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(71) Applicant(s)
Innovia Security Pty Ltd

(72) Inventor(s)
Lee, Robert Arthur;Lok, Phei

(74) Agent / Attorney
Watermark Patent and Trade Marks Attorneys, 302 Burwood Road, Hawthorn, VIC, 3122

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ABSTRACT

An optical device including: a substrate which defines a plane; and a plurality of optical elements corresponding to structures projecting from and/or into the substrate, wherein the plurality of optical elements are configured to provide three or more different images, each image associated with a unique viewing direction, when viewed from a particular viewing position when the optical device is rotated about a rotational axis projecting from the plane, and method for the manufacture thereof.

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MULTICHANNEL OPTICAL DEVICE

FIELD OF THE INVENTION

[0001] The invention generally relates to the field of security features for documents, in particular optically variable security features.

BACKGROUND TO THE INVENTION

[0002] It is well known that many of the world's banknotes, as well as other security documents, carry optical devices which produce images that vary with angle of view of the device or angle of illumination by an external light source. Because the image on the device varies in this way, it cannot be copied by conventional photographic, computer scanning or other reprographic printing technologies.

[0003] However, such variation is dependent on tilting of the security document. Though this provides a useful security visual effect, the result is a broad range of security visual effects based on the same underlying principle (i.e. the tilting of the security document). It would be desirable to provide an optically variable effect which is dependent on a different, or at least further, action than simple tilting.

SUMMARY OF THE INVENTION

[0004] According to a first aspect of the present invention, there is provided an optical device including: a substrate which defines a plane; and a plurality of optical elements corresponding to structures projecting from and/or into the substrate, wherein the plurality of optical elements are configured to provide three or more different images, each image associated with a unique viewing direction, when viewed from a particular viewing position when the optical device is rotated about a rotational axis projecting from the plane.

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[0005] The rotation axis preferably projects perpendicularly from the plane. Advantageously, this allows for ease of use by a user viewing the optical device.

[0006] Optionally, there are four identifiable images. Each image may be associated with a particular viewing direction, and the viewing directions may be arranged at 90 degree intervals about the axis. Having four viewing directions advantageously corresponds to the four sides of common documents (such as banknotes).

[0007] In some embodiments, the structures project from the substrate. In other embodiments, the structures project into the substrate. In further embodiments, the structures project partially into the substrate and partially from the substrate.

[0008] Preferably, for each image, each optical element includes a region associated with the image, and each region is structured to determine the appearance of the optical element when viewed from a viewing direction associated with the region.

[0009] In an optional configuration, each region is configured to appear as one of: an off state; and an on state, when viewed from the viewing direction associated with the region. The on state may correspond to a structure including at least one angled face, angled with respect to the plane, wherein the normal of the angled face is substantially parallel to the viewing direction associated with the region. The off state may correspond to a structure including a face substantially parallel to the plane. The off state may include only faces parallel and perpendicular to the plane, thereby defining a cuboid structure. Advantageously, the structures described in respect of on and off states may be relatively easy to implement and effective. In optional configurations, each structure including an angled face includes a diffraction grating formed on the angled face. Advantageously, a diffraction grating may provide a more interesting visual effect.

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[0010] In an alternative optional configuration, each region is configured to appear in one of three or more states, when viewed from the viewing direction associated with the region, each state having a different associated brightness. Therefore, each image may be a greyscale image. Advantageously, this may provide for more complicated images than a device with two states. One of the states may correspond to an off state, one of the states may correspond to an on state, and the remaining one or more states may therefore correspond to intermediate states. The on state may corresponds to a structure including an angled face, angled with respect to the plane, wherein the normal of the angled face is substantially parallel to the viewing direction associated with the region, and the off state may correspond to a structure including a face substantially parallel to the plane, and the, or each, intermediate state may include both an angled face and a parallel face. Advantageously, this arrangement may effectively provide intermediate states while maintaining a high contrast between states. There may be two or more intermediate states, and each intermediate state may therefore have an associated brightness, the associated brightness determined by a ratio of the area of angled face to parallel face of each intermediate state. Advantageously, this may allow for ease of design of the optical element. In optional configurations, each structure including an angled face includes a diffraction grating formed on the angled face. Advantageously, a diffraction grating may provide a more interesting visual effect.

[0011] Where applicable, the diffraction grating of each angled face may be a zero-order diffraction grating.

[0012] In some preferred embodiments, a plan view of each region has a first side and a second side, each side with length less than 250 microns, in particular each region has a first side with length between 30 and 60 microns, and a second side with length between 30 and 60 microns. In other embodiments, the size of each region is preferably sufficiently large to allow for coloured ink to be printed in register to each region, such that each region is associated with a colour.

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Preferably, each region is rectangular, and more preferably square-shaped in plan view.

[0013] Optionally, the optical device is configured as a reflective optical device. In an alternative option, the optical device is configured as a transmissive optical device.

[0014] Preferably, the optical elements are formed from an embossed radiation curable ink.

[0015] Optionally, the optical elements are arranged in a grid, which may advantageously allow for ease of design.

[0016] The optical device is preferably a security device, for example as incorporated into a security document such as a banknote.

[0017] According to a second aspect of the present invention, there is provided a security document including an optical device according to the first aspect.

[0018] The security document may further include at least one further security feature. Advantageously, this may provide for stronger security. The security document may be a banknote.

[0019] According to a third aspect of the present invention, there is provided a method for manufacturing an optical device according to the first aspect, the method including the steps of: applying a radiation curable ink to a surface of a substrate; embossing the radiation curable ink using an embossing tool, the embossing tool configured for forming a structure in the radiation curable ink corresponding to the optical elements of the device; and curing the radiation curable ink.

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[0020] According to a fourth aspect of the present invention, there is provided a method for manufacturing a security document, the security document including a substrate, the method including the step of: in a region of a first surface of the substrate, forming an optical device according to the method of the third aspect.

Preferably, the substrate is a transparent or translucent substrate. Optionally, the method may further include the step of applying a first opacifying layer to the first surface of the substrate, the first opacifying layer being omitted in a region to form a window region corresponding, in location, to the optical element. Optionally, the method may further include the step of applying a second opacifying layer to a second surface of the substrate, opposite the first surface. The second opacifying layer may be omitted in a window region corresponding, in location, to the optical element. Alternatively, the second opacifying layer may cover the optical element on said second surface to form a half-window region.

[0021] Alternatively, the substrate is an opaque substrate.

Security Document or Token

[0022] As used herein the term security documents and tokens includes all types of documents and tokens of value and identification documents including, but not limited to the following: items of currency such as banknotes and coins, credit cards, cheques, passports, identity cards, securities and share certificates, driver's licenses, deeds of title, travel documents such as airline and train tickets, entrance cards and tickets, birth, death and marriage certificates, and academic transcripts.

[0023] The invention is particularly, but not exclusively, applicable to security documents or tokens such as banknotes or identification documents such as identity cards or passports formed from a substrate to which one or more layers of printing are applied. The diffraction gratings and optically variable devices described herein may also have application in other products, such as packaging.

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Security Device or Feature

[0024] As used herein the term security device or feature includes any one of a large number of security devices, elements or features intended to protect the security document or token from counterfeiting, copying, alteration or tampering. Security devices or features may be provided in or on the substrate of the security document or in or on one or more layers applied to the base substrate, and may take a wide variety of forms, such as security threads embedded in layers of the security document; security inks such as fluorescent, luminescent and phosphorescent inks, metallic inks, iridescent inks, photochromic, thermochromic, hydrochromic or piezochromic inks; printed and embossed features, including relief structures; interference layers; liquid crystal devices; lenses and lenticular structures; optically variable devices (OVDs) such as diffractive devices including diffraction gratings, holograms and diffractive optical elements (DOEs).

Substrate

[0025] As used herein, the term substrate refers to the base material from which the security document or token is formed. The base material may be paper or other fibrous material such as cellulose; a plastic or polymeric material including but not limited to polypropylene (PP), polyethylene (PE), polycarbonate (PC), polyvinyl chloride (PVC), polyethylene terephthalate (PET), biaxially-oriented polypropylene (BOPP); or a composite material of two or more materials, such as a laminate of paper and at least one plastic material, or of two or more polymeric materials.

Transparent Windows and Half Windows

[0026] As used herein the term window refers to a transparent or translucent area in the security document compared to the substantially opaque region to which printing is applied. The window may be fully transparent so that it allows the transmission of light substantially unaffected, or it may be partly transparent or translucent partially allowing the transmission of light but without allowing objects to be seen clearly through the window area.

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[0027] A window area may be formed in a polymeric security document which has at least one layer of transparent polymeric material and one or more opacifying layers applied to at least one side of a transparent polymeric substrate, by omitting least one opacifying layer in the region forming the window area. If opacifying layers are applied to both sides of a transparent substrate a fully transparent window may be formed by omitting the opacifying layers on both sides of the transparent substrate in the window area.

[0028] A partly transparent or translucent area, hereinafter referred to as a "half-window", may be formed in a polymeric security document which has opacifying layers on both sides by omitting the opacifying layers on one side only of the security document in the window area so that the "half-window" is not fully transparent, but allows some light to pass through without allowing objects to be viewed clearly through the half-window.

[0029] Alternatively, it is possible for the substrates to be formed from an substantially opaque material, such as paper or fibrous material, with an insert of transparent plastics material inserted into a cut-out, or recess in the paper or fibrous substrate to form a transparent window or a translucent half-window area.

Opacifying layers

[0030] One or more opacifying layers may be applied to a transparent substrate to increase the opacity of the security document. An opacifying layer is such that $L_T < L_0$, where L_0 is the amount of light incident on the document, and L_T is the amount of light transmitted through the document. An opacifying layer may comprise any one or more of a variety of opacifying coatings. For example, the opacifying coatings may comprise a pigment, such as titanium dioxide, dispersed within a binder or carrier of heat-activated cross-linkable polymeric material. Alternatively, a substrate of transparent plastic material could be sandwiched between opacifying layers of paper or other partially or substantially opaque material to which indicia may be subsequently printed or otherwise applied.

