(72) Inventors: DI TRAPANI, Paolo; Via Sarfatti 2, 22020
Cavallasca (IT). FOLCIO, Franco; Via Arcellazzi 27,
22035 Canzo (IT). BONANOMI, Simone; Via Cellini
2/B, 20835 Muggiò (IT).

(54) Title: STRATIFIED PANEL STRUCTURE FOR SUN-SKY-IMITATING LIGHTING SYSTEMS
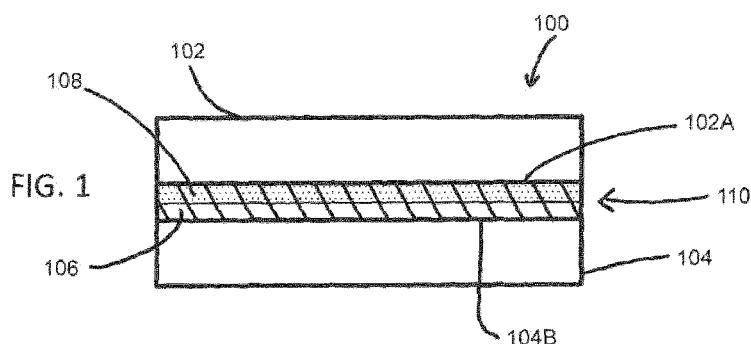
FIG. 1

(57) Abstract: A chromatic stratified panel structure(100) for generating a sun-sky-imitating effect in lighting systems (1) comprises
two cover panels (102, 104) at least one of which being a transparent panel; an adhesive transparent polymeric layer (106) sand-
wiched between the two inner faces of the two cover panels; and at least one nanoparticle-based Rayleigh-like diffusing coating
(108) applied to an inner face of at least one of the two cover panels (102, 104) and/or to a face of the adhesive transparent polymer-
ic layer (106) and forming an interlayer between one of the cover panels (102, 104) and the adhesive transparent polymeric layer
(106).

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Description

STRATIFIED PANEL STRUCTURE FOR
SUN-SKY-IMITATING LIGHTING SYSTEMS

Technical Field

[01]   The present disclosure relates generally to lighting systems, in particular to lighting systems for optically providing a widened perception/impression of the ambient space and in particular for imitating natural sunlight illumination. Moreover, the present disclosure relates generally to panel structures such as glass structures with chromatic features.

Background

[02]   Several applications of the applicants such as EP 2 304 478 A1, EP 2 304 480 A1, and WO 2014/076656 A1 disclose lighting systems that use a light source producing visible light, and a panel containing nanoparticles used in transmission, i.e. the light source and the illuminated area are positioned on opposing sides of the panel.

[03]   Further applications such as the not yet published PCT applications PCT/EP2014/059802 filed on 13 May 2015 and to be published on 19 November 2015 or PCT/EP2015/000407 filed on 23 February 2015 disclose lighting systems that use a light source producing visible light, and a chromatic mirror structure containing nanoparticles used in reflection.

[04]   During operation of those lighting systems, the panel receives the light from the light source and acts in transmission as a so-called Rayleigh diffuser, namely it diffuses light rays similarly to the earth atmosphere in clear-sky conditions. Specifically, the concept uses directional light with lower correlated color temperature (CCT), which corresponds to sunlight and generates shadows in presence of lit objects, and diffuse light with larger CCT, which corresponds to the light of the blue sky and, in principal, can generate shadows with a blue tinge.

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[05]   Generally it is known that coatings can provide properties such as anti-scratch, anti-fog, flame retardant, anti-reflection, optical features and the like. Furthermore, dispersing absorbing pigments in a resin gives the possibility to make chromatic coatings by modifying the spectrum of impinging light on the coating by absorption. Another way to chromatically modifying the spectrum of impinging light is to use nano-sized particles able to diffuse light by Rayleigh-like scattering.

[06]   The present disclosure is directed, at least in part, to improving or overcoming one or more aspects of prior systems.

Summary of the Disclosure

[07]   Some or all of those aspects are addressed by the subject-matters of the independent claims. Further developments of the invention are given in the dependent claims.

[08]   Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[09]   The accompanying drawings, which are incorporated herein and constitute a part of the specification, illustrate exemplary embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure. In the drawings:

            Fig. 1 is a schematic illustration of a stratified panel structure;

            Figs. 2A and 2B are schematic illustration of exemplarily lighting systems using a Rayleigh-like acting panel in transmission and reflection configurations, respectively;

            Figs. 3A to 4C are schematic illustrations of panel structures with one or two nanoparticle-based Rayleigh-like diffusing coatings provided as interlayers;

            Figs. 5 is an overview of three support materials for exemplary panel structures;

            Figs. 6 is an overview of an exemplary coatings to be applied on selective surfaces of the support materials;

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Figs. 7A to 7F is an overview of exemplary panel structure configurations using an adhesive polymeric layer as an interlayer;

Fig. 8 is an overview of modifications of an adhesive polymeric layer to perform itself Rayleigh-like scattering; and

Figs. 9A to 9E is an overview of further exemplary panel structure configurations using the modified adhesive polymeric layer as an interlayer;

Fig. 10 is a schematic illustration of a further stratified panel structure.

Detailed Description

[10]   The following is a detailed description of exemplary embodiments of the present disclosure. The exemplary embodiments described therein and illustrated in the drawings are intended to teach the principles of the present disclosure, enabling those of ordinary skill in the art to implement and use the present disclosure in many different environments and for many different applications. Therefore, the exemplary embodiments are not intended to be, and should not be considered as, a limiting description of the scope of patent protection. Rather, the scope of patent protection shall be defined by the appended claims.

[11]   The disclosure is based in part on the realization that compact configurations of the herein disclosed Rayleigh-like scattering feature will allow downsizing of lighting systems using the Rayleigh-like scattering feature for sun–sky-imitation effects.

[12]   In particular it was realized that implementing the Rayleigh-like scattering based on a coating provided within a sandwich structure such as a stratified glass structure may allow protection of the Rayleigh-like scattering layer as well as simplification of production processes as well as an increase in quality of the homogeneity of the Rayleigh-like scattering layer.

[13]   The basic configuration of a chromatic stratified panel structure 100 for generating the sun-sky-imitation possible comprises two cover panels 102, 104. At least one of the two cover panels 102, 104 is configured to provide for the required transmission, i.e. is a transparent panel such as a glass sheet.

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[14]   An adhesive transparent polymeric layer 106 is sandwiched between two inner faces 102A, 104B of the two cover panels 102, 104. At least one nanoparticle-based Rayleigh-like diffusing coating 108 is applied to one of the inner face 102A, 104B of at least one of the two cover panels 102, 104. Alternatively or additionally, nanoparticle-based Rayleigh-like diffusing coating may be applied to a face of adhesive transparent polymeric layer 106 that prior formation of stratified panel structure 100 is a self-supporting structure and, thus, can act, for example, as a support material for a coating. Nanoparticle-based Rayleigh-like diffusing coating 108, therefore, forms an interlayer between one of the cover panels 102, 104 and adhesive transparent polymeric layer 106. In brief, a four-layer system with the Rayleigh-like diffusing coating/paint is disclosed where the coating/paint is protected inside the stratified e.g. glass structure. In Fig. 1, the layers between cover panels 102, 104 are herein referred to as an adhesive interlayer 110.

[15]   Before describing further details and embodiments of chromatic stratified panel structure 100, exemplary sun-sky-imitation lighting system are disclosed. In connection with Fig. 2A, a lighting system in transmission mode with respect to chromatic stratified panel structure 100 is disclosed, and in connection with Fig. 2B, a lighting system in reflection mode with respect to chromatic stratified panel structure 100 is disclosed.

[16]   Referring to Fig. 2A, a lighting system 1 is illustrated schematically in a cut view of a room 30.

[17]   In detail, lighting system 1 comprises a first light source 2, configured to emit light in an emission solid angle to form a light beam 3 propagating along a main light beam direction 4. Moreover, first light source 2 emits light in the visible region of the light spectrum, for example, with wavelengths between 400 nm and 700 nm. Moreover, first light source 2 emits light (visible electromagnetic radiation) with a spectral width preferably larger than 100 nm, more preferably higher than 170 nm. The spectral width may be defined as the standard deviation of the first light source's wavelength spectrum.

[18]   For further details of the exemplary lighting system 1 it is referred to WO2015135560 such as with respect to a lamp shade-like structure 10 with a bottom unit 12 and a screen structure 14 as well as (dark) box 16 and a screen structure 14.

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[19]   Bottom unit 12 comprises a diffused light generator based on chromatic stratified panel structure 100 disclosed herein and operates as a Rayleigh-like diffuser, which substantially does not absorb light in the visible range and which diffuses more efficiently the short-wavelength in respect to the long-wavelength components of the impinging light, e.g. a panel which substantially does not absorb light in the visible range and which diffuses light at the wavelength 450 nm (blue) at least 1.2 times, for example at least 1.4 times, such as at least 1.6 times more efficiently than light in the wavelength range around 650 nm (red), wherein a diffusion efficiency is given by the ratio between the diffused light radiant power with respect the impinging light radiant power. Optical properties and microscopic characteristic of Rayleigh like diffusers are also described in detail in the patent application EP 2 304 478 A1 mentioned above. A further insight on the microscopic features is also provided in what follows.

[20]   Chromatic stratified panel structure 100 will separate an incident light beam 3 of light source 2 in four components, particularly in:

          a transmitted (directed non-diffuse) component (light beam 3A), formed by light rays that pass through and do not experience significant deviations, e.g. is formed by light rays experiencing a deviation smaller than 0.1 °; a luminous flux of the transmitted component is a significant fraction of the overall luminous flux incident on diffused light generator 20;

          a forward diffuse component, formed by scattered light propagating into lightwell 40/room 30 (with the exception of that light beam direction and of directions differing from that light beam direction by an angle smaller than 0.1 °); a luminous flux of the forward diffuse component corresponds to a blue skylight fraction generated from the overall luminous flux incident on chromatic stratified panel structure 100;

          a backward diffuse component, formed by scattered light propagating into box 16; a luminous flux of the backward diffuse component is, in general, in the range of but preferably less than the blue skylight fraction; and

          a reflected component, formed by reflected light and propagating along a direction at a mirror angle into box 16, a luminous flux of the reflected component depends,

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for example, on the incident angle of the light beam onto chromatic stratified panel structure 100.

