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KORISTE-ELEMENTTI, KORISTE-ELEMENTIN KÄSITTÄVÄ TURVADOKUMENTTI JA MENETELMÄ KORISTE-ELEMENTIN VALMISTAMISEKSI

Dekorativt element och säkerhetsdokument med ett dekorativt element

DECORATIVE ELEMENT AND SECURITY DOCUMENT COMPRISING A DECORATIVE ELEMENT

(56) Viitejulkaisut - Anförda publikationer - References cited
EP-A1- 2 077 459; EP-A1- 2 264 491; WO-A1-2007/131375; DE-A1-102010 050 031; DE-B3-102011 014 114;

Decorative element as well as security document having a decorative element

The invention relates to a decorative element, in particular in the form of a transfer film, a laminating film or a security thread, as well as a security document and a method for producing such a decorative element.

Firstly, the practice of using microstructures in security documents is known, said microstructures showing a rainbow-like colour gradient during tilting. Holograms are the best known example of this. The colour gradient is generated due to the wavelength-dependent diffraction of the light in the first and higher diffraction orders. The colour gradient is thus not visible in the zeroth diffraction order, for example during viewing of the security document in the mirror reflex in reflection, but rather is only visible during tilting out of the zeroth diffraction order in a tilt angle range which corresponds to the first or higher diffraction orders.

DE 10 2010 050 031 A1 describes a security element having a pattern region consisting of a design element, said pattern region providing an optically perceptible piece of information. The pattern region is surrounded by a background region, wherein zones of the pattern region have an opaque reflection layer.

EP 2 264 491 A1 discloses a method for producing a zeroth order diffraction grating consisting of three layers by means of a wet coating method, wherein the central layer has a material having a higher refractive index than the surrounding layers.

DE 10 2011 014 114 B3 describes a multilayer body in whose surface a plurality of facet faces is moulded, and which have dimensions between 1 µm and 300 µm, wherein one or more of the parameters of the facet faces is pseudo-randomly varied, and a reflective layer is applied to each of the facet faces.

EP 2 077 459 A1 relates to a display which has two regions having different diffraction structures. Here, the first region is formed by a surface structure which corresponds to a line grating. The second region is formed by a structure, which is characterised by a period which is smaller in comparison to the first region and is formed by depressions or projections.

WO2007/131375A1 discloses the preamble of claim 1 and describes an element having at least one surface region having an optically effective surface relief microstructure (12), wherein the surface relief microstructure has a surface relief modulation made of transitions from upper regions (13) to lower regions (14) as well as from lower regions (14) to upper regions (13).

The object of the invention is to now specify a decorative element as well as a method for producing a decorative element which is characterised by memorable colour effects.

This object is solved by a decorative element according to claim 1.

This object is furthermore solved by a method for producing a decorative element according to claim 6.

The generation of the first colour in scattered light is a solution not in accordance with the invention.

Here, the microstructure is preferably coated with a layer which strengthens the reflection, in particular coated with a layer made of metal or a highly refractive material, e.g. with aluminium or zinc sulphide (ZnS).

Here, highly refractive means a material having a refractive index in the visible spectral region (typically at a wavelength of approx. 635 nm) of more than 1.7. Examples for such highly refractive first materials are listed in Table 1. The numerical values are only rough indicative values, because the concrete current refractive index of a layer depends on many parameters such as crystal structure, porosity, etc.

Table 1:

Material	**Molecular formula**	**Refractive index n**
Lead sulphide	PbS	4.33
Zinc telluride	ZnTe	3.04
Silicon carbide	SiC	2.64
Iron oxide	Fe_2O_3	2.92
Barium titanate	$BaTiO_3$	2.41
Titanium dioxide (Diffraction index is dependent on the crystal structure)	TiO_2	> 2.4
Zinc sulphide	ZnS	2.35

Neodymium oxide	Nd_2O_5	2.32
Zirconium oxide	ZrO_2	2.21
Tantalum pentoxide	Ta_2O_5	2.2
Zinc oxide	ZnO	2.1
Silicon nitride	Si_3O_4	2.02
Indium oxide	In_2O_3	2.0
Silicon monoxide	SiO	1.97
Hafnium oxide	HfO_2	1.91
Yttrium oxide	Y_2O_3	1.9
Aluminium oxynitride	AlON	1.79
Magnesium oxide	MgO	1.74

In the theoretical description and the practical understanding of the interaction of diffractive microstructures (e.g. diffraction gratings or scattering microstructures) with light, said diffractive microstructures being also additionally able to be combined with a thin film layer system, the question of an adequate theoretical or phenomenological description arises. The interactions of such microstructures are fully described in an exact way by the exact electromagnetic theory in the form of Maxwell's equations and the corresponding constraints, i.e. diffraction efficiencies, wavefronts, electromagnetic field distributions or intensity distributions can be calculated when the respective systems are sufficiently known. However, this exact approach is usually less informative and therefore additional phenomenological descriptions within specific models are often used. Here, the following should be mentioned in particular: the Huygen principle for propagation (named after the Dutch physicist Cristiaan Huygens) and Fresnel Interference (named after the French physicist Augustin-Jean Fresnel). The grating diffraction occurring at periodic microstructures is a special type of diffraction and can be understood phenomenologically as a combination of Huygen propagation and Fresnel interference.

By corresponding choice of the first spacing, it is thus possible to generate a colour effect which is optically detectable for the human viewer by constructive or destructive interference of the light which is reflected on adjacent element faces and base faces or transmitted through adjacent element faces or base faces.

The first spacing is preferably chosen in such a way that a colour is generated by interference of the light which is reflected on the base face and the element faces in the zeroth diffraction order in incident light and/or by interference of the light transmitted through the element faces and the base face in transmitted light in the zeroth diffraction order, in particular the first colour or the second colour is generated.

Light which reaches the eye of a viewer, coming from the base face, traverses a different optical path length in comparison to light which comes from the element faces. The ratio of the face of the base elements in comparison to the face of the base face determines the efficiency with which the light beams interfere with the various path lengths. This ratio thus also determines the strength of the colour or the colour impression.

The zeroth diffraction order corresponds to the direct reflection or direct transmission. Direct reflection appears, for example, in the mirror reflex of a light source.

The first spacing is preferably set to achieve the respective desired first colour during viewing in the first or a higher diffraction order or in scattered light. Here, preferably, the first spacing for effects in reflection is chosen to be between 150 nm and 1000 nm and more preferably between 200 nm to 600 nm. For effects in transmitted light, the first spacing is preferably chosen to be between 300 nm and 4000 nm and more preferably between 400 nm to 2000 nm. Here, the spacing to be set depends on the diffraction index of the material which is located between the two planes.

For achieving a unified colour impression, a good consistency of the structure height or the spacing is necessary. Preferably, this spacing varies in a region having a unified colour impression of less than +/- 50 nm, more preferably less than +/- 20 nm, even more preferably less than +/- 10 nm. The base face and the element faces are thus preferably arranged in parallel to one another in such manner that the first spacing or the second, third or fourth spacing vary by not more than +/- 50 nm, preferably less than +/- 20 nm, further preferably less than +/- 10 nm, in particular vary in the first region.

Colours which produce a (neutral) shade of grey when mixed with the original colour are called complementary. Here, a colour pair can be perceived as complementary in colour psychology, even when these are not complementary in technical and physical terms (i.e.

in RGB values, R = red, G = green, B = blue). In this document, the colour psychology aspect of complementary is meant.

Here, colour is furthermore preferably understood to mean a change in the spectrum of the incident or transmitted light in the visible wavelength range, for example a red or blue colour impression with a white light source.

Here, preferably, the first colour impression is the desired colour impression which is relevant for the visual effect and eye-catching.

It has furthermore been shown that the colour impressions described above occur especially strongly when at least one lateral extension of the projections of the base elements onto the base plane are between 0.25 to 50 μm, preferably between 0.4 μm and 20 μm and more preferably between 0.75 μm and 10 μm, in particular all lateral extensions of the projection of each base element onto the base plane fulfils this condition.

Here, projection of a base element onto the base plane is understood to mean the face arising during viewing of the base element perpendicularly to the base plane, said face being covered by the base element.

It is furthermore advantageous to choose the minimum spacing of adjacent base elements to be no greater than 500 μm, in particular between 0.2 μm and 300 μm, more preferably to be between 0.4 μm and 50 μm. It has been shown that the colour impressions described above occur especially strongly with such a choice of this parameter.

Here, distancing of adjacent base elements is understood to mean the spacing of adjacent base elements in the base place, i.e. the distancing of the projections of adjacent base elements onto the base plane. The minimum spacing of adjacent base elements thus represents the minimum spacing of the projection of adjacent base elements onto the base plane, i.e. the minimum distancing of adjacent base elements produced in a plan view perpendicular to the base plane.

According to the invention, the central face covering of the base plane with the base elements in the first region or in a sub-region of the first region is chosen to be between 30 % and 70 %, more preferably between 40 % and 60 %, and particularly preferably approx. 50 %. It has been shown that the colour impressions described above occur especially strongly with such a choice of the face covering.

Here, central face covering of the base plane with the base elements is preferably understood to mean the surface area of the projections of the base elements onto the base plane on the entire face of the respective region.

The flank of the microstructure is preferably defined as the face whose height is at least 10 % of the step height (distancing of the adjacent element faces from the adjacent base face in a direction running perpendicular to the base plane) higher than the adjacent base face and at least 10% of the step height deeper than that of the adjacent element face.

In the case of a two-dimensional structure of the period p and a face Δf of the flank projected onto the base plane, the surface area of the flank projected onto the base plane is

$$100\% \bullet 2 \bullet \frac{\Delta f}{p}$$

This surface area of the flanks is preferably smaller than 50 %, more preferably smaller than 40 %, even more preferably smaller than 30 %, and particularly preferably smaller than 20 %. The surface area of the flank is furthermore preferably greater than 1 %, more preferably greater than 3 %. It has been shown that an increase in the surface area of the flanks leads to a reduction in efficiency and that the colours additionally become more pastel-like, i.e. more impure or containing more white.

So that the surface area of the flanks is smaller than XX %, the central flank angle γ must fulfil the following condition:

$$\gamma \geq \arctan\left[\frac{h}{(100\% - 2 \bullet 10\%) \bullet XX\% \bullet p}\right]$$

If the surface area of the flanks of a 0.5 µm high structure are, e.g., less than 20 %, the flank angle must thus be greater than 72° with a structure having 1 µm periods, with a structure having 2 µm periods it must be greater than 57° and with a structure having 5 µm periods it must be greater than 32 °.

The flank angle of the flanks of the base elements is preferably to be chosen to be greater than 70 degrees and more preferably greater than 80 degrees and particularly preferably approx. 90 degrees.

The flank angle is preferably understood to mean the angle enclosed by the flanks of the base elements having the base plane, with respect to the region of the base plane oriented towards the base element.

It is furthermore possible that all values of the variation range can be selected pseudo-randomly with the same probability. It is, however, also possible and preferred that the values of the variation range are selected pseudo-randomly with a probability according to a function, in particular a Gaussian function or an inverse Gaussian function. It has been shown that the conciseness of the colour impression can be further improved by means of such a selection.

The variation ranges for the parameters described above are preferably chosen as follows:

Variation range for the parameter of positioning of the base element: Deviation of +/- 0.5 μm to +/-30 μm and further +/- 1 μm to +/- 10 μm from the respective regulation position.

Variation for the parameter of distancing of the base elements from the nearest adjacent base element: 0.2 μm to 500 μm, more preferably 0.4 μm to 50 μm and more preferably 0.5 μm to 10 μm.

Variation range of the parameter of shape of the projection of the base element onto the base plane: selection from a predefined wealth of shapes comprising, for example, letters, various symbols, or for example a circle, a square and a rectangle. The arrangement of the various shapes can take place randomly, but a local grouping of the various shapes can also be present.

Variation range of the parameter of face size of the projection of the base element onto the base plane: variation of at least one lateral dimension of the projection of the base element onto the base planes in a variation range of 0.5 μm to 30 μm and more preferably from 1 μm to 10 μm.

Variation range of the parameter of lateral preferred direction of the projection of the base element onto the base plane: angle range of + 180 degrees to – 180 degrees, angle range of + 90 degrees to – 90 degrees, angle range of + 30 degrees to – 30 degrees.

It is furthermore advantageous when an angle position of the respective base element in the base plane is defined for each of the base elements arranged in the first region or in the first sub-region by a two-dimensional grid spanned by the coordinate axis x and the coordinate axis y.