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Diffractive Optical Elements (DOEs)

[0031] As used herein, the term diffractive optical element refers to a numerical-type diffractive optical element (DOE). Numerical-type diffractive optical elements (DOEs) rely on the mapping of complex data that reconstruct in the far field (or reconstruction plane) a two-dimensional intensity pattern. Thus, when substantially collimated light, e.g. from a point light source or a laser, is incident upon the DOE, an interference pattern is generated that produces a projected image in the reconstruction plane that is visible when a suitable viewing surface is located in the reconstruction plane, or when the DOE is viewed in transmission at the reconstruction plane. The transformation between the two planes can be approximated by a fast Fourier transform (FFT). Thus, complex data including amplitude and phase information has to be physically encoded in the micro-structure of the DOE. This DOE data can be calculated by performing an inverse FFT transformation of the desired reconstruction (i.e. the desired intensity pattern in the far field).

[0032] DOEs are sometimes referred to as computer-generated holograms, but they differ from other types of holograms, such as rainbow holograms, Fresnel holograms and volume reflection holograms.

Refractive index n

[0033] The refractive index of a medium n is the ratio of the speed of light in vacuum to the speed of light in the medium. The refractive index n of a lens determines the amount by which light rays reaching the lens surface will be refracted, according to Snell's law:

[0034] $$n_1 * Sin(\alpha) = n * Sin(\theta),$$

[0035] where α is the angle between an incident ray and the normal at the point of incidence at the lens surface , θ is the angle between the refracted ray and the normal at the point of incidence, and n_1 is the refractive index of air (as an approximation n_1 may be taken to be 1).

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Embossable Radiation Curable Ink

[0036] The term embossable radiation curable ink used herein refers to any ink, lacquer or other coating which may be applied to the substrate in a printing process, and which can be embossed while soft to form a relief structure and cured by radiation to fix the embossed relief structure. The curing process does not take place before the radiation curable ink is embossed, but it is possible for the curing process to take place either after embossing or at substantially the same time as the embossing step. The radiation curable ink is preferably curable by ultraviolet (UV) radiation. Alternatively, the radiation curable ink may be cured by other forms of radiation, such as electron beams or X-rays.

[0037] The radiation curable ink is preferably a transparent or translucent ink formed from a clear resin material. Such a transparent or translucent ink is particularly suitable for printing light-transmissive security elements such as sub-wavelength gratings, transmissive diffractive gratings and lens structures.

[0038] In one particularly preferred embodiment, the transparent or translucent ink preferably comprises an acrylic based UV curable clear embossable lacquer or coating.

[0039] Such UV curable lacquers can be obtained from various manufacturers, including Kingfisher Ink Limited, product ultraviolet type UVF-203 or similar. Alternatively, the radiation curable embossable coatings may be based on other compounds, eg nitro-cellulose.

[0040] The radiation curable inks and lacquers used herein have been found to be particularly suitable for embossing microstructures, including diffractive structures such as diffraction gratings and holograms, and microlenses and lens arrays. However, they may also be embossed with larger relief structures, such as non-diffractive optically variable devices.

[0041] The ink is preferably embossed and cured by ultraviolet (UV) radiation at substantially the same time. In a particularly preferred embodiment, the radiation curable ink is applied and embossed at substantially the same time in a Gravure printing process.

[0042] Preferably, in order to be suitable for Gravure printing, the radiation curable ink has a viscosity falling substantially in the range from about 20 to about 175 centipoise, and more preferably from about 30 to about 150 centipoise. The viscosity may be determined by measuring the time to drain the lacquer from a Zahn Cup #2. A sample which drains in 20 seconds has a viscosity of 30 centipoise, and a sample which drains in 63 seconds has a viscosity of 150 centipoise.

[0043] With some polymeric substrates, it may be necessary to apply an intermediate layer to the substrate before the radiation curable ink is applied to improve the adhesion of the embossed structure formed by the ink to the substrate. The intermediate layer preferably comprises a primer layer, and more preferably the primer layer includes a polyethylene imine. The primer layer may also include a cross-linker, for example a multi-functional isocyanate. Examples of other primers suitable for use in the invention include: hydroxyl terminated polymers; hydroxyl terminated polyester based co-polymers; cross-linked or uncross-linked hydroxylated acrylates; polyurethanes; and UV curing anionic or cationic acrylates. Examples of suitable cross-linkers include: isocyanates; polyaziridines; zirconium complexes; aluminium acetylacetone; melamines; and carbodi-imides.

Metallic Nanoparticle Ink

[0044] As used herein, the term metallic nanoparticle ink refers to an ink having metallic particles of an average size of less than one micron.

BRIEF DESCRIPTION OF THE DRAWINGS

[0045] Embodiments of the invention will now be described with reference to the accompanying drawings. It is to be appreciated that the embodiments are given by way of illustration only and the invention is not limited by this illustration. In the drawings:

[0046] Figure 1a shows a security document including a optical device located within a half-window region;

[0047] Figure 1b shows a security document including a optical device located within a window region;

[0048] Figure 2 shows an arrangement of optical elements of the surface of a substrate;

[0049] Figure 3a shows an optical element including four regions and associated viewing directions;

[0050] Figure 3b shows a top-down schematic of a single optical element;

[0051] Figure 4 shows the appearance of the optical device when viewed from four different directions;

[0052] Figure 5a shows the structure of a region corresponding to an off state;

[0053] Figure 5b shows the structure of a region corresponding to an on state;

[0054] Figure 6a shows the effect on incident light by a reflective region configured in an off state;

[0055] Figure 6b shows the effect on incident light by a reflective region configured in an on state;

[0056] Figure 7a shows the effect on incident light by a transmissive region configured in an off state;

[0057] Figure 7b shows the effect on incident light by a transmissive region configured in an on state;

[0058] Figure 8a shows an optical element including four regions configured in off states;

[0059] Figure 8b shows an optical element including one region configured in an on state and three regions configured in off states;

[0060] Figure 8c shows an optical element including two regions configured in on states and two regions configured in off states;

[0061] Figure 8d shows an optical element including three regions configured in on states and one regions configured in an off state;

[0062] Figure 8e shows an optical element including four regions configured in on states;

[0063] Figure 9 shows a method for viewing the different images of a optical device;

[0064] Figure 10 shows a method for producing a optical device;

[0065] Figure 11 shows four different regions configured for different intensities; and

[0066] Figure 12 shows a region including diffractive elements.

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DESCRIPTION OF PREFERRED EMBODIMENT

[0067] Referring to Figures 1a and 1b, there is shown a security document 2 including an optical device 4 and an optional further security feature 6. The optical device 4 can correspond to a security device of the security document 2. The security document 2 includes a transparent or translucent substrate 8. The optical device 4 also includes a substrate 8, which in the present case is the same substrate 8 as the security document 2, though this is not a requirement.

[0068] Also shown are first and second opacifying layers 7a, 7b. In Figure 1a, the optical device 4 is shown located in a half-window region 3 of the security document 2, in which the first opacifying layer 7a is omitted, and the second opacifying layer 7b covers the optical device 4. Alternatively, as shown in Figure 1b, the optical device 4 can be located in a full window region 5 of the security document 2, where both the first and second opacifying layers 7a, 7b are absent in the region of the optical device 4. Though the opacifying layers 7a, 7b are shown contiguous with the optical device 4, this is not necessary. For example, there may be a gap between the edge of the optical device 4 and the edge of the opacifying regions 7a, 7b. Optional further security features 6 include: windows; diffractive optical devices; holograms; microlens based optical variable devices; and any other suitable security feature(s), and can be located within window or half-window regions 9 of the substrate 8 as necessary and/or desired. Alternatively, the substrate 8 can be opaque, and the optical device 4 can be formed on a surface of the opaque substrate 8.

[0069] Within this disclosure, a group of common elements within the figures are labelled with a number, and specific elements within the group are labelled with the number and a letter suffix (for example, referring to Figure 3, a viewing direction in general can be referred to with label 14, and a specific viewing direction with a label such as 14a).

[0070] Referring to Figure 2, the optical device 4 includes an arrangement of optical elements 10. The arrangement shown in Figure 2 is a regular grid arrangement; however, other arrangements can be utilised, including non-regular arrangements.

[0071] Figure 3a shows four different viewing directions 14 for viewing the optical device 4. It is understood that the optical device 4 can have associated with it three or more viewing directions 14. The viewing directions 14 are distinguished by rotation about an axis 13 projecting from a surface 11 of the substrate 8. The viewing directions 14 are also angled away from the axis 13, as shown. Typically, a viewing direction 14 represents an average or ideal direction from which the user, viewing the optical device 4, will perceive a maximal visual effect, however any visual effects generated by the optical device 4 associated with a particular viewing direction 14 may be visible despite viewing a small angle away from the specified viewing direction 14. Furthermore, the position and arrangement of the light source(s) used to illuminate the optical device 4 can affect the ideal viewing position.

[0072] Figure 3b shows a top-down schematic of a single optical element 10. The optical element 10 includes four different regions 12a, 12b, 12c, 12d. Each region 12 is associated with a viewing direction 14 (i.e. 12a with 14a, 12b with 14b, 12c with 14c, and 12d with 14d). The viewing directions 14 shown in Figures 3a and 3b are at right angles. In general, it is required that angle between adjacent viewing directions 14 differs sufficiently such that the visual effect associated with one viewing direction 14 does not, or at least minimally, interferes with the visual effect associated with another viewing direction 14.

