OPTICALLY VARIABLE DEVICE

Cross-Reference to Related Application

[0001] The present application claims priority from Australian provisional application no. 2021900998 filed on 6 April 2021, the content of which is incorporated herein in its entirety.

Technical Field

[0002] The invention relates generally to optically variable devices and methods of manufacture or verification thereof. In particular, the present invention relates to optically variable devices having diffractive elements or structures which exhibit at least one visual effect when viewed using a point light source and at least one visual effect when viewed in diffuse lighting conditions. Such optically variable devices can be utilised as security features when applied to documents and the like.

Background

[0003] Optically variable devices are commonly used in connection with valuable documents as a means of avoiding unauthorised duplication or forgery. These optically variable devices typically produce optical effects and/or features which may be difficult for a potential counterfeiter to replicate. The optical effects and/or features may also be used for verification of the valuable documents.

[0004] Counterfeiting of banknotes and other valuable documents has become an increasingly important issue in recent times due to ready availability of colour photocopiers and computer scanning equipment. This technology provides counterfeiters with an easier route to copying of valuable documents issued using traditional security printing technologies. In response, central banks and banknote printers have turned to technologies and devices which produce images that vary with changing angle of view, and which therefore cannot be easily photographed.

[0005] One available technology that is used as an anti-counterfeiting device on security documents, such as banknotes, is a diffractive lens image (DLIM) feature. The DLIM feature utilises a lenticular array of lenses located on one surface of the banknote and a lenticular image on an opposed surface of the banknote. The lenticular image has diffraction gratings on a planar surface located within the focal plane of the lenticular array of lenses. The lenticular lenses focus on and magnify the lenticular image of the diffraction gratings. The diffraction gratings produce an optical effect when viewed through the lenticular array of lenses under desired conditions, ie, when viewed from an appropriate viewing angle and sample orientation relative to a point light source.

[0006] The PCT document WO2018/204982, of the present applicant, relates to an optical security device and method of production thereof. The security elements described in that document are DLIM features that provide an optical effect. The content of WO2018/204982 is incorporated herein by reference.

[0007] Figure 1 shows a cross-sectional view of an existing security device 500 having a diffractive lens image (DLIM) feature such as described in WO2018/204982. The security device 500 includes a substrate 505, onto a first side 506 of which a lenticular lens array 501 is provided. The lens array 501 having an elongate axis perpendicular to the page. On an opposed second side 507 of the substrate 505 there is provided a series of diffraction gratings 503 formed in a radiation curable ink 502, applied to the substrate during manufacture. The gratings 503 preferably being aligned perpendicularly to the longitudinal axis L of the lens array 501. Optionally a coating 504 is applied over the diffraction gratings 503. The diffraction gratings 503 form at least part of image elements or pixels which are associated with a respective lens of the lens array 501.

[0008] Possible optical effects that can be provided by such DLIM features include 3D images, colour-flips, contrast switches, and animation effects. The optical effects being visible when the DLIM features are viewed in favourable lighting conditions as the viewing angle to the lenticular lens array 501 is changed.

[0009] One problem of the present DLIM features is that optical effects that they provide are only easily visible in point source lighting conditions. In diffuse lighting conditions, the visibility of the optical effects of the DLIM features is very difficult or not possible. The reason for this is that the imagery components of the DLIM features are diffraction gratings which diffract the incident light into their constituent colours, but the colours will only be visible if: (a) the light source is a point source or substantially similar to a point source; and (b) the location of the viewer's eye is within the angular range of the diffracted light. The requirement (b) is dependent on the orientation of the DLIM feature relative to the point source.

[0010] Due to this problem and the requirements for viewing the DLIM feature's optical effect discussed above, the viewer will often have to continuously manipulate the orientation of the substrate holding the DLIM feature, and/or the light source, and/or the viewer's observation angle in order to discover the optimal viewing conditions. These problems can make the authentication of a DLIM feature on a security document difficult and/or slow, particularly for untrained individuals. These difficulties are further exacerbated by attempts to view the DLIM feature in non-point light source and diffuse lighting conditions.

[0011] It is therefore desirable to provide an authentication feature suitable for a security document which overcomes at least one of the problems associated with the prior art. For example, it is desired to provide a optically variable device providing one or more optical effects that are visible in point light source and diffuse lighting conditions, and/or that can be authenticated in point light source and diffuse lighting conditions, and/or that can be more easily observed in general.

Summary of Invention

[0012] An aspect of the present disclosure provides an optically variable device comprising: a substrate having a first side and a second side opposite to the first side; an array of focusing elements on the first side; and a plurality of image elements on the second side, the image elements comprising a first group of sub-elements that are magnified by the focusing elements at a first range of viewing angles, and a second group of sub-elements that are magnified by focusing elements at a second range of viewing angles, wherein the image elements comprise a plurality of recessed regions that are recessed on the second side and a corresponding plurality of non-recessed regions, at least a first portion of the recessed regions and/or non-recessed regions comprising diffraction gratings, wherein a first segregated ink is present in the recessed regions but not in the non-recessed regions.

[0013] According to embodiments, the diffraction gratings are within the first portion of the recessed regions. The diffraction gratings may be only within the recessed regions.

[0014] According to embodiments, the focusing elements are lenticular lenses or cylindrical lenses.

[0015] According to embodiments, the first segregated ink is segregated into the first portion of the recessed regions.

[0016] According to embodiments, the diffraction gratings are oriented perpendicularly to a longitudinal axis of the focusing elements.

[0017] According to embodiments, the first segregated ink is a reflective ink.

[0018] According to embodiments, at least one recessed region of the first portion of recessed regions comprises diffraction gratings having a first spatial frequency, and wherein at least another recessed region of the first portion of recessed regions comprises diffraction gratings having a second spatial frequency different to the first spatial frequency.

[0019] According to embodiments, a second portion of the recessed regions are void of diffraction gratings, the second portion of recessed regions being overprinted with a second ink. Optionally, the second ink is segregated into the second portion of the recessed regions. Optionally, the second ink is the same ink as the first segregated ink. Optionally, the second ink is a pigmented non-reflective ink and/or an opacifying ink.

[0020] According to embodiments, the second portion of recessed regions are surrounded by non-recessed regions that comprise diffraction gratings. The second portion of the recessed regions may be overprinted with a second ink. The surrounding non-recessed regions that comprise diffraction gratings may be overprinted with a third ink. The third ink is preferably a reflective ink.