Here, it is furthermore advantageous to vary the parameter “Positioning of the base element” pseudo-randomly according to the following approach: the position of the base elements in the first region or in the first sub-region is then determined by a pseudo-random shift of the base element from the respective regulation position in the direction determined by the coordinate axis x and/or the coordinate axis y. Here, preferably, the regulation position refers to the centroid of the projection of the respective base element onto the base plane.

It is furthermore possible to pseudo-randomly vary the parameter “positioning of the base element” by means of each of the other pseudo-random arrangement of the base elements.

The variation range of the random shift from the regulation position is preferably between + D/2 and – D/2, wherein D is the dimension of the projection of the base element onto the base plane in the direction of the coordinate axis x or the coordinate axis y. The grid width of the grid is preferably selected to be between 0.5 µm to 100 µm, more preferably between 1.5 µm and 20 µm.

According to a further preferred exemplary embodiment, the parameters which are pseudo-randomly varied in a first of the first sub-regions and in a second of the first sub-regions are chosen to be different and/or at least one variation range of the varied parameters is chosen to be different in a first of the first sub-regions and in a second of the first sub-regions. By means of the different variation of the parameters which are varied pseudo-randomly, and/or the different variation ranges, a different scattering of the light in the first of the first sub-regions and the second of the second sub-regions can be caused, such that different colour effects are generated in the first of the first sub-regions and in the second of the second sub-regions by tilting out of the zeroth diffraction order, and thus these regions are able to be differentiated. The different variation of the parameters can, however, also be chosen such that colour effects are generated in the first of the first sub-regions and in the second of the second sub-regions by tilting out of the zeroth diffraction order which appear to the human eye simultaneously, but the differences are detectable with a microscope. For example, a text or a pattern which is visible with a microscope can be shaped by the sub-regions. This can be used as a hidden feature.

Preferably, the shape of the projection of the base elements onto the base face differs from two or more base elements in the first region or in the first sub-region.

Preferably, one or more of the base elements are formed as symmetrical base elements. Here, symmetrical base elements are understood to mean base elements in which the projection of the base elements onto the base plane has a symmetrical shape, i.e. understood to mean base elements which are symmetrical with respect to the shaping of their projection. Examples of this are circles, squares, equilateral triangles, etc.

It is furthermore advantageous when one or more base elements are asymmetrical or anisotropic base elements. Here, asymmetrical or anisotropic base elements are understood to mean base elements in which the projection of the base element onto the base plane has an asymmetrical shape having a lateral dimension in a preferred dimension which is greater than the lateral dimension of the projection transverse to the preferred direction. Asymmetrical or anisotropic base elements are thus understood to mean base elements having an asymmetrical shaping of the projection of the base element onto the base plane. Examples of this are ellipses, rectangles or isosceles triangles.

Preferably, the lateral dimension of the projection in the preferred dimension is more than 2 times greater, preferably more than 5 times greater than transverse to the preferred direction.

According to a further exemplary embodiment which is not claimed, the base elements in the first region or in a sub-region of the first region are asymmetrical base elements whose preferred direction is pseudo-randomly varied in a predefined variation range. Firstly, an enlargement of the scattering angle range can be achieved by means of such a design, and, depending on selection of the variation range, the colour effect described above can be observed at a specific angle. The variation range is preferably formed of an angle range of plus 180 degrees to minus 180 degrees or plus 90 degrees to minus 90 degrees to achieve the first effect described above, and of an angle range of less than plus 90 degrees to minus 90 degrees, for example plus 30 degrees to minus 30 degrees, to achieve the second effect described above.

According to a further preferred embodiment, one or more first cells and/or one or more second cells are provided in the first region or in the first sub-region of the first region. The base elements arranged in the first and second cells are formed as asymmetrical base elements. Here, the asymmetrical base elements of the first cells have a uniform first preferred direction, and the asymmetrical base elements of the second cells have a second uniform preferred direction. The first and second preferred direction are chosen to be different and preferably differ by at least 5 degrees, more preferably by at least 10 degrees.

During rotation of the decorative element about an axis perpendicular to the base plane, the effect already described above is generated in the first and second cells. If the first and second cells are chosen to be in the macroscopic range in terms of their dimension, i.e. the lateral dimensions of the first and second cells parallel to the base plane are chosen to be greater than 300 µm, then, during rotation of the decorative element about an axis perpendicular to the base plane, the shaping of the first and second cells becomes visible to the viewer (with corresponding tilting out of the zeroth order), such that a piece of information determined by the shape of the first and second cells, e.g. a denomination, becomes visible.

In an alternative embodiment having cells having dimensions in the macroscopic range, movement effects are generated during rotation, e.g. rolling bar type effects. To generate a “rolling bar” effect, it is possible, for example, to place several elongated cells having the asymmetrical base elements next to one another, wherein the preferred direction of the base elements varies continuously from cell to cell, for example, in 10 degree steps, preferably increases in maximum 5 degree steps. The size of the elongated cells is, for example, 20 mm in the longitudinal direction and 500 µm in the transverse direction. If 19 such cells are arranged next to one another, wherein the preferred direction of the first cell is 0 degrees and the preferred direction of the other cells increases in 10 degree steps, the central cell thus has the preferred direction of 90 degrees and the last cell 180 degrees (or 0 degrees again). If a decorative element of such an embodiment is now observed at a suitable fixed tilt angle and then rotated, the brightness of the colour impression varies like a light band over the decorative element.

A “rolling bar” effect is an optical effect similar to a reflective cylindrical lens. Here, the regions of the cylindrical lens which reflect the light in the direction of a viewer appear brighter than the regions which reflect the light in other directions. This function thus generates a type of “light band” which visibly wanders over the cylindrical lens when the multilayer body is tilted in the direction of the viewing angle.

It is furthermore also possible to choose the size of the first and second cells such that they have a lateral dimension parallel to the base plane of less than 300 µm, in particular less than 100 µm. The effect which is generated by the first and second cells thereby mingles for the human viewer during viewing without an aid, such that the first and second cells cannot be differentiated for this viewer and a colour impression is shown during rotation about an axis perpendicular to the base plane, said colour impression arising from colour mixing of the colour effects generated in the first and second cells. Firstly, more interesting colour effects can thereby be generated during rotation. Furthermore, the division which is not visible to the human viewer into first and second cells can serve as an additional hidden security feature, which can, for example, only be checked using a microscope.

It is furthermore also possible that the first region or the first sub-region of the first region has one or more third cells and the base elements arranged in the third cells are symmetrical base elements. Depending on the choice of the size of the third cells, the two effects described above can be provided, supplemented with a further design feature, due to the different scattering behaviour of the third cells with corresponding combination of first and second cells, and the attractivity of the decorative element can thus be further improved.

It is furthermore also possible to combine the effects described above with one another and, for example, to provide first, second and third cells which have a macroscopic lateral dimension in a first of the first sub-regions, and to provide first, second and third cells which have at least one lateral dimension parallel to the base plane of less than 300 µm, in particular less than 100 µm, in a second of the first sub-regions.

According to the invention, the base elements follow on from one another periodically; according to a further preferred exemplary embodiment of the invention, the base elements follow on from one another periodically at least regionally in one or more second sub-regions of the first region, in particular with a period between 0.75 µm and 10 µm. The base elements are thus preferably positioned according to a regular one- or two-dimensional grid.

The base elements are furthermore preferably shaped identically in the one or more second sub-regions and have an identical shaping, in particular with respect to their projection onto the base plane.

The azimuth angle of the base elements in the first region or second sub-region is determined by the direction in which the base elements follow on from one another periodically, and the period of the base elements in the first region or second sub-region is determined by the distancing of the centroids of the projection of the base elements onto the base plane. The microstructure can thus be constructed, for example, of web-shaped, dot-shaped or rectangle-shaped base elements (during viewing perpendicularly to the base plane) which are oriented isotropically or pseudo-isotropically according to an azimuth angle.

According to a further preferred exemplary embodiment, it is furthermore possible that the base elements have a circular ring-shaped shaping during viewing perpendicularly to the base plane, and form a circular grating.

According to a preferred exemplary embodiment, the decorative element has one or more cells respectively having several second sub-regions in which the base elements follow on from one another periodically. The sequence of the base elements in each of these second sub-regions is defined here by the parameters: azimuth angle and/or base element shape and/or spatial frequency. One or more of the parameters of azimuth angle and/or base element shape and/or spatial frequency of the sub-regions arranged in the cells are pseudo-randomly varied from second sub-region to second sub-region within a variation range which is predefined for the cells.

The second sub-regions preferably respectively have at least one lateral dimension parallel to the base plane between 5 µm and 100 µm, preferably 10 µm and 50 µm. The cells preferably have at least one lateral dimension parallel to the base plane between 40 μm to 300 μm, preferably between 80 μm and 200 μm.

In the second sub-regions, the light is thus diffracted differently in different directions. Here, the diffracted light does not have the typical rainbow colour effect due to the special design of the microstructure or has it only strongly weakened. Rather, the diffracted light shows a colour which mostly has the complementary colour impression in comparison to the light beam which is reflected or transmitted in the zeroth order, probably due to the energy conservation. A correspondingly wide deflection of the light out of the zeroth diffraction order is thus furthermore caused by the special design and positioning of the base elements arranged in the cells, and thus a similar effect to that with the scattering of the light on the base elements as previously described.

The parameter of azimuth angle is preferably varied in a variation range of minus 180 degrees to plus 180 degrees, minus 90 degrees to plus 90 degrees or minus 30 degrees to plus 30 degrees, preferably in 15 degree steps. By the choice of the variation range of plus 90 degrees to plus 90 degrees, similar effects can be achieved by the cells to those which are described by the arrangement of symmetrical base elements in the previously described third cells. If the variation range of the azimuth angle is chosen to be smaller than plus 90 degrees to minus 90 degrees, similar optical effects can be achieved to that which is described previously by means of asymmetrical microstructures in the first and second cells. The previous embodiments with respect to the dimension of the cells and the combination of different cells to the first, second and third cells are thus similarly applicable in this exemplary embodiment and, with respect to this, are thus referred to in the previous embodiments.

Preferably, a decorative element which is not claimed, and which is formed as depicted above is formed as described in the following:

- Hot stamping foil vaporised with approx. 30 nm Al. The microstructures are preferably embedded in polymer having a breaking index n_1 of approx. 1.5.
- Circular random structures having a lateral extension of the projections of the base elements of 2.5 μm and a first spacing of 300 nm. Central face covering is 50 % and flank angle close to 90 degrees. These structures lead, for example, to a violet

first colour impression in scattered light and a green second colour impression in the zeroth diffraction order.

According to a preferred embodiment, the arrangement of the base elements and the face dimension of the projection of the respective base elements in the first region or in the third sub region is determined by a function f (x,y) which describes a binary diffraction structure which deflects the incident light to generate a first piece of information by diffraction, preferably deflects it by diffraction into the first diffraction order. The first spacing which is established as described above or a multiple of the first spacing, and not the relief height "normally" provided for the binary diffraction structure, is chosen as distancing of the element faces of the base elements from the base face, such that a piece of colour information which is thereby determined is generated as a second piece of information in the first region or the third region. The binary diffraction structure is thus combined with a structure depth which is significantly enlarged compared to the usual structure depth used for diffraction structures, and thus an additional piece of colour information is generated in the first diffraction order as well as in the zeroth diffraction order, as stated above.

The binary diffraction structure preferably deflects the light according to a predefined, freely selectable, three-dimensional freeform face having one or more freeform elements. Here, the freeform elements are preferably selected from: freeform elements in the shape of a cut-out of a surface of a three-dimensional object, lens-like enlargement effect, reduction effect or distortion effect in the shape of an alphanumerical sign, a geometrical figure (e.g. cylindrical lens or round lens) or another object-generating freeform element, e.g. a logo, a number or a letter.

By means of equipping such a freeform face with a defined colour, not only a simple colouration but a visually very attractive interaction of the colour effect with the spatial effect of the freeform face arises, similar to the partially metallic appearing structural colour effects occurring in nature on certain butterfly wings (e.g. Blue Morpho Didius). This interaction of colour effect and spatial freeform face effect is very important for the visual perception.

It is furthermore also possible to achieve the following additional advantageous effects by a corresponding modification of such a freeform face-generated microstructure:

It is advantageous to combine the freeform face effects with colour variations or colour gradients, e.g. “blue to green”. To achieve this effect, the distancing of the element face of the base elements from the base plane is regionally chosen to be different, as further generally described below, for example it also varies linearly, in particular, according to the colour run to be achieved.