[0073] The size of an optical element 10 or a region 12 as used herein is defined as the surface area of the substrate 8 of the optical device 4 covered by the optical element 10 or region 12. In the embodiments described herein, the regions 12 are rectangular or square-shaped in plan view, with the length of each side of the region 12 less than 250 microns, preferably between 30 and 60

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microns. In particular embodiments, each region 12 is square, and each optical element 10 is square. It is understood that other sizes of optical element 10 can be utilised. In one example alternative embodiment, the size of the regions 12 are selected to be sufficiently large to allow for printing of coloured ink onto the regions, for example in register, such that each region 12 can have an associated colour.

[0074] Referring to Figure 4, each viewing direction 14a, 14b, 14c, 14d is associated with a different image 16a, 16b, 16c, 16d, respectively. Each image 16 corresponds to a visual effect, and is configured to be viewable from the associated viewing direction 14, and not viewable from other viewing directions 14. It is understood that each image 16 can be viewable from a range of angles, with the viewing direction 14 defining a centre of a range of angles. Each optical element 10 corresponds to a pixel of each image 16 and the configuration of each region 12 of a particular optical element 10 determines the appearance of the optical element 10 when viewed from the associated viewing position 14. In this way, each optical element 10 effectively acts as four different pixels, each of which is expressed when viewed from a particular viewing direction 14.

[0075] Referring to Figures 5a and 5b, each region 12 can be in one of two states, corresponding to “off” 18a and “on” 18b. An on state 18b corresponds to a region 12 being configured to reflect and/or transmit light (depending on the optical device 4 configuration) substantially towards the associated viewing direction 14, and an off state 18a corresponds to a region 12 being configured not to reflect or transmit light towards the associated viewing direction 14. It is understood that an off state 18a may correspond to some light being reflected and/or transmitted, however it is necessary that sufficiently less light is reflected and/or transmitted towards the associated viewing direction 14 such that the off 18a states are distinguishable from the on states 18b.

[0076] The structure of the region 12 corresponding to an off state includes an upward facing face 20, as shown in Figure 5a. The upward facing face 20 is

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substantially parallel to the plane defined by the substrate 8. In the example shown, the upward facing face 20 corresponds to the top face of a cuboid structure, however it is envisaged that the upward facing face 20 could simply correspond to the surface of the substrate 8. The structure of the region 12 corresponding to an on state includes an angled face 22, as shown in Figure 5b.

[0077] Figures 6a and 6b show the different effect on incident light of the two regions types (when configured for reflection) respectively, when viewed from the viewing position associated with the region 12. Figure 7a shows the effect of a particular region 12 configured in an off state, where angled incident rays are predominantly not reflected back towards the viewer. Figure 7b shows the effect of a particular region 12 configured in an on state, where angled incident rays are reflected substantially back in the direction of the incident rays, and therefore will appear bright when viewed at the associated viewing position.

[0078] Figures 7a and 7b show the different effects on incident light of the two regions types (when configured for transmission). Figure 7a shows the effect of a region 12 configured in an off state, where light incident in a normal direction from the opposite side of the substrate 8 is transmitted through the optical element 10 without change in direction from the normal. Figure 7b shows the effect of a region 12 configured in an on state, where light incident from the opposite side of the substrate 8 to the optical element 10 is refracted by the angled face 22, and therefore tends to be directed towards the observer.

[0079] Figures 8a to 8d show a selection of different optical element 10 configurations based on different combinations of regions 12 configured in an on state and regions 12 configured in an off state. Figure 8a shows an optical element 10 configured with four off regions (12a, 12b, 12c, 12d). Figure 8b shows an optical element 10 with one on region (12c) and three off regions (12a, 12b, 12d), and will therefore appear bright only when viewed from one viewing direction (i.e. viewing direction 14c of Figure 3b). Figure 8c shows an optical element 10 with two on regions (12b, 12c) and two off regions (12a, 12d), and will

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therefore appear bright when viewed from two viewing directions (i.e. viewing directions 14b and 14c of Figure 3b). Figure 8d shows an optical element 10 with three on regions (12b, 12c, 12d) and one off region (12a), and will therefore appear bright when viewed from three viewing directions (i.e. viewing directions 14b, 14c, and 14d, of Figure 3b). Finally, Figure 8e shows an optical element 10 with four on regions (12a, 12b, 12c, 12d), which will appear bright when viewed from all four viewing positions 14a, 14b, 14c, 14d of Figure 3b.

[0080] Figure 9 shows the optical device 4 being rotated about an axis 24 extending from the substrate 8, (for example, the axis 24 is extending perpendicularly to the surface of the substrate 8) while viewed from a viewing position 26. The optical device 4 is positioned such that the optical device 4 is viewed at an angle away from the axis 24. As the optical device 4 is rotated, the appearance of the optical device 4 will change between the different images 16a, 16b, 16c, 16d.

[0081] Referring to Figure 10, an embossing tool in the form of a shim is prepared including a base with a surface profile corresponding to the inverse of the required optical device 4 surface profile, at step 50. The shim can be prepared using known methods, for example utilising e-beam or photo lithography and electroplating. A radiation curable ink (RCI) is applied to a suitable substrate 8, for example biaxial polypropylene (BOPP), preferably by printing, at step 52. The RCI is then embossed using the shim at step 54 and simultaneously, or shortly after, embossing, the RCI is cured using an appropriate radiation source, for example a UV light source, at step 56. The substrate 8 may include a primer layer configured for aiding the adhesion of the RCI to the substrate 8. For reflective optical devices, the RCI may subsequently be coating with a metallic layer to provide suitable reflectivity at optional step 58. The substrate 8 can include opacifying layers 7a, 7b, or opacifying layers 7a, 7b can be printed or otherwise applied to the substrate 8 after formation of the optical device 4.

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[0082] Referring to Figure 11, in an embodiment, each region 12 is configured in one of more than two possible states. In particular, as well as the on (slanted face 22) and off (top face 20) states previously described, there can be one or more intermediate states, configured to have an intermediate brightness (when viewed from an associated viewing angle 14). One technique for incorporating different brightness levels is shown in Figure 11, where each region can be selected from an entirely slanted face 22 (on state), an entirely upward facing face 20 (off state), or a combination of slanted face and upward facing face 28a, 28b (intermediate state). The relative brightness of an intermediate state is proportional to the area of slanted face. In the example shown, configuration 28a is less bright than configuration 28b. Each region 12 can be selected from a finite set of on, off, and intermediate states. It is understood that brightness refers to the relative brightness between different states. Allowing for more than two possible states allows for grey-scale images to be created, each grey scale image associated with a viewing direction 14.

[0083] Referring to Figure 12, the angled faces 22 can include diffraction gratings 30. In a particular embodiment, the angled faces 22 include zero-order diffraction gratings 30, where the grating spacing of the grating elements 32 of the diffraction grating 30 is sufficiently small to remove first and higher order diffraction peaks. This can be achieved by having a grating spacing less than the wavelength of the incident light. An example grating spacing is 200 microns. Zero-order diffraction gratings 30 can be tuned, through selection of materials and grating spacing, to appear as particular colours at particular angles. In this way, the ‘on’ regions can appear coloured, which can advantageously provide a more interesting visual effect. An extension of this embodiment is incorporating different coloured gratings, such that full colour imagery can be produced.

[0084] It is understood however that the regions 12 and optical elements 10 are arranged such that the structures associated with each region 12 do not combine to create a diffractive effect.

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[0085] Further modifications and improvements may be made without departing from the scope of the present invention. For example, further security features can be incorporated onto the upward facing faces of the off regions, such as, for example, DOE based security features, holograms, and/or printed images. Also, it is envisaged the regions 12 can correspond to structures projecting partially into the substrate 8, and partially from the substrate 8, or, alternatively, structures entirely projecting into the substrate 8.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An optical device including: a substrate which defines a plane; and a plurality of optical elements corresponding to structures projecting from and/or into the substrate, wherein the plurality of optical elements are configured to provide three or more different images, each image associated with a unique viewing direction, when viewed from a particular viewing position when the optical device is rotated about a rotational axis projecting from the plane.

2. An optical device as claimed in claim 1, wherein the rotation axis projects perpendicularly from the plane, and including four identifiable images such that the viewing directions are arranged at 90 degree intervals about the axis, and wherein, for each image, each optical element includes a region associated with the image, each region being structured to determine the appearance of the optical element when viewed from a viewing direction associated with the region, and wherein each region is configured to appear as one of: an off state; and an on state, when viewed from the viewing direction associated with the region, wherein the on state corresponds to a structure including an angled face, angled with respect to the plane, wherein the normal of the angled face is substantially parallel to the viewing direction associated with the region, and wherein the off state corresponds to a structure including a face substantially parallel to the plane.

3. An optical device as claimed in claim 1, wherein the rotation axis projects perpendicularly from the plane, and including four identifiable images such that the viewing directions are arranged at 90 degree intervals about the axis, and wherein, for each image, each optical element includes a region associated with the image, each region being structured to determine the appearance of the optical element when viewed from a viewing direction associated with the region, wherein each region is configured to appear in one of three or more states, when viewed from the viewing direction associated with the region, each state having a different associated brightness, wherein one of the states corresponds to an off

state corresponding to a structure including a face substantially parallel to the plane, one of the states corresponds to an on state corresponding to a structure including an angled face, angled with respect to the plane, wherein the normal of the angled face is substantially parallel to the viewing direction associated with the region, and the remaining one or more states correspond to intermediate states, wherein the, or each, intermediate state includes both an angled face and a parallel face.

4. A security document including an optical device as claimed in any one of the previous claims, wherein the optical device is a security device.

5. A method for manufacturing an optical element according to any one of claims 1 to 3, including the steps of:

- applying a radiation curable ink to a surface of a substrate;
- embossing the radiation curable ink using an embossing tool, the embossing tool configured for forming a structure in the radiation curable ink corresponding to the optical element; and
- curing the radiation curable ink.