[0021] According to embodiments, at least a subset of the non-recessed regions comprise diffraction gratings. Optionally, the subset of the non-recessed regions comprising diffraction gratings are overprinted with a fourth ink. Optionally, the fourth ink is the same ink as the first segregated ink. Optionally, the subset of non-recessed regions have a width of at least 50 microns.

[0022] According to embodiments, wherein the second side comprises a protective layer over the image elements. Optionally, the protective layer is transparent or translucent. Optionally, the protective layer is an opacifying layer.

[0023] According to embodiments, wherein the recessed regions have a depth in a range from about 2 microns to about 12 microns. The recess depth may be in a range from about 1 micron to about 20 microns. The recess depth may be in a range from about 1 micron to about 15 microns. The recess depth may be in a range from about 2 microns to about 15 microns. Preferably, the depth is in a range from about 3 microns to about 10 microns More preferably, the depth is in the range from about 3 microns to about 7 microns.

[0024] According to embodiments, the substrate comprises a plurality of substrate layers.

[0025] According to embodiments, the recessed regions and non-recessed regions are formed on the second substrate side in a radiation curable ink. Optionally, the radiation curable ink is UV curable ink. Optionally, the radiation curable ink is embossable. Preferably, the diffraction gratings are formed in the radiation curable ink.

[0026] According to embodiments, the image elements comprise more than two groups of sub-elements. The image elements may each have four sub-elements. The image elements may each have eight sub-elements. The image elements may each have from two to ten sub-elements. The image elements may each have from two to twenty sub-elements. The image elements may include moiré image sub-elements. The image elements may include integral image sub-elements. The optical variable device may comprise at least one lenticular integral image and at least one lenticular moiré image.

[0027] According to embodiments, the diffraction gratings are on the first portion of the non-recessed regions. The diffraction gratings may be only on the non-recessed regions. According to embodiments, the first segregated ink is a non-reflective ink.

[0028] According to embodiments, the non-reflective ink is a pigmented non-reflective ink and/or an opacifying ink.

[0029] According to embodiments, the diffraction gratings fill a surface of the non-recessed regions.

[0030] According to embodiments, the focusing elements are lenticular lenses or cylindrical lenses.

[0031] According to embodiments, the diffraction gratings are oriented perpendicularly to a longitudinal axis of the focusing elements.

[0032] According to embodiments, the recessed regions with the first segregated ink and non-recessed regions with diffraction gratings are overprinted with a reflective ink.

[0033] According to embodiments, the recessed regions have a depth in a range from about 2 microns to about 12 microns, preferably wherein the depth is in a range from about 3 microns to about 10 microns, more preferably wherein the depth is in the range from about 3 microns to about 7 microns.

[0034] According to embodiments, the image elements comprise more than two groups of sub-elements.

[0035] Another aspect of the present disclosure provides a security document comprising the optically variable device of any one of the above aspects or embodiments.

[0036] Optionally, the security document is a banknote.

[0037] Optionally, the optically variable device is provided in a window region or half window region of the security document.

[0038] An aspect of the present disclosure provides a optically variable device comprising: a substrate having a first side and a second side opposite to the first side; an array of focusing elements on the first side; and a plurality of image elements on the second side, the image elements comprising a first group of sub-elements that are magnified by the focusing elements at a first range of viewing angles, and a second group of sub-elements that are magnified by focusing elements at a second range of viewing angles, wherein the image elements comprise: a plurality of recessed regions that are recessed on the second side, at least a first portion of the recessed regions comprising diffraction gratings overprinted with a first segregated ink; and a plurality of non-recessed regions on the second side.

[0039] According to another aspect of the present disclosure there is provided a optically variable device comprising: a substrate having a first side and a second side opposite to the first side; an array of focusing elements on the first side; and a plurality of image elements on the second side, the image elements comprising a first group of sub-elements that are magnified by the focusing elements at a first range of viewing angles, and a second group of sub-elements that are magnified by focusing elements at a second range of viewing angles, wherein the image elements comprise: a plurality of recessed regions that are recessed on the second side, wherein a non-reflective ink is segregated within each of the recessed regions; and a plurality of non-recessed regions on the second side, wherein at least a portion of the non-recessed regions comprise diffraction gratings.

Definitions:

Security document

[0040] As used herein, the term security document 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 licences, deeds of title, travel documents such as airline and train tickets, entrance cards and tickets, birth, death and marriage certificates, and academic transcripts.

[0041] 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.

[0042] The diffraction gratings and optically variable devices described herein can also have application in other products, such as packaging.

Security Device or Security Feature

[0043] 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, and alteration or tampering. Security devices or features can 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 can 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) comprising reflective optical structures including reflecting surface relief structures and diffractive devices including diffraction gratings, holograms and diffractive optical elements (DOEs).

Transparent Windows and Half Windows

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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

[0048] 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 $L_T < L_O$, where L_O 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.

Radiation Curable Ink

[0049] The term radiation curable ink used herein refers to any ink, lacquer or other coating which may be applied to the substrate in an application process. In one embodiment, the ink can be embossed while soft to form a relief structure and cured by radiation to fix the embossed relief structure. In another embodiment, the ink can be printed onto the substrate and cured by radiation to fix the relief structure. The curing process, preferably, does not take place before the radiation curable ink is formed (embossed or printed, for example), but either after application or at substantially the same time as the relief structure forming step. Alternatively, the ink may be partially cured before being formed. 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.

[0050] 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.

[0051] In one particularly preferred embodiment, the radiation curable ink preferably comprises an acrylic based UV curable clear lacquer or coating. Furthermore, the radiation curable ink is preferably embossable.

[0052] 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, e.g. nitro-cellulose.

[0053] The radiation curable inks and lacquers used herein have been found to be particularly suitable for forming microstructures, including diffractive structures such as diffraction gratings and holograms, and micro lenses and lens arrays. However, they may also be used to form larger relief structures, such as non- diffractive optically variable devices.

[0054] The ink is preferably cured by ultraviolet (UV) radiation at substantially the same time as application of a tool incorporating the relevant structure to a substrate. In one embodiment, the radiation curable ink is cured and embossed at substantially the same time in a Gravure printing process. In another embodiment, the ink is applied to a printing tool and cured when the printing tool is in contact with the substrate.