[21]   That having being stated, the optical properties of chromatic stratified panel structure 100 are such that

the blue skylight fraction is within the range from 5 % to 50 %, such within the range from 7 % to 40 %, or even in the range from 10 % to 30 %, or within the range from 15 % to 20 %;

the average CCT of the forward diffuse component is significantly higher than the average correlated color temperature CCT of the transmitted component, for example it may be higher by a factor of 1.2, or 1.3, or 1.5 or more;

chromatic stratified panel structure 100 does not absorb significantly incident light, namely the sum of the four components is at least equal to 80 %, or 90 %, or even 95 %, or 97 % or more;

chromatic stratified panel structure 100 scatters mostly forward, namely more than 1.1, or 1.3, or eve 1.5, or 2 two times more than is back scattered; and

chromatic stratified panel structure 100 may have low reflection, namely less than a portion of 9 %, or 6 %, or even less than 3 %, or 2 % of the impinging light is reflected.

[22]   Referring to Fig. 2B, aspects of an optical setup as well as the perceptive aspects of illuminations systems as generally described herein are described for a reflective lighting system 1.

[23]   Lighting system 1 comprises again light source 2, configured to emit light in an emission solid angle to form a light beam 3 (in Fig. 1 delimited by dashed lines 13) propagating along a main light beam direction 4 (also referred to as main beam axis). Generally, light source 2 can be, for example, a cool white light source. Exemplary embodiments of light sources may comprise LED based light emitters or discharge lamp based light emitters or hydrargyrum medium-arc iodide lamp based light emitters or halogen lamp based light emitters and respective optical systems downstream of the respective light emitter.

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[24]   To reduce the dimension of illumination system 1, the optical systems downstream of the respective light emitter may include an optical system such as folding optics (see also Fig. 2A) Illumination system 1 further includes a reflector unit 6 that couples the light originating from light source 2 to a region to be lit up. In general, reflector unit 6 comprises a reflective structure 8 providing a reflective surface 8A and chromatic stratified panel structure 100.

[25]   Reflective surface 8A is generally any type of optical acting interface that reflects light having passed through adhesive interlayer 110. For example, reflective surface 8A may be a surface of an aluminum layer or an interface between components, such as a reflective coating. Due to reflective surface 8A, light of light beam 3 being incident on reflective surface 8A is redirected to pass again through chromatic stratified panel structure 100, thereafter forming an illuminating light beam 3A (in Fig. 2B delimited by dash-dash-dotted lines 7A). In Fig. 1, a range 7 of sun-observer locations is illustrated, where it is referred in the wording "sun-observer locations" exemplarily to the "sun" because an especially impressive type of embodiments of lighting system 1 relates to sun-like illumination. Illuminating light beam 3A is, thus, directed in the to be illuminated region and comprises directed light (herein also referred to as directed (light) component of the lighting system).

[26]   Chromatic stratified panel structure 100 is generally configured for emitting diffuse light (later also referred to as diffuse (light) component of the illumination system) at a first color, e.g. in case of a sky imitation a bluish sky color, extends in front of reflective surface 8A, and comprises a visible front area section 100A that an observer can see when looking at reflector unit 6. In the exemplary embodiment of Fig. 1, a frame-like area 14A of a frame structure 14 extends next to and surrounding visible front area section 100A.

[27]   For example, the first color and the second color may be separated in the CIE 1976 (u',v') color space by, at least 0.008 such as at least 0.01, 0.025, or 0.04, where the color difference $\Delta u'v'$ is defined as the Euclidean distance in the u'v' color space. In particular for sun-imitation configurations, the illuminating light beam CCT of the second color may be close to the Planckian locus (e.g. in the range from 800 K to 6 500 K). In some

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embodiments the second color may correspond to u'v' points with a maximum distance from the Planckian locus of e.g. 0.06. In other words, a distance from the Planckian locus is, for example in the range from 800 K to 6500 K, given by $\Delta u'v' \leq 0.060$.

[28]   As it is apparent to the skilled person, depending on the specific interaction of chromatic stratified panel structure 100 with light beam 3, the color and/or CCT of light beam 3 and illuminating light beam 3A may be essentially identical or may differ. Depending from the type of nanoparticles and their concentration, the CCT difference may be, for example, at least 300 K or even 1 000 K or more.

[29]   Looking from within range 7 onto reflector unit 6, an observer may have an optical perception as schematically indicated in Fig. 2B within range 7. The optical perception essentially depends on reflector unit 6 and the light coming therefrom as illustrated by dash-dotted lines 7B being specific for the respective observer position. Specifically, lighting system 1 is configured such that light of significant intensity incident within range 7 of sun-observer locations originates from chromatic stratified panel structure 100. The light of significant intensity comprises light of light beam 3A (originating from light source 2 and being light of light beam 3 redirected by reflector unit 6), and diffuse light originating from visible front area section 10A. In addition, the optical perception will – for the embodiment of Fig. 1 – comprise a, for example dark colored, frame-like area 18 around visible front area section 100A.

[30]   In line with the optical perception illustrated in Fig. 2B, the observer, when looking from within range 7 of sun-observer locations onto reflector unit 6, will see a large area 16 corresponding to visible front area section 10A based on the homogenously emitted diffuse light at the first color. Large area 16 will be surrounded by frame-like area 18. In addition, the observer will see a sun-like spot 19 at the second color caused by the a reflected (directed non-diffuse) component of the light of light source 2, specifically of illuminating light beam 3A.

[31]   Nanoparticle-based Rayleigh-like diffusing material used in the chromatic stratified panel, comprises a solid matrix of a first material (e.g. resins having excellent optical transparency), wherein nanoparticles of a second material (organic or inorganic

nanoparticles such as ZnO, TiO_2, SiO_2, Al_2O_3 and similar) are dispersed. The refractive indexes of the two materials are different, and this mismatch on the refractive index on the nano-scale is responsible of the Rayleigh-like scattering phenomenon. The absorption of the first and the second material in the visible wavelength range can be considered negligible. Moreover the chromatic stratified panel 100 may be uniform, in the sense that, given any point of the chromatic stratified panel, the physical characteristics of the panel in that point does not depend on the position of that point. The nanoparticles may be monodisperse or polydisperse, they may be spherically shaped or shaped otherwise. In any case the effective diameter d of the nanoparticles falls within the range [5 nm-350 nm], such as [10 nm-250 nm], or even [40 nm-180 nm], or [60 nm-150 nm], where the effective diameter d is the diameter of the equivalent spherical particle, namely the effective diameter spherical particle having similar scattering properties as the aforementioned nanoparticles.

[32]   Diameter, refractive index mismatch and areal density (number per square meter) of the nanoparticles are the parameters that define the cross section of the scattering phenomenon in the chromatic panel. In addition, the amount of the impinging light scattered from the chromatic panel increases by increasing one of the parameters mentioned above. In order to simplify the description we can consider just the regular transmittance property $T(\lambda)$ of the material at a certain wavelength. Herein, as defined in the Standard Terminology of Appearance, ASTM international, E 284 – 09a, the transmittance is in general the ratio of the transmitted flux to the incident flux in the given conditions. The regular transmittance $T(\lambda)$ is the transmittance under the undiffused angle, $i.e.$ the angle of incidence. In the context of the present disclosure, for a given wavelength and a given position on the chromatic diffusing layer, the regular transmittance is intended for non-polarized incident light with an incident angle corresponding to the main light beam propagation.

[33]   To obtain a sun-sky-imitation lighting system, some particular range of regular transmittance are required. Note that both the first material (the matrix) and the second material (nanoparticles) are almost non-absorbing in the visible range, so the portion of the light that is not regular transmitted is totally scattered in the Rayleigh-like scattering mode. Regarding the transmission configurations as the one described in Fig. 2A the regular

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transmittance for the blue T[450 nm] may be in general within the range [0.05-0.9]. In particular in some embodiments aiming at a pure clear sky the range would be [0.3-0.9], such as [0.35-0.85] or even [0.4-0.8]; in the embodiments aiming at a Nordic sky the range would be [0.05-0.3], such as [0.1-0.3] or even [0.15-0.3]. Since the transmittance measurement is a feasible way to evaluate the optical properties of the presented materials, herein this approach is applied similarly to the reflective chromatic stratified panels.

[34]   Considering that in the reflection configuration (Fig. 2B) the nano-loaded scattering coating is crossed twice by an impinging light (due to the presence of the mirror), in order to obtain comparable transmittance data with respect to the transmission configuration, the mirror coating has to be removed. The regular transmittance for the blue T[450 nm] of a chromatic stratified panel before the mirroring of the outer surface may be in general within the range [0.2-0.95]. In particular in some embodiments aiming at a pure clear sky the range would be [0.55-0.95], such as [0.6-0.92] or even [0.62-0.9]; in the embodiments aiming at a Nordic sky the range would be [0.2-0.55], such as [0.3-0.55] or even [0.4-0.55]. The transmittance of a pure clear sky is higher than the one of a Nordic sky. For example, considering the same light source impinging on two chromatic stratified panels, one in the pure clear sky configuration and one in Nordic configuration, the chromatic properties in the sun-sky effect will be different. The sky in the Nordic configuration will be whitish compared to the one in the pure clear sky. The sun in the Nordic configuration will be more yellow than the one in the pure clear sky.

[35]   Combining the above features of the nanoparticle-based Rayleigh-like diffusing coating with the structural features disclosed herein may allow addressing one or more aspects of the prior art as will be exemplarily described below for various exemplary embodiments.

[36]   The chromatic effect is further based on nanoparticles having a refractive index that is different than the refractive index of the embedding matrix. To scatter, the nanoparticles have a real refractive index n_p sufficiently different from that of the matrix n_h, (also referred to as host material) in order to allow light scattering to take place. For

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example, the ratio m between the particle and host medium refractive indexes (with $m \equiv \frac{n_p}{n_h}$)

may be in the range $0.5 \leq m \leq 2.5$ such as in the range $0.7 \leq m \leq 2.1$ or $0.7 \leq m \leq 1.9$.