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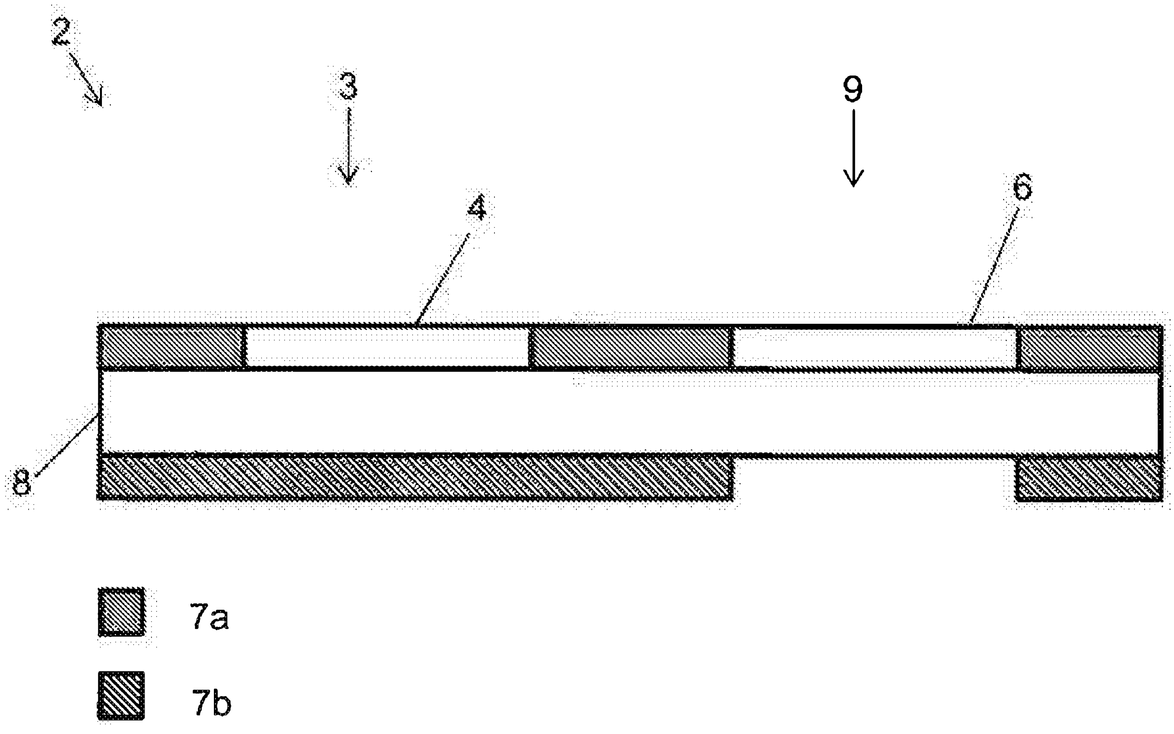

Figure 1a

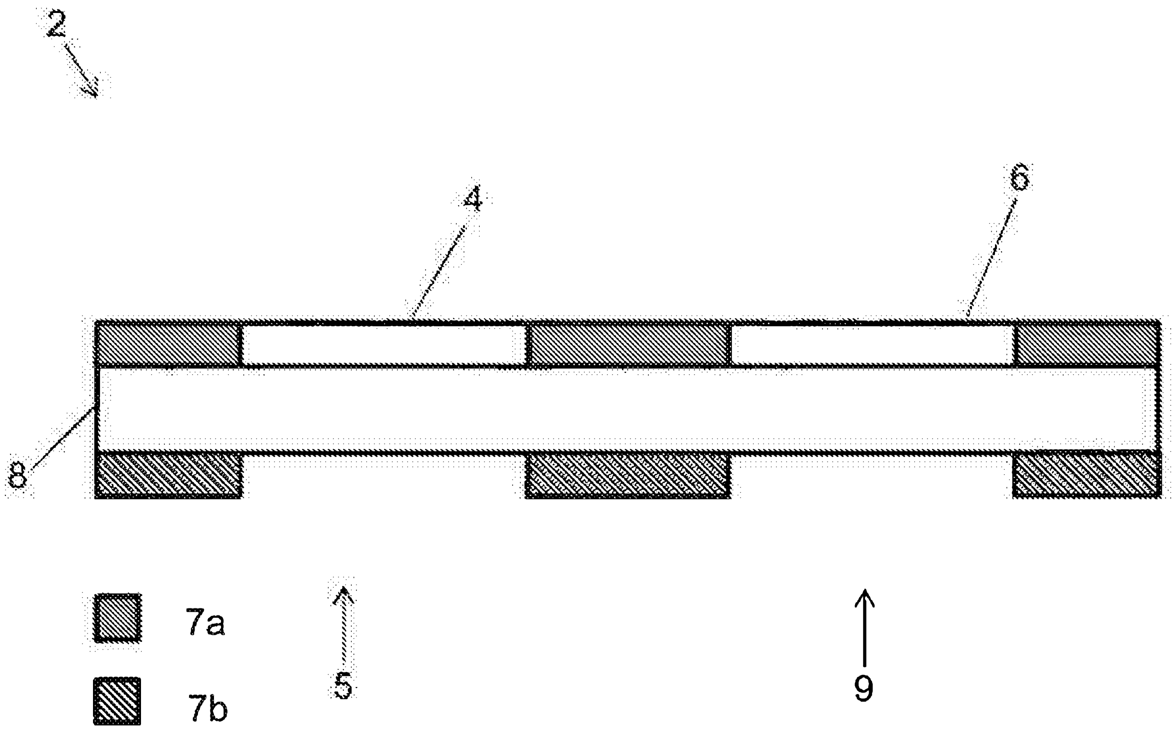

Figure 1b

20131011172 02 Sep 2013

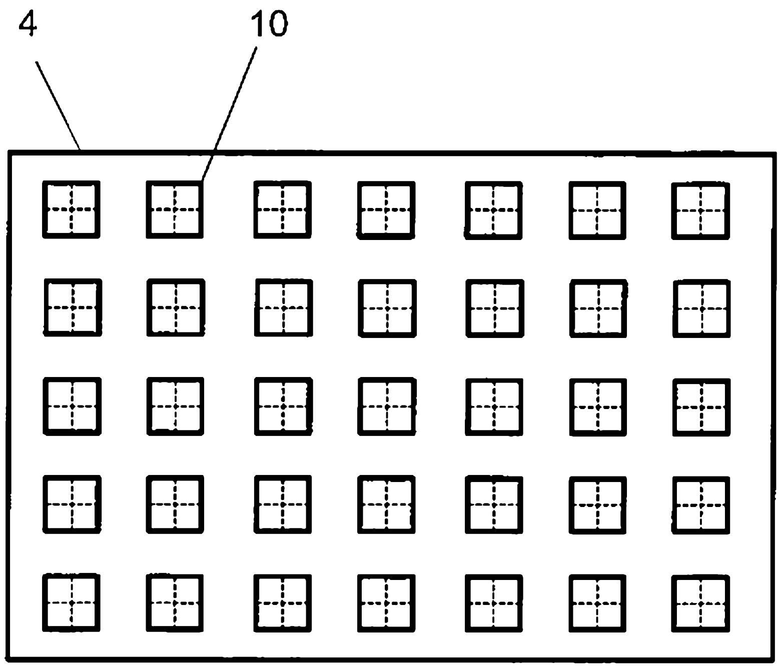

Figure 2

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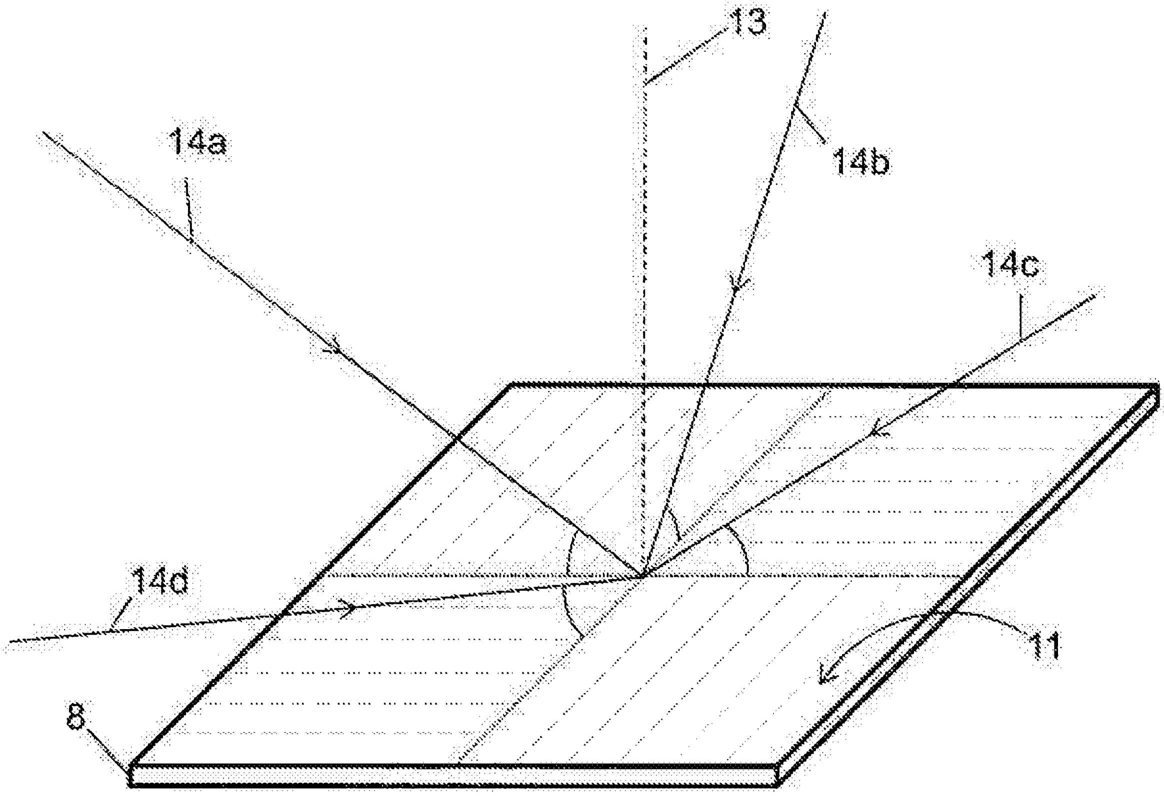

