fiber may be clamped to at least one holder.

When a voltage is applied to drive the pair of electrodes 113-114, the electrostatic forces between the electrodes may lead to a decrease or an increase of the thickness of the electro-active material 115 that is directly between the electrodes.

As the fiber is clamped between the two holders, the thickness reduction Δy that occurs directly under the pair of electrodes leads to a thickness increase in a location that is remote from the electrodes, as illustrated in **Fig. 5B**. This latter thickness increase changes the distribution of the scattering centers 104 which are positioned in the optical path of the out-coupled light 106 and thus dynamically changes the speckle pattern of the out-coupled light 106.

This results in a dynamic superposition of the first speckle pattern that arises from the first scattering structure 103 (in out-coupled light 106) and the second speckle pattern arising from the second scattering structure 104, thereby yielding an overall speckle contrast reduction of the final illumination light 107.

Static Reduction

In accordance with another embodiment of the invention, an illumination device with reduced speckle noise in the illumination light 107 may be designed, by adapting the size, the refractive index and the concentration of the scattering particles forming the second scattering zone 104 that is inside the coating 102 of the waveguide, or/and the size, the refractive index and the concentration of the first scattering zone 103 so that multiple speckle pattern and polarization states are generated inside one of these scattering zones. This is referred to as a "static" solution because it does not require any relative motion between the speckle sources during operation of the illumination device. In one embodiment, the particle sizes of the second scattering zone, the first scatting zone, or both may be in the range of 1 to 30 microns and a concentration of under 10% in volume. In another embodiment, the particle sizes of the second scattering zone, may be of the order of microns up to several hundreds of micron and a concentration of under 30% in volume. Other particle size and concentrations may be possible.

Figs. 6A and **6B** show two different embodiments where the coating 102 has integrated therein small sized scattering centers (**Fig. 6B**) and large sized scattering centers (**Fig. 6A**). In the case of small sized scattering centers (**Fig. 6B**), the out-coupled light 106 meets with a larger number of scattering centers (higher concentration of scattering centers) in its optical path. The depolarization effect may therefore be stronger and the superposition of multiple speckles patterns may contribute to a reduced speckle contrast. As a side consequence, the use of smaller sized scattering centers (**Fig. 6B**) may lead to a larger diffusion angle α (alpha) relative to the case where larger sized scattering centers are used (**Fig. 6A**).

Adapting the size of the particles that are dispersed in the material of the coating 102, their density and refractive index (forming the scattering zones 104), the overall refractive index of the coating 102, as well as the thickness of the coating 102 enables control of both the speckle contrast and the angle α of the illumination light 107, as illustrated in **Fig. 6A** and **Fig. 6B**).

While certain embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that the invention is not limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those of ordinary skill in the art. For instance, in all the figures mentioned, the scattering zones or centers 103 inside the waveguide are represented as a tilted grating and the scattering zones or centers 104 in the coating are represented by particles. The invention however is not limited to these types or combination of scattering centers. The description is thus to be regarded as illustrative instead of limiting.

CLAIMS

What is claimed is:

1. An illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

means for vibrating a light spot of the coherent light relative to the waveguide, or dynamically changing a focus of the light spot, so that light coupling of the coherent light into the waveguide changes over time thereby generating different speckle patterns in the waveguide that overlap with the first scattering zone.

2. The system of claim 1 wherein the waveguide comprises a core medium in contact with a cladding medium, and the first scattering zone is a laser-induced modification of the core medium that scatters the propagating coherent light.

3. The system of claim 1 wherein the vibrating means is to vibrate the waveguide directly.

4. The system of claim 1 wherein the vibrating means is to directly vibrate a light coupling through which the coherent light is coupled into the waveguide, or directly vibrate a coherent light source, relative to the waveguide.

5. The system of claim 1 further comprising a coating outside the waveguide and having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone.

6. The system of claim 5 wherein the second scattering zone contains photo-luminescence particles.

7. The system of claim 5 wherein the coating is formed on an outer surface the waveguide.

8. The system of claim 5 wherein the coating is spaced apart from an outer surface of the waveguide.

9. An illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

means for dynamically stretching or compressing the in a direction of the longitudinal axis.

10. The system of claim 9 further comprising a coating outside the waveguide and having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone.