Radius of curvature R

[0055] The radius of curvature of a lenslet is the distance from a point on the surface of the lens to a point at which the normal to the lens surface intersects a line extending perpendicularly through the apex of the lenslet (the lens axis).

Image pixel and sub image pixel

[0056] Throughout the description terms such as image element(s) and image pixel(s) are used interchangeably and they are intended to have the same meaning. Terms such as sub pixels, sub image pixels, and sub elements are also intended to have the same meaning as each other and used interchangeably.

Brief Description of Drawings

[0057] Embodiments of the invention will now be described with reference to the accompanying drawings. It is to be understood that the embodiments are given by way of illustration only and the invention is not limited by this illustration. In the drawings:

[0058] Figure 1 shows a cross-section of a prior art optically variable device;

[0059] Figure 2 shows a cross-section of a optically variable device according to an embodiment of the disclosure;

[0060] Figure 3 shows a top view of sections of grating imagery located beneath one lenticular lens of the embodiment of figure 2;

[0061] Figure 4 shows an example of an integrated design visible to a viewer of a optically variable device according to the present disclosure;

[0062] Figure 5 shows a cross-section of a optically variable device according to another embodiment of the disclosure;

[0063] Figure 6 is another example of an integrated design visible to a viewer of a optically variable device according to the present disclosure; and

[0064] Figure 7 shows a cross-section of a optically variable device according to another embodiment of the disclosure.

Detailed Description of Embodiments

[0065] Aspects and embodiments of the present invention provide optically variable devices that give optical effects that are visible to a viewer both in point light source and diffuse lighting conditions. The present invention is therefore advantageous for at least providing those improvements over the prior art DLIM features of the optically variable device structure depicted in figure 1, and discussed in the Background section above.

[0066] Figure 2 shows one embodiment of a optically variable device 10 according to the present disclosure that can display to a viewer optical effects in both point light source and diffuse lighting conditions. The optically variable device 10 has a substrate 11 with a first substrate side 12 and second substrate side 13. On the first substrate side 12 is a focussing element array, in the form of a lenticular lens array 14, which comprises a plurality of lenses 15. In this embodiment, and all other embodiments described herein, the focussing element array can be any suitable structures for focussing light, such as refractive lenses or diffractive lenses. A longitudinal axis of each lens 15 of the lenticular lens array 14 being into or out of the page as viewed in figure 2. Opposed to the first substrate side 12 is second substrate side 13, each of the first substrate side and second substrate side being substantially planar. On the second substrate side are a plurality of recessed regions 17 and non-recessed regions 18. Diffraction gratings 19 are located within the recessed regions 17. A reflective ink 20 is applied over the diffraction gratings in a manner such that it is, substantially, segregated into the recessed regions only. Of course, the reflective ink 20 in a practical process of applying or printing may be present on the non-recessed regions 18 in an amount which does not affect the intended operation. That is, the reflective ink 20 may be present on the non-recessed regions in such small amounts that the amount of reflection, relative to the recessed regions 17, is insignificant.

[0067] When viewed at varying angles to the lenticular lens array 14 with a point light source the optically variable device 10 having the structure as shown in figure 2 will show a multi-colour optical effect. The multi-colour optical effect being provided by the diffraction gratings acting to diffract the light from the point light source into desired colour components and a variance in viewing angle will result in a change in perceived colour from the various diffraction gratings 19 as well as due to the change in position of the focal point through the relevant microlens 15. It can be difficult to see the multi-colour optical effect in diffuse lighting conditions. However, when viewed in diffuse lighting conditions, a single colour optical effect, which is the colour of the reflective ink 20 will be viewable. The single colour optical effect will provide the same image, at a particular angle of view, as the multi-colour optical effect, albeit with only one colour rather than many colours. The single colour effect may be easier to view compared to the multi-colour optical effect and may require less manipulation of the optically variable device relative to a light source for the single colour effect to be seen.

[0068] According to the embodiment shown in figure 2, a radiation curable ink 16 is applied onto the second substrate side 13. The radiation curable ink 16 is preferably UV curable ink. The recessed regions 17 are formed from a radiation curable ink 16 (as described above). The diffraction gratings 19 are also formed in the radiation curable ink 16. According to one embodiment, the recessed regions 17, non-recessed regions 18 and diffraction gratings 19 are printed onto the second substrate side 13, and where they are printed in radiation curable ink 16, the ink 16 is cured to provide the structures shown in figure 2. Alternatively, a radiation curable ink 16 is applied to the second substrate side 13, then the structure of the recessed regions 17, non-recessed 18 and diffraction gratings 19 are embossed into the radiation curable ink 16, and cured. According to embodiments, the recessed regions 17, non-recessed regions 18 and diffractions gratings 19 are formed in the same process. According to alternative embodiments, the recessed regions 17 and non-recessed regions 18 are formed in a first process and the diffraction gratings 19 are formed in a second process. The first and second process may or may not be the same type of process.

[0069] Optionally, a protective coating 21 is applied over the structure of the recessed regions 17, non-recessed regions 18 and reflective ink 19. The protective coating may be transparent. The protective coating may be translucent. The protective coating may be an opacifying layer. A protective coating (not shown) may be applied over the lenticular lens array 14, or other focusing elements used in the optically variable device. The protective coating is preferably transparent.

[0070] The recessed regions have a depth x. For example, the distance perpendicular to the plane of the substrate between the recessed regions and non-recessed regions is preferably the depth x. The preferred recess depth is in the range from about 1 micron to about 20 microns. More preferably the recess depth is about 2 microns to about 12 microns. Yet more preferably, the recess depth is about 3 microns to about 10 microns. Most preferably the recess depth is about 3 microns to about 7 microns.

[0071] The substrate 11 is preferably formed at least partially from a polymeric material. The substrate may be formed entirely from a polymeric material. The substrate 11 may comprise at least one window area and/or at least one half-window area. The optically variable device 10 may be formed in the window area or the half window area of the substrate. According to alternative embodiments, the substrate 11 may be multi-layered and formed from layers of material. The substrate 11 may comprise a transparent polymeric material and optionally at least one opacifying layer.