Figure 3a

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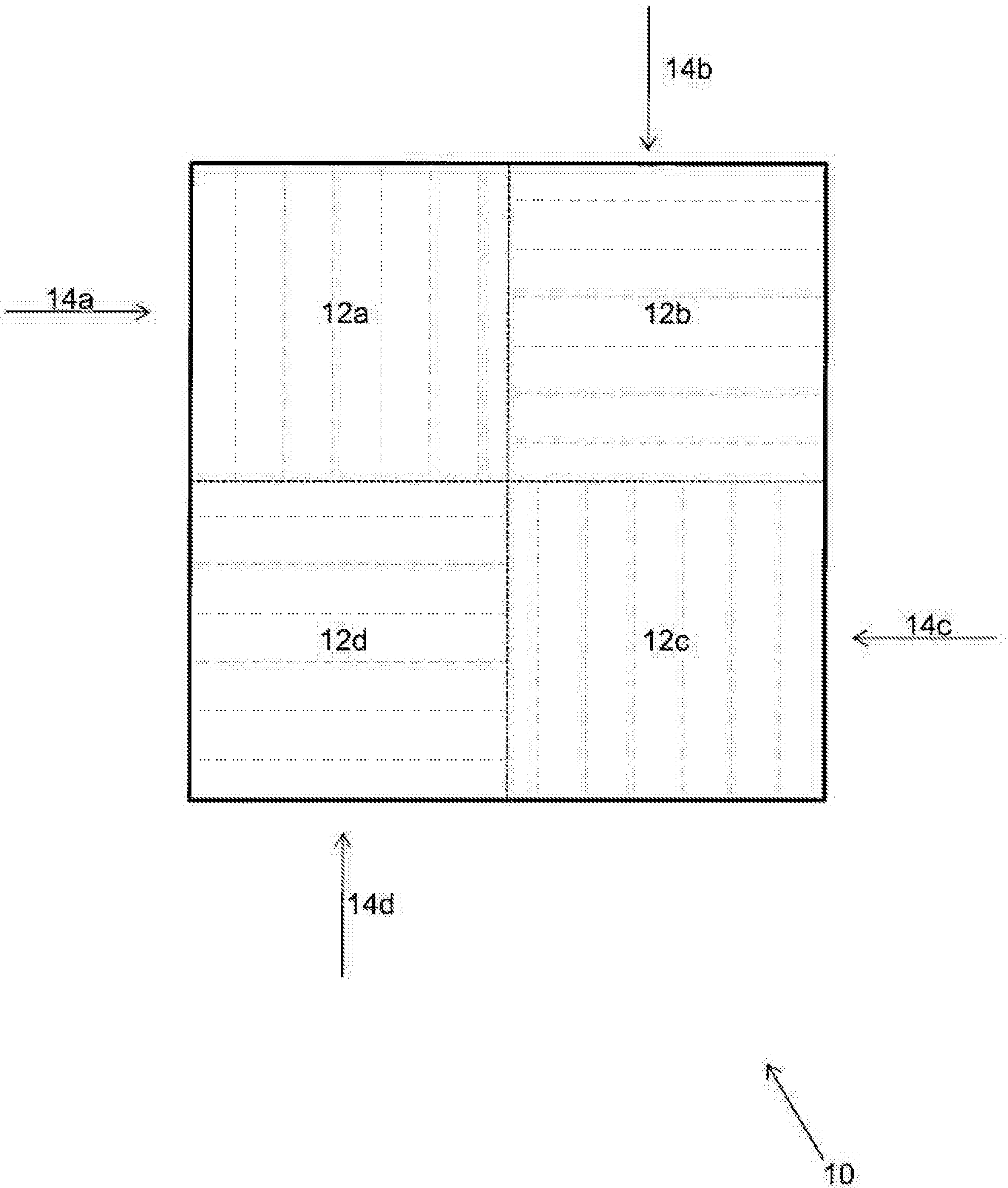

Figure 3b

2013101172 02 Sep 2013

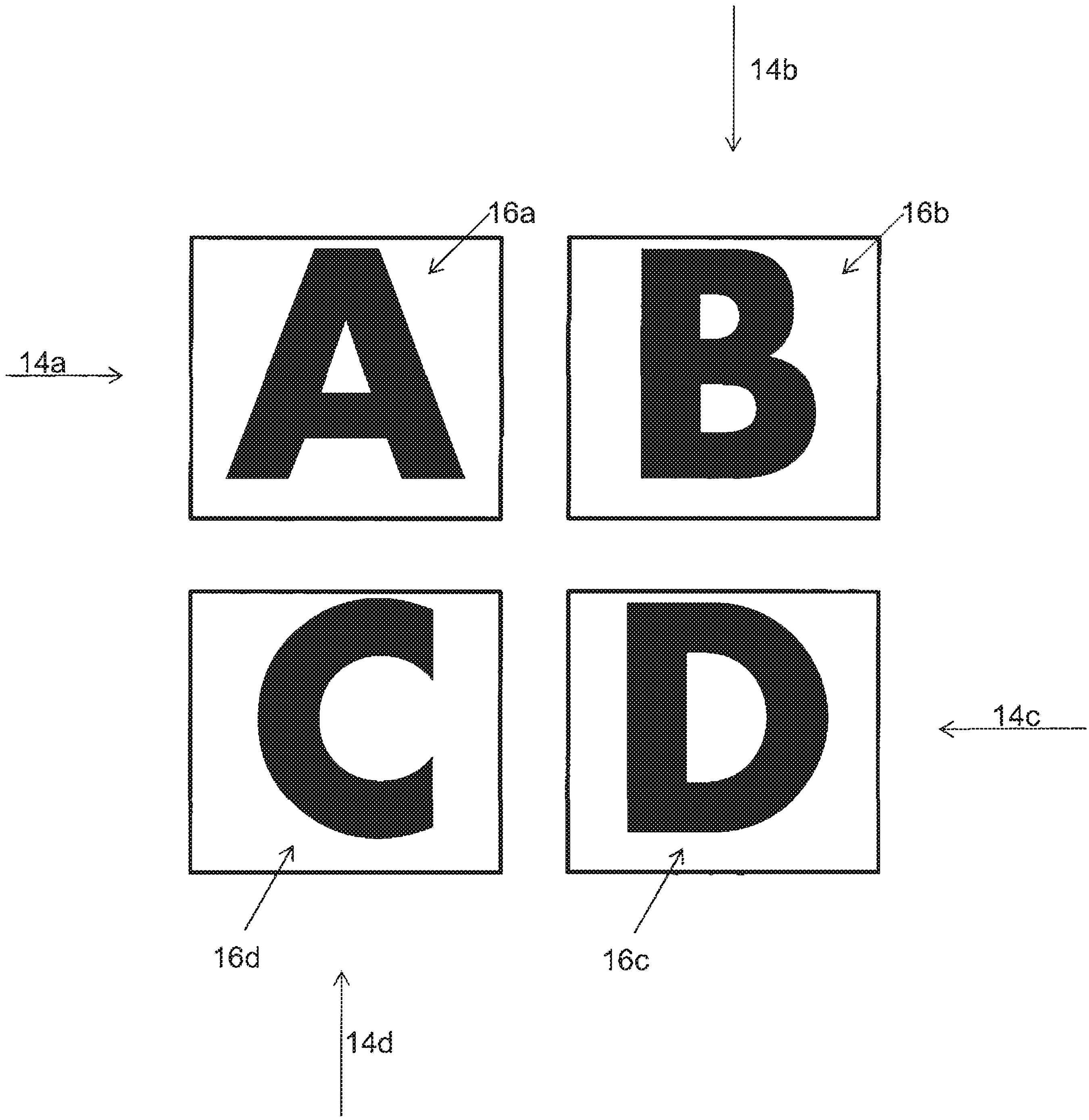

Figure 4

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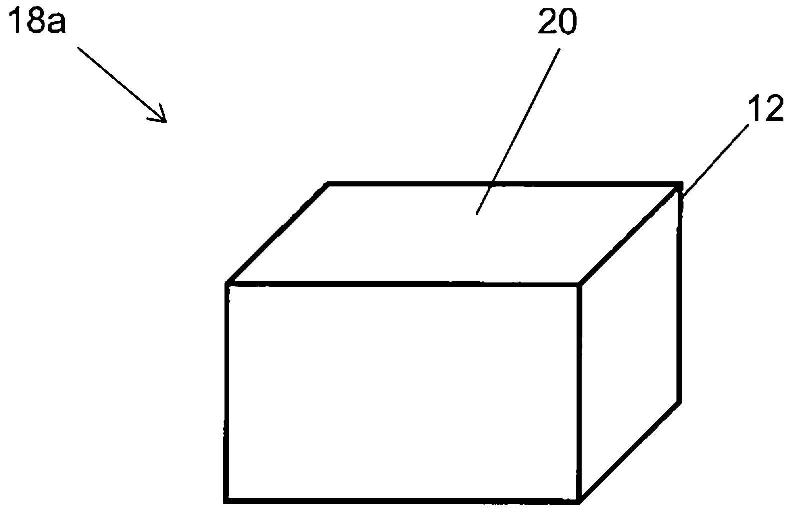