11. The system of claim 10 wherein the second scattering zone contains photo-luminescence particles.

12. The system of claim 10 wherein the coating is formed on an outer surface the waveguide.

13. The system of claim 10 wherein the coating is spaced apart from an outer surface of the waveguide.

14. An illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

means for dynamically stretching or compressing the waveguide in a direction that is substantially transverse to the longitudinal axis so that overall speckle contrast of the light that is being scattered out of the waveguide and that illuminates a nearby surface is reduced.

15. The system of claim 14 further comprising a coating outside the waveguide and having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone.

16. The system of claim 15 wherein the second scattering zone contains photo-luminescence particles.

17. The system of claim 15 wherein the coating is formed on an outer surface the waveguide.

18. The system of claim 15 wherein the coating is spaced apart from an outer surface of the waveguide.

19. A waveguide apparatus for an illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

an electro-active coating outside the waveguide having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone.

20. The waveguide apparatus of claim 19 further comprising means for applying a voltage to drive the electro-active coating that causes the coating to dynamically change its shape, thereby reducing overall speckle contrast when the light that is scattered out of the coating illuminates a nearby surface.

21. The apparatus of claim 19 wherein the second scattering zone contains photo-luminescence particles.

22. The waveguide apparatus of claim 19 wherein the coating is formed on an outer surface the waveguide.

23. The waveguide apparatus of claim 19 wherein the coating is spaced apart from an outer surface of the waveguide.

24. A waveguide apparatus for an illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

a coating outside the waveguide having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone, wherein the second scattering zone comprises an outer or inner face of the coating being textured in a way that reduces overall speckle contrast when the light that is scattered out of the coating illuminates a nearby surface, as compared to when the texturing is absent.

25. The waveguide apparatus of claim 24 wherein the coating is formed on an outer surface the waveguide.

26. The waveguide apparatus of claim 25 wherein the coating is spaced apart from an outer surface of the waveguide.

27. The waveguide apparatus of claim 24 wherein the second scattering zone comprises a portion of the coating that contains photo-luminescence particles positioned next to the texturing.

28. A waveguide apparatus for an illumination system, comprising:

a waveguide in which coherent light is to propagate along its longitudinal axis, the waveguide having formed therein a first scattering zone that runs along the longitudinal axis and that is to scatter the propagating coherent light out of the waveguide at a non-zero angle relative to the longitudinal axis; and

a coating outside the waveguide having formed therein a second scattering zone that is positioned to receive the scattered light from the first scattering zone,

wherein a) one of particle size or concentration of scattering centers that define the first scattering zone in the waveguide, and/or b) one of particle size, concentration and refractive index of scattering centers that define the second scattering zone in the coating, have been adapted in such a way that reduces overall speckle contrast when the light that is scattered out of the coating illuminates a nearby surface.

29. The waveguide apparatus of claim 28 wherein the coating is formed on an outer surface the waveguide.

30. The waveguide apparatus of claim 28 wherein the coating is spaced apart from an outer surface of the waveguide.

31. The waveguide apparatus of claim 28 wherein the second scattering zone contains photo-luminescence particles.

32. The waveguide apparatus of claim 28 wherein the coating comprises a polymer matrix with dispersed particles therein that define the second scattering zone.