It is furthermore possible to overlay the freeform face effect with a piece of colour information, for example, to thus code an additional piece of information in the region of the freeform face effect, for example, a red “OK” on a green background. In a pattern image which is pattern shaped, for example shaped in the shape of the “OK”, the distancing of the element face of the base elements from the base face is chosen to be different to the distancing of the element face of the base elements from the base face in the background region for this purpose.

It is furthermore advantageous when the freeform face effect appears in various sub-regions in various colours, for example appears in “blue”, “green” and “red”, preferably also in combination with a referenced printed colour which is applied, for example, in offset printing or intaglio printing. The distancing of the element face of the base elements from the base face is also chosen to be different in the different sub-regions for this purpose. Preferably, such a design of the microstructure is also chosen in combination with referenced optically variable colours (OVI, Spark etc.). Here, it is preferable to carry out the arrangement of these optically variably colours in register, i.e. carry it out in a precise position with respect to the sub regions. It is furthermore also advantageous to use such a design of the microstructure in combination with a reflection layer, in particular metallic, which is only provided regionally, wherein the reflection layer is preferably to be used in register, i.e. arranged in a precise position with respect to the sub-regions.

It is furthermore also possible to vary the microstructure described above which provides a spatial freeform space effect locally in the spacing between the element faces and the base face, as described in the following, in order to, for example, combine the freeform face effect with a multicolour image or true colour image.

A decorative element having a microstructure generating a freeform face effect, which is preferably formed as depicted above, is furthermore preferably designed as follows:

- Hot stamping foil vaporised with Al/Cu/Cr etc. or ZnS or alternative materials; or also with HRI/metal combinations (e.g. ZnS/(Al)
- freeform face effect (surface relief effect), e.g. diffraction structures which simulate a macroscopic freeform face, in combination with other visual effects
- freeform face effect (surface relief effect), e.g. diffraction structures which simulate a macroscopic freeform face, having a binary grating structure in which the periodicity/orientation according to a predetermined function varies, with the goal of visualising a spatially protruding element.
- Distancing of the element faces from the base face between 150 nm and 500 nm, covered by a material having a diffraction index between 1.4 and 1.7.

It is furthermore advantageous when the arrangement of the base elements and the face dimension of the projection of the respective base elements is chosen according to a function which arises from the binarisation of a function of a hologram, of a computer-generated hologram or of a kinoform, and in which the first spacing or a multiple of the first spacing is chosen as spacing of the element faces of the base elements, as described above. Also, here, the piece of colour information is determined by the first spacing and the viewing angle ranges at which these colour effects occur, by means of the deflection of the light by diffraction. For binarisation, the function which describes, for example, the relief height h depending on the x and y coordinates, i.e. $h = F(x, y)$ is compared to a threshold value or limit value h_s, and base elements are provided in which $h \geq h_s$. The spacing of the element face of the base elements from the base face is determined here by the first spacing and not by h or h_s. On the one hand, in scattered light or in the light diffracted according to the hologram function such a decorative element shows the first colour impression defined by the first spacing, as well as the second colour impression in the zeroth order. On the other hand, it additionally shows a reconstruction of the hologram, above all during illumination with strongly directed light, in particular laser light. In this way, a hidden security feature can be integrated directly into the face of the decorative elements which has the colour effect. It is also possible to choose the image of a homogenous face as a hologram. This leads to a homogenous colour face, similar to with the random structures. Nevertheless, in this case the arrangement of the base elements is not pseudo-random or random, but rather following a function. Here, the homogenous colour face can also project forwardly or rearwardly out of the plane of the decorative element when the image of the face from which the hologram was calculated was in front of or behind the hologram.

According to the invention, the microstructure has base elements having a different distancing of the element face from the base face with respect to a direction perpendicular to the base plane.

In one or more second and/or third zones of the first regions, the element faces of the base elements and the base face are spaced apart in a direction running perpendicular to the base plane in the direction of the coordinate axis z with a second or third spacing which differs from the first spacing and is chosen in such a manner that a third or fourth colour is generated in the one or more second or third zones, in particular by means of interference of the light reflected on the base face and the element faces in incident light in the first diffraction order or in scattered light or in the zeroth diffraction order, said colour differing from the first or second colour. As well as such second or third zones, further zones can also be provided, in which the element faces of the base element are spaced apart in a direction running perpendicular to the base plane in the direction of the coordinate axis z with one or more further spacings which differ from the first, second and third spacings and are chosen such that corresponding further colours are generated in the one or more further zones, in particular by interference of the light reflected on the base face and the element faces in incident light and/or, in particular by interference of the light transmitted through the element faces and the base face, said further colours differing from the first, third and fourth colours. The second, third and further spacing is set as depicted above to achieve the respective colour during viewing in the zeroth diffraction order or to achieve a corresponding (complementary) colour in a viewing direction which deviates from the zeroth diffraction order, wherein, preferably, the second, third and further spacing is chosen to be between 150 nm and 1000 nm, preferably between 200 nm to 600 nm (preferably for effects in incident light). For effects in transmitted light, the second, third and further spacing is preferably chosen to be between 300 nm and 4000 nm, preferably between 400 nm to 2000 nm.

By means of such a design of the microstructure, different colour impressions can be generated in the first region both during viewing in the zeroth diffraction order and also during tilting, whereby a further class of colour effects is provided as a security feature by the decorative element.

Here, according to a further preferred exemplary embodiment, the one or more first, second, third and further zones are respectively shaped in such a manner that they have lateral dimensions parallel to the base plane in the macroscopic range and, in particular, have lateral dimensions, for example width and length, of more than 300 µm, preferably between 300 µm to 50 mm. By means of the shaping of these first, second, third, fourth and/or further zones as patterns and/or background regions, a piece of optically recognisable information can thus be provided in the first region by the microstructures, which becomes visible, in particular, during viewing in the zeroth diffraction order and/or with special tilting out of the zeroth diffraction order.

Preferably, the face covering of the respective zones with the base elements is varied locally in the one or more first, second and/or third zones. Here, by means of such a variation of the face covering, locally modulating the colour brightness value of the respective zone is enabled and, for example, additionally providing a piece of information in the manner of a greyscale image.

According to a further exemplary embodiment of the invention, one or more of the first, second, third and/or further zones have at least one lateral dimension parallel to the base plane of less than 300 µm, preferably between 20 µm and 250 µm, more preferably between 30 µm and 150 µm. By means of such a shaping of the zones, numerous optical effects can be generated which can be generated, in particular, by additive colour mixing of the first, second, third and/or further zones.

It is thus possible, for example, that the face covering of the respective zones with the base elements is chosen to be different in one or more of these first, second, third and/or further zones, in order to thus achieve a different colour brightness of the respective zones. Two or more of the first, second, third or further zones thus differ in the face covering of the respective zone with the base elements and thus still have the same colour value but a different colour brightness.

It is furthermore advantageous to provide one or more fourth zones having a microstructure in which the microstructure is formed from a moth-eye structure, and to arrange the zones provided with the moth-eye structure, as well as first, second, third and/or further zones, next to one another in order to thus locally achieve a variation of the colour brightness. Here, diffraction structures having a spacing of the structural elements below the wavelength of visible light, preferably below 400 nm, are preferably used as moth-eye structures. These structures are preferably provided from crossed gratings or hexagonal gratings having a period in the range of 200 nm to 400nm and a grating depth/period ratio between 0.5 and 2.

According to a further preferred exemplary embodiment of the invention, first, second, third and/or further zones are used for generating a multicolour image or true colour image. Preferably, an output image is divided into a plurality of pixel regions for this purpose. An assigned colour value and an assigned colour brightness value is determined for each of the pixel regions of the output image. In the decorative element, an assigned pixel region is provided for each of the pixel regions of the output image, wherein each pixel region has at least one lateral dimension parallel to the base plane of less than 300 µm, in particular less than 150 µm. The pixel regions of the decorative element are respectively covered with one or more zones selected from first, second, third, fourth and further zones. The selection of the zones as well as the surface area of the respective zone on the pixel region is chosen here in such a manner that the assigned colour value and colour brightness value of the pixel region arises for a defined viewing angle (e.g. 25 degrees). Here, the colour value of at least one pixel region of the decorative element preferably arises by means of additive colour mixing of the colours generated by two or more different zones of the microstructure which are arranged in the pixel region. Here, the surface area of these zones on the pixel region determines the colour value of the respective pixel region. The entire face of these zones and/or the surface area of the zones covered with the moth-eye structures determines the colour brightness value of the respective pixel region.

If asymmetrical base elements are selected as base elements in at least one of the first, second, third, fourth and/or further zones, the colour impression of the respective pixel region and thus the appearance of the multicolour image thus varies during rotation about an axis perpendicular to the base plane. The preferred direction of the asymmetrical base elements can be equal in all zones having asymmetrical base elements, but it can also vary. By means of the microstructure it is thereby possible to generate a corresponding multicolour image or true colour image in the image region which is shown dynamically during rotation. The image can, for example, become brighter or darker during rotation or it can change from true colours to false colours or at least distorted colours.

The first, second, third and/or further zones of the first region can overlap in any way with the first sub-regions, second sub-regions, third sub-regions and cells described above. The shaping of the projection of the respective base element onto the base plane as well as the arrangement of the base elements on the base plane is determined according to the above explanations of the first, second and third sub-regions as well as cells. The spacing of the element face from the base plane is chosen with respect to the respective zone, and thus, for example, the first spacing, the second spacing, the third spacing or the further spacing is chosen. Further interesting combination effects thus arise which further increase the security against forgery.

Here, it is particularly advantageous to arrange the first, second and third cells to respectively overlap with first, second and third zones, and thus space the element faces of the base elements, and the base face, apart in a direction running perpendicular to the base plane in the one or more first cells with the first spacing, in the one or more second cells with the second spacing and the one or more third cells with the third spacing. It is furthermore also possible to form only a part of the first, second and third cells as first zones, a part of the first, second and third cells as second zones and a part of the third cells as first, second and third zones, in order to provide, for example, a multicolour image changing with the viewing angle or multicolour image changing during rotation about a vertical to the base plane of the axis. Several second sub-regions can furthermore also be provided in a cell, which are formed as different first, second, third and/or further zones and which thus respectively differ in the spacing of the element face from the base face. Here, interesting colour change effects also arise by means of the additional additive colour mixing, depending on the choice of the variation ranges of the parameter. Furthermore, the first piece of information can also be overlaid with a piece of multicolour information, whereby memorable colour effects arise, for example by the corresponding overlaying of a third sub-region with first, second, third and/or further zones.

According to a further preferred exemplary embodiment of the invention, it is possible to form the microstructure in the first region not only in two steps but also in multiple steps for increasing the colour purity. Thus, one or more of the base elements preferably have one or more further element faces which respectively run substantially in parallel to the base face. The one or more further element faces are spaced apart from the base face in the direction of the Z axis with a multiple of the first spacing with arrangement of the base elements in one of the first zones, are spaced apart with a multiple of the second spacing with arrangement of the base elements in one of the second zones and are spaced apart with a multiple of the third spacing with arrangement of the base elements in one of the third zones, correspondingly are spaced apart with the further spacing with an arrangement in the further zone. The more steps the base elements have, the cleaner or stronger the colour impression is. The higher colour purity of multi-step base elements is helpful, in particular, for decorative elements having colour mixing and true colour images. For the strongest possible colour impression or the highest possible colour purity, it is advantageous when the surface of all element faces of the base elements is approximately the same size.

It is furthermore advantageous to modulate the element face in the first region or in a fourth sub-region of the first region for providing a hidden piece of information which can be read out, in particular, by means of a laser or by means of a polariser. It is thus possible, for example, to modulate the element faces according to the surface of a hologram which only shows its information during irradiation with a laser in order to thus provide a hidden piece of information. It is furthermore also possible to modulate the element face and/or base face with a diffraction grating of a grating period between 100 nm to 2000 nm, more preferably between 200 nm to 500 nm, in order to thus introduce a piece of information which can be read by means of a polariser. The modulation depth of the hologram or the diffraction grating is preferably less than 100 nm, particularly preferably less than 50 nm and more preferably less than 30 nm. The interference thus only disrupts the modulation which generates the colour effect.

In this context, the term “element face running substantially in parallel to the base face” means that the spacing of the element face from the base face runs over the region of the element face in a range of values, such that, as already described above, a colour is generated by interference of the light which is reflected on the element face and the base face or transmitted through these in the zeroth order, as has already been described above. Preferably, for this purpose, the spacing of the element face of the base element from the base face varies in the direction of the z axis not more than 20 %, preferably not more than 10%, from its average value.