[37]   The chromatic effect is further based on the number of nanoparticles per unit area seen by the impinging light propagating in the given direction as well as the volume-filling-fraction f. The volume filling fraction f is given by $f = \frac{4}{3}\pi(\frac{d}{2})^3 \rho$ with ρ [meter^{-3}] being the number of particles per unit volume. By increasing f, the distribution of nanoparticles in the diffusing layer may lose its randomness, and the particle positions may become correlated. As a consequence, the light scattered by the particle distribution experiences a modulation which depends not only on the single-particle characteristics but also on the so called structure factor. In general, the effect of high filling fractions is that of severely depleting the scattering efficiency. Moreover, especially for smaller particle sizes, high filling fractions impact also the dependence of scattering efficiency on wavelength, and on angle as well. One may avoid those "close packing" effects, by working with filling fractions $f \leq 0.4$, such as $f \leq 0.1$, or even $f \leq 0.01$.

[38]   The chromatic effect is further based on a number N of nanoparticles per unit area of the chromatic diffusive layer in dependence of an effective particle diameter $D = d$ n_h. Thereby, d [meter] is the average particle size defined as the average particle diameter in the case of spherical particles, and as the average diameter of volume-to-area equivalent spherical particles in the case of non-spherical particles, as defined in [T.C. GRENFELL, AND S.G. WARREN, "Representation of a non-spherical ice particle by a collection of independent spheres for scattering and absorption of radiation". Journal of Geophysical Research 104, D24, 31,697–31,709. (1999)]. The effective particle diameter is given in meters or, where specified in nm.

[39]   In some embodiments: $N \geq N_{min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given

in [$meters$]) and $N \leq N_{max} = \frac{2.03 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]

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[40]   Considering the transmission configuration:

[41]   For example, for embodiments aiming at simulating the presence of a pure

clear sky, $N \geq N_{min} = \dfrac{7.13 \times 10^{-29}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{max} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}] such as $N \geq N_{min} = \dfrac{1.10 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}]

and $N \leq N_{max} = \dfrac{7.11 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{min} = \dfrac{1.51 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}] and $N \leq N_{max} = \dfrac{6.20 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}].

[42]   In other embodiments aiming at simulating a Nordic sky,

$N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{max} = \dfrac{2.03 \times 10^{-27}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}] such as $N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}]

and $N \leq N_{max} = \dfrac{1.56 \times 10^{-27}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}] and $N \leq N_{max} = \dfrac{1.28 \times 10^{-27}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}].

[43]   Considering the reflection configuration:

[44]   For example, for embodiments aiming at simulating the presence of a pure

clear sky, $N \geq N_{min} = \dfrac{3.47 \times 10^{-29}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{max} = \dfrac{4.05 \times 10^{-28}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}] such as $N \geq N_{min} = \dfrac{5.65 \times 10^{-29}}{D^6} \left| \dfrac{m^2+2}{m^2-1} \right|^2$ [meters^{-2}]

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and $N \leq N_{\text{max}} = \dfrac{3.46 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{\text{min}} = \dfrac{7.13 \times 10^{-29}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq N_{\text{max}} = \dfrac{3.13 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}].

[45]   In other embodiments aiming at simulating a Nordic sky,

$N \geq N_{\text{min}} = \dfrac{4.05 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{\text{max}} = \dfrac{1.03 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] such as $N \geq N_{\text{min}} = \dfrac{4.05 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]

and $N \leq N_{\text{max}} = \dfrac{7.71 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{\text{min}} = \dfrac{4.05 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq N_{\text{max}} = \dfrac{6.37 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}].

[46]   Summarizing, a light beam passing through a diffusive coating will generate scattered light and transmitted light. The coating features can modify both the spectral properties and the intensity distribution of the transmitted light. In particular the morphology of the coating (i.e. flatness, smoothness or orange peel) may give rise to a phase variation, which implies a modulation of the intensity distribution of the transmitted light. In other words, if the faces of a layer are not parallel, and in particular if there is a modulation in the thickness of that layer, then focusing and defocusing effects occur for an impinging light beam. If a flat top uniform illumination profile passes through such a layer that has a thickness modulation, the outgoing profile has intensity disuniformity.

[47]   For the application of sun-sky-imitation, the uniformity in the transmission of an illumination profile is an important feature, if not a feature of paramount importance.

[48]   The inventors realized that, when considering a rough (non-planar on a small scale) surface, the phase variation for a light beam increases by increasing the index

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mismatch between the two media separated by the rough surface. If a coating is exposed to the air, then the mismatch is the one between the coating and the refractive index of air. The inventors realized that a reduction of the refractive index mismatch will decrease the phase variation, and thus it will increase the uniformity in transmission (double transmission in the case of reflective configurations).

[49]   Accordingly, the inventors suggest herein inter alia a configuration for a flat transparent support coated with a diffusive paint in which any modifications and distortions of a light beam passing through the coating is reduced due to refractive index adaptation.

[50]   With respect to the various layers, it is referred to the respective sections below. In the following, two simplified process for manufacturing chromatic stratified panel structure 100 are disclosed exemplarily for a stratified glass structures.

[51]   In the first exemplary process illustrated in Fig. 3A, a glass sheet 202 is coated with a nanoparticle loaded (hereinafter nano-loaded) diffusive paint 208 (herein also referred to as coating when its dry form is considered). A transparent adhesive polymeric layer 206 (such as a PVB, EVA or similar) is sandwiched between this coated glass 202 and another glass sheet 204 wherein coating 208 is in contact with adhesive layer 206. Through a lamination process, adhesive layer 206 joins the two glass sheets 202, 204. Since the refractive index mismatch between coating 208 and adhesive layer 206 is much lower than the one that would be present between coating 208 and the air and further considering that the flatness of an outer surface of the glass sheets 202, 204 can be achieved much higher than the one achievable with a coating, the intensity profile of a light beam 3 passing through this stratified glass panel structure remains almost unmodified.

[52]   In the second exemplary process illustrated in Fig. 3B, a transparent adhesive polymeric layer 206 (such as a PVB, EVA or similar) is coated with nano-loaded diffusive paint 208. Transparent adhesive polymeric layer 206 is then sandwiched between two glass sheets 202, 204. Through a lamination process, adhesive layer 206 joins the two glass sheets 202, 204. Again, light beam 3 passing through this stratified glass panel structure remains almost unmodified in terms of intensity distribution.

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[53]   The result for both process can be, for example, a safety dichroic glass sheet with the structure as shown in Fig. 1.

[54]   In this system configuration, the diffusing layer may be protected against atmospheric agents like UV light, dust, humidity and so on, which could change the chromatic and optical properties of the diffusing layers. Furthermore the panel may be strong enough in order to fulfill architectural requirements such as fire resistance, shock resistance, scratch resistance and the like.

[55]   A typical lamination process of a pair of, for example, 3 mm thick glass sheets and one commercial EVA film in-between the glass sheets starts with bringing the layers in close contact. That assembly is then introduced, for example, in a plastic bag and a low vacuum is applied to the system in order to remove any air in the bag. The vacuum-packed bag can then be introduced in an oven and the temperature be raised to 85 °C (with a raising rate of, for example, 3.5°C/min). The assemble is maintained at that temperature for about 10 min. Subsequently in a second step, the temperature is further raised to about 125°C (raising rate 3.5°C/min) and maintained at that temperature for about 30 min. The assembly is than cooled to room temperature in, e.g. about 20 min and the stratified glass panel structure is removed from the plastic bag.

[56]   In Figs. 4A to 4C, starting points of a lamination process is illustrated for a chromatic stratified panel structure with two nano-loaded diffusive coatings 306. In the resulting structure, the layers of nano-loaded diffusive coatings 306 are separated by a transparent adhesive polymeric layer 308.

[57]   As can be seen, the starting point of the lamination process can be based on two glass sheets 302, 304 each coated with a nano-loaded diffusive paint 306 at their inner surfaces (Fig. 4A). Alternatively, both sides of transparent adhesive polymeric layer 308 may be coated (Fig. 4C) or one side of one of the glass sheets 302, 304 and transparent adhesive polymeric layer 308 may be coated (Fig. 4B).

[58]   The panel structure generally comprises three main free stranding (self-supporting) components suitable for coating purposes (herein also referred to as support layer) so that at four internal surfaces need to be joined. This allows up to four internal

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surfaces being coated with nano-loaded diffusive paint 306, wherein all layers together provide the desired Rayleigh-like scattering effect. In configurations having multiple surfaces coated, the randomness in layer thickness of the various coatings may reduce the overall variations in thickness of the combined layers such that the uniformity with respect to the Rayleigh-like scattering process over the panel structure can be increased.

[59]   In general, different type of glass sheets may be used such as normal float glass, tempered, Anti Reflective (AR) coated glass, surface etched glass and similar. In addition, one of the two external glass surfaces of the stratified panel structure may be provided with a reflective coating (*i.e.* aluminum coating).

[60]   In general, by using a structured surface glass in the micrometer scale range, it is possible to achieve a diffusing effect on to transmitted/reflected light. Several methods for creating a microstructured surface glass are known in the art.

[61]   Among these, the most extensively applied in the industry involve the treatment of the glass surface with an etching solution comprising hydrofluoric acid as an active component. Different parameters can affect the final results of etching process for example the composition of the etching liquid, the reaction time and temperature, the application method of the etching liquid, the surface quality of the glass and the glass composition . A similar process involving the use of etching cream based on fluoride compounds has been developed in order to minimize problems of toxicity and safety related with the handling of Hydrofluoric Acid.

[62]   An alternative technique often used commercially is based on the mechanical abrasion of the glass surface -Abrasive Blasting or Sandblasting. In this case air, under high pressure, mixed with an abrasive material is directed towards the glass surface. A deep cut is formed to create the desired custom etched glass.

[63]   A less common method involve the use of a mold in a process called Mold Etching. In this case the glass is formed inside a structured mold, when removing the glass, it will have the shape and roughness of the mold. This is one of the cheapest methods in the glass industry.

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[64]   With respect to the nanoparticle-based Rayleigh-like diffusing coating, herein, the terms "paint", "coating" and "film" refer, in contrast to the term "adhesive polymeric layer", to a layer that is/needs to be applied on a support structure. In contrast, the "adhesive polymeric layer" is considered an independent structural unit.