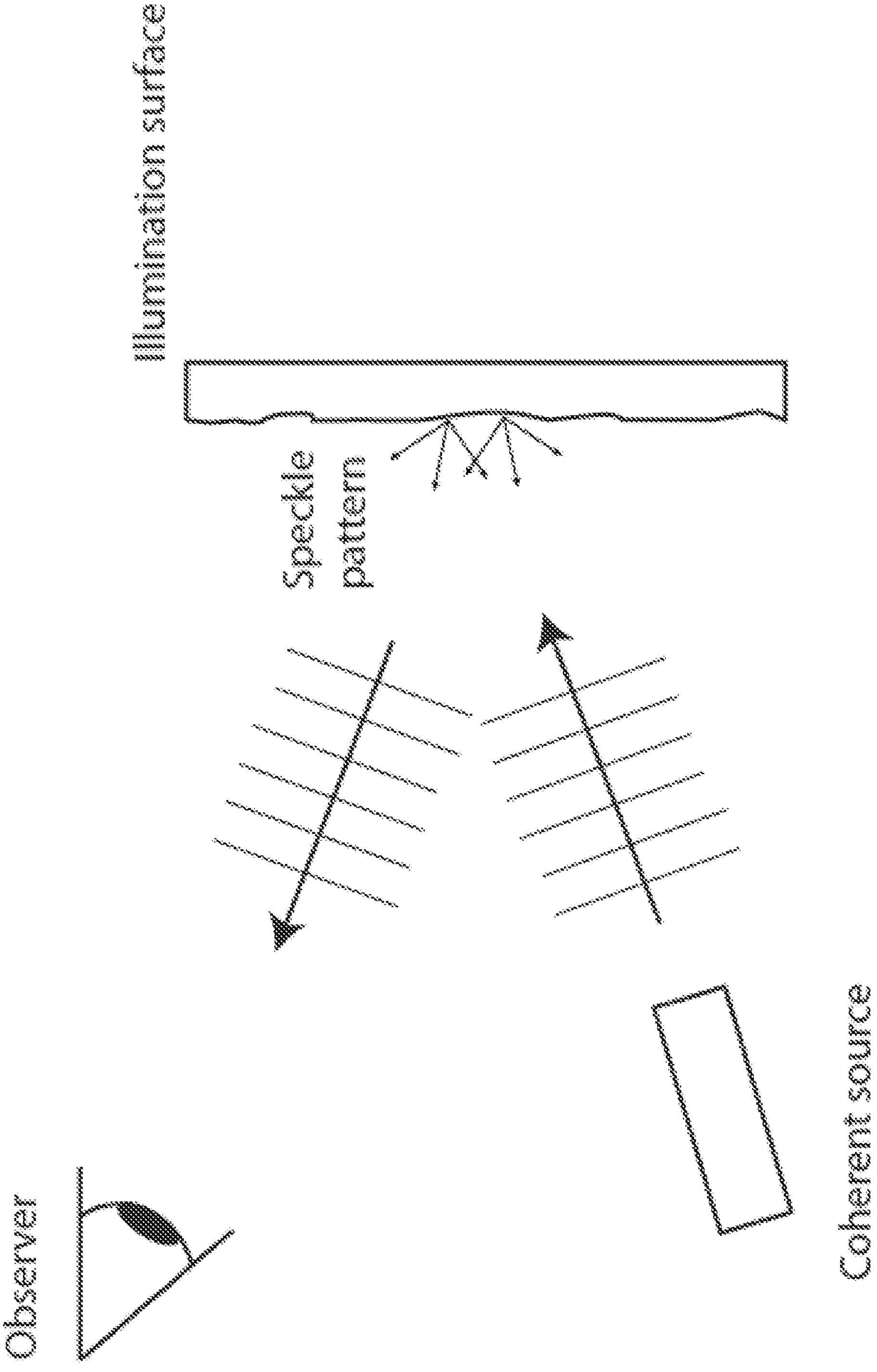

Illumination surface
Speckle pattern
Coherent source
Observer

Fig. 1

Fig. 2a