According to a preferred exemplary embodiment of the invention, the microstructure is moulded at least regionally between a first layer of the decorative element and a second layer of the decorative element, wherein the first layer is a transparent layer having a refractive index n_1 and the second layer is a reflective layer, in particular a metal layer, an HRI layer (HRI = High Refractive index) or a reflective multi-layer system. The metal layer can be opaque or semi-transparent. The material of the metal layer can have very good reflective qualities (e.g. aluminium or silver) or also be partially absorbent (e.g. copper or chromium). By a skilful choice of the material of the reflective layer, the colour effect can be made even more clearly visible.

Here, transparent layer is understood to mean a layer having a transmission of at least 50 %, more preferably at least 80 %, in the visible wavelength range.

If such an element is viewed in reflection, the first, second or third spacing is preferably determined by the refractive index n_1 multiplied by the optical spacing, which is determined by the fulfilment of the $\lambda/2$ condition for a wavelength λ in the range of visible light. Here, however, the viewing angle must be considered.

It is furthermore also possible that the microstructure is moulded at least regionally between a first layer of the decorative element and a third layer of the decorative element, wherein the first layer is a transparent layer having a refractive index n_1 and the third layer is a transparent layer having a refractive index n_2, and wherein the refractive index n_1 and the refractive index n_2 differs by at least 0.2, preferably differs between 0.4 and 1.4. If such a microstructure is viewed in transmission, the first spacing, the second spacing or third spacing is preferably determined by the following equation:

$$\lambda = \frac{|n_1 - n_2| \times h}{\cos(\alpha)}$$

According to a further preferred exemplary embodiment of the invention, the microstructure has a second region in which the microstructure is formed in the shape of a linear or crossed sinusoidal or rectangular diffraction grating, a 2D/3D hologram or 3D hologram, a Kinegram®, a microlens structure, a coloured or achromatic blaze grating, a macrostructure, an isotropic or anisotropic matt structure, a combination of the above structures, a volume hologram, a thin layer colour system or similar, which generates a further piece of optically recognisable information. Preferably, the information generated by the first region and by the second region has complementary or mutually related related information, whereby forgery attempts become directly visible. The first and second region can, for example, be interlocked in a mosaic-like manner. However, the second region can also be arranged in the shape of thin lines, e.g. guilloches, over the first region, etc. The second region can also be a one-colour or multicolour printed surface.

The decorative element is preferably formed in the shape of a transfer film, a laminating film, a security thread or a label. As well as the microstructure, the decorative element preferably has another one or more plastic layers and/or paper layers, adhesive layers, adhesion-promoting layers and also further decorative layers which preferably provide more further information in the decorative element.

The decorative element can be used to create an especially good protection from forgery. It is used on documents such as bank notes, credit cards, passport documents, personal passes, etc., in order to impede counterfeiting. Decorative elements having a diffractive structure can also be integrated as a layer construction into a credit card, an ID card, into an identification document, an identity card etc. Stickers having holograms are also located on commercial products or goods to be protected. Packages of commercial products or goods to be protected or printed material are also provided with such decorative elements as protection against forgery and/or as a decoration element for providing a decorative effect.

The invention is described by way of example in the following, using several exemplary embodiments, with the aid of the accompanying drawings.

Fig. 1a shows a schematic plan view of a security document having a decorative element.

Fig. 1b shows a schematic sectional depiction of the security document according to Figure 1a.

Fig. 1c show a schematic sectional depiction of a cut-out of the decorative element according to Figure 1a.

Fig.1d shows a schematic sectional depiction of a cut-out of a microstructure

Fig.2a and
Fig. 2b respectively show a schematic, three-dimensional depiction of a microstructure.

Fig. 2c shows a schematic plan view of a microstructure having several base elements.

Fig. 3a shows a schematic sectional depiction of a decorative element having several base elements.

Fig. 3b shows a schematic plan view of two base elements for illustrating the light scattered on the base elements.

Fig. 3c shows a schematic sectional depiction of a decorative element having several base elements.

Fig. 4 shows a schematic plan view of a microstructure having several base elements.

Fig. 5a shows a schematic plan view of a region of a microstructure having several asymmetrical base elements.

Fig. 5b shows a schematic plan view of a region of a microstructure having several asymmetrical base elements.

Fig. 5c shows a schematic plan view of a region of a microstructure which has sub-regions having differently oriented asymmetrical base elements.

Fig. 5d shows a schematic plan view of a region of a microstructure having asymmetrical and symmetrical base elements.

Fig. 6a and
Fig. 6b respectively show a schematic depiction of a region of a microstructure having asymmetrical base elements with a different illumination direction and/or viewing direction.

Fig. 7 shows a schematic plan view of several base elements.

Fig. 8a shows a schematic three-dimensional depiction of a microstructure having several base elements.

Fig. 8b shows a schematic sectional depiction of the microstructure according to Figure 8a.

Fig. 9a shows a schematic plan view of a cell of a decorative element which is divided into several sub-regions which are respectively covered with base elements.

Fig. 9b shows a schematic depiction for illustrating the construction of the microstructures in the region of the cell according to Figure 9a.

Fig. 10a shows a photograph of a plan view of a region of the decorative element.

Fig. 10b shows a spectrum of a first colour impression of the decorative elements according to Figure 10a as well as the associated colour diagram.

Fig. 11a shows a schematic plan view of a cut-out of a microstructure having several base elements.

Fig. 11b shows a schematic sectional depiction of a decorative element in the region of the cut-out according to Figure 11a.

Fig. 11c and
Fig. 11d respectively show diagrams which illustrate the wavelength-dependent diffraction efficiency of a microstructure.

Fig. 12a shows diagrams for illustrating the binarisation of a function.

Fig. 12b shows schematic plan views of depictions.

Fig. 12c shows schematic plan views of sections of the depictions according to Figure 12b.

Fig. 12d shows a photo of a binary hologram.

Fig. 13a shows a schematic three-dimensional depiction of a cut-out of a microstructure having two base elements of different heights.

Fig. 13b show several schematic plan views of a region of a decorative element.

Fig. 13c shows a schematic plan view of a region of a decorative element during viewing at different viewing/illumination angles.

Fig. 14a shows a schematic plan view of an image region of a decorative element.

Fig. 14b shows a schematic plan view of a cut-out of the image region according to Figure 14a having several pixel regions.

Fig. 14c shows a schematic sectional depiction of a cut-out of the decorative element according to Figure 14b.

Fig. 15 shows several diagrams for illustrating the modulation of element faces of a microstructure having several base elements.

Fig. 16 shows a schematic three-dimensional depiction of a cut-out of a microstructure.

Fig. 17 shows a schematic sectional depiction of a decorative element.

Figures 2a to 8b and 10a to 12d and 13b show embodiments which are not claimed, which facilitate understanding of the invention. Fig. 9 shows an embodiment of the invention.

Fig. 1a and Fig. 1b show a plan view or a sectional depiction of a security document 1 which is provided with a decorative element 2.

In the embodiment according to Fig. 1a and Fig. 1b, the security document 1 is a banknote. However, it is also possible that the security document 1 is any other security document, for example an ID document such as an identity card, a passport or a security pass, a credit card or cash card, a software certificate, a security sticker for securing goods or a security label.

The security document 1 has a carrier substrate 10 to which the decorative element 2 is applied. Here, the carrier substrate 10 preferably consists of a paper substrate. However, it is also possible that the carrier substrate 10 consists of a plastic substrate or of a multi-layer substrate having one or more plastic layers and/or paper layers. It is furthermore also possible that security features, for example watermarks or micro-perforations, are introduced into the carrier substrate 10, and that the carrier substrate 10 is provided with further decorative elements, imprints and similar, which provide further security features.

The decorative element 2 has – as shown in Fig. 1a – a strip-shaped shaping and spans the entire width of the carrier substrate 10 from the upper longitudinal edge of the carrier substrate to the lower longitudinal edge of the carrier substrate. A transparent window 11 is furthermore introduced into the carrier substrate 10, which is covered by the decorative element 2. The transparent window 11 can – as shown in Fig. 1b – be achieved in the form of a cavity in the carrier substrate 10, which is introduced into the carrier substrate 10, for example, by a corresponding punch or corresponding watermark. It is, however, also possible that the transparent window 11 is formed of a transparent region of the carrier substrate, particularly when the carrier substrate consists of a transparent plastic substrate.

The decorative region 2 now has several regions in which an optical effect is generated from the decorative element 2 in incident light or in transmitted light. In Fig. 1a, regions 31 and 33 of these regions are firstly shown which are arranged in the region of the transparent window and which generate an optical effect when viewed in transmitted light. Furthermore, regions 32 and 34 are shown in Fig. 1a, in which an optical effect is generated when viewed in incident light, i.e. in reflection. The regions 31 and 33 are furthermore surrounded by a background region 36, in which the decorative element 2 shows a transparent appearance, for example when viewed in transmitted light. Furthermore, the regions 32 and 24 are surrounded by a background region 36, in which the decorative element 2 shows an optical effect in reflection, for example, a glossy metallic or matt or also coloured appearance.

The decorative element 2 has a microstructure in the region 31, 32, 33 and 34, which generates an optical effect as described above in incident light or in transmitted light. Here, the microstructure has a special design in the regions 31 and 32 and comprises a base face and several base elements which respectively have an element face which is elevated and depressed with respect to the base face and a flank arranged between the element face and the base face. The exact design of the microstructure in the regions 31 and 32 is described in detail in the following using the Figures Fig. 1c to Fig. 16.

In the region 33 and 34, the microstructure is shaped in the shape of a diffraction grating, a hologram, a KINEGRAM®, a microlens structure, a blaze grating, a macrostructure or another relief structure which differs from the embodiment of the microstructure in the region 31 and 32, such that the decorative element 2 generates different optical effects on the one hand in the regions 31 and 32 and in the other hand in the regions 33 and 34, in particular generates different optically variable effects. Preferably – as indicated in Figure 1a – the regions 32 and 34 and optionally also the regions 31 and 33 are arranged adjacent to one another and preferably form depictions which are complementary and/or inter-locked in a mosaic-like manner, in order to thus further increase the security against forgery.

The arrangement of the regions 31 and 33 in the region of the transparent window 11 as well as the arrangement of the regions 32 and 34 in the reflective region of the decorative element 2 is not restricted to the arrangement shown in Fig. 1a, but rather, both the number and the arrangement of the regions 31 to 36 can take place in any manner. Furthermore, the shaping of the decorative element 2 can also differ from the shaping shown in Fig. 1a and Fig. 1b and, for example, have the shape of a patch or a security thread. It is furthermore also possible that the decorative element 2 does not have a transparent region which is designed for viewing in transmitted light, and thus only has the regions 34, 32 and 36. Conversely, it can also be the case that the decorative element 2 is designed only for viewing in transmitted light and thus only has the regions 31, 33 and 35.

The decorative element 2 is formed as a laminating film according to the embodiment according to Fig. 1a and Fig. 1b. According to further preferred exemplary embodiments, the decorative element 2 is formed as a transfer film, in particular as hot stamping film, or as a security thread. It is also furthermore advantageous to integrate the decorative element 2 into the laminated structure of the security document 1, for example when the security document 1 is a card-shaped security document, for example a credit card or an ID document, in particular a multi-sheet polycarbonate card. In this case, the decorative element is provided by one or more layers of the security document. It is furthermore also possible that the decorative element 2 is not part of a security document and is formed, for example, in the shape of a transfer film, a label or a sticker.

Fig. 1c now shows a sectional depiction of a cut-out of the decorative element 2, in an embodiment of the decorative element 2 as laminating film.

In this exemplary embodiment, the decorative element 2 has a carrier film 21, an adhesion-promoting layer 22, a plastic layer 23, a reflection layer 24, a plastic layer 25 and an adhesive layer 26.

The carrier film 21 preferably consists of a transparent plastic film, for example a PET film or BOPP film, of a layer thickness between 20 µm and 250 µm. The surface of the transfer film can be provided with one or more function layers, e.g. for improving the printability. The plastic layer 23 preferably consists of a transparent plastic layer which has a transmissivity of more than 50 %, preferably of more than 80 %, in the region of visible light. Here, it is also possible that the plastic layer 23 or the carrier film 21 is also coloured with a dye. A colouring can change the colour impression and influences, in particular, the formation of the complementary colour impression.

The plastic layer 23 is preferably a lacquer layer which enables the moulding of a relief structure into a surface of the plastic layer 23 by thermal replication or by UV replication. The plastic layer 23 is thus preferably a thermoplastic lacquer or a UV-curable lacquer.