[65]   In general in the application of sun-sky-imitation, a paint may be a clear material that is applied in liquid form on a surface and after a time produces a dry adherent film. Paint is essentially composed of a binder, particles, and a solvent.

[66]   Binder refers to the non-volatile portion of the vehicle of a coating material that binds the particles together and the film as a whole to the support substrate. Binders can include synthetic or natural resins and can further be classified according to the mechanisms for drying or curing.

[67]   Particles refers to a material, usually with nano or micrometric size that is practically insoluble in the medium and commonly used because of its optical, protective or decorative properties. Particles are broadly classified as either organic or inorganic.

[68]   A solvent refers to a liquid, single or blended, which is volatile under normal drying conditions and in which the binder is soluble.

[69]   Additional components of a paint may be thinners (a volatile liquid, able to facilitate application), catalysts, thickeners, stabilizers, flatteners, emulsifiers, adhesion promoters, UV stabilizers etc. In addition in order to increase the adhesion of the paint to the desired substrate a primer can be used before application.

[70]   The herein disclosed paints/coatings/films can be made by using as a binder an organic polymer commonly used in industry such as polystyrene, polyurethane, acrylics, alkyd polymer, polyester, siloxane-containing polymer, epoxy-containing polymer etc or a combination of them. In addition, depending on the nature of the binder different types of a diluting agent can be added, including water or organic (*i.e.* alcohol, ethers, ketone, esters, aliphatic and aromatic hydrocarbons or others) acting as solvent. Examples of solvent commonly employed in the coating industries include, for example, xylene, hexane, acetone, diethyleneglycol, and isopropyl alcohol.

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[71]   The nature of binder and the relative amount of components added in the resulting paint mixture will depend on several parameters such as the glass surface properties, the application method, and the interaction of the coating with the adhesive layer during the lamination process.

[72]   The material for the nanoparticles or their core may be made with one or more materials that essentially do not absorb light in the visible range having an organic or inorganic nature. In the first case, the inventors are referring to polymers (optionally crosslinked) while in the second case preferably to metal oxides (e.g. TiO_2, SiO_2, ZnO, ZrO_2, Fe_2O_3, Al_2O_3, Sb_2SnO_5, Bi_2O_3, CeO_2 or a combination thereof) with a single phase structure or a core/shell structure. The external surface of the nanoparticle core is preferably functionalized with a specific organic coating in order to guarantee an optimal compatibility and dispersion in the paint matrix. A poor compatibility of nanoparticles with the paint matrix may lead to the formation of large aggregate/agglomerates and inhomogeneous distribution that will strongly affect the scattering properties of the diffusing coating and consequently of the resulting embodiment.

[73]   The particle sizes (of particles intended to be contribute to the Rayleigh-like scattering) may be selected to obtain the required chromatic properties. For example, diameter size may be between about 5 nm to 250 nm such as between 20 nm and 150 nm.

[74]   Functionalized nanoparticles may be introduced directly in the binder/solvent mixture or in the paint with the desired final composition. The dispersion process may use low/high shear mixing equipment such as magnetic stirrer and/or static mixers.

[75]   The coating can be applied on the glass or directly on the adhesive polymeric layer by commonly used processes such as dip coating, spray coating, inkjet coating, electrodeposition, serigraphy and similar.

[76]   Referring to the adhesive polymeric layer, suitable materials mainly include that one typically employed in the stratification industry such as transparent thermoplastic materials (TPU or PVB, EVA) or transparent thermoset material (EVA). At present EVA and PVB covered almost 100% of the production of the stratified glass.

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[77]   EVA: (PEVA) PolyEthylene-vinyl acetate, is the copolymer of ethylene and vinyl acetate. The weight percent vinyl acetate usually varies from 10% to 40%, with the remainder being ethylene. Different mechanical/adhesive and chemical properties varying depending on the ratio between ethylene and vinyl acetate employed during the synthetic process. The main advantages of EVA are related to its excellent transparency, good adhesion and compatibility, resistance to humidity and long term reliability.

[78]   PVB: Poly(Vinyl Butyral) is prepared from polyvinyl alcohol by reaction with butyraldehyde. Elasticity, mechanical strength, toughness, high light transmission and the adhesion to glass are the most significant PVB properties.

[79]   In the following, a syntax for describing chromatic stratified panel structures under consideration of additional coatings and number of coatings is described.

[80]   The syntax is based on support materials shown in Fig. 5, wherein G represents a glass panel (or generally a light transmitting panel), F represents a microstructured surface glass (i.e. a support material with one side being provided with a microstructure) and A represents an adhesive polymer layer.

[81]   For each type of support material, the sides are identified by indices "j" and "i".

$$\text{Material} \longrightarrow X_i^j \genfrac{}{}{0pt}{}{}{} \text{Side}$$
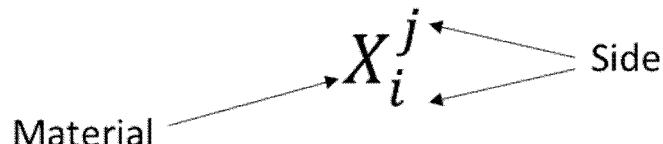
[82]

[83]   For the materials forming the out layers such as the "glass panel" and the "microstructured surface glass", in G_i^o and F_i^o "j" refers to the outer side, "o", and "i" to the inner side, "i".

[84]   For the inner sandwiched material "adhesive polymeric layer", in A_i^r "j" refers to the right side, "r", and "i" to the left side, "l".

[85]   Furthermore, the syntax is based on coating types shown in Fig. 6 that include a nanoparticle-based Rayleigh-like diffusing coating (a), a microparticle-based diffusing

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coating (b), a coating combining nanoparticle-based Rayleigh-like diffusing and microparticle-based diffusing (c), an antireflective coating (d), and a mirror (reflective e.g. in the visible) coating (e).

[86]   The nanoparticle-based Rayleigh-like diffusing coating (a) has been described before with respect to its scattering features.

[87]   The microparticle-based diffusing coating (b) is obtained with the same procedure stated above in the case of nanoparticles diffusing coating but adding particles with a micrometric size instead of nanometric size. More specifically the desired particles size range is comprised between 1 µm to 20 µm. Materials composing the particles can have organic or inorganic nature, in the first case we refer mainly to polymers while in the second case to metal oxide or similar preferably not absorbing in the visible. As in the case of nanoparticles, additional functionalization can also be included on the microparticle's surface in order to increase the compatibility between the particles and the transparent paint.

[88]   Microparticles may be present in an amount of about 1 to about 40% (w/w) with respect to the binder. The resulting coating after paint dry may have a thickness of about 2 µm to about 100 µm. These particles are beyond of the Rayleigh scattering regime because of their size. Both the chromatic and the distribution intensity of the light scattered by these microparticles are different to the one scattered by the nanosized particles. The spectrum and the intensity of the scattered light is strongly dependent to the scattering angle. In general, considering a sample of microparticles not perfectly monodispersed, the scattered light will be mostly forward scattered without any dependence on the wavelength. By increasing the microparticles size, the scattering angle (the cone angle defined by the intensity profile of the forward scattering) becomes narrower. The microparticle diffusive layer provokes a blurry effect on the panel.

[89]   The coating (c) combines the nanoparticle-based Rayleigh-like diffusing features and the microparticle-based diffusing features.

[90]   The antireflective coating (d) is a physico-chemical surface treatment that allows increasing the regular transmittance of a material. This treatment has to be optimized on a defined wavelength range (visible range for the present application) and strongly

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depends on the optical properties of the materials facing the antireflective coating. An antireflective coating optimized for the interface glass-air in the visible spectrum, makes the panels shown in Fig. 2 more efficient in terms of transmittance and decrease the intensity of the reflected scene.

[91]   The mirror coating (e) can be applied on the outer surface of the stratified panels in order to obtain high quality surface chromatic stratified mirror. A typical way to produce mirror is to deposit metals such as aluminum or silver on a glass surface. The reflection efficiency depends on the deposited material and the quality of the reflected image depends on the flatness/roughness of the glass.

[92]   The various surfaces defined for the support materials A, G, and F can be coated, for example, with the following coating types:

[93]   For A_l^r, "l" and," r" can be (a), (b), or (c).

[94]   For G_i^o, "i" can be (a), (b), or (c), while "o" can be (b), (d) or (e).

[95]   Furthermore, for F_i^o identifies that the microstructure is located on the external side while $\widetilde{F_i^o}$ identifies that the structure is located on the internal side.

[96]   If there is no index listed, that means that no coating was applied.

[97]   Based on the above, Figs. 7A to 7F illustrate exemplary sandwich structures. Figs. 7A and 7B correspond to Figs. 3A and 3B, respectively.

[98]   Fig. 7C illustrates a sandwich structure having a microstructure on one outer surface. A microstructure surface has the effect of blurring the perceived scene behind the microstructure surface. This property may be desired because those objects seen through (unwanted structures beyond) and virtual images on the panel (reflected images coming from objects of the scene) will be perceived blurry. Accordingly, the variation of the luminance - typical in an observed surface – may originally have sharp edges but can be smoothed by the microstructure surface based, thereby enhancing the depth perception.

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[99]   Fig. 7D illustrates a structure similar to Fig. 4B, wherein one nanoparticle-based Rayleigh-like diffusing coating is replaced with a microparticle-based diffusing coating such that forward scattering and a respective blurring effect is introduced.

[100]   Fig. 7E illustrates a sandwich structure having a microstructure on one outer side and an antireflective coating on the inner side. In this case the antireflective coating allows, for example, increasing the transmittance of the panel, thereby making the lighting system more efficient.

[101]   Fig. 7F illustrates a sandwich structure having a mirror coating on one outer side. This configuration can be used in the reflection mode as the lighting system described in connection with Fig. 2B.

[102]   The stratified configurations described up to here included at least one coating providing nanoparticle-based Rayleigh like scattering. In the following, a generic three layer structure is disclosed that incorporates the nanoparticle-based Rayleigh like scattering within the adhesive layer. Accordingly, the embodiments are modified in that the diffusing property of the diffusing layer is transferred from a separate coating, being applied e.g. on the interface surfaces including on the side wall of a stand alone adhesive polymeric layer, to being directly inside in the polymeric adhesive layer.