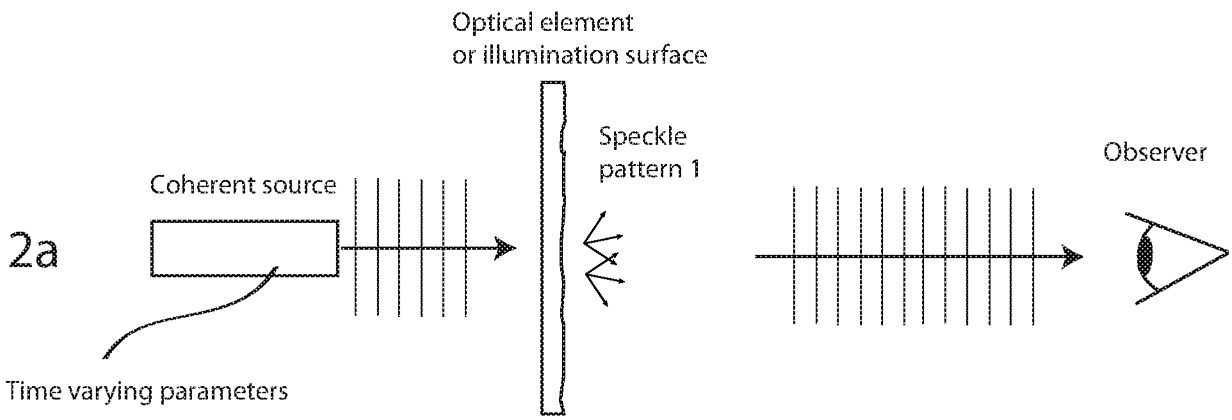


Fig. 2b

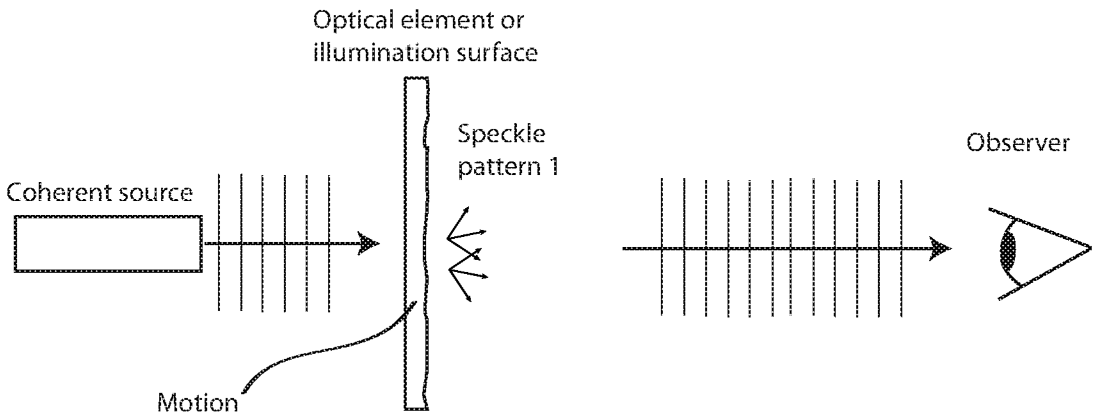
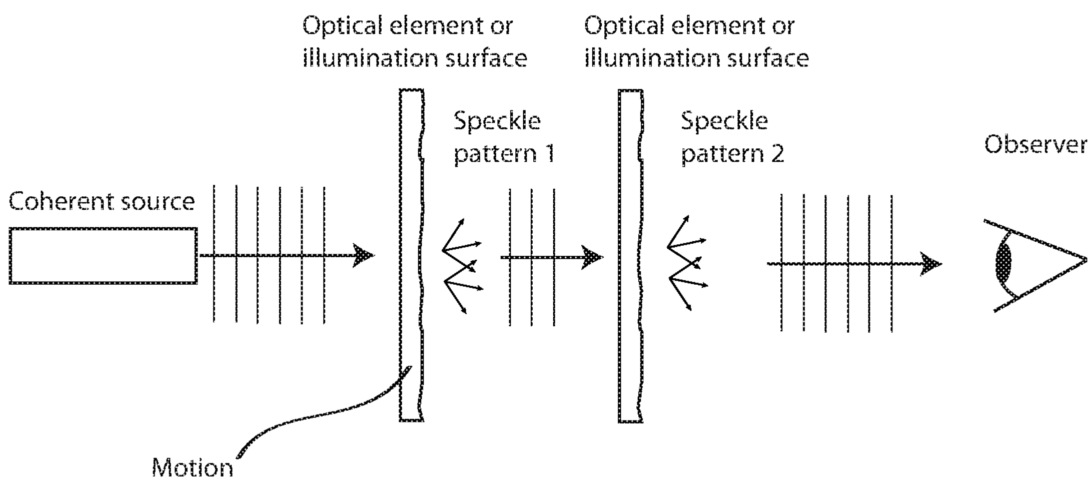