The reflection layer 24 is preferably an opaque reflection layer which preferably has a transmissivity of less than 50 %, more preferably of less than 20 %, in the region of light visible to the human eye. These values are based on regions without a microstructure, i.e. mirror surfaces.

The reflection layer 24 is preferably a reflection layer made of metal, in particular of aluminium, silver, chromium or copper. It is furthermore also possible that the reflection layer 24 is made of a highly refractive material (HRI = high refractive index), for example of ZnS or TiO_2. In its design as a metal layer, the reflection layer 24 preferably has a thickness in the range of 10 nm to 100 nm and between 40 nm and 200 nm in its design made of an HRI material. The reflection layer 24 can be present over the entire surface or only partially.

It is furthermore also possible that the reflection layer 24 consists of a multilayer system. The reflection layer 24 can thus consist, for example, of a sequence of highly refractive and low refractive materials or from a sequence of an absorption layer, a distance layer and a reflection layer and thus, for example, be formed as a Fabry Pérot filter. Such a multilayer system thus preferably consists of a semi-transparent metal layer, a dielectric distance layer and a mirror layer, for example of an 8 nm chromium layer, a 400 nm SiO_2 layer or polymer layer and a 50 nm aluminium layer. The reflection layer 24 can be present over the entire surface or only partially.

The plastic layer 25 preferably consists of a transparent polymer material and has – as further described below – a refractive index at least in the region of the regions 31, which differs from the refractive index of the plastic layer by at least 0.2. When no reflection layer 24 is provided, the plastic layer 25 can fulfil the function of a reflection layer.

The plastic layers 23 and 25 preferably have a layer thickness between 1 µm and 8 µm.

The adhesive layer 26 has a layer thickness between 1 µm and 10 µm and serves for fixing the decorative element 2 on the carrier substrate 10. The adhesive layer 26 preferably consists of a hot adhesive, a cold adhesive, and/or of a UV-curable adhesive. Here, it is also possible that the adhesive layer 26 is formed to be two-sheet or multi-sheet.

The decorative element 2 is furthermore formed to be transparent in the region of the transparent window 11, such that all layers provided in the region of the transparent window 11 are formed to be transparent. Thus, for example, the adhesive layer 26 is preferably also formed to be transparent and clear, at least in the region of the transparent window 11.

As well as the layers shown in Fig. 1c, the decorative element 2 can also have further decorative layers, adhesion-promoting layers, adhesive layers and carrier layers. It is furthermore also possible that the decorative element only consists of the layer 23 and, in particular, dispenses with the adhesion-promoting layer 22, the carrier film 21, the plastic layer 25 and/or the adhesive layer 26.

Firstly, the adhesion-promoting layer 22 and then the plastic layer 23 are applied to the carrier film 21 to produce the decorative element 2. A microstructure 4 is then moulded into the plastic layer 23 by means of a replication tool, for example a replication roller. Here, the moulding of the microstructure 4 can take place, for example, with the application of heat and pressure, using a thermoplastic replication lacquer for the plastic layer 23 or by means of subsequent UV radiation, with the application of a UV curable replication layer as a plastic layer 23. Subsequently, the reflection layer 24 is applied, for example vapour-deposited or deposited by sputtering or imprinted. Subsequently, the reflection layer 24 is optionally removed again regionally, for example removed again in the region of the transparent window 11. Here, it is also possible to provide the reflection layer 24 only in a pattern-shaped form in the region 32, 33 and 36 and thus to introduce an additional design element in the decorative element 2. Subsequently, the plastic layer 25 and then the adhesive layer 26 are, for example, applied by means of a printing method.

The microstructure 4 is shaped, for example, as a mirror surface in the regions 35 and 36 and as a diffractive structure 42 in the regions 33 and 34. In the regions 31 and 32, the microstructure 4 has a base face 40 and several base elements 41 which each have an element face which is elevated or depressed with respect to the base face and a flank arranged between the element face and the base face. The element faces of the base elements 41 respectively run substantially in parallel to the base face 40. In one or more first zones of the regions 31 and 32, the element faces of the base elements 41 and the base face are spaced apart in a base plane that is perpendicular to a base plane defined by the base face 40 with a first spacing which is chosen such that a first colour is generated in the one or more first zones by interference of the light reflected on the base face 40 and the element faces in the regions 32 in incident light in the first or a higher diffraction order or in scattered light, and/or a first colour is generated in the one or more first zones by interference of the light transferred through the element faces and the base face 40 in the regions 31 in transmitted light in the first or a higher diffraction order or in scattered light.

Fig. 1d shows a cut-out of the microstructure 4 in the region 31, 32. The microstructure 4 has the base face 40 and the base elements 41, which respectively have an element face 411 which is elevated or depressed with respect to the base face 40 and a flank 410 arranged between the element faces 411 and the base face 40. The element faces 411 of the base elements 41 run substantially in parallel to the base plane. The element face 411 adjacent to the respective flank 410 and the base face 40 adjacent to this element face are spaced apart from one another in a direction perpendicular to the base plane at a step height h. Preferably, the flank 410 of the microstructure 4 is defined as a surface whose height is at least 10% of the step height h higher than the adjacent base face 40 and at least 10 % of the step height h deeper than that of the adjacent element face 411.

In the case of a two-dimensional structure of the period p and a face Δf of the flank 410, said face being projected onto the base plane, the surface area of the flank projected onto the base plane is

$$100\% * 2 * \frac{\Delta f}{p}$$

This surface area of the flanks 410 is preferably smaller than 50 %, more preferably smaller than 40 %, even more preferably smaller than 30 % and particularly preferably smaller than 20 %. It has been shown that an increase in the surface area of the flanks 410 leads to a reduction in efficiency, and the colours additionally become more pastel-like, i.e. more impure. So that the surface area of the flanks is smaller than XX %, the central surface angle γ must fulfil the following condition:

$$\gamma \geq arctan \left[\frac{h}{(100\% - 2 * 10\%) * XX\% * p} \right]$$

The special design of the microstructure 4 in the regions 31 and 32 is now described in the following using figures Fig. 2a to Fig. 16.

In the regions 31 and 32 or in a sub-region of the regions 31 and 32, the microstructure 4 has, for example, the shaping shown in the schematic three-dimensional depictions of Fig. 2a and Fig. 2b. Here, the microstructure 4 has the base face 40 which, as indicated in the figures Fig. 2a and Fig. 2b, defines a base plane spanned by the coordinate axes x and y. The base elements 41 have element faces 411, which, as shown in the Figures Fig. 2a and Fig. 2b, are arranged to be elevated with respect to the base face 40. It is furthermore also possible that the microstructure 3 is not moulded in the lower surface of the plastic layer 23 but rather in its upper surface, and thus the element faces 411 are not arranged to be elevated but rather to be depressed with respect to the base face 40. Further flanks 410 are arranged between the element faces 411 and the base face 40. In the exemplary embodiment according to Fig. 2a and Fig. 2b, the base elements 41 consist respectively of an element face 411 and a flank 410 surrounding this element face 411. The element face 411 is spaced apart from a base plane defined by the coordinate axes x and y in the direction of a coordinate axis z, with a special spacing which is chosen in such a manner that a first colour is generated in incident light or in transmitted light in the first or a higher diffraction order or in scattered light, as is also described in further detail later.

In the exemplary embodiment according to Fig. 2a, the base elements 41 are shaped in the form of cylinders which are arranged pseudo-randomly on the base plane. It is furthermore also possible that the base elements 41 have any other shaping. Thus, for example, Fig. 2b shows a shaping of the base elements 41 in the shape of boxes.

The element faces 411 are, as shown in the Figures Fic. 2a and Fig. 2b, preferably arranged in parallel to the base face 40. However, it is also possible that the element faces 411 are arranged only substantially in parallel to the base face 40 and thus, for example, the element faces 411 are slightly tilted with respect to the base face 40. Here, it has also advantageously become apparent that tilting of the element faces 411 with respect to the base face 40 in the range between 5 degrees and 30 degrees, preferably in the range of 5 degrees to 15 degrees, enables an enlargement of the scattering angle range as well as the colour spectrum. “Substantially in parallel” is understood in this context to also mean such tilting of the element faces 411 with respect to the base face 410.

The face covering of the region or sub-region having the base elements is preferably between 30 % and 70 %, more preferably between 40% and 60 %, and further preferably if possible approx. 50 % or ½. This applies for two-step microstructures. In three-step microstructures, the face covering is preferably if possible approx. 2/3, in four-step microstructures if possible approx. 3/4, etc.

The flank angle of the flanks 410 is preferably greater than 70 degrees, more preferably greater than 80 degrees, and more preferably if possible approx. 90 degrees, as shown in the embodiments according to the following exemplary embodiments.

Fig. 2c now shows an embodiment in which the base elements 41 are arranged pseudo-randomly in the regions 31 and 32 or in a sub-region of the regions 31 and 32. The microstructure 4 is thus made up of one or more base elements, wherein the arrangement of the base elements in the x/y plane is pseudo-random. This pseudo-random arrangement suppresses or reduces undesired diffractive effects, because period structures such as in a grating are no longer present. Fig. 2c now shows a plan view in a direction perpendicular to the base plane, i.e. in the direction of the z coordinate axis, of a cut-out of such a region of the microstructure 4 having several base elements 41 and the base face 40. In the depiction according to Figure 2c, the projections of the base elements 41 are thus shown on the base plane in a direction perpendicular to the base plane, said projections coinciding with the element faces 411 here due to the formation of the flank angle of the flanks 410 as a 90 degree angle. If the flank angle is chosen to be lower, the surface of the projection thus increases correspondingly.

The lateral extensions Δx and Δy of the base elements in the x/y plane are in the range of 0.25 μm to 50 μm, preferably between 0.4 μm and 20 μm and more preferably between 0.75 μm and 10 μm. Here, "lateral extension of the base elements" is understood to mean the lateral extension of the projection of the base elements in a direction perpendicular to the base plane. The minimum spacing of adjacent base elements Δs is chosen pseudo-randomly in the exemplary embodiment according to Fig. 2c. Here, preferably, the minimum spacing of adjacent base elements Δs cannot assume all possible values, but rather only values from a narrower, predefined variation range. Preferably, the arrangement of the base elements 41 is restricted in such a manner that the base elements 41 do not overlap and simultaneously the minimum spacing Δs is not greater than 300 μm, preferably is not greater than 50 μm. If overlapping base elements are admitted, these are preferably produced such that the plane at the overlapping region has the same height as non-overlapping regions of the base elements. Preferably, the minimum spacing Δs between two adjacent base elements is between 0.5 μm and 50 μm, further preferably between 0.5 μm and 20 μm,

Such a pseudo-random arrangement of the base elements 41 is preferably achieved by a two dimensional grid spanned by the x and y axes being provided in the corresponding region or sub-region, said grid defining a regulation position of the respective base element 41 in the base plane. The base elements are now positioned in this region or in this sub-region by a pseudo-random shift from the respective regulation position in the direction of the coordinate axes x and/or y, wherein the variation range of this pseudo-random shift is chosen such that the conditions described above for the minimum spacing of two adjacent base elements 41 are preferably met.

It is furthermore also possible that the minimum spacing of two adjacent base elements is respectively determined pseudo-randomly and then, based on these two base elements, the minimum spacing of the two base elements adjacent to these base elements is in turn selected pseudo-randomly, etc., and in this way, a corresponding pseudo-random positioning of the base elements 41 is achieved.

Here, the pseudo-random variation, for example the pseudo-random shift of the base elements from the regulation position or the pseudo-random variation of the minimum spacing of the base elements can consider all values from a narrower, predefined variation range having the same probability. However, it is also possible that a mathematical function is used for the probability of the consideration of a value from this variation range. Examples of such functions are the Gauss function as well as an inverted Gauss function. It is furthermore also possible that the predefined variation range comprises several predefined values, from which one value is selected pseudo-randomly. It is thus possible, for example, to select the minimum spacing Δs of two base elements 41 from a variation range which comprises, for example, 10 values in an increment of 0.5 µm.