[0072] The diffraction gratings 19 are preferably oriented perpendicularly to the longitudinal axis L of the lenses 15, as shown in Figure 3. This perpendicular orientation of the diffraction gratings 19 to the longitudinal axis of the lenses 15 may ensure that each lens 15 of the lenticular lens array 14 projects a constant colour to a viewer at each point along the lenticular axis L of the lenses 15. Figure 3 shows a top view of an image element 30 beneath and associated with a single lens 15. The image element 30 is split into five channels or groups 31-35. Embodiments of the present disclosure will include at least two channels or groups. Each of the channels may provide a respective frame of a

3D image, animation, flip effect, contrast switch or other effect image. When the image element 30 is viewed through the associated lens 15 at a first angle, the first group 31 will be viewed. As the optically variable device is rotated relative to the user or viewed from a varying angle the second group 32, third group 33, fourth group 34 and fifth group 35 will be viewed. In other words, gradual rotation of the device relative to the viewer or gradual changing of the viewing angle will gradually manoeuvre through and allow viewing of each of the groups 31 to 35 one after the other. Each group 31-35 of the image element 30 has diffraction gratings 36, 37, 38 of varying spatial frequency and non-recessed areas 39 with no gratings. The diffraction gratings 36, 37, 38 and non-recessed areas 39 of the group being viewed of each image element 30 of each respective lenticular lens 15 combine together to provide a viewer with an overall image at a given viewing angle.

[0073] The spatial frequency of the diffraction gratings 36, 37, 38 may be selected such that a desired colour is visible at the given viewing angle of the group in which that diffraction grating lies. In figure 3, grating 36 will provide a red colour to a viewer, grating 37 will provide a green colour to a viewer, and grating 38 will provide a blue colour to a viewer. Through using combinations of diffraction gratings that provide the colours red, green and blue (RGB) a full colour image may be created to a viewer. A pixel of an image to be displayed to a viewer may have each of a red, green and blue component. The red, green or blue components respectively each being a sub-pixel or sub-element of the pixel. Other colour spaces could be similarly used to create a full colour image, such as CMY. Alternatively, greyscale images could be created. The brightness of each colour displayed or sub-pixel or sub element of a pixel may be controlled through any suitable method such as by varying grating depth, grating profile and/or grating curvatures. In addition, each of the sub-elements may include an effective grating area that includes the diffraction grating element, and a non-diffractive area that does not include any grating elements, and a brightness value of each sub-element is varied by changing the effective grating area within each sub-element and/or the non-diffractive area of the sub-element. The grating area of a sub-element (sub-pixel) is provided in a recessed region 17 of the optically variable device and the non-diffractive area is provided in a non-recessed region 18, in the embodiment shown in figure 2. The applicant's PCT document WO2018/204982 provides a detailed description of the creation of RGB and greyscale colour space pixels, the content of which is recreated herein by reference.

[0074] Functionally, the focusing elements, which are preferably lenticular lenses or cylindrical lenses, on the first substrate side will focus on image elements located substantially within the focal plane of the lenses. The focusing elements will sample and magnify portions of the image elements. Each image element is associated with one focusing element and each image element is split into at least two channels or groups, such that one of the channels or groups may be sampled and magnified by the focusing element at a time and dependent on a viewing angle. This will generate a first optical effect image.

[0075] The image element comprises an imagery structure that includes recessed regions and non-recessed regions. The recessed regions are preferably recessed with respect to a second substrate side. The second substrate side may comprise a layer in which the recessed and non-recessed regions are formed. For example, the layer on the second substrate side may be formed from a radiation curable ink. The recessed regions and non-recessed regions are located in a predetermined design within the imagery structure in correspondence with the first optical effect image. Preferably, the recessed regions each have a recess depth in the range from about 1 micron to about 20 microns. More preferably the recess depth is from about 2 microns to about 12 microns. Yet more preferably, the recess depth is from about 3 microns to about 10 microns. Most preferably the recess depth is from about 3 microns to about 7 microns. At least some of the recessed regions comprise diffraction gratings. All of the recessed regions may comprise diffraction gratings. The diffraction gratings may be oriented perpendicularly to a longitudinal axis of the focusing elements. The diffraction gratings have predetermined locations, orientations and spatial frequencies within the imagery structure in correspondence with the first optical effect image. The recessed regions, whether having diffraction gratings or not, are overprinted with an ink that segregates into the recessed regions. The segregated ink is preferably a reflective ink. The segregated ink may be limited to the recessed regions and may avoid the non-recessed regions. As mentioned previously, application of the segregated ink in a practical process may result in a minor proportion of the segregated ink being present on the non-recessed regions, in an amount which does not affect the intended operation. That is, the segregated ink may be present on the non-recessed regions in such small amounts that the function effect, relative to the recessed regions, is insignificant

[0076] The first optical effect image may be a 3D integral image and/or an interlaced image. The first optical effect image may include an animation optical effect, a 3D interlaced image effect, a 2-flip image effect, a contrast switch effect, any other desired transitory image effect, or any combination of two or more thereof.

[0077] According to further possible embodiments of a optically variable device of the present disclosure, not shown in figure 2, recessed regions may be provided that do not contain diffraction gratings. These recessed regions would be similarly overprinted with a segregated ink. The segregated ink is preferably a reflective ink. The segregated ink may be the same ink as overprinted on the recessed regions that contain diffraction gratings as the recessed regions that do not contain diffraction gratings. Alternatively, different segregated ink may be used for each of the recessed regions that contain diffraction gratings and the recessed regions that do not contain diffraction gratings. The segregated ink overprinted on at least the recessed regions that are absent diffraction gratings may be a non-reflective ink, such as pigmented non-reflective ink. When viewed through the focusing elements at varying angles, the recessed regions absent diffraction gratings will display a single colour optical effect which is the colour of the overprinted ink that is segregated into these regions.

[0078] As a further optional feature, a non-reflective ink may be applied over and segregated into recessed regions. The recessed regions that receive the non-reflective ink may have diffraction gratings and/or may not have diffraction gratings. The areas overprinted with non-reflective ink that is segregated into recessed regions with and/or without diffraction gratings will display a single colour optical effect, relating to the colour of the non-reflective ink, when viewed in all lighting conditions, in other words when viewed in both point light source and diffuse lighting conditions.