Fig. 2c



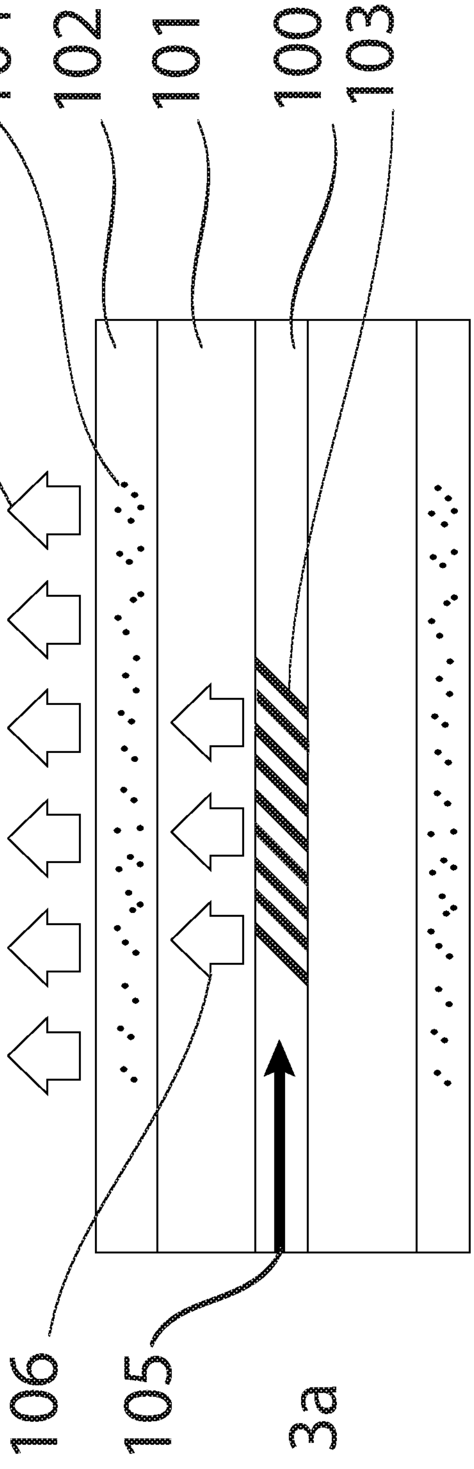


Fig. 3a

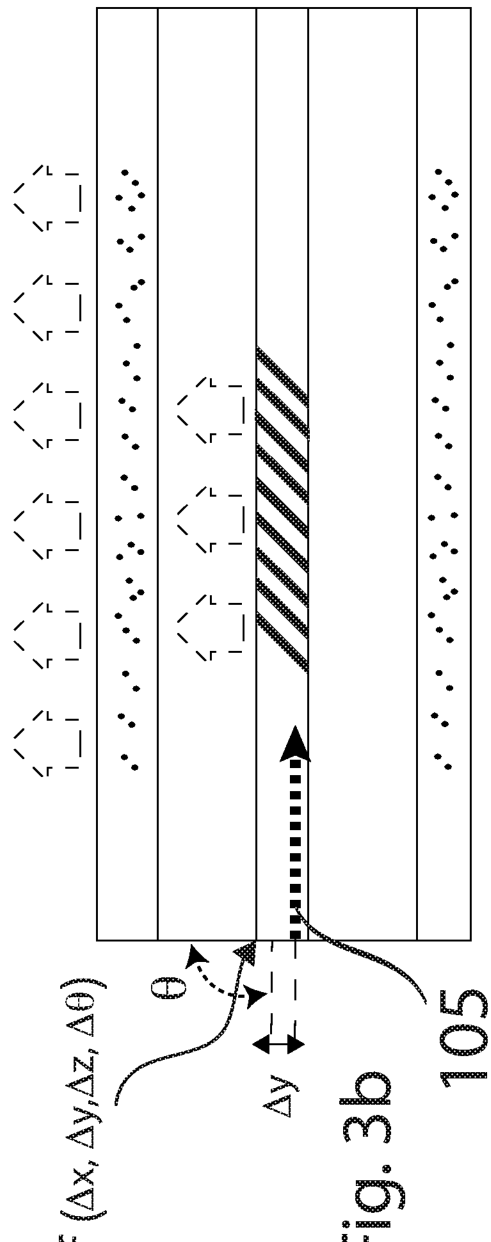


Fig. 3b

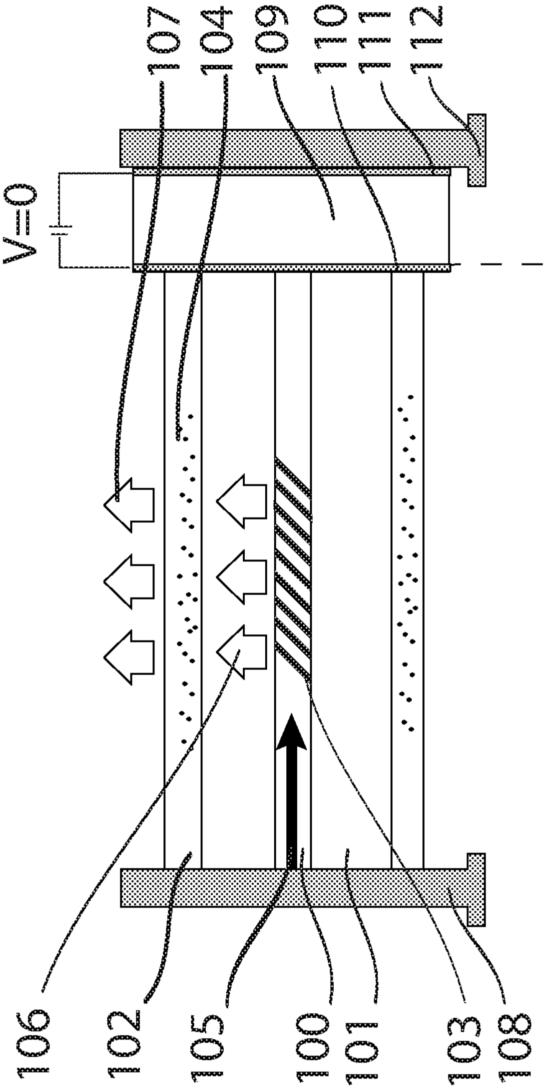