Figure 5a

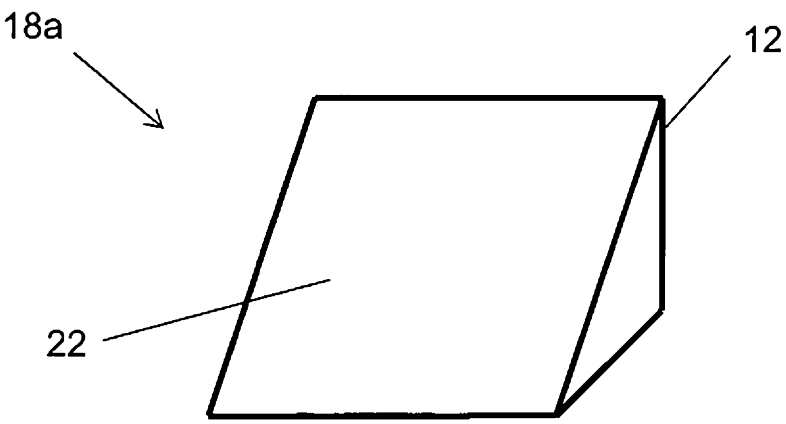


Figure 5b

2013101172 02 Sep 2013

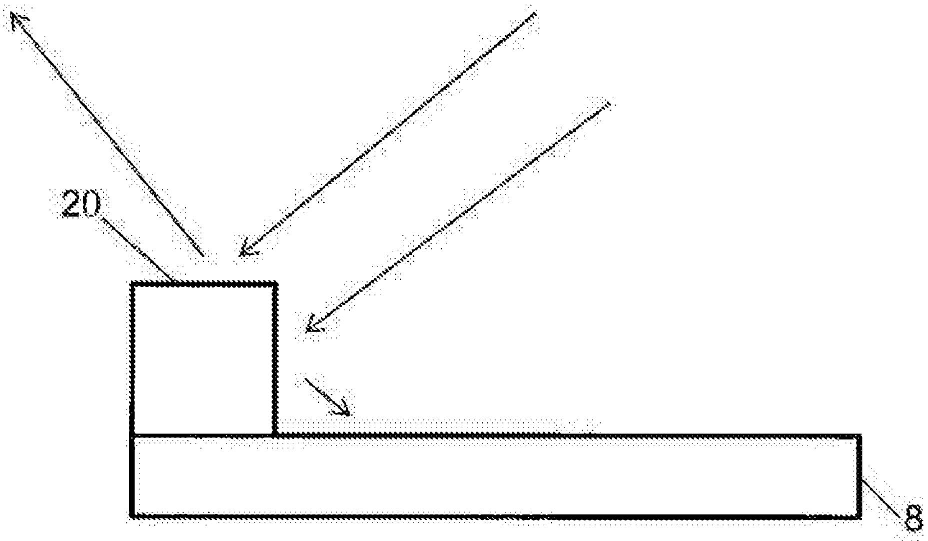


Figure 6a

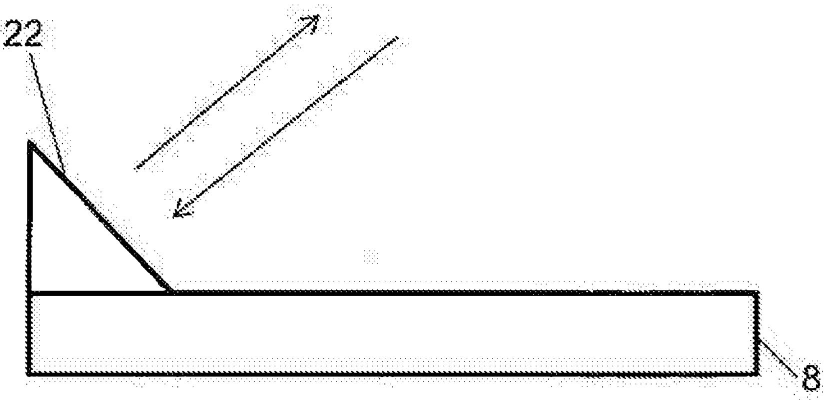
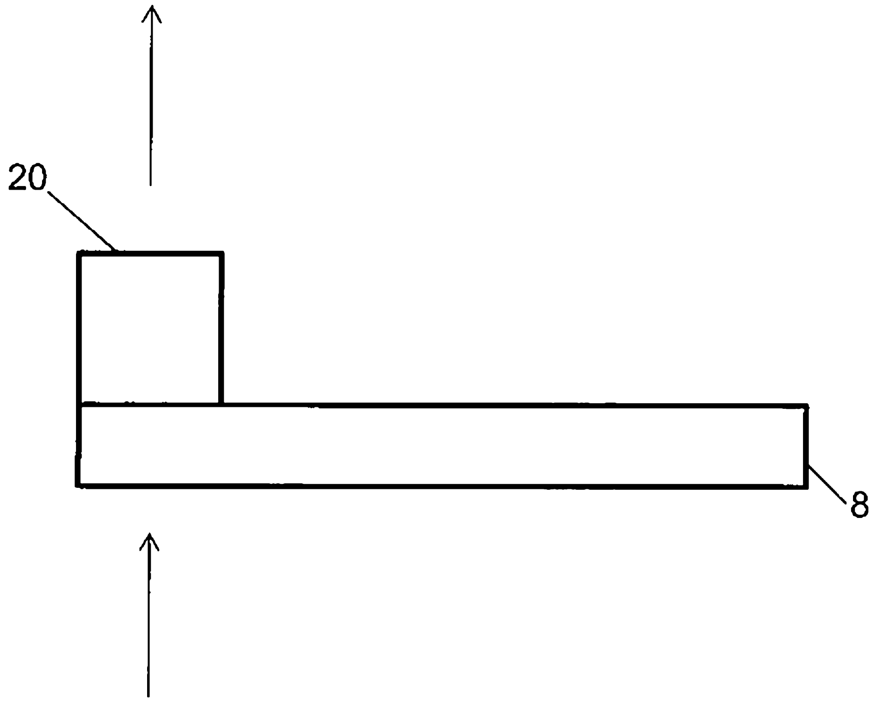


Figure 6b

2013101172 02 Sep 2013



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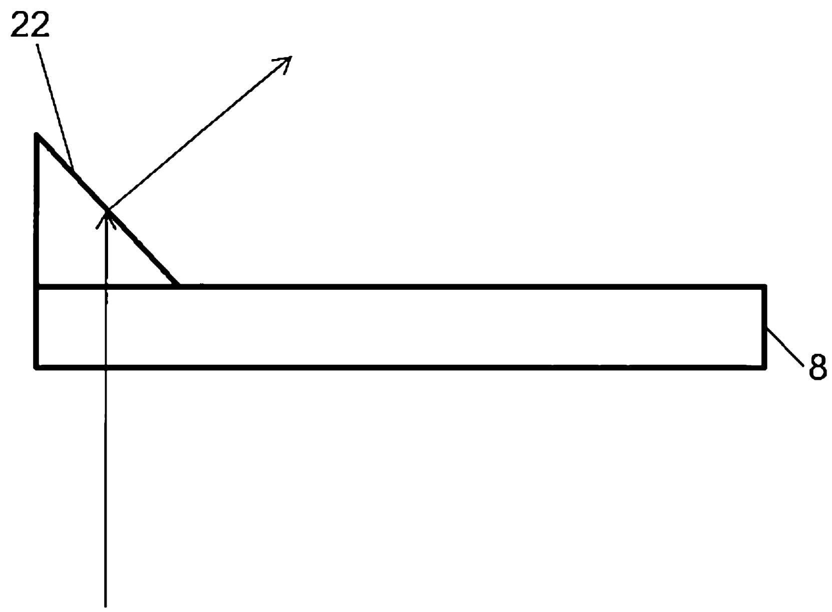