Fig. 3a now shows a schematic sectional depiction of the decorative element 2 in the region of the microstructure 4 according to Fig. 2c. Here, the decorative element 2 has the plastic layers 23 and 25 as well as the reflection layer 24. The plastic layer 23 has a diffraction index n_1 and the plastic layer 25 has a diffraction index n_2. The microstructure 4 has the base face 40 as well as several base elements 41 having the element faces 411 and the flanks 410. The microstructure 4 is coated with the reflection layer 24 which has a thickness d and is furthermore embedded in the plastic layers 23 and 25. As already described above, the flank angle of the flanks 410 is greater than 70 degrees, in particular greater than 80 degrees and preferably formed to be virtually perpendicular (virtually 90 degrees). The lower surfaces of the reflection layer 24 are spaced apart from one another towards the z axis in the region of the element faces 411 and in the region of the base faces 40 with a height h, such that the first spacing, i.e. the spacing 61 of the element faces 411 from the base faces 40 likewise has the value h.

The light 50 from air which is incident on the decorative element 2 at an angle of incidence α^* is refracted on the plastic layer 23 and thus strikes the base elements 41 as well as the base face 40 of the microstructure 4 at the angle α, taking into account the diffraction of the base element 41. Here, the law of refraction applies of

$$\sin(\alpha^*) = n_1 \times \sin(\alpha)$$

The light 50 which is incident on the microstructure interacts with the microstructure 4 in two ways. Firstly, the incident light 50 is reflected due to the reflection on the reflection layer 24 in the planes which are determined by the element faces 411 and the base face 40, spaced apart with the spacing 61 and thus the value h. Here, the law of reflection of angle of incidence = output angle applies. The light reflected by these two planes interferes constructively and destructively. Constructive interference arises for the wavelength λ when there is:

$$\lambda = 2 \times n_1 \times h \times \cos(\alpha)$$

For the angle α of 20 degrees and $n_1 = 1.5$, a blue colour impression, for example, thus arises in direct reflection, i.e. in the zeroth diffraction order, when the height h = 160 nm. A greenish colour impression arises for h = 195 nm and a reddish colour impression for h = 230 nm. Depending on spacing 61 and thus height h of the microstructure as well as the diffraction index n_1, a different colour impression thus arises during viewing of the decorative element 2 in the zeroth diffraction order. Here, the height h is preferably in the range of 150 nm to 1000 nm, particularly preferably between 200 nm and 600 nm.

In an analogous way, a colour is generated in the zeroth diffraction order by the microstructure 4 in the region 31 or in a sub-region of the region 31 during viewing in transmitted light, in transmission, by means of interference. In contrast to the formation of the decorative element 2 according to Fig. 3a, the reflection layer 24 can be not provided in this layer, such that the microstructure 4 is directly embedded between the plastic layers 23 and 25 here.

The interference condition then also depends on n_2. Without the reflection layer 25 and disregarding the light refraction on the border surface between the plastic layers 23 and 25, constructive interference between the parts of the incident light 50 arises in a first approximation, said parts being transmitted through the base elements 41 and the base face 40, when:

$$\lambda = \frac{|n_1 - n_2| \times h}{\cos(\alpha)}$$

For an angle α of 20 degrees and $n_1 = 1.40$ and $n_2 = 1.65$, a blue colour impression arises during viewing in transmitted light in the zeroth diffraction order when the height h= 1710 nm. Greenish arises for h = 2070 nm and reddish for h = 2440 nm.

Alternatively, a transparent highly refractive reflection layer is used.

As well as the interference due to the special choice of the spacing 61, there is the simultaneously light scattering due to the lateral extension, for example the lateral extension Δx of the base elements, as described above. Due to the lateral extension of the base elements which has been chosen as described above in parallel to the base plane, scattered radiation occurs. Here, structures in the order of magnitude of the base elements 41 scatter light in a multiplied manner in the forward direction. The light scattered by the irregularly arranged base elements 41 spreads out here in a solid angle region around the directly reflected or directly transmitted light beams, i.e. around the zeroth diffraction order. Here, the lateral extension of the base elements determines the angle range at which the light scattered around the zeroth diffraction order is generated by the microstructure. The greater the lateral extension of the base element 41, the more strongly pronounced the forward scattering is. Consequently, the scattering angle β, which surrounds the angle range in which the light is deflected out of the zeroth diffraction order through the microstructure by scattering, is smaller, the greater the base elements 41 are.

Fig. 3b and Fig. 3c illustrate this effect. Fig. 3b shows a plan view of two base elements 41 which depict forward scattering of different strengths of two base elements 41 which are formed exemplarily to be different sizes. Figure 3c shows a corresponding sectional depiction of the decorative element 2 having the plastic layers 23 and 25 as well as the reflection layer 24 and the microstructure 4 having the base elements 41 and the base face 40. Here, the light 50 which is incident at the angle α* is firstly reflected from the decorative element directly into the zeroth order and thus the light 53 is generated. Furthermore, scattered light 54 is generated by the microstructure 4 in an angle region β around the light 53 reflected in the zeroth diffraction order.

Scattered light is correspondingly generated in an analogous way, also with a microstructure 4 designed for viewing in transmitted light, such that here, reference is likewise made to the above embodiments.

Isotropically formed base elements 41 such as the base elements shown in Fig. 2a and 2c, generate scattered light up to the scattering angle β. Here, the scattering angle β is given by the minimum length of the projection of the base elements 41 used onto the base plane and thus by the corresponding lateral dimension of the base element 41, for example determined by the diameter of the circle, with a circular disc-shaped projection of the base element onto the base plane. Preferably, β is in the range of +/- 30 degrees and more preferably of +/- 15 degrees.

When the incident light 50 is white light and all materials of the layers 23, 24, 25 are transparent in a colour-neutral manner or reflective in a colour-neutral manner, the scattered light 54 generally has the complementary colour impression in comparison to the light beam 53 which can be observed in the zeroth diffraction order. Due to energy conservation, in this case, the incident white light must be divided into the directly reflective light 53 and the scattered light 54, which leads to the complementary colour impression. The incident light 50 which does not go constructively into direct reflection or transmission and is not absorbed is to be found in the scattered light for the most part. If the scattered light, for example, thus appears greenish, the light which is reflected directly in the zeroth diffraction order appears violet. The complementary colour impression arises above all when the reflective layer 24 consists of a colour-neutral reflective material such as, for example, aluminium or silver. Aluminium, for example, reflects light over the entire visible spectral range with approx. 90 % efficiency and is thus suitable for achieving complementary colour impressions. In contrast, copper has a stronger absorption in the short-wave, i.e. blue spectral range, and correspondingly changes the colour impression, because copper is not reflected in a colour-neutral manner.

As well as the pseudo-random positioning of the base elements 41, the size of the base elements can also additionally be pseudo-randomly varied. Fig. 4 thus shows, for example, a plan view of the microstructure 4 having the base face 40, the base elements 41 and the element faces 411. Here, the element faces 411 of the base elements 41 have a square shaping, where in the size of the squares is varied from base element 41 to base element 41 in a predetermined variation range. Preferably, the dimension of the projection of the respective base element onto the base plane in the direction of the x axis and/or y axis is varied pseudo-randomly within a predetermined variation range for variation of the face size of the projection of the base element 41 onto the base plane. Thus, for example, the lateral dimension Δx of the element faces or the projection of the base element in the x direction or the lateral dimension of the element faces or the projection of the base element in the y direction is varied pseudo-randomly within a predefined variation range of, for example, 1 µm to 10 µm.

As well as the positioning of the base elements, spacing of the base elements from the nearest adjacent base element, the surface area of the projection of the base element onto the base plane, it is also furthermore possible to vary the shape of the projection of the base element onto the base plane or onto the lateral preferred direction of the projection of the base element onto the base plane pseudo-randomly within a predefined variation range. It is furthermore also possible that only one of the parameters previously referred to is varied pseudo-randomly within a predefined variation range.

In the embodiments above, base elements 41 are described which form symmetrical base elements in the sense that their projections onto the base plane in a direction perpendicular to the base plane have a symmetrical surface shape. However, the use of asymmetrical base elements is particularly advantageous, in which the projection of the respective base element onto the base plane has an asymmetrical shape having a lateral dimension in a preferred direction in the base plane, said preferred direction being greater than the lateral direction of the projection transverse to the preferred direction, preferably 50 % greater, preferably by more than 80% greater, more preferably more than 2 times and in particular more than 5 times greater than the dimension transverse to the preferred direction. Complex optical effects can be achieved with such asymmetrical base elements.

Fig. 5a shows such a region 312 of the decorative element 2, in which the microstructure 4 comprises a plurality of base elements 41 which have an asymmetrical shaping. The projection of the base elements 41 onto the base plane or the element faces thus have a shaping which is formed to be elongated, for example elliptical, the longitudinal axis of which, as shown in Fig. 5a, defines a preferred direction 418. The base elements 41 in the region 312 are formed identically, such that the preferred directions 418 of the base elements 41 in the region 312 are oriented in parallel to one another. Furthermore, the base elements 41 are positioned pseudo-randomly on the base face 40, as already described above.

Here, the scattering angle $\beta_{x\text{-}z}$ during illumination and viewing in the x/z plane and the scattering angle $\beta_{y\text{-}z}$ during illumination and viewing in the y/z plane differs in the region 312, as depicted in Figures 6a and 6b. Fig. 6a thus shows a depiction of the microstructure 4 having the base elements 41 and the base face 40 in the region 312 during illumination and viewing in the x/z plane and Fig. 6b during illumination and viewing in the y/z plane. Because the scattering angle β, as depicted above, is dependent on the lateral dimension of the base elements in the viewing/illumination direction, the scattering angles $\beta_{x\text{-}z}$ differ, as depicted in the Figures Fig. 6a and Fig. 6b. This leads to the colour impression of the scattered light changing during rotation of the security element in the x/y plane, i.e. during rotation about the x axis and when the viewing angle is maintained. For example, the scattered light can appear cyan-coloured or bright blue or turquoise during viewing in the x/z plane and change to dark blue/green or dark grey during rotation in the y/z plane. Here, the effect appears in the manner of a colour with an anisotropic/matt appearance.

Fig. 5b shows the formation of the microstructure 4 in a region 313 of the decorative element. Here, the microstructure 4 has a plurality of base elements 41 and the base face 40. The base elements 41 are also shaped as asymmetrical base elements. However, here the base elements 41 are not positioned pseudo-randomly in the base plane, but rather their preferred direction 418 is also furthermore also varied pseudo-randomly within a predefined variation range from base element to base element. Here, no change of the scattered light occurs during rotation of the decorative element. The scattering angle range is nevertheless greater in comparison to symmetrical base elements. The pseudo-random variation of the preferred direction of the base elements 41 can comprise the entire angle range of minus 180 degrees to plus 180 degrees. However, the angle range can also be restricted and here, as already described above, preferably be between minus 90 degrees and plus 90 degrees, more preferably between minus 30 degrees and plus 30 degrees.

Fig. 5c shows a further exemplary embodiment of the formation of the microstructure 4 in the regions 31 and 32 of the decorative element 2.

In this exemplary embodiment, the region 31 or the region 32 has one or more first cells 314, in which the base elements 41 are formed as asymmetrical base elements having a first preferred direction, and one or more second cells 315, in which the base elements are formed as asymmetrical base elements having a second preferred direction. In the first cells 314, the base elements thus have an identical preferred direction 418. Similarly, the base elements in the one or more second cells 315 have identical preferred directions 415. As shown in Fig. 5c, the preferred direction of the base elements 41 in the one or more first cells 314 and in the one or more second cells 315 is chosen to be different. However, an optical effect as described above is generated in the first and second cells during a rotation of the decorative element 2 about a direction perpendicular to the base plane at a corresponding angular displacement relative to one another, such that the first and second cells generate different optical effects. It is furthermore also possible to provide not only first and second cells in the region 31 or 33, but also to provide one or more third cells in which the base elements are formed as symmetrical base elements. Fig. 5d shows an exemplary embodiment of such a design of a region of the microstructure 4 of the decorative element 2 having a first cell 314 and a third cell 316, in which the base elements 41 are formed as symmetrical base elements.

It is furthermore also possible to provide further cells which are formed like the first and second cells and in which the preferred direction of the base elements differs from the preferred direction of the first and second cells, and to combine these cells with the first and second cells in any way. Preferably, the size of the cells is more than 300 µm, more preferably more than 500 µm, more preferably more than 1 mm and, in particular, more than 5 mm. In an embodiment having cells with dimensions in the macroscopic range, movement effects are generated during rotation, e.g. “rolling bar” type effects. To generate a “rolling bar effect” it is possible, for example, to place several elongated cells having the asymmetrical base elements next to one another, wherein the preferred direction of the base elements varies continuously from cell to cell, for example increases in steps of 10 degrees. The size of the elongated cells is, for example, 20 mm in the longitudinal direction and 500 µm in the transverse direction. If 19 such cells are arranged next to one another, wherein the preferred direction of the first cell is 0 degrees and the preferred direction of the other cells increases in 10 degree increments, the central cell thus has the preferred direction of 90 degrees and the last cell 180 degrees (or 0 degrees again). If a decorative element of such an embodiment is now viewed at a suitable fixed tilt angle and then rotated, the brightness of the colour impression varies like a light band over the decorative element.