V=0
107
104
109
110
111
112
106
102
105
100
101
103
108

Fig. 4a

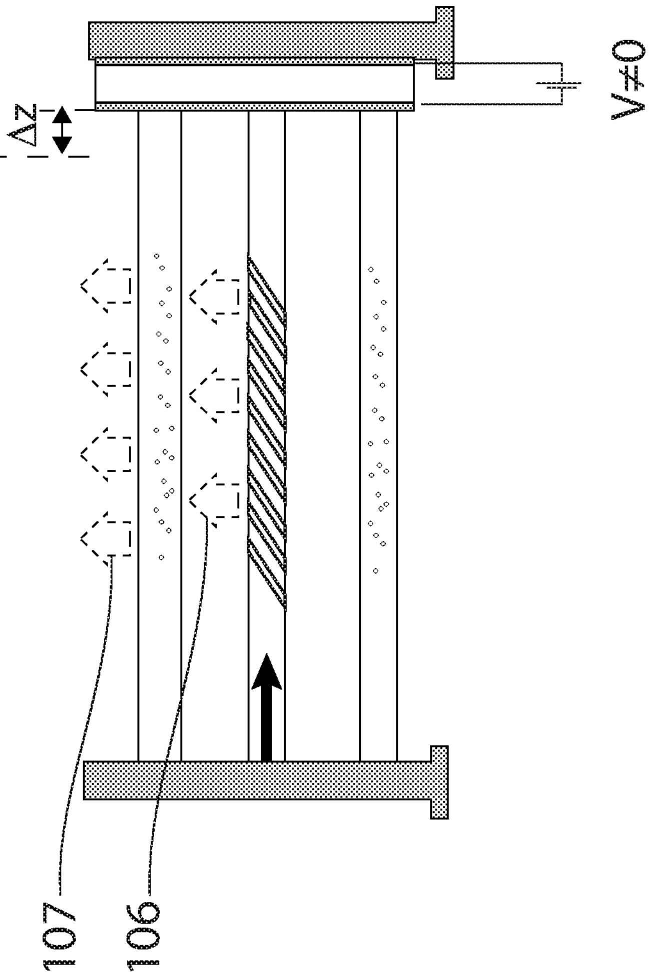

Δz
V≠0
107
106

Fig. 4b