Figure 7b

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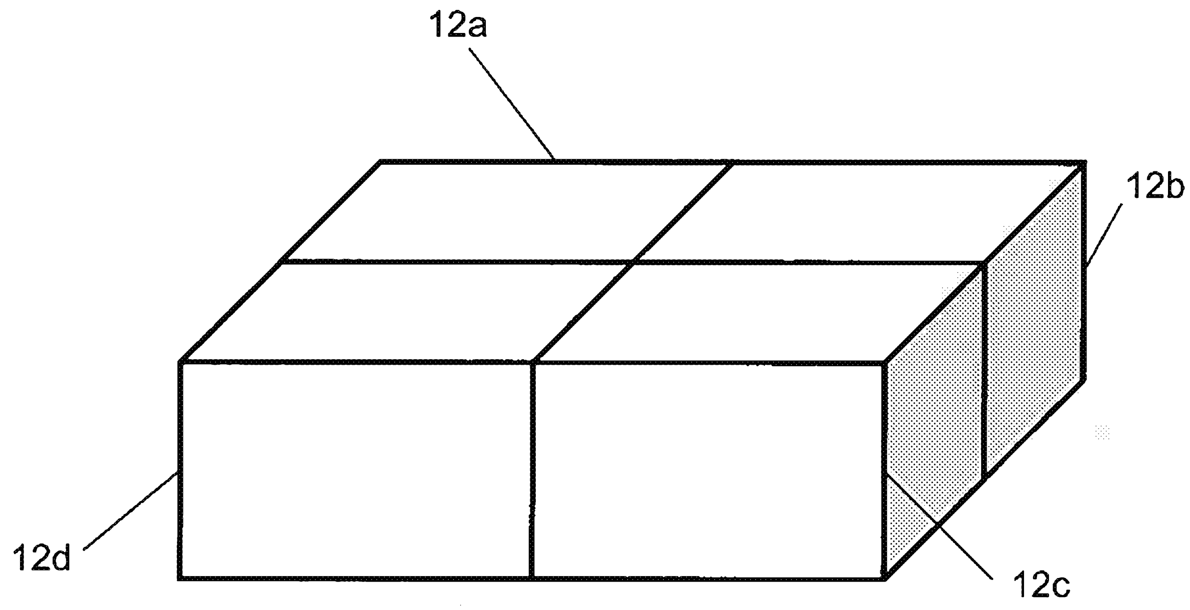
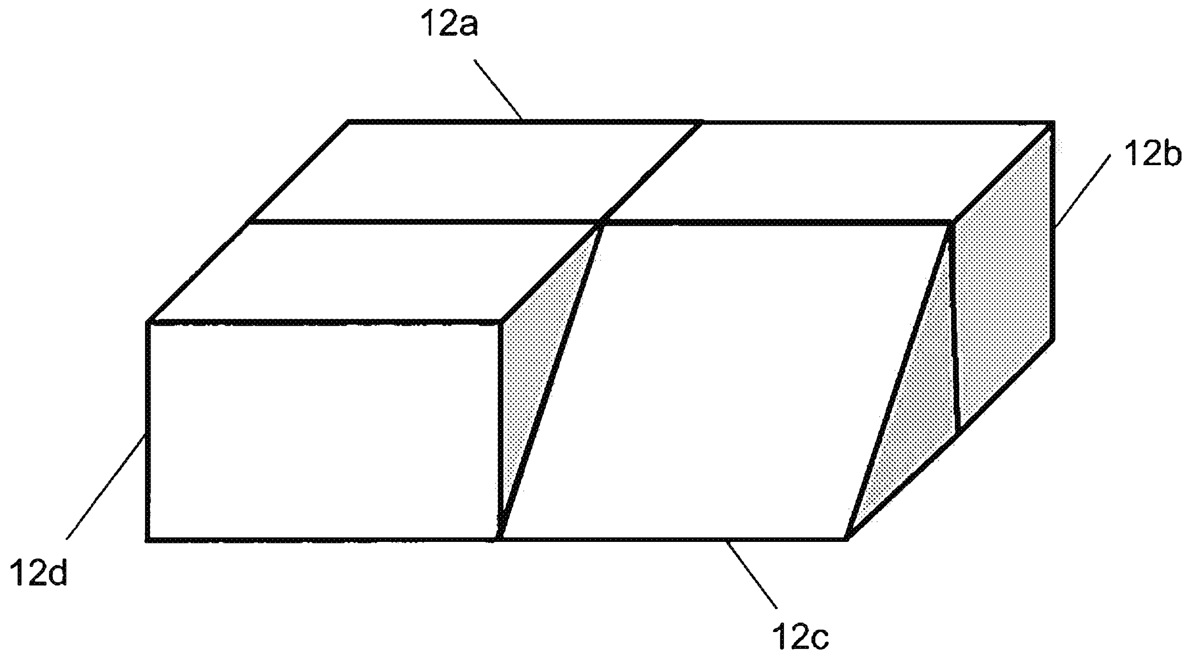


Figure 8a



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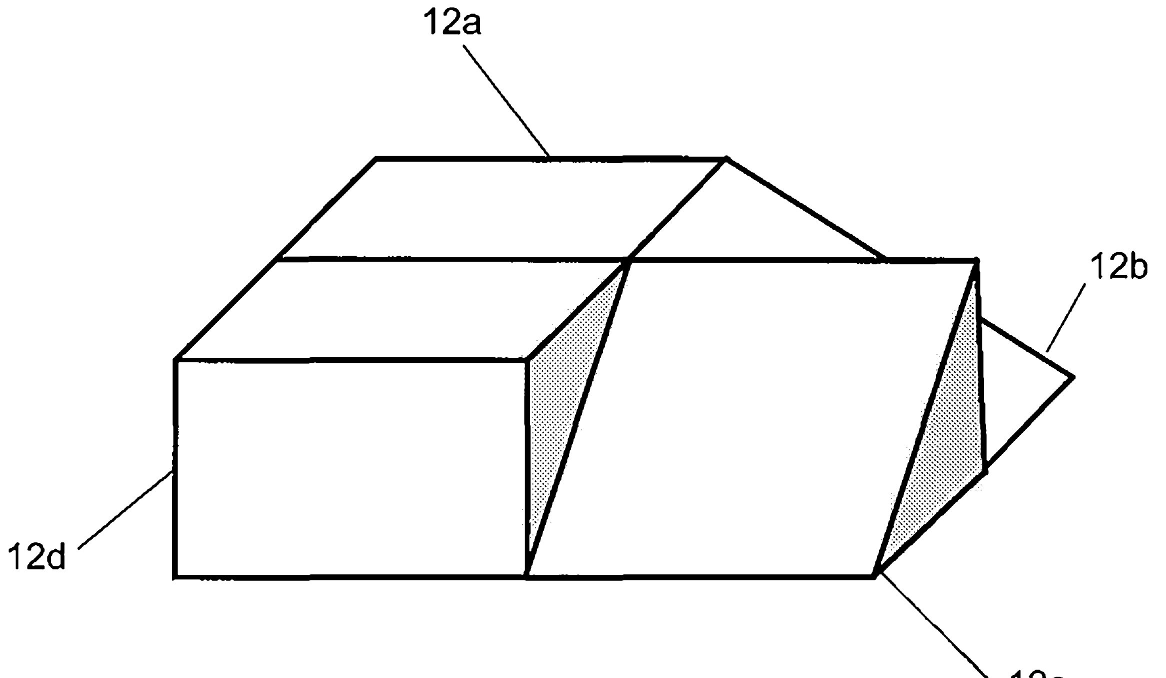

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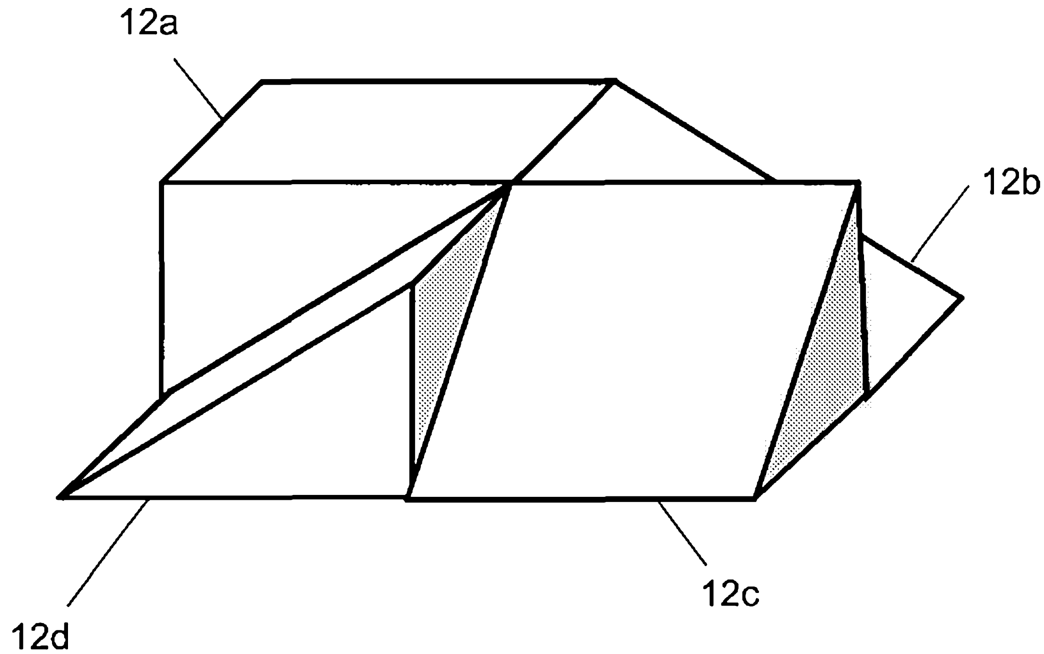