[103]   Accordingly, those new embodiments comprises a stratified-glass panel structure composed of two float glass sheets 104 and 106 sandwiching, and affixed to each other, by way of an adhesive transparent polymeric layer (e.g. an EVA, PVB layer or similar) that is loaded with nanoparticles. In further configurations, the adhesive polymeric layer can - in addition to nanoparticles - be loaded with (larger) microparticles together.

[104]   The modified adhesive transparent polymeric layer is herein referred to as nanoloaded adhesive polymeric layer. A nanoloaded adhesive polymeric layer may be obtained by different processes available in the industry. One possible process may comprise melting of a solid thermoplastic resin in an extruder followed by addition of the desired amount of nanoparticles. After blending the two component, the mixture is extruded in sheet form with the desired thickness. The method may further comprises pre-mixing the solid thermoplastic resin and the nanoparticles prior to melting the solid thermoplastic resin.

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[105]   A second type of process may comprise a direct dissolution and mixing of the nanoparticles with monomers (the simplest unit, or the repeating unit, of a polymer) prior of the polymerization process. This process can lead to a higher degree of dispersion of the nanoparticles even though it has some drawback for the scale up in an industrial plant.

[106]   As for the case of a nanoparticle coating, the adhesive polymeric layer may be based on suitable materials including those that are typically employed in the stratification industry such as transparent thermoplastic materials (TPU or PVB, EVA) or transparent thermoset material (EVA).

[107]   Nanoparticles and microparticles features (material type, size etc.) are the same as previously stated for the nanoparticle coating.

[108]   In order to maintain a good nanoparticle dispersion inside the polymeric adhesive layer, and consequently in the final stratified structure, it may be convenient to modify the surface structure of the nanoparticles itself with a specific agent (molecule, polymer etc.) able to guarantee a good compatibility between the particles and the polymeric layer.

[109]   In a similar way microparticles may be added during the mixing process together with the nanoparticles.

[110]   As will be apparent the integration of nanoparticles from the coating into the adhesive layer allows simplifying the process from an industrial point of view.

[111]   The inner sandwiched material, i.e. the "adhesive polymeric layer" used for incorporating the nanoparticle for the Rayleigh-like diffusing, is referred to in the syntax introduced above as NA. In an alternative configuration, the inner sandwiched material "adhesive polymeric layer" may be used for incorporating microparticles for diffusing light - additionally to the nanoparticles for the Rayleigh-like diffusing. Herein, that layer is referred to as NA'. Respective support structures are schematically indicated in Fig. 8 similar to Fig. 5, which also illustrates the glass panels G and F.

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[112]   It is noted that in the case of most simple sandwich structures, none of the

support structures has an "inner" coating, i.e. NA^{r}_{l} is only NA (same for NA'), and G^{o}_{i} is

only G^{o}.

[113]   The outer surfaces defined for the materials can be coated, for example, with
an antireflective coating (d), and a mirror (reflective e.g. in the visible) coating (e).

[114]   Based on the above, Figs. 9A to 9E illustrate exemplary sandwich structures.
The embodiments of Figs. 9A and 9B correspond to simple three-layer structures without
and with a microstructured outer surface, respectively.

[115]   The embodiment of Fig. 9C combines Rayleigh-like scattering features with
forward scattering features.

[116]   The embodiment of Fig. 9D uses microstructure at the inner side of one of the
glass panels for diffusing, thereby also strengthening the adhesion between NA and that glass
panel. In addition, an outer side is coated with an antireflecting coating to e.g. suppress any
back scattering from the background.

[117]   The embodiment of Fig. 9E relates to the reflective lighting system
configurations and uses a coating combining nanoparticle-based Rayleigh-like diffusing and
microparticle-based diffusing to similarly suppress any back scattering from the background.
It is noted that only exemplary configurations are illustrated in Figs. 7A to 7F and Figs. 9A
to 9E. Further embodiments are identifiable based on the present disclosure.

[118]   As described above for the nano-coating embodiment, the structural elements
based on the above considerations such as the ones illustrated in Figs. 9A to 9E may be
subject to a lamination process as described above (illustrated schematically by arrows in the
drawings).

[119]   Fig. 10 schematically shows a resulting chromatic stratified panel structure
400e.g. for generating a sun-sky-imitating effect in lighting systems. Chromatic stratified
panel 400 comprises two cover panels 102, 104, at least one of which being a transparent
panel and/or having a microstructure surface at one side. Chromatic stratified panel 400
comprises further as an interlayer 110, an adhesive transparent polymeric layer 406 (left side

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of the embodiment illustrated in Fig. 10) as described above or a modified adhesive polymeric layer 406' incorporating microparticles for diffusing light in additionally to the nanoparticles for the Rayleigh-like diffusing (right side of the embodiment illustrated in Fig. 10) as also described above. The adhesive polymeric layers 406 , 406' are sandwiched between the two inner faces of the two cover panels 102, 104. Moreover, they may be essentially transparent in the visible.

[120]   Although the preferred embodiments of this invention have been described herein, improvements and modifications may be incorporated without departing from the scope of the following claims.

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Claims

1.   A chromatic stratified panel structure (100) for generating a sun-sky-imitating effect in lighting systems (1), the chromatic stratified panel (100) comprising:

two cover panels (102, 104) at least one of which being a transparent panel;

an adhesive transparent polymeric layer (106) sandwiched between the two inner faces of the two cover panels; and

at least one nanoparticle-based Rayleigh-like diffusing coating (108) applied to an inner face of at least one of the two cover panels (102, 104) and/or to a face of the adhesive transparent polymeric layer (106) and forming an interlayer between one of the cover panels (102, 104) and the adhesive transparent polymeric layer (106).

2.   A chromatic stratified glass structure (100) comprising:

two glass sheets (102, 104); and

an adhesive transparent polymeric layer (106) sandwiched between the two glass sheets (102, 104),

wherein the face of one of the two glass sheets (102, 104) facing the adhesive polymeric layer (106) is coated with a nanoparticle-loaded paint (108) as a Rayleigh-like diffusing interlayer for visible light which preferentially scatters short-wavelength components of impinging light with respect to long-wavelength components of impinging light.

3.   A chromatic stratified glass structure (100) comprising:

two glass sheets (102, 104); and

an adhesive transparent polymeric layer (106) sandwiched between the two glass sheets,

wherein the adhesive polymeric layer (106) is coated with a nanoparticle-loaded paint (108) acting as a Rayleigh-like diffusing interlayer for visible light which

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preferentially scatters short-wavelength components of impinging light with respect to long-wavelength components of impinging light.

4.   The structure of any one of the preceding claims,

wherein the Rayleigh-like scattering relates to light having a wavelength spectrum extending in the visible spectrum, for example, over at least 150 nm;

wherein the Rayleigh-like diffusing coating (108)has been applied as a paint comprising a dispersion of light-scattering centers of an average size smaller than 250 nm, e.g. having a peak at particle sizes below 250 nm in the particle size distribution;

wherein the diffusing layer is configured to scatter light in Rayleigh-like regime.

5.   The structure of any one of the preceding claims,

wherein two nanoparticle-loaded coatings (108) acting as a Rayleigh-like diffusing interlayer, each being provided at one side of the adhesive transparent polymeric layer (106) and the neighboring cover panel/glass sheet (102, 104).

6.   The structure of any one of the preceding claims, wherein the number N of nanoparticles acting as Rayleigh-like scatterers per unit area of the chromatic diffusive layer in dependence of an effective particle diameter $D = d\, n_h$, is within the range defined by

$$N \ge N_{\min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{], } (D \text{ given in } [meters]) \text{ and } N \le$$

$$N_{\max} = \frac{2.03 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{];}$$

for example, for embodiments aiming at simulating the presence of a pure

clear sky, $N \ge N_{\min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in [meters]) and $N \le$

$N_{\max} = \frac{8.15 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] such as $N \ge N_{\min} = \frac{1.10 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]

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and $N \leq N_{max} = \dfrac{7.11 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{min} = \dfrac{1.51 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq N_{max} = \dfrac{6.20 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]; and

for example, for embodiments aiming at simulating a Nordic sky,

$N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{max} = \dfrac{2.03 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] such as $N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]

and $N \leq N_{max} = \dfrac{1.56 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], more specifically

$N \geq N_{min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq N_{max} = \dfrac{1.28 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}].

7.   The structure of any one of the preceding claims, wherein the number N of nanoparticles acting as Rayleigh-like scatterers per unit area of the chromatic diffusive layer in dependence of an effective particle diameter $D = d\, n_h$, is within the range defined by

$N \geq N_{min} = \dfrac{7.13 \times 10^{-29}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$N_{max} = \dfrac{2.03 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}];

for example, for embodiments aiming at simulating the presence of a pure

clear sky, $N \geq N_{min} = \dfrac{3.47 \times 10^{-29}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in [*meters*]) and $N \leq$

$$N_{max} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}] \text{ such as } N \geq N_{min} = \frac{5.65 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}]$$

and $N \leq N_{max} = \frac{3.46 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}]$, more specifically

$$N \geq N_{min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}] \text{ and } N \leq N_{max} = \frac{3.13 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}]; \text{ and}$$

for example, for embodiments aiming at simulating a Nordic sky,

$$N \geq N_{min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}], (D \text{ given in } [meters]) \text{ and } N \leq$$

$$N_{max} = \frac{1.03 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}] \text{ such as } N \geq N_{min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}]$$

and $N \leq N_{max} = \frac{7.71 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}]$, more specifically

$$N \geq N_{min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}] \text{ and } N \leq N_{max} = \frac{6.37 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 [\text{meters}^{-2}].$$

8.   The structure of any one of the preceding claims, wherein cover panels (102, 104) are configured as light transmitting support materials such as glass sheets, glass panels or as a microstructured surface glass, e.g. including at one side a microstructure.

9.   The structure of any one of the preceding claims, further comprising at least one of a nanoparticle-based Rayleigh-like diffusing coating (a), a microparticle-based diffusing coating (b), a coating combining nanoparticle-based Rayleigh-like diffusing and microparticle-based diffusing (c), an antireflective coating (d), and a mirror coating (e).