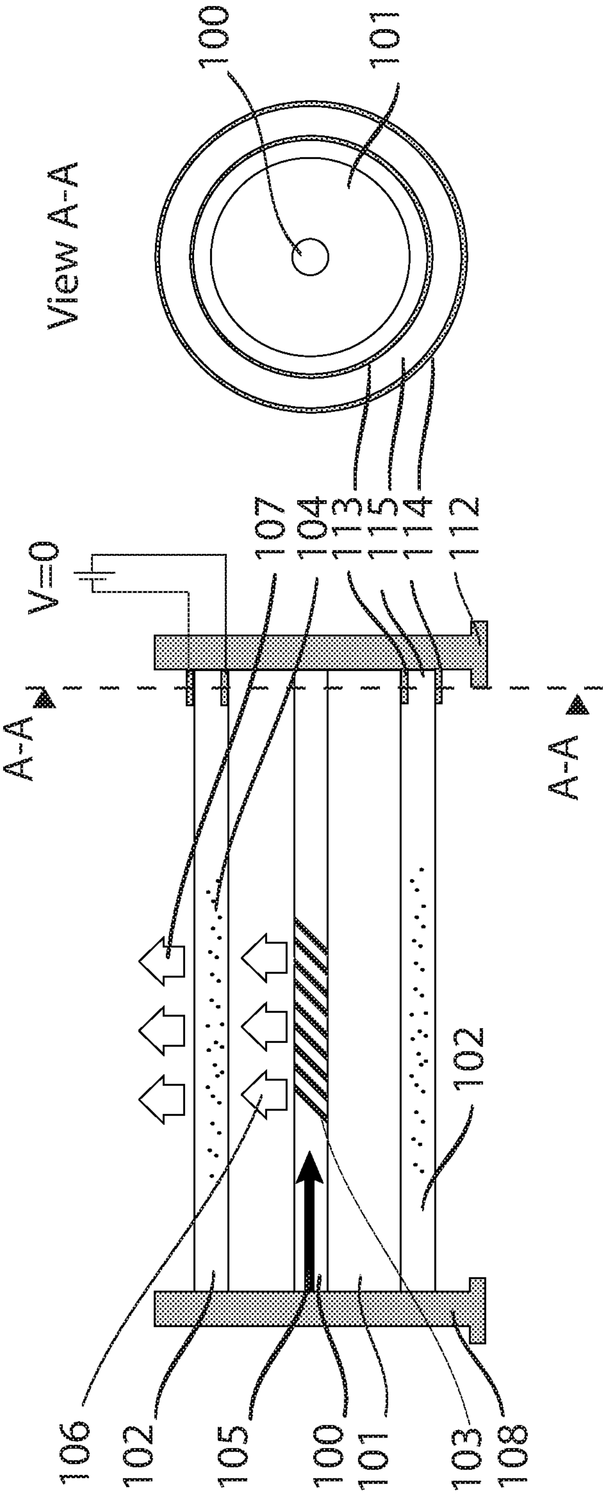

View A-A
100
101
113
115
114
V=0
107
104
113
115
114
112
A-A
A-A
102
106
102
105
100
101
103
108