[0079] As an additional feature, grating imagery may be provided in non-recessed regions. These non-recessed regions with diffraction gratings may function similarly to a standard DLIM feature. The diffraction gratings on the non-recessed regions are preferably perpendicular to the longitudinal axis L of the focusing elements. Preferably, diffraction gratings are provided on non-recessed regions that exceed a width of about 50 microns. The diffraction gratings in non-recessed regions may be overprinted with a reflective ink. Unlike the diffraction gratings within recessed regions that have ink overprinted in a segregated manner, the reflective ink that is applied over the diffraction gratings in non-recessed regions will not be segregated. In other words, the ink applied over the diffraction gratings in non-recessed regions will not be segregated and will also be deposited on non-recessed regions that don't have diffraction gratings that are adjacent to the non-recessed regions with diffraction gratings. For that reason, a single colour optical effect viewable in diffuse lighting is not produced by this feature of diffraction gratings overprinted with a reflective ink in non-recessed regions. Instead, a multi-colour optical effect is produced by these areas of diffraction gratings in non-recessed regions overprinted with ink that is visible in point light source conditions but difficult to view in diffuse lighting conditions. By implementing this feature in addition to the diffractions gratings in recessed regions with segregated ink, there is provided an additional authentication step which requires the user to view the further feature in a point light source in order to detect its presence.

[0080] Figure 4 provides an example of an image 40 that may be viewed using a optically variable device with features as described above. The image 40 is preferably one frame of multiple frames of images that are displayed when the optically variable device is viewed from varying angles. The large font 'AU' design 41 is formed by recessed regions having diffraction gratings that are overprinted with a segregated reflective ink, such as shown in figure 2. The 'AU' design 41 is seen by a viewer as a 3D optical effect that appears to float in front of the banknote. The 'AU' design 41 is visible as a multi-colour image when viewed with a point light source and is visible as a single colour image corresponding to the colour of the reflective ink when viewed in diffuse lighting conditions.

[0081] The large font '50' design 43 is formed by gratings applied to non-recessed regions and overprinted with a reflective ink that is not segregated. The '50' design 43 is seen by a viewer as a multi-colour 3D optical effect that appears to float in front of the banknote when viewed in point light source. The '50' design is not visible to a viewer in diffuse lighting conditions or is extremely hard to view in diffuse lighting conditions. The small font 'AU50' designs 42 shown in figure 4 is formed by recessed regions without diffraction gratings overprinted with a segregated ink. The 'AU50' designs 42 is seen by a viewer as 3D optical effects that appears to float behind the banknote, and behind the 'AU' design 41 and the '50' design 43. The background of the image 40 may be formed by overprinting the second side of the optically variable device with an ink, preferably a reflective ink, to a desired shape, such as a rectangle as shown in figure 4.

[0082] Figure 5 shows a cross-section of a optically variable device according to an embodiment of the present invention and including features as discussed above. The optically variable device 60 has a substrate 61 with a first substrate side 62 and second substrate side 63. On the first substrate side 62 is a focussing element array, in the form of a lenticular lens array, 64 which comprises a plurality of lenses 65. A longitudinal axis of each lens 65 of the lenticular lens array 64 is into and/or out of the page as viewed in figure 5. Opposed to the first substrate side 62 is second substrate side 63, each of the first substrate side 62 and second substrate side 63 being substantially planar. On the second substrate side 63 are a plurality of recessed regions 67 and non-recessed regions 68. Diffraction gratings 69 are located within a first portion of the recessed regions 67. A reflective ink 70 is applied over the diffraction gratings 69 within the first portion of the recessed regions 67 in a manner such that the reflective ink is segregated into at least the first portion of the recessed regions 67. The diffraction gratings 69 in the recessed regions 67 overprinted with a segregated reflective ink 70 provides a multi-colour optical effect when viewed with a point light source at varying angles through the lens array 64 by a viewer. When the same structures are viewed through the lens array 64 by a viewer in diffuse lighting conditions a single colour optical effect which is the colour of the reflective ink 70 is seen. The multi-colour optical effect being the same optical effect as the single colour optical effect other than the difference in colour.

[0083] A second portion 73 of the recessed regions 67 do not have diffraction gratings. The second portion 73 of recessed regions 67 are overprinted with a segregated ink 74. The ink 74 may be the same as the reflective ink 70. Alternatively, the ink 74 may be different to the reflective ink 70. The second portion 73 of recessed regions overprinted with ink 74 provide a single colour optical effect to a viewer observing through the array of lenticular lenses 64. The single colour optical effect being the colour of the ink 74. The ink 74 is preferably a reflective ink. Alternatively, the ink 74 may be a pigmented non-reflective ink.

[0084] A portion of the non-recessed regions 68 have diffraction gratings 75 therein. The diffraction gratings 75 preferably being oriented substantially perpendicular to the longitudinal axis L of the lenses 65. The diffraction gratings are preferably provided on non-recessed regions 68 that have a width dimension of at least about 50 microns. Adjacent to the diffraction gratings 75 on the non-recessed regions 68 are sections 77 that are absent diffraction gratings. The diffraction gratings 75 and sections 77 being overprinted with an ink 76. Preferably the ink 76 is a reflective ink. The ink 76 may be the same ink as one or both of ink 74 and reflective ink 70. Alternatively, the ink 76 may be different to both of ink 74 and reflective ink 70. When the non-recessed regions 68 with diffraction gratings 75 and adjacent sections 77 absent gratings that are overprinted with ink 76 are viewed through the lens array 64 a multi-colour optical effect or grey-scale optical effect can be seen. In diffuse lighting conditions it is extremely difficult to view the same multi-colour optical effect.

[0085] According to the embodiment shown in figure 5, a radiation curable ink 66 is applied onto the second substrate side 63. The radiation curable ink 66 is preferably UV curable ink. The radiation curable ink 66 is preferably embossable. The recessed regions 67, diffraction gratings 69 and diffraction gratings 75 are formed into the radiation curable ink 66 using techniques discussed herein. According to embodiments, the recessed regions 67, non-recessed regions 68 and diffractions gratings 69, 75 are formed in the same process. According to alternative embodiments, the recessed regions 67 and non-recessed regions 68 are formed in a first process and the diffraction gratings 69, 75 are formed in a second process. The first and second process may or may not be the same type of process.