10.   The structure of any one of the preceding claims,

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wherein at least one of the two cover panels/glass sheets (102, 104) and the adhesive transparent polymeric layer (106) comprises a nanoparticle based small angle diffuser coating; and/or

wherein

a reflective coating and/or an an antireflecting coating is applied to an outer face (o) of at least one of the two cover panels/glass sheets (102, 104) or

a reflective coating forms an interlayer between one of the two cover panels/glass sheets (102, 104) and the adhesive transparent polymeric layer (106).

11.   An adhesive transparent polymeric layer structure for generating a chromatic stratified panel structure as recited in any one of the preceding claims, the adhesive transparent polymeric layer structure comprising:

a polymeric layer (106) configured to act as an adhesive base structure during a lamination process, and

at least one nanoparticle based Rayleigh-like diffusing coating (108) applied to the elastic polymeric film.

12.   The adhesive transparent polymeric layer structure of claim 11,

wherein the polymeric layer (106) is self-supporting to form a support structure for a coating, and is in particular elastic and/or its material is selected from the group of polymeric materials comprising transparent thermoplastic materials such as TPU , PVB, and EVA, or similar.

13.   An adhesive transparent polymeric layer (406) for generating a chromatic stratified panel structure, the adhesive transparent polymeric layer structure comprising:

a polymeric layer (106) configured to act as an adhesive base structure during a curing process, wherein the polymeric layer (106) comprises nanoparticles for Rayleigh-like scattering of visible light, wherein the number N of nanoparticles acting as Rayleigh-like

scatterers per unit area of the chromatic diffusive layer in dependence of an effective particle diameter $D = d \, n_h$, is within the range defined by

$$N \geq N_{\min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{ [meters}^{-2}\text{]}, \, (D \text{ given in } [meters]) \text{ and } N \leq$$

$$N_{\max} = \frac{2.03 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{ [meters}^{-2}\text{]}.$$

14.   The adhesive transparent polymeric layer of claim 13, wherein the number N is within the range defined by, for example, for embodiments aiming at simulating

the presence of a pure clear sky, $N \geq N_{\min} = \dfrac{7.13 \times 10^{-29}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in

$[meters]$) and $N \leq N_{\max} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] such as

$N \geq N_{\min} = \dfrac{1.10 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq N_{\max} = \dfrac{7.11 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}],

more specifically $N \geq N_{\min} = \dfrac{1.51 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] and $N \leq$

$N_{\max} = \dfrac{6.20 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]; and

for example, for embodiments aiming at simulating a Nordic sky,

$N \geq N_{\min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], (D given in $[meters]$) and $N \leq$

$N_{\max} = \dfrac{2.03 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}] such as $N \geq N_{\min} = \dfrac{8.15 \times 10^{-28}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}]

and $N \leq N_{\max} = \dfrac{1.56 \times 10^{-27}}{D^6} \left| \dfrac{m^2 + 2}{m^2 - 1} \right|^2$ [meters^{-2}], more specifically

$$N \geq N_{\min} = \frac{8.15 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{] and} \quad N \leq N_{\max} = \frac{1.28 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}.$$

15.   The adhesive transparent polymeric layer of claim 13, wherein the number N is within the range defined by, for example, for embodiments aiming at simulating the presence of a pure clear sky, $N \geq N_{\min} = \frac{3.47 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}$, ($D$ given in [*meters*]) and $N \leq N_{\max} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}$ such as

$$N \geq N_{\min} = \frac{5.65 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{] and} \quad N \leq N_{\max} = \frac{3.46 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]},$$

more specifically $N \geq N_{\min} = \frac{7.13 \times 10^{-29}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{] and} \quad N \leq$

$$N_{\max} = \frac{3.13 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]; and}$$

for example, for embodiments aiming at simulating a Nordic sky,

$$N \geq N_{\min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}, (D \text{ given in [}meters\text{]}) \text{ and} \quad N \leq$$

$$N_{\max} = \frac{1.03 \times 10^{-27}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{] such as} \quad N \geq N_{\min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}$$

and $N \leq N_{\max} = \frac{7.71 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}$, more specifically

$$N \geq N_{\min} = \frac{4.05 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{] and} \quad N \leq N_{\max} = \frac{6.37 \times 10^{-28}}{D^6} \left| \frac{m^2 + 2}{m^2 - 1} \right|^2 \text{[meters}^{-2}\text{]}.$$

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16.   The structure of any one of claim 13 to 15,

        wherein the adhesive transparent polymeric layer (NA) comprises a microparticle based small angle diffuser coating; and/or

        wherein a reflective coating and/or an antireflecting coating is applied to an outer face (o) of at least one of the two cover panels/glass sheets (102, 104).

17.   A chromatic stratified panel structure (400) for generating a sun-sky-imitating effect in lighting systems (1), the chromatic stratified panel (400) comprising:

        two cover panels (102, 104) at least one of which being a transparent panel and/or having a microstructure surface at one side; and

        an adhesive transparent polymeric layer (406, NA) as recited in any one of claims 13 to 15, the adhesive transparent polymeric layer (NA) being sandwiched between the two inner faces of the two cover panels.

18.   The structure of claim 17, wherein a reflective coating and/or an antireflecting coating is applied to an outer face (o) of at least one of the two cover panels/glass sheets (102, 104).

19.   A lighting system (1) comprising:

        a light source (2) configured to generate a visible light beam (3);

        a chromatic stratified panel structure as recited in any one of the preceding claims, illuminated by the light source (2), wherein

        a portion of the light beam forms an illuminating light beam (3A) by passing through the chromatic stratified panel structure essentially unscattered, and a portion if the light of the light beam is Rayleigh-like scattered by the nanoparticles within the chromatic stratified panel structure.

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20.   The lighting system of claim 19, wherein a first color of the Rayleigh-like scattered light and a second color of the essentially not Rayleigh-like scattered direct light are separated in u'v'-color space by at least 0.008 such as at least 0.02 or 0.03; and/or

a direct light correlated color temperature is close to the black body color temperature, for example in the range from 800 K to 6 500 K; and/or

a first color is associated with a diffuse light correlated color temperature that is different from, in particular larger than, the direct light correlated color temperature of the light beam; and/or