According to an alternative exemplary embodiment of the invention, the size of the first, second and third cells 314 to 316 is chosen to be below the resolution limit of the human eye, preferably smaller than 300 µm and more preferably chosen to be smaller than 100 µm. With such a shaping of the cells 314 to 316, a mixture of the effects of the individual cells 314 to 316 arises as the colour impression of the scattered light. In this embodiment, the decorative element contains a hidden security element. During viewing with a microscope, the brightness of the various cells differs when the resolution is chosen to be sufficiently high.

It is furthermore also possible to design the shapes of the base elements to be different than in the previous exemplary embodiments according to Fig. 2a to Fig. 6b. The projection of the base elements onto the base plane can thus, for example, have the shapings shown exemplarily in Fig. 7, and thus, for example, the shape of a circular disk, a square, an ellipsis, a rectangle, a hexagon, a currency sign, denomination sign, a letter, the shape of a symbol, for example a heart shape, a cross, a ring, a circle having nanotext or a star. The base elements or their projection onto the base plane can furthermore also be formed of letters and symbols which form microtext due to the arrangement of the base elements on the base plane. Preferably, the base elements which form the microtext have a pseudo-random variation of the positioning of the base elements in the first region or in at least one first sub-region of the first region, wherein the microtext is readable despite the variation. In this way, the shape of the base elements or the shape of the projection of the base elements onto the base plane can also provide a hidden security feature in the decorative element 2. By analysis of the decorative element, for example by means of optical microscope technology, the shaping of the base elements or the shaping of the projection of the base elements onto the base plane can be demonstrated and thus the hidden security feature checked. Furthermore, the arrangement of a shape of the base elements can also carry a hidden piece of information. If, for example, the microstructure is formed up to 95% of base elements of a shape – e.g. circles – and up to 5 % of base elements of a different shape – e.g. crosses – the arrangement of the cross can be the hidden information.

According to a further exemplary embodiment it is also possible that the base elements 41 have not only one element face, but also have several element faces which influence the interference of the incident light and thus the generation of the colours. Such an embodiment is exemplarily described in the following using the Figures Fig. 8a and Fig. 8b.

Fig. 8a shows a three-dimensional depiction of the cut-out of the microstructure 4 in one of the regions 31 and 32. Here, the microstructure 4 has the base face 40 as well as a plurality of base elements 41, of which four pieces are shown in Fig. 8a. The base elements 41 not only respectively have the element face 411, but also have further element faces 412 and 413. These element faces 412 and 413 are likewise respectively arranged in parallel to the base face 40 and are further spaced apart from the base face in the direction of the z axis with arrangement of the base elements 41 in one of the first zones at a multiple of the first spacing, i.e. the spacing 61. The element faces 412 and 413 are thus likewise spaced apart from each other as well as from the element face 411 with the spacing h, such that the interference condition, as has been previously described using Fig. 3a, is likewise fulfilled for the element faces 412 and 413. The surface of the element faces 411, 412 and 413 is preferably as similar a size as possible. This means that the surface area of each step including the base face is approximately the same size, i.e. with four step base elements, approx. 1/4.

Fig. 8b shows a corresponding sectional depiction of a cut-out of the decorative element 2 having the plastic layers 23 and the reflection layer 24. The light 50 which is incident at the angle α is reflected here in the zeroth diffraction order as light 53, wherein the light beams which are reflected on the base face 40, on the element faces 411, on the element faces 412 and on the element faces 413 overlap and a colour is generated by constructive or destructive interference by the microstructure 4. Here, the base elements 411 can be designed to be not only three-stage, but also two-stage or multi-stage, and thus, as well as the element surface 411, can have one or more further element faces which are preferably arranged as previously described.

The colour purity during viewing in the zeroth diffraction order is significantly increased by the introduction of these further planes. Here, it is preferred that the surface area of the various element faces on the projection of the base elements 41 onto the base plane are equal, whereby the purest colours also arise. The height h at which the further element faces 412 and 413 are spaced apart is preferably equal. Preferably, the height h is in the range of 150 nm to 1000 nm and particularly preferably in the range of 200 nm to 600 nm. The multi-stage nature has the advantage of a better oriented constructive interference and thus a stronger colour impression. The greater the number of element faces which are spaced apart from one another, the narrower the spectrum of the constructively reflected light becomes. The number of element faces of the base elements, said element faces being spaced apart from one another, is preferably chosen to be in the range of 2 to 6.

With respect to the shaping of the projection of the base elements onto the base plane as well as the positioning of the base elements in the base plane, the above carried out applies correspondingly with respect to the base elements 41. The projection of the base elements 41 can thus have the shaping shown in figures Fig. 7, Fig. 5a to Fig. 5d, Fig. 4 and Fig. 2a to Fig. 2c. Here, preferably, the further element faces and the element face 411 are furthermore shaped such that they produce a concentric, pyramid-shaped construction and thus the element faces have a band-shaped shaping following the outer contour. Preferably, the surface area of the element faces is the same size.

According to the invention, the microstructure has a periodic arrangement of base elements 41 in the regions 31 and 32 or in one or more sub-regions of the regions 31 and 32, the projection of said base elements onto the base plane preferably having an identical shaping. The projection of the base elements onto the base plane preferably has the form of webs or dots. Furthermore, the base elements preferably follow on from one another isotropically or pseudo-isotropically in the direction of an azimuth angle which thus describes the spatial direction of the sequence in the x/y plane. Here, the spacing of the element faces of the base elements from the base plane is preferably constant.

Figures Fig. 9a and Fig. 9b now exemplarily clarify such an embodiment. Fig. 9a shows a plan view of a sub-region of the microstructure 4, said sub-region forming a cell 320. The cell 320 comprises several sub-regions 321 in which the base elements 41 respectively follow on from one another periodically. This is described exemplarily in Fig. 9b. Thus, in the regions 321, the microstructure 4 has the base face 40 and the base elements 41 having the element faces 411 and the flanks 410. Here, the base elements are formed in the shape of webs, whose cross-section is shown in the depiction below of Fig. 9b and whose extension in the x/y plane is indicated by a corresponding line in figures Fig. 9a and Fig. 9b. Here, the cross-section of the base elements 41 of the respective sub-region is identical and the projection of the base elements 41 onto the base plane follows after one another periodically, as indicated in figures Fig. 9a and Fig. 9b, in the direction of a respective azimuth angle 419. The microstructure 4 is thus determined respectively in the sub-regions 321 by the parameter azimuth angle 419 by means of the base element shape, for example the web-shaped shaping according to the depiction below according to Fig. 9b, and by the spatial frequency and thus the period at which the base elements 41 follow on from one another in the direction of the azimuth angle 419.

Preferably, one or more of the parameter azimuth angle, base element shape and/or spatial frequency of the sub-regions 321 arranged in the cell 320 are now varied pseudo-randomly from sub-region to sub-region within a variation range predetermined for the cell 320.

The cell 320 shown in Fig. 9a thus has, for example, sub-regions 321, in which the azimuth angle 419 and thus the orientation of the base elements 41 is varied pseudo-randomly in the various sub-regions 321. Thus, for example, the azimuth angle varies pseudo-randomly and thus isotropically between 0 and 180 degrees in 15 degree steps. Here, the spacing of the element face of the base elements 41 in the sub-regions is preferably constant, however it can also be varied pseudo-randomly.

The pseudo-random orientation of the azimuth angle 419 can comprise the entire angle range of minus 180 degrees to plus 180 degrees. However, it is also advantageous to restrict the angle range and thus the variation range of the pseudo-random variation. It is thus further preferred to vary the azimuth angle 419 between minus 90 degrees and plus 90 degrees, more preferably between minus 30 degrees and plus 30 degrees.

It is furthermore also advantageous to form the microstructure 4 in the regions 31 and 32 or in sub-regions of the regions 31 and 32 in the form of a crossed grating in which the base elements 41 preferably have a circular ring-shaped shaping.

It applies generally for the microstructures described previously that the period in which the base elements follow on from one another is preferably in the range of 0.75 µm to 10 µm. The size of the sub-regions 321 is preferably in the range of 5 µm to 100 µm and more preferably between 10 µm and 30 µm. The size of the cells 320 is preferably chosen to be between 40 µm and 300 µm, more preferably between 80 µm and 200 µm. Here, the base element can also be formed to be multi-step having several element faces according to the embodiments according to Fig. 8a and Fig. 8b. The several steps can be symmetrical – i.e. like a stair which ascends and then descends again – or be asymmetrical – i.e. like a stair which only ascends or only descends. Preferably, the spacing of the element faces 411 from the base face 30 is in the range of 150 to 2000 nm, more preferably in the range of 200 to 1000 nm, and more preferably in the range of 200 to 500 nm.

In contrast to the embodiments described using the Figures Fig. 2a to Fig. 8b, in the decorative element according to Fig. 9a and Fig. 9b, the complementary colour impression occurs not in scattered light but rather in diffraction in the first and partially higher order. Here, the diffraction does not appear as a rainbow effect, or at least only appears in a strongly weakened state. Due to the energy conservation, a large part of the light which is not constructively deflected in the zeroth diffraction order goes into the first or higher diffraction order, such that the colour impression during at least one viewing outside of the zeroth diffraction order is substantially determined by the complementary colour impression during viewing in the zeroth diffraction order. Preferably, the period and shaping of the base elements 41 is to be chosen here such that a large part of the light deflected out of the zeroth diffraction order in an angle range β of +/- 30 degrees is deflected around the zeroth diffraction order in order to achieve the advantageous optical effect as described above.

According to a further embodiment that is not claimed, the base elements 41 of the microstructure 4 in the regions 31 or 32 or in a sub-region of the regions 31 and 32 are positioned following a non-periodic function. Fig. 10 exemplarily shows a plan view of a region 322 of the decorative element 2 which generates the piece of optical information shown in Fig. 10a by means of such an arrangement of the base elements. Fig. 10b shows an assigned spectrum of a first colour impression as well as the associated colour diagram. The structural dept is h = 350 nm and the structure borders on air, i.e. n = 1.0. Here, the base elements are arranged with a spacing 61 of the element faces 411 and the base face 40 of 330 nm, and the arrangement of the base elements on the base plane as well as the shaping of the projection of the base elements onto the base plane are formed as described subsequently according to the Figures Fig. 11a to Fig. 11d. The shape of a three-dimensional object, for example the key shown in the depiction according to Fig. 10a, thus becomes visible to the viewer, for example, in the region 322. The depiction of the three-dimensional object appears blueish in the regions of the three-dimensional object which visualise a strong curve. The three-dimensional object appears in a yellow colour in the other regions. The surfaces which appear blue and yellow change correspondingly during tilting of the decorative element, such that a three-dimensional impression of the three-dimensional object of the decorative element is visualised.

Fig. 11a now shows a plan view of a cut-out of the region 322 during viewing perpendicular to the plane spanned by the base plane. Fig. 11b shows a corresponding sectional depiction of the decorative element 2 in a sub-region of the region 322 along the line A-A’ from Fig. 11a.

In the sub-region 322, the decorative element 2 thus has the plastic layers 23 and 25 as well as the reflection layer 24. The microstructure 4 is furthermore provided, which has the base face 40 as well as the base elements 41 in the sub-region 322, the element faces 411 of which are spaced apart from the base face 40 with the spacing 61 in the direction of the x axis. Here, the base elements are – as shown in the Figures Fig. 11a and Fig. 11b – generally not arranged in a periodic sequence and furthermore differ in the shaping and size of the projections onto the base plane. The arrangement of the base elements 41 and the face dimension of the projections of the respective base elements 41 in the region 322 are determined here by a function which describes a binary diffraction structure which deflects the incident light according to a predefined three-dimensional freeform face having one or more freeform elements. Such a freeform element can be formed, for example, from a cut-out of the surface of a three-dimensional object, as takes place, for example, in the depiction according to Fig. 10. Here, the freeform element is formed from a cut-out of the surface of a three-dimensional object, namely a key. It is furthermore also possible that freeform elements are freeform elements generating enlarging, decreasing and/or distortion effects, said freeform elements being in the shape of an alphanumerical sign, a geometrical figure or another object.