[0086] Another possible feature of the present disclosure may be provided by recessed regions with diffraction gratings and/or recessed regions without diffraction gratings and/or non-recessed regions having diffraction gratings, that are overprinted with a plurality of segregated ink layers. The segregated ink layers may or may not be overlapping one another. The plurality of segregated ink layers are preferably each reflective ink or pigmented non-reflective ink. Each segregated ink layer may provide a separate optical effect in that colour when viewed in at least diffuse lighting conditions. A segregated ink layer may be an opacifying layer of the security document on which the optically variable device is located. The segregated ink layers may be in place of the segregated ink 20, 70, 74 of the embodiments shown in figures 2 and 5.

[0087] Figure 6 shows a view 80 of one embodiment of an optically variable device with segregated ink layers as described above. The view 80 is preferably one frame of multiple frames of images that are displayed when the optically variable device is viewed from varying angles. The large font 'AU' design 81 is formed by recessed regions having diffraction gratings that are overprinted with a segregated reflective ink, such as shown in figure 2. The 'AU' design 81 is seen by a viewer as a 3D optical effect that appears to float in front of the banknote. The 'AU' design 81 is visible as a multi-colour image when viewed with a point light source and is visible as a single colour image corresponding to the colour of the reflective ink when viewed in diffuse lighting conditions.

[0088] The large font '50' design 83 is formed by gratings applied to non-recessed regions and overprinted with a reflective ink that is not segregated. The '50' design 83 is seen by a viewer as a multi-colour 3D optical effect that appears to float in front of the banknote when viewed in point light source. The '50' design is not visible to a viewer in diffuse lighting conditions or is extremely hard to view in diffuse lighting conditions. The small font 'AU50' designs 82 shown in figure 6 is formed by recessed regions without diffraction gratings overprinted with a segregated ink. The 'AU50' designs 82 are seen by a viewer as 3D optical effects that appear to float behind the banknote, and behind the 'AU' design 81 and the '50' design 83.

[0089] The rectangular background section 84 behind the AU design 81 and '50' design 83 of the image 80 is formed by overprinting the second side of the optically variable device with a reflective ink. In other words, all of this rectangular background section 84 shows the colour of the reflective ink applied over the entirety of this region on the second side of the security document. The reflective ink is preferably applied beneath a protective coating. The protective coating may be transparent or translucent.

[0090] The rectangular background section 85 is located between the section 84 and section 86. The rectangular background section 85 does not have an ink applied over it. In this case the optically variable device that forms the image 80 may be provided in a window region, in which case the section 85 displays a transparent appearance and will show a viewer the 3D optical effect in the colour of the light transmitted through the window region to the viewer. A transparent protective layer may be applied over the structure on the second side of the optically variable device in the window of section 85.

[0091] The rectangular background section 86 is located about the perimeter of the image 80. The section 86 is formed by overprinting the second side of the optically variable device with an opacifying layer. In other words, all of this rectangular background section 86 shows the colour of the opacifying layer that is applied over the entirety of this region on the second side of the optically variable device. The opacifying layer is preferably applied beneath a protective coating, ie the protective coating is applied over the opacifying layer. The protective coating may be transparent or translucent.

[0092] Figure 7 shows a cross-section of a optically variable device 100 according to an alternative embodiment of the present disclosure. The optically variable device 100 has a substrate 101 with a first substrate side 102 and second substrate side 103. On the first substrate side 102 is a focussing element array, in the form of a lenticular lens array 104, which comprises a plurality of lenses 105. A longitudinal axis L of each lens 105 of the lenticular lens array 104 is into and/or out of the page as viewed in figure 7. Opposed to the first substrate side 102 is second substrate side 103, each of the first substrate side 102 and second substrate side 103 being substantially planar. On the second substrate side 103 are a plurality of recessed regions 107 and non-recessed regions 108.

[0093] Diffraction gratings 109 are disposed on the non-recessed regions 108. The diffraction gratings 109 are preferably perpendicular to the longitudinal axis L of the focusing elements 105. The recessed regions 107 shown in figure 7 do not contain diffraction gratings. A non-reflective ink 110 is segregated into the recessed regions 107. The non-reflective ink 110 is preferably pigmented. The non-reflective ink 110 may be an opacifying ink. The non-reflective ink 110 may be applied into the recessed regions 107 by overprinting and is segregated into the recessed regions. A reflective ink 111 is applied over the recessed regions 107 already containing non-reflective ink 110 and over the non-recessed regions 108 that have diffraction gratings 109. The reflective ink 111 may provide an outer layer on the second side of the optically variable device. Alternatively, one or more further layers may be applied over the reflective ink 111 (not shown in figure 7). For example, a protective layer may be applied over the reflective ink 111. The protective layer may be transparent or translucent.

[0094] The recessed regions 107 are provided in a predetermined first imagery design and provide a first optical effect. The first optical effect of the recessed regions 107 containing non-reflective ink 110 may be easily visible in all lighting conditions, in other words in both point light source and diffuse lighting conditions. The non-reflective ink 110 and reflective ink layer 111 are preferably different colours such that the non-reflective ink 110 is easily visible over the reflective ink layer 111. When viewed under non-point light source through the lens array 105 the viewer may see a contrast between the colour of the non-reflective ink 110 and the colour of the reflective ink 111.

[0095] In point light source conditions, a viewer may be able to view a multi-colour effect provided by the diffraction gratings in the non-recessed regions. The multi-colour effect is provided by the lenses 105 sampling the diffracted colours produced by the diffraction gratings 109. The colour projected from the diffraction gratings 109 will vary depending on at least the grating spatial frequency, viewing angle and orientation of the optically variable device. When viewing the recessed regions 107 and non-recessed regions 108 of the optically variable device 100 through the lens array 104 in a point light source, a viewer will see the first optical effect image provided by the recessed regions 107 having non-reflective ink 110 in the foreground and the multi-colour effect of the non-recessed regions 108 with diffraction gratings 109 as a background behind the first optical effect image.

[0096] According to embodiments, all of the non-recessed regions 108 surrounding the recessed regions 107 may comprise diffraction gratings 109. This would give a coloured background behind the first optical effect image of the recessed regions 107 with non-reflective ink 110. According to other possible embodiments, the diffraction gratings

109 may be applied over the non-recessed regions in a second imagery design to provide a second effect image when viewed through the lens array 104.