Figure 8d

2013101172 02 Sep 2013

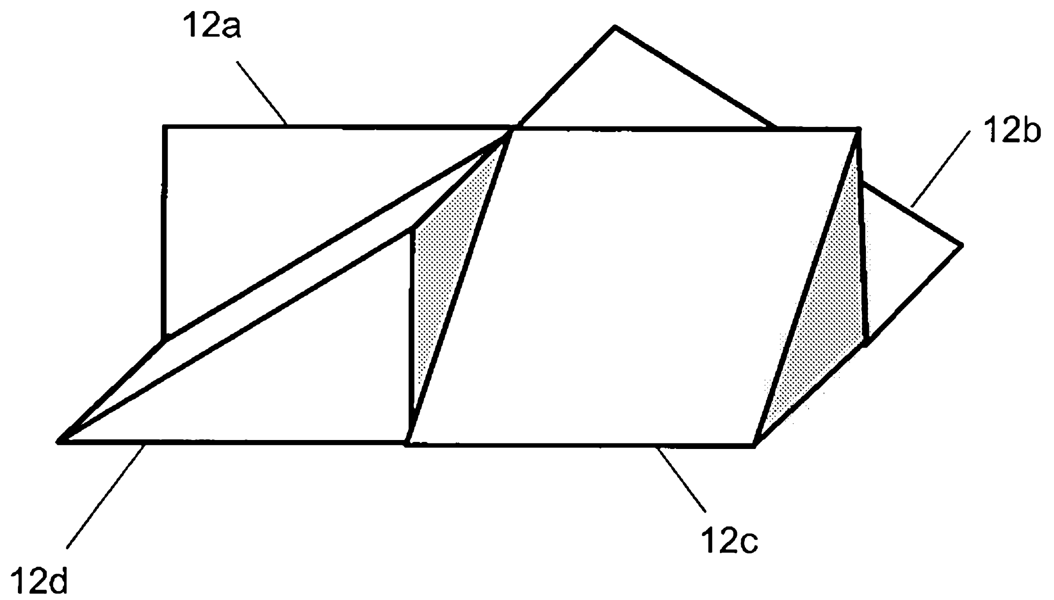

Figure 8e

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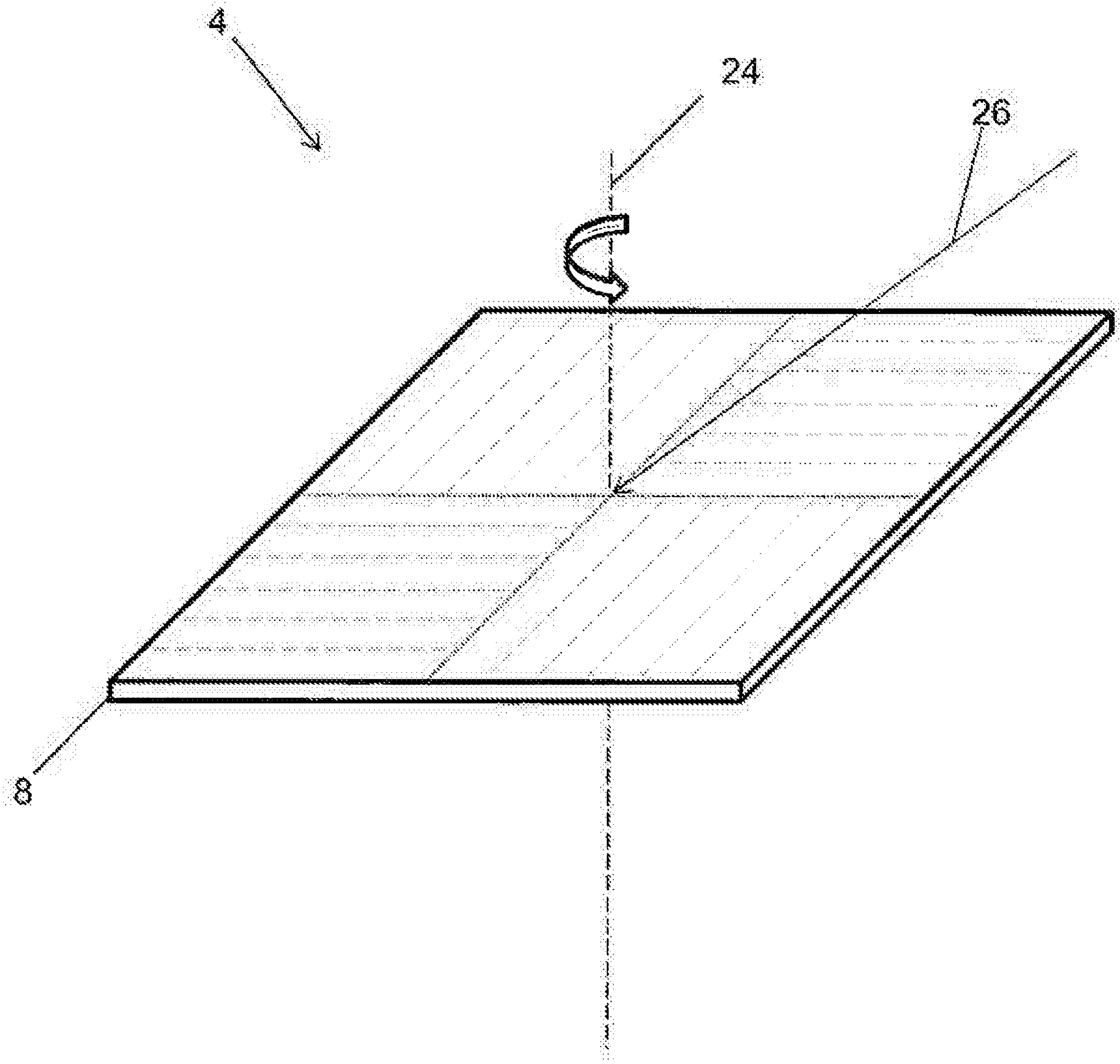

Figure 9

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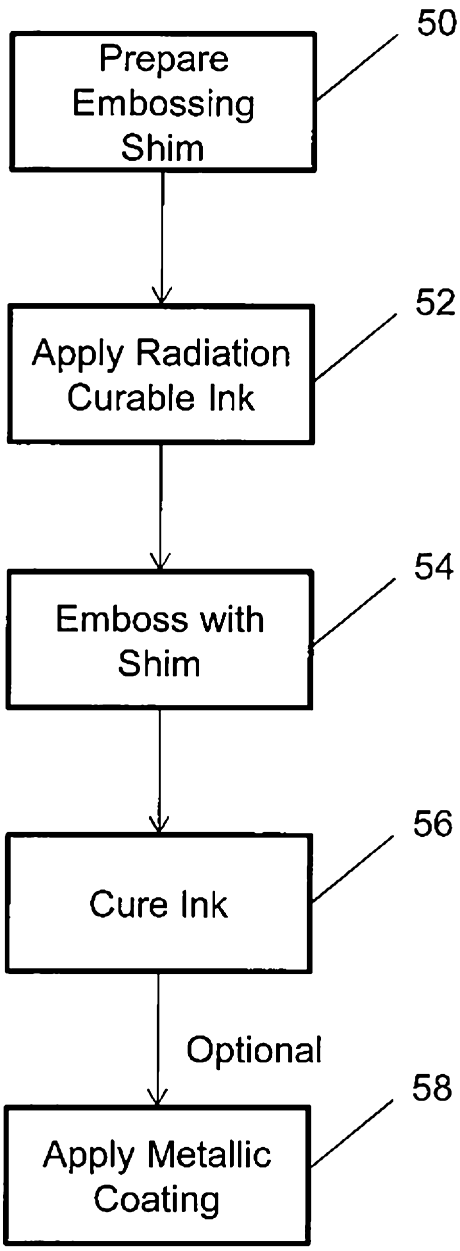

Figure 10

2013101172 02 Sep 2013

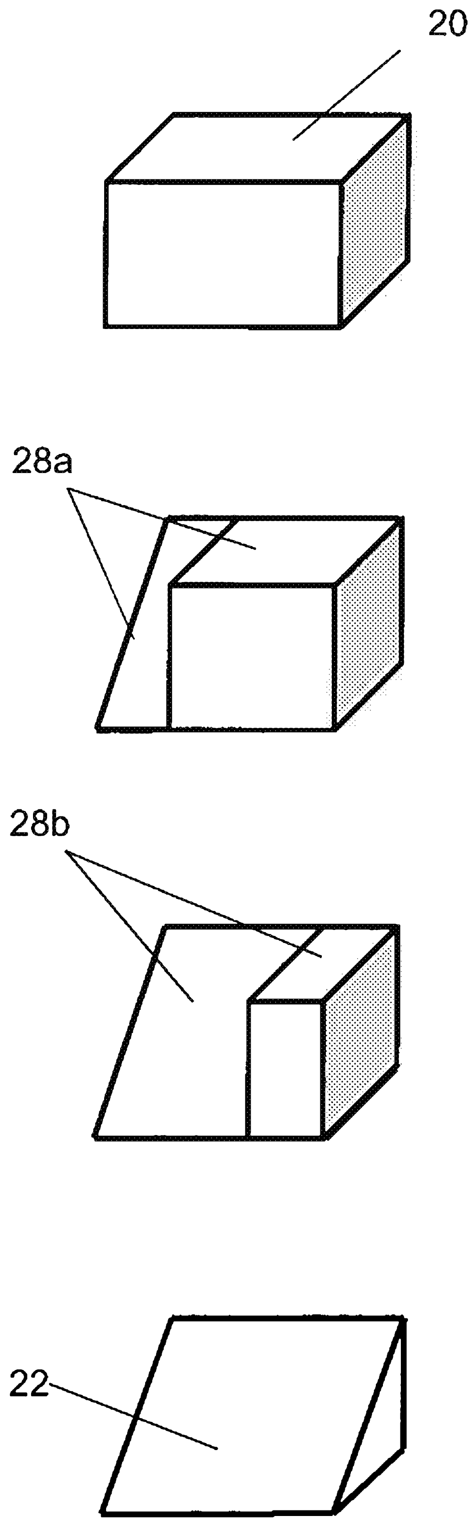

Figure 11

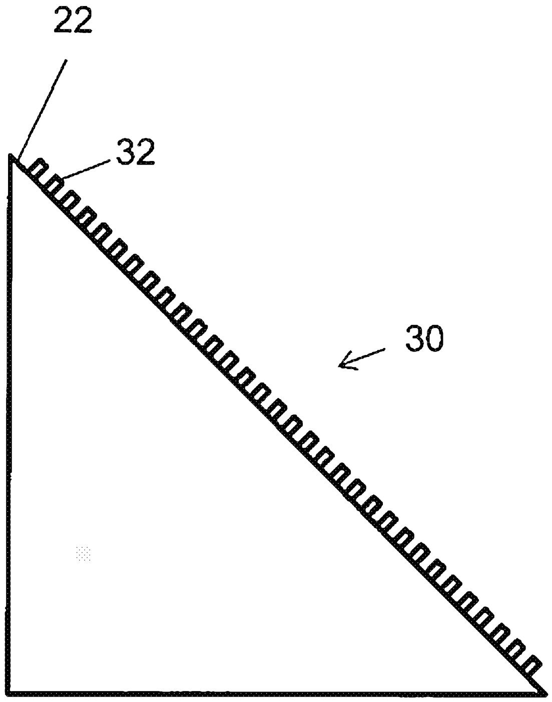

Figure 12