a direct light correlated color temperature differs from a diffuse light correlated color temperature by a factor of 0.85 or less.
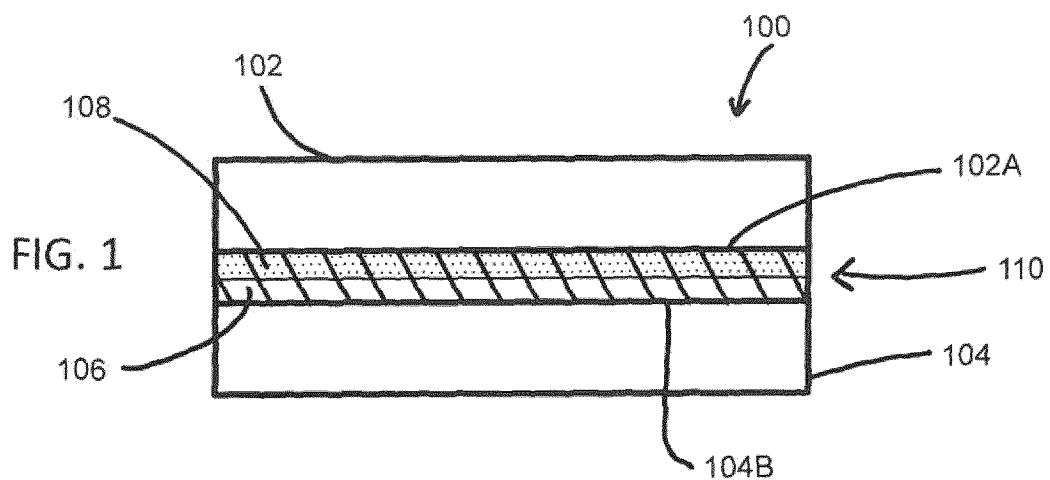
FIG. 1
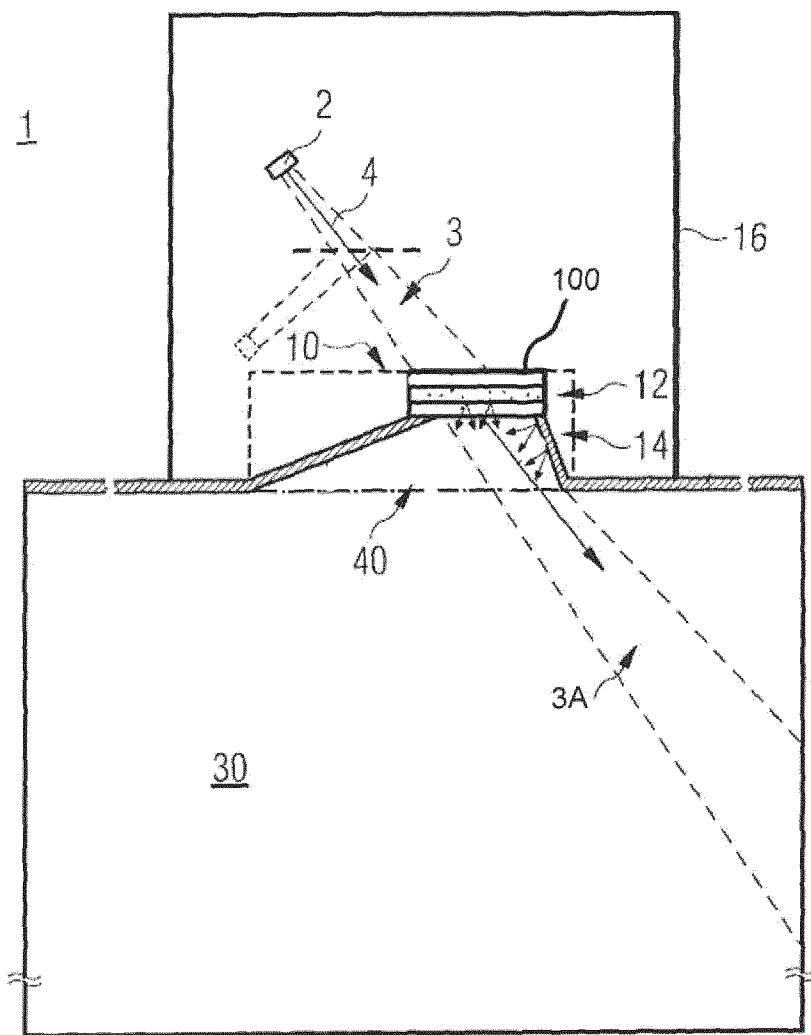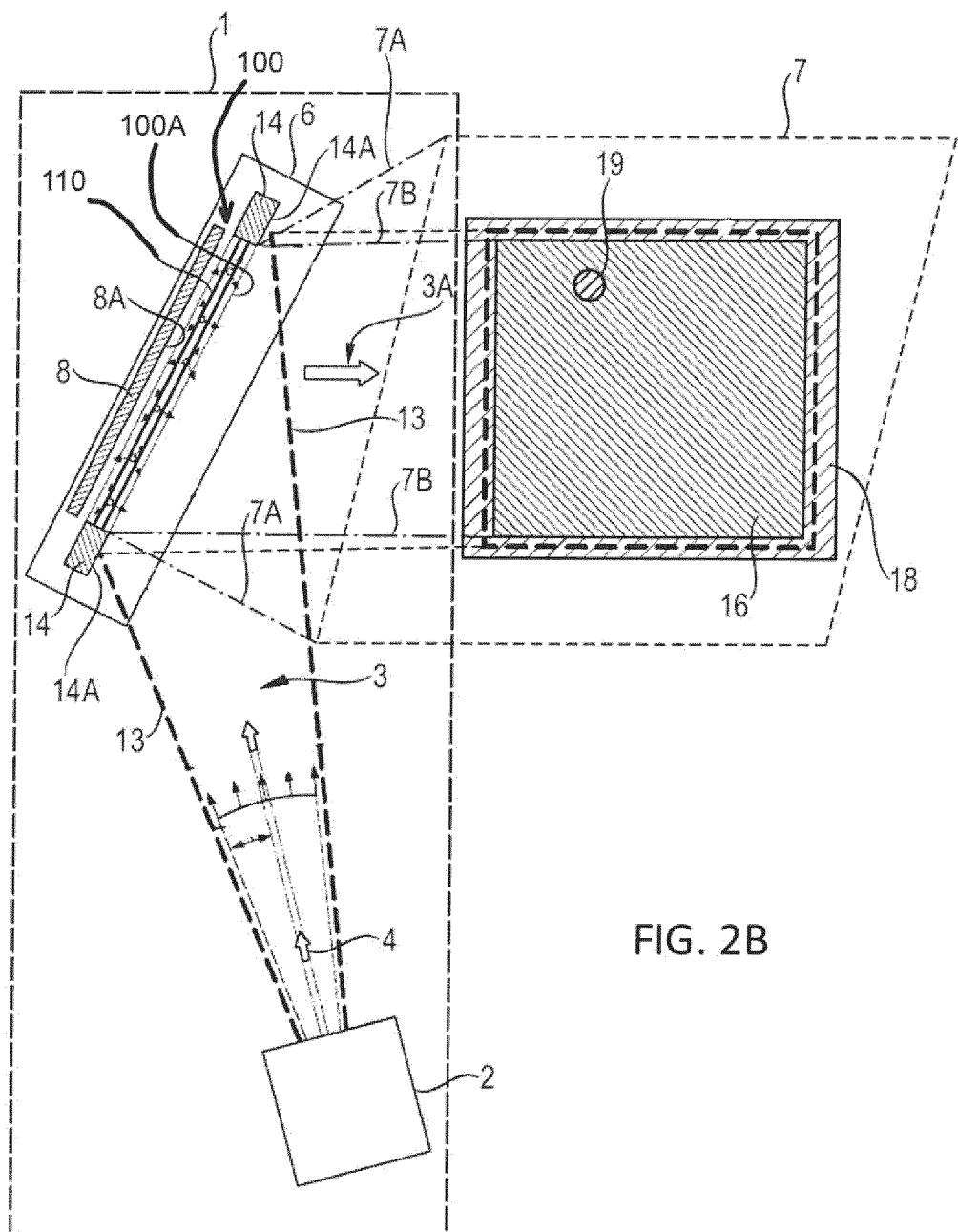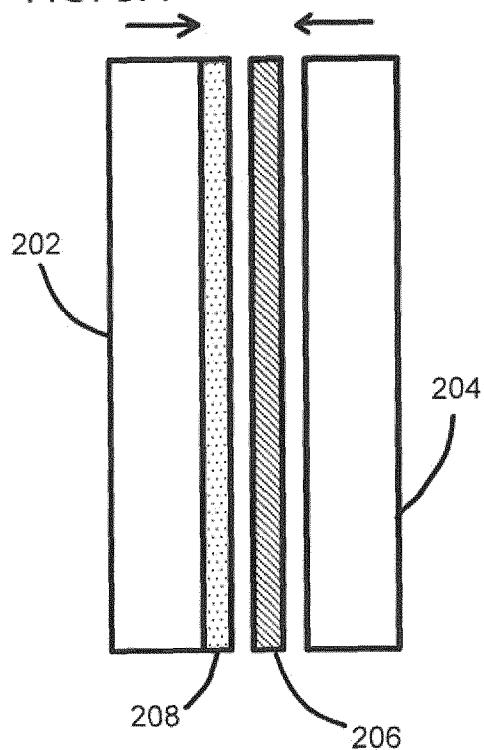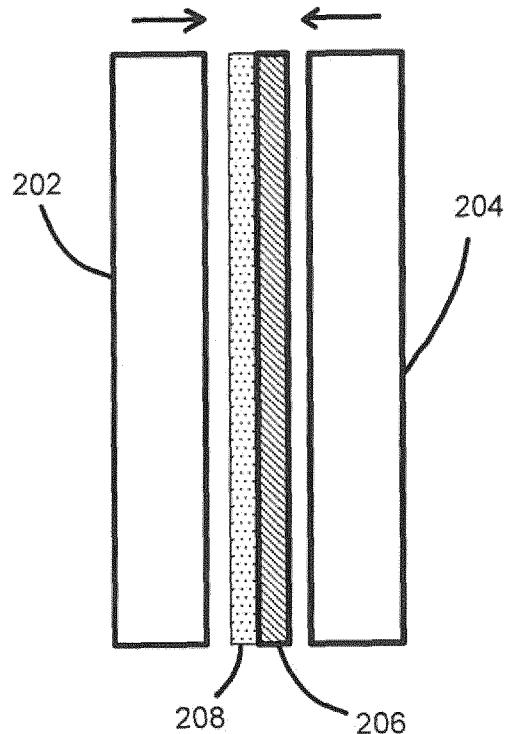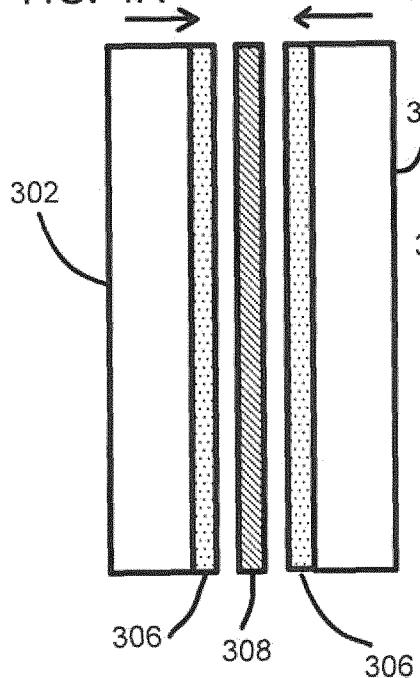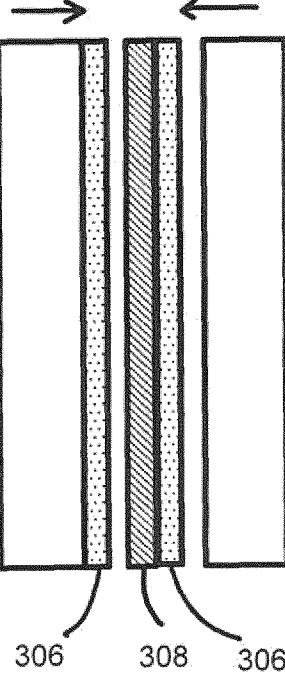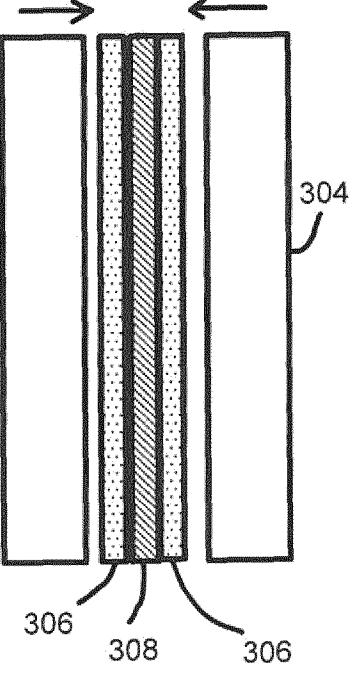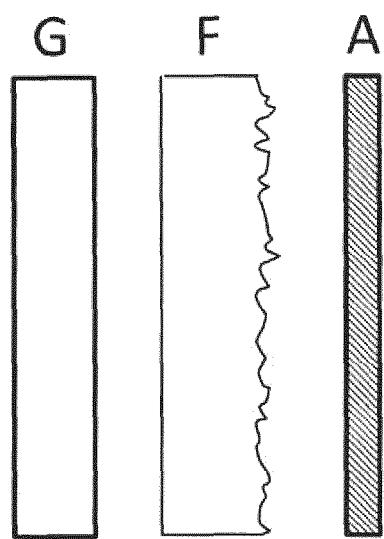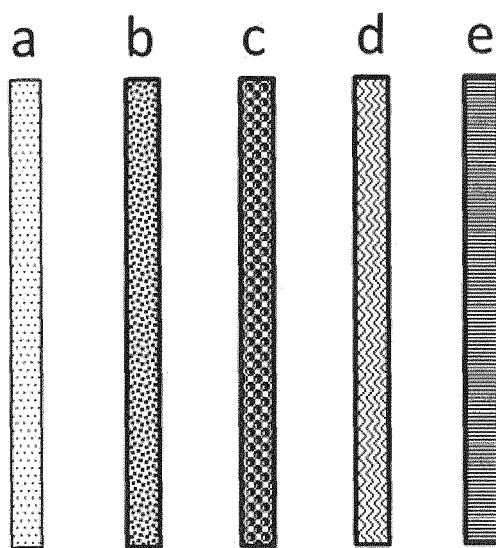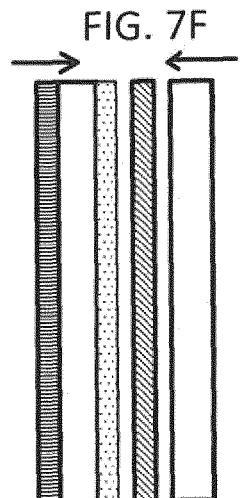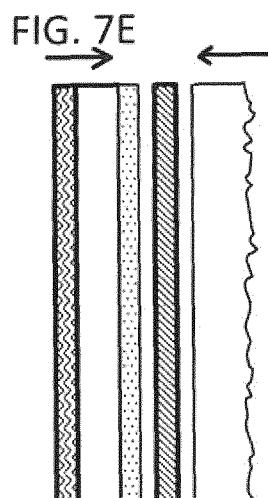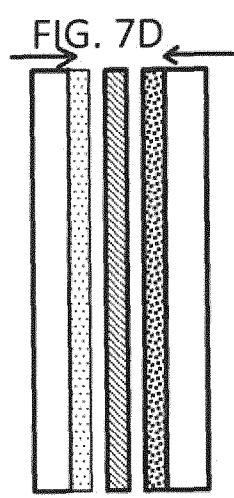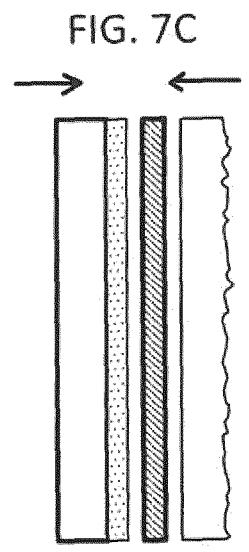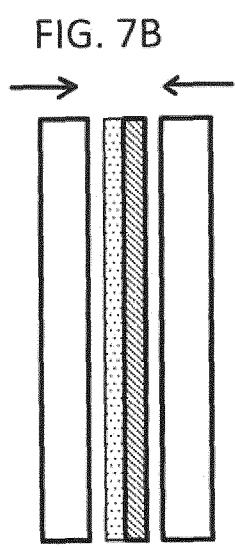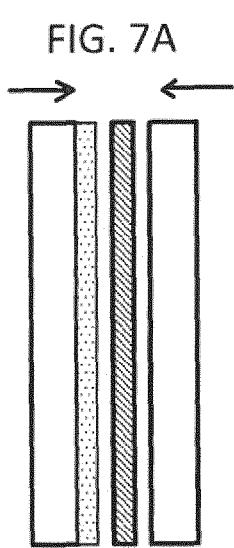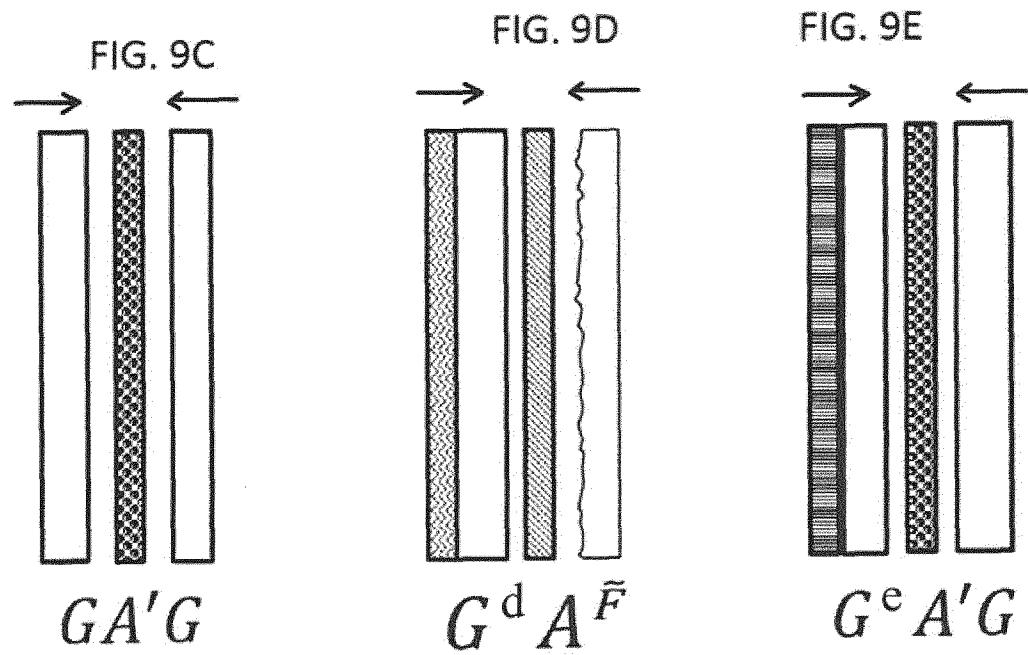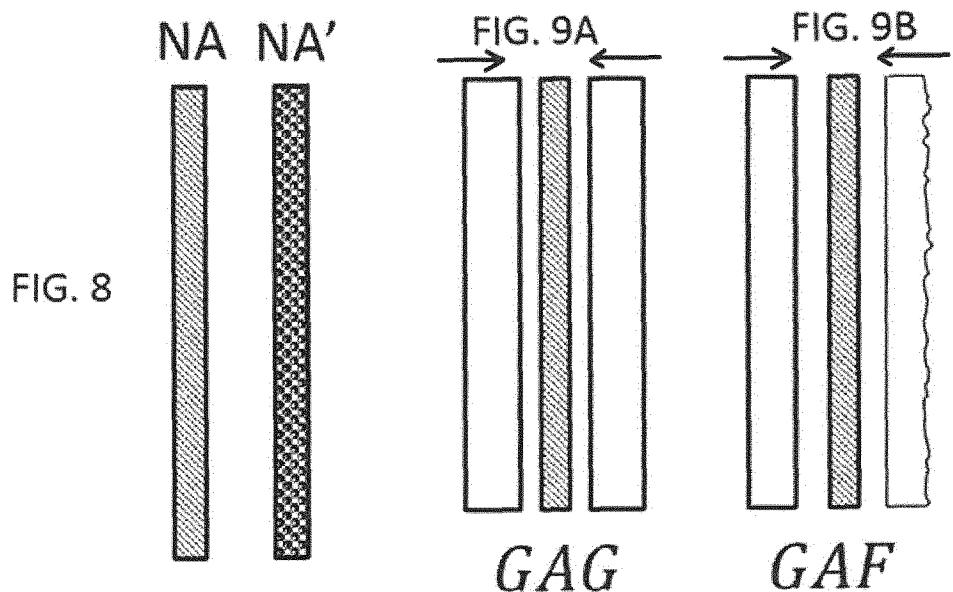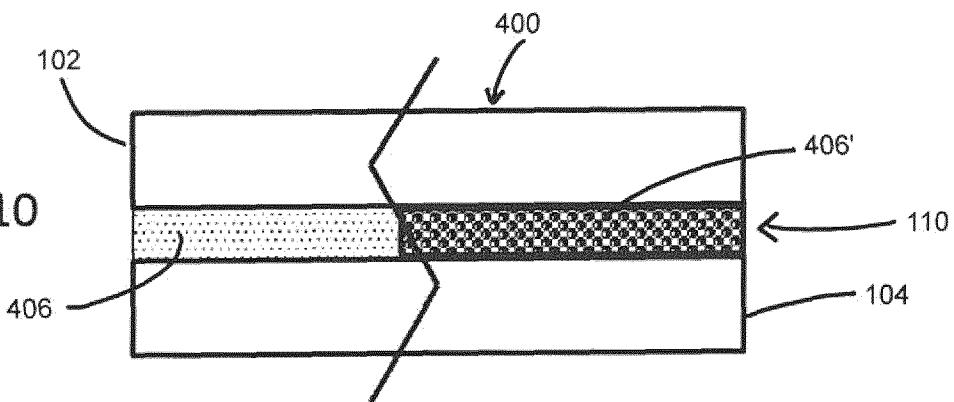
FIG. 2A