[0097] According to the embodiment shown in figure 7, a radiation curable ink 106 is applied onto the second substrate side 103. The radiation curable ink 106 is preferably UV curable ink. The radiation curable ink 106 is preferably embossable. The recessed regions 107, non-recessed regions 108 and/or diffraction gratings 109 are formed into the radiation curable ink 106 using techniques discussed herein. According to embodiments, the recessed regions 107, non-recessed regions 108 and diffractions gratings 109 are formed in the same process. According to alternative embodiments, the recessed regions 107 and non-recessed regions 108 are formed in a first process and the diffraction gratings 109 are formed in a second process. The first and second process may or may not be the same type of process.

[0098] According to other possible embodiments, the features of the optically variable device 100 shown in figure 7 could be combined with one or more of the features of the optically variable device shown and described in relation to figure 2 or figure 5. For example, the features of recessed regions 107 containing non-reflective ink 110, non-recessed regions 108 having diffraction gratings 109, and reflective ink layer 111 may be formed as a part or section of a security device that contains a number of other authentication features.

[0099] According to other possible embodiments of the aspects described above, focusing elements other than lenticular lenses could be used. The focusing elements may be cylindrical lenses. Alternatively, diffractive lenticular focusing structures could be provided as focusing elements. These diffractive lenticular focusing structures may be formed by the application of a radiation curable ink to the first substrate side and embossed when the radiation curable ink is soft or by printing of the radiation curable ink onto the first side of the substrate. The ink is then cured, usually whilst the tool is still in contact with the substrate, to fix the diffractive lenticular focusing structures. Each diffractive lenticular focusing structure may include a diffractive cylindrical lens or zone plate.

[0100] The recessed regions, non-recessed regions and diffraction gratings of each embodiment of the present disclosure may be formed through the use of radiation curable ink. The radiation curable ink may be printed in the desired thickness and pattern to create the recessed regions, non-recessed regions and diffraction gratings. The radiation curable ink may be applied as a layer and while soft may be embossed to form the recessed regions, non-recessed regions and diffraction gratings. Once the recessed regions, non-recessed regions and diffraction gratings have been formed the radiation curable ink is cured to harden the ink and fix the recessed regions, non-recessed regions and diffraction gratings in place. Of course, other suitable methods may be used to form the recessed regions, non-recessed regions and diffraction gratings. For example, the recessed regions, non-recessed regions and diffraction gratings may be directly embossed into the second substrate side, or may be embossed into a layer provided on the second substrate side. Alternatively, the recessed regions, non-recessed regions and diffraction gratings may be directly printed onto the second substrate side. The use of radiation curable ink is preferable as it permits a high resolution image and structures in the micron size range to be formed. The use of radiation curable ink may also provide a more consistent image when repeated on a large number of security documents.

Manufacture process

[0101] A security document, such as a banknote, that incorporates the optically variable device according to the present disclosure may be formed through a roll-fed gravure printing process. As noted above, according to preferred embodiments, the optically variable device according to the present disclosure may be formed at least in part through UV radiation (such as UV) curable embossing, such as soft embossing or radiation (such as UV) curable printing. The radiation curable ink application process is preferably formed in-line with the roll-fed gravure printing process to create a security document having the optically variable device.

[0102] Manufacture of a banknote or other security document incorporating the optically variable device of the present disclosure may include one or more of the following process steps:

1. A transparent polymer web is provided as a substrate for the banknote or security document. The substrate has a first side and a second side.

2. The substrate is processed in a rotogravure printing press in roll form.

3. An adhesion promoting layer is applied to the first side of the substrate, using a first rotogravure printing station. Alternatively, the substrate may have a pre-printed adhesion promoting layer on the first side, in which case the application of the adhesion promoting layer is not required.

4. A first UV lacquer layer is applied to the first side of the substrate, using a second rotogravure printing station. The first UV lacquer layer is printed directly on top of the adhesion promoting layer on the first side.

5. The first UV lacquer layer is brought into contact with an image embossing roller or an image embossing shim to provide an image structure. The first UV lacquer layer is simultaneously through-cured with a UV light source, thereby fixing the embossed image structure into the first UV lacquer layer. Alternatively, or potentially additionally, a second UV lacquer layer is applied to a printing tool having the desired image structure and the printing tool is brought into contact with the first side of the substrate, typically, where the first UV lacquer layer is present. Again, the UV lacquer layers are through-cured simultaneously with printing. The image structure includes recessed and non-recessed regions and/or diffraction gratings.

6. Optionally, the first/second UV lacquer layer is UV post-cured in a further UV curing station.

7. A second adhesion promoting layer is applied to the second side of the substrate using a third rotogravure printing station. Alternatively, the substrate may have a pre-printed adhesion promoting layer on the second side, in which case the application of the adhesion promoting layer is not required.

8. A third UV lacquer layer is applied to the second side of the substrate, using a fourth rotogravure printing station. The third UV lacquer layer is printed directly on top of the adhesion promoting layer on the second side.

9. The third UV lacquer layer is brought into contact with a lens embossing roller or a lens embossing shim to provide a lens structure. The third UV lacquer layer is simultaneously through-cured with a UV light source, thereby fixing the embossed lens structure into the third UV lacquer layer. Alternatively, or potentially additionally, a fourth UV lacquer layer is applied to a printing tool having the desired lens structure and the printing tool is brought into contact with the first side of the substrate, typically, where the first UV lacquer layer is present. Again, the UV lacquer layers are through-cured simultaneously with printing. Preferably, the lens structure includes a lenticular lens array. Alternatively, the lens structure may comprise focusing elements other than a lenticular lens array.

10. Optionally, the third/fourth UV lacquer layer is UV post-cured in a further UV curing station.

11. The steps 3 to 6 may be performed before steps 7 to 10. Alternatively, the steps 7 to 10 may be performed before the steps 3 to 6. In other words the image structure may be formed before the lens structure or vice versa.

12. At least one ink layer may be applied to the first side of the substrate over the image structure. The at least one ink layer may include a reflective ink layer or non-reflective ink layer. The at least one ink layer may include an opacifying layer. The at least one ink layer may be applied using a further rotogravure print station, or where there are a plurality of ink layers they may be applied in a plurality of further rotogravure prink stations..