Fig. 5a

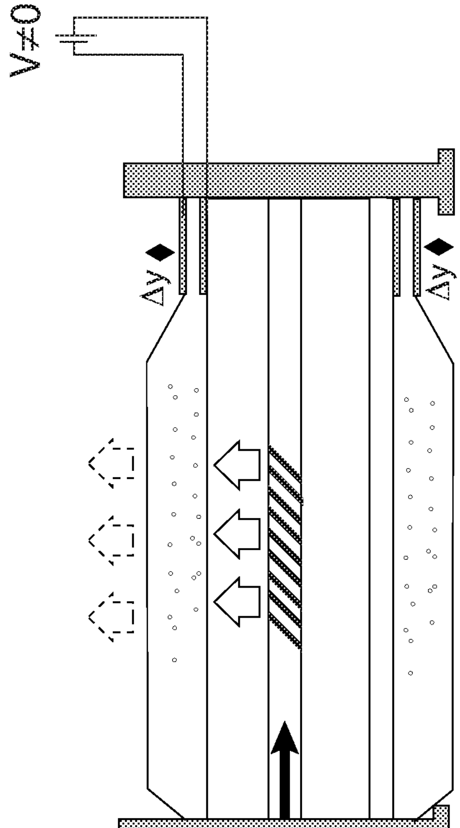

V≠0
Δy
Δy

Fig. 5b

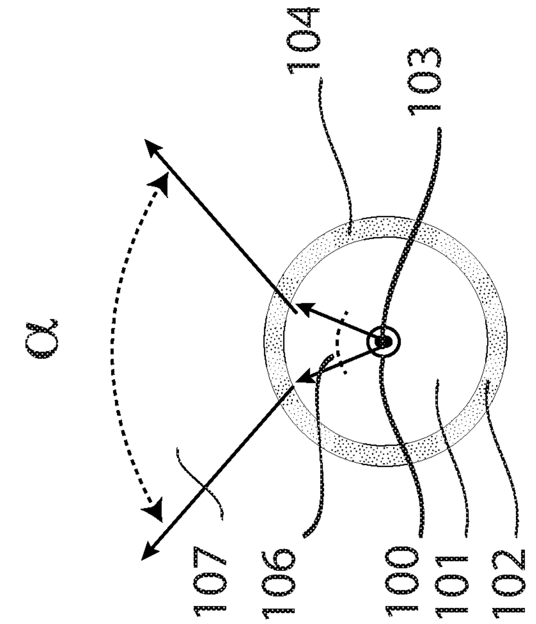


Fig. 6b

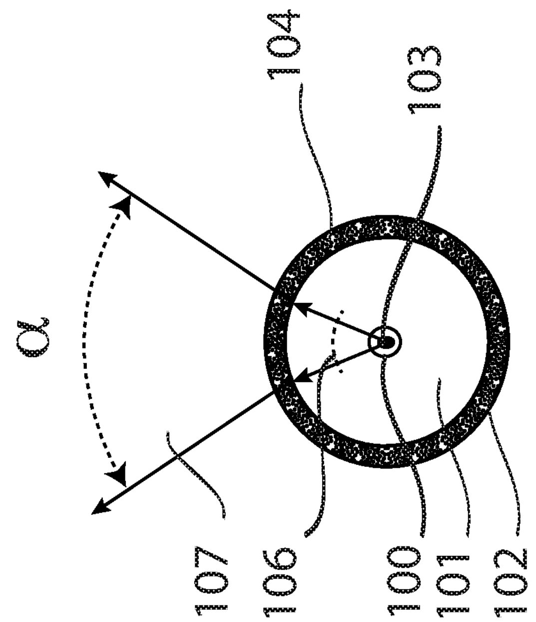


Fig. 6a

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/063098

A. CLASSIFICATION OF SUBJECT MATTER
INV. F21V8/00
ADD.

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 A61B G02F

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 2010/238374 A1 (OHSE NORIHIRO [JP]) 23 September 2010 (2010-09-23) abstract; figures 6,2	1-18
Y	US 2013/003343 A1 (SUDARSHANAM VENKATAPURAM [US] ET AL) 3 January 2013 (2013-01-03) paragraphs [57&81] - [0083]; figures 17,18, 22, 13,15	1,3,14
Y	US 4 011 403 A (EPSTEIN MAX ET AL) 8 March 1977 (1977-03-08) abstract; figure 1	1,4
Y	EP 2 399 508 A1 (FUJIFILM CORP [JP]) 28 December 2011 (2011-12-28) abstract; figures 16-19	9,14
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2014	08/01/2015

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	Elflein, Wilhelm

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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.
X	WO 2012/146960 A1 (TISSOT YANN [CH]) 1 November 2012 (2012-11-01) cited in the application	19,21-23
Y	abstract; figure 1	2,5-8, 10-13, 15-18
A		20
A	US 4 726 651 A (WEI TA-SHENG [US] ET AL) 23 February 1988 (1988-02-23) abstract	19

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2014/063098

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2010238374	A1	23-09-2010	CN	101839407 A	22-09-2010
			JP	2010218980 A	30-09-2010
			US	2010238374 A1	23-09-2010
US 2013003343	A1	03-01-2013	US	2013003343 A1	03-01-2013
			WO	2012100261 A1	26-07-2012
US 4011403	A	08-03-1977	NONE		
EP 2399508	A1	28-12-2011	CN	102293623 A	28-12-2011
			EP	2399508 A1	28-12-2011
			JP	5417268 B2	12-02-2014
			JP	2012005785 A	12-01-2012
			US	2011319712 A1	29-12-2011
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			JP	2014523603 A	11-09-2014
			US	2014092620 A1	03-04-2014
			WO	2012146960 A1	01-11-2012
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			DE	3277241 D1	15-10-1987
			EP	0084736 A1	03-08-1983
			JP	H0339282 B2	13-06-1991
			JP	S58127902 A	30-07-1983
			US	4726651 A	23-02-1988

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2014/063098

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-23

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-23

   An illumination system comprising a waveguide having a first scattering zone, andmeans for vibrating a light spot of the coherent light relative to the waveguide, or dynamically changing a focus of the light spot (i.e. the combination of features of claim 1).

   ---

2. claims: 24-32

   An illumination system comprising a waveguide having a first scattering zone, anda coating outside the waveguide having formed therein a second scattering zone wherein the coating is textured.