FIG. 2B

FIG. 3A

202

204

208   206

FIG. 3B

202

204

208   206

FIG. 4A

302

304

306   308   306

FIG. 4B

304

302

306   308   306

FIG. 4C

304

302

306   308   306

FIG. 5

FIG. 6

FIG. 7A

$G_a AG$

FIG. 7B

$GA_a G$

FIG. 7C

$G_a AF$

FIG. 7D

$G_a AG_b$

FIG. 7E

$G_a^d AF$

FIG. 7F

$G_a^e AG$

FIG. 8

NA   NA'

FIG. 9A

GAG

FIG. 9B

GAF

FIG. 9C

GA'G

FIG. 9D

$G^d A^{\tilde{F}}$

FIG. 9E

$G^e A'G$

FIG. 10

A. CLASSIFICATION OF SUBJECT MATTER

INV. B32B17/10   C03C17/00   F21V3/04   F21V9/02
ADD. C08K9/06

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)

C08K   B32B   C03C   F21V

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2015/158274 A1 (YABUKI KAYO [JP] ET AL) 11 June 2015 (2015-06-11) paragraph [0071] paragraph [0120]; figure 3 claims 1,13-16 -----	1-4,6-8, 11-15,17
A	US 2014/182679 A1 (ROSENBERG VICTOR [AU] ET AL) 3 July 2014 (2014-07-03) paragraph [0091] - paragraph [0095]; claims 1,19,20; figure 1 -----	1-18
	-/--	

X Further documents are listed in the continuation of Box C.   X See patent family annex.

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"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
9 February 2017	17/02/2017

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	Lindner, Thomas

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page 1 of 2

C(Continuation).   DOCUMENTS CONSIDERED TO BE RELEVANT

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