[0103] While the invention has been described in conjunction with a limited number of embodiments, it will be appreciated by those skilled in the art that many alternative, modifications and variations in light of the foregoing description are possible. Accordingly, the present invention is intended to embrace all such alternative, modifications and variations as may fall within the spirit and scope of the invention as disclosed.

[0104] Any reference to or discussion of any document, act or item of knowledge in this specification is included solely for the purpose of providing a context for the present invention. It is not suggested or represented that any of these matters or any combination thereof formed at the priority date part of the common general knowledge, or was known to be relevant to an attempt to solve any problem with which this specification is concerned.

[0105] In this specification, the terms 'comprises', 'comprising', 'includes', 'including', or similar terms are intended to mean a non-exclusive inclusion, such that a method, system or apparatus that comprises a list of elements does not include those elements solely, but may well include other elements not listed.

List of References:

x – Depth of recess

L – longitudinal axis of focusing elements/lenticular lens array

10 – Optically variable device

11 – Substrate

12 – First substrate side

13 – Second substrate side

14 – Lenticular lens array

15 – Lens

16 – Radiation curable ink

17 – Recessed regions

18 – Non-recessed regions

19 – Diffractive gratings

20 – Segregated ink

21 – Protective coating

22 – Second side of optically variable device 10

30 – Image element

31 – First channel/group

32 – Second channel/group

33 – Third channel/group

34 – Fourth channel/group

35 – Fifth channel/group

36 – Red diffraction grating

37 – Green diffraction grating

38 – Blue diffraction grating

39 – Non-recessed area

40 – Image

41 – AU Design

42 – AU50 Design

43 – '50' Design

60 – Optically variable device

61 – Substrate

62 – First substrate side

63 – Second substrate side

64 – Lenticular lens array

65 – Lens

66 – Radiation curable ink

67 – Recessed regions

68 – Non-recessed regions

69 – Diffraction gratings in recessed regions

70 – Segregated ink over diffraction gratings

71 – Protective coating

72 – Recessed region

72 – Second side of optically variable device 60

73 – Recessed regions without diffraction gratings

74 – Segregated ink in recessed regions with diffraction gratings

75 – Diffraction gratings in non-recessed regions

76 – Reflective ink over non-recessed regions

77 – non-recessed region without diffraction gratings with reflective ink applied

80 – Image

81 – AU Design

82 – AU50 Design

83 – '50' Design

84 – Background section with reflective ink area

85 – Background section with window area

86 – Background section with opacifying ink area

100 – Optically variable device

101 – Substrate

102 – First substrate side

103 – Second substrate side

104 – Lenticular lens array

105 – Lens

106 – Radiation curable ink

107 – Recessed regions

108 – Non-recessed regions

109 – Diffractive gratings

110 – Segregated ink

111 – Reflective ink

500 – Optically variable device (prior art)

501 – Lenticular lens array (prior art)

502 – Radiation curable ink (prior art)

503 – Diffraction gratings (prior art)

504 – Ink (prior art)

505 – Substrate (prior art)

506 – First side of substrate 505 (prior art)

507 – Second side of substrate 505 (prior art)

Claims

1. An optically variable device comprising:

a substrate having a first side and a second side opposite to the first side; an array of focusing elements on the first side; and

a plurality of image elements on the second side, the image elements comprising a first group of sub-elements that are magnified by the focusing elements at a first range of viewing angles, and a second group of sub-elements that are magnified by focusing elements at a second range of viewing angles,

wherein the image elements comprise a plurality of recessed regions that are recessed on the second side and a corresponding plurality of non-recessed regions, at least a first portion of the recessed regions and/or non-recessed regions comprising diffraction gratings, wherein a first segregated ink is present in the recessed regions but not in the non-recessed regions.

2. The optically variable device according to claim 1, wherein the diffraction gratings are within the first portion of the recessed regions.

3. The optically variable device according to claim 2, wherein the first segregated ink is segregated into the first portion of the recessed regions.

4. The optically variable device according to any one of claims 1 to 3, wherein the diffraction gratings are oriented perpendicularly to a longitudinal axis of the focusing elements.

5. The optically variable device according to any one of claims 1 to 4, wherein the first segregated ink is a reflective ink.

6. The optically variable device according to any one of claims 1 to 5, wherein at least one recessed region of the first portion of the recessed regions comprises diffraction gratings having a first spatial frequency, and wherein at least another recessed region of the first portion of recessed regions comprises diffraction gratings having a second spatial frequency different to the first spatial frequency.

7. The optically variable device according to any one of claims 1 to 6, wherein a second portion of the recessed regions are void of diffraction gratings, the second portion of recessed regions being overprinted with a second ink.

8. The optically variable device according to claim 7, wherein the second ink is segregated into the second portion of the recessed regions.

9. The optically variable device according to claim 7 or 8, wherein the second ink is the same ink as the first segregated ink.

10. The optically variable device according to claim 7 or 8, wherein the second ink is a pigmented non-reflective ink and/or an opacifying ink.

11. The optically variable device according to claim 10, wherein the second portion of recessed regions are surrounded by non-recessed regions that comprise diffraction gratings, and the second portion of the recessed regions overprinted with a second ink and the surrounding non-recessed regions that comprise diffraction gratings are overprinted with a third ink.

12. The optically variable device according to claim 11, wherein the third ink is a reflective ink.

13. The optically variable device according to any one of the preceding claims, wherein at least a first subset of the non-recessed regions comprise diffraction gratings.

14. The optically variable device according to claim 13, wherein the first subset of the non-recessed regions comprising diffraction gratings are overprinted with a fourth ink.

15. The optically variable device according to claim 14, wherein the fourth ink is the same ink as the first segregated ink.

16. The optically variable device according to any one of claims 13 to 15, wherein the subset of non-recessed regions have a width of at least 50 microns.

17. The optically variable device according to any one of the preceding claims, wherein the image elements comprise more than two groups of sub-elements.

18. The optically variable device according to claim 1, wherein the diffraction gratings are on the first portion of the non-recessed regions.

19. The optically variable device according to claim 18, wherein the recessed regions with the first segregated ink and non-recessed regions with diffraction gratings are overprinted with a reflective ink.

20. The optically variable device according to claim 18 or 19, wherein the image elements comprise more than two groups of sub-elements.