Here, the binary diffraction structure can be generated, for example, by means of a lithographic mask process or by means of a lithographic direct writing process (e.g. Ebeam or laser writer). It is thus possible, for example, to optically detect the three-dimensional surface of the freeform element and to vary the spacing of the base elements and the surface area of the projection of the base elements depending on the respective curve of the three-dimensional object, in order to thus generate, for example, a depiction according to Fig. 10: the projections of the base elements or the element faces of the base elements are thus chosen depending on the local curvature of the three-dimensional object, wherein in the region of a strong curvature, the spacing of the base elements as well as the face dimension of the projections or the element faces transverse to the course of the curvature are reduced. An arrangement running substantially concentrically of the projections or element faces in parallel to the regions of strong curvature of the three-dimensional object thus arises, wherein the spacing of the base elements as well as the face extensions of the projections of the base elements transverse to the regions of the curvatures vary and have minima in the region of the largest curvatures.

Fig. 11a and Fig. 11b exemplarily show a cut-out of such an arrangement of the base elements. The base elements 41 contributing primarily to the colour impression in the region of the curvatures of the freeform shape have a lateral extension in the x/y plane in at least one direction in the range of 0.25 µm to 500 µm, preferably between 4 µm and 100 µm. The width of the base elements 41 in the cut-out shown in Fig. 11a as well as the spacing of the base elements is thus dimensions from the above-mentioned range along the section line A-A'. The variation in the width of the base elements 41 as well as the intermediary space between the base elements 41 follows a function f (x, y) here, which reflects the shape of the freeform face and – as depicted above – the change in the increase in the freeform shape with respect to the z axis. The spacing 61 of the element faces 41 from the base face 41 is chosen as depicted above. Surprisingly, it has been shown using the practically produced prototypes that, by means of the significantly wider choice of the structural depth 61 according to the principles discussed previously, the optical effect of a three-dimensional freeform face is only insubstantially changed, and an additional piece of colour information is generated. By means of the corresponding choice of the spacing 61 as depicted above, the first or higher diffraction order obtains a colour modulation which appears as a clear non-rainbow colour, in combination with the effect of a three-dimensional freeform face, which remains unchanged. The first diffraction order usually has a complementary colour impression in comparison to the directly reflected light beam. The incident light which is neither reflected constructively in the zeroth diffraction order nor scattered is again located largely in the first diffraction order. By means of the equipping of the effect of a three-dimensional freeform face with a defined colour, not only a simple colouring arises but also a very visually attractive interplay of colour effects with spatial effects of a three-dimensional freeform face, similar to the structural, partially metallic appearing colour effects of butterfly wings which occur in nature (e.g. Blue Morpho Didius). This interplay of colour effects and effects of the three-dimensional form-free face is of great significance for the visual perception. Thus, the perceptibility of the key depicted in the depiction according to Fig. 10a in the region 322 is determined by the portions of the reflected light which are diffracted into the first order and changed in colour, said light appearing blueish, and the light reflected in the zeroth order which appears yellowish tends to recede in perception.

Fig. 11c and Fig. 11d thus illustrate the different effect of the microstructure 3 with a corresponding change in the spacing between element faces 411 and base face 40 corresponding to the spacing 61 (h = 300 nm) in Fig. 11d and with a lower choice of the spacing (h = 11 nm) in Fig. 11c. A microstructure according to Fig. 11c shows no pronounced dependency of the diffraction efficiency of the wavelength in the visible spectral range and thus shows a known rainbow colour effect during viewing with the human eye. Such a microstructure shows practically no memorable colour effect in accordance with the invention, said colour effect occurring first with a significantly pronounced dependency of the diffraction efficiency on the wavelength, as depicted, for example, in Fig. 11d.

A further variant, which is not claimed, of an arrangement of the base elements 41 according to a non-periodic function is described in the following using Fig. 12.

Here, a hologram of one or more virtual 2D and/or 3D objects is calculated and ideally both the amplitude and also the phase of the hologram is calculated here, and the hologram is binarised. Thus, for example, a binary computer-generated hologram (CGH = Computer-generated Hologram), for example a Kinoform, is used as a function.

Fig. 12a shows the binarisation using a possible phase sequence 600 of a computer-generated hologram. A schematic depiction of a step having height in the z direction as a function of the position in the x/y direction is shown. During the binarisation, the phase value above a limit value indicated by a dashed line is set to a maximum value of the height and below it is set to a minimum value of the height. As shown in the below depiction of Fig. 12a, a binary function thus arises. The difference between maximum value of the height and the minimum value of the height is now chosen corresponding to the spacing 61 as determined above and thus determines the colour impression of the corresponding region of the decorative element 2. The optimal laser wavelength for the reconstruction of the hologram is two times the step height times the refractive index of the surrounded medium, wherein the spacing 61 is chosen here as step height. In this embodiment of the invention, the face covering is determined by the hologram information and the binarisation information.

An example for a computer-generated binary hologram is shown schematically in Fig. 12b and Fig. 12c.

The template 601 which is used for calculating the hologram is shown on the left in Fig. 12b. In this case, this is the letter “K”. In the centre, the desired target image 602 on the basis of this template 601 is shown, which is calculated as a hologram. Here, the K hovers behind the hologram plane, wherein the right edge of the K is closer to the hologram plane than the left edge. This is indicated by the shadow cast. On the right, the reconstruction 603 of the binarisation of the calculated computer-generated hologram is shown.

Fig. 12c shows schematically the respective section 611, 612 or 613, i.e. a section in the x/z plane. On the left, i.e. in the step 611, the K 614 is in the hologram plane. In the centre, i.e. in the section 612. the K 614 is depicted behind the hologram plane 615. On the right in Fig. 12b, the section 613 of the reconstruction of the hologram is depicted by the binary computer-generated hologram. Because the hologram is binary, not only the target image arises, i.e. the K 614 behind the hologram plane 615, but also the mirror image 614’, which appears to hover in front of the hologram plane.

As well as the colour effect in the shape of the “K”, the reconstruction with depth and the overlay of the two pictures additionally leads to a movement effect during tilting. As a rule, however, during the reconstruction, the reconstructed K for which the hologram has been calculated dominates, here the rear K, see also Fig. 12d, which shows a photo of such a binary hologram.

It is furthermore also possible to use not only base elements having an element face, but also base elements having two or more element faces according to the exemplary embodiment according to Fig. 8a and Fig. 8b in the previously described embodiment of the microstructure according to the Figures Fig. 11a to Fig. 12a - c, such that the relevant embodiments also apply here analogously.

According to a further embodiment, the base elements 41 of the microstructures in the regions 31 and 32 do not have a uniform distancing of the element faces from the base face. As well as one or more first zones in which the spacing of the element faces of the base elements 41 from the base face 40 corresponds to the spacing 61 or a multiple of the spacing 61 (see embodiment according to Fig. 8a, 8b), the microstructure has another one or more second and/or third zones in the regions 41, in which the element faces are spaced apart in the direction of the coordinate axis z from the base face 40 with a second or third spacing or a multiple of a second or third spacing, which is different from the first spacing. Here, the second and third spacing are chosen such that a third or fourth colour is generated in the one or more second or third zones by interference of the light reflected on the base face and the element faces 411 in incident light in the first diffraction order or in scattered light and/or by interference of the light transmitted through the element faces 411 and the base faces 40 in the first or higher diffraction order or in scattered light, said third or fourth colour differing from the first colour.

Fig. 13a now shows a region of the microstructure 4, in which two base elements 41 are provided on the base face 40. The element face 411 of the one base element 41 is spaced apart from the base face 40 in the direction of the z axis with the spacing 61 and the element face 421 of the other baes element 41 is spaced apart in the direction of the z axis is spaced apart from the base face 40 with a spacing 62.

If the microstructure consists of a mixture of base elements 41 having different spacings 61 and 62, a corresponding colour impression arises, which is formed of a mixture of the individual colour impressions.

This effect can be combined, for example, advantageously with the use of asymmetrical base elements, as has previously been described using Figures Fig. 5a to Fig. 6b. Furthermore, it can also be combined advantageously with the use of periodically arranged base elements or a function of the following base elements, as has been previously described using the Figures fig. 9a to Fig. 12.

Fig. 13b thus shows exemplarily an embodiment in which asymmetrical base elements 41 having a spacing 61 and asymmetrical base elements 42 having a spacing 62 are provided in a region 332. As indicated in Fig. 13b of the depiction below, the base elements 41 have not only a different spacing of the base face from the element faces, but also a different preferred direction and thus enclose a 90 degree angle in the exemplary embodiment 13b with respect to its preferred direction. Furthermore, the region 332 is formed to be pattern-shaped as a foreground region in the shape of a K, which is surrounded by a background region 331. In this arrangement, the following colour effects can be achieved by rotation of the decorative element 2 about an axis perpendicular to the base plane: generating, for example, the base elements 41 having the spacing 61 for a specific viewing angle a* and, during viewing in parallel to the longitudinal axis of the base element (i.e. in the y direction) a clearly visible, reddish colour impression in scattered light, during rotation by 90 degrees (maintaining the viewing angle a*), an (only weakly visible) reddish colour impression or colour impression, and during viewing in parallel to the longitudinal axis of the base element (i.e. in the x direction), a clearly visible, greenish colour impression in scattered light and, during rotation by 90 degrees (while maintaining the viewing angle α, an only weakly visible greenish colour impression or no colour impression, the security element thus has a colour rotation effect of a reddish K on a green background. Additionally, this produces a very clearly visible colour effect having a security feature of high security.

It is furthermore also possible that a microstructure is provided in the regions 31 and 32 or in a sub-region of the regions 31 and 32, which uses base elements 41 having different spacings 61 and 62, wherein the base elements are not mixed, but rather are present in at least two macroscopic regions. The lateral size of these regions is typically greater than 300 µm and smaller than 50 mm. Here, the macroscopic regions can be formed in the shape of logos, characters or similar. Fig. 13c now clarifies an exemplary embodiment of this embodiment, wherein, here, first zones 333 are provided, in which base elements 41 having a spacing 61 of the element faces from the base face are provided and several second zones 334, in which base elements 41 having a spacing 62 of the element faces from the base face are provided. Here, the effect illustrated in Fig. 13c is shown, for example, in which a contrast change effect arises during tilting of the decorative element 2 about the x axis, and, for example, the circle appears strongly green at the one tilt and the background appears violet, and during tilting by approx. 30 degrees, the colour impressions of these regions interchange.

If the base elements of the one zone are formed as symmetrical base elements and those of the other zone are formed as asymmetrical base elements, the one zone is thus colour constant during rotation, while the other zone varies in the brightness of the colour, and thus, for example, the zones 334 arranged in the background vary in the brightness of their colour.

It is furthermore also possible that the face covering of the base plane with the base elements varies in the zones 333 and 334, in order to thus vary the colour brightness of the respective zone for generating a greyscale image. With a face covering of a respective sub-regions of the zones 333 and 334 with the base elements close to 50 %, the greatest brightness of the colour arises and with a reduction or increase of the face covering of the respective sub-region, the brightness of the colour decreases. The colour value of the colour is determined by the spacing of the element faces of the base elements of the base face, i.e. by the spacings 61 and 62 of the base elements 51. It is thus possible, for example, that, in this way, an additional piece of information is coded in the zones 334 or 333, thus, for example, the zone 334 also has a portrait of a person visible in a greyscale depiction as an additional piece of information.

The brightness of this greyscale image can furthermore also be varied by overlaying with further grating structures. Here, it is particularly advantageous to provide moth-eye structures. These structures are preferably provided by crossed gratings or hexagonal gratings having a period in the range of 200 nm to 400 nm and a grating depth/period ratio between

0.5 and 2. By means of the use of such moth-eye structures, sub-regions of the zones 333 and 334 can be formed to be darker and in this way a greyscale image can be generated. It is thus, for example, also possible to generate the greyscale image only through targeted, partial overlaying of the zones 333 and 334 with such moth-eye structures and thus, for example, to keep the face covering with the base elements constant within the zones 333 and 334 and to only set the brightness level by the zones 333 and 334 in the sub-regions being partially overlaid with moth-eye structures.

It is furthermore also possible to generate multicolour images or true colour images by means of the use of first, second and third zones having different spacings 61, 62 and 63 of the element faces from the base faces. Fig. 14a thus shows exemplarily a true colour image 70. The image region of the true colour image 70 is now divided into a plurality of pixel regions and the colour value as well as the colour brightness is determined in the respective pixel region. Subsequently, an image region of the decorative element 2 is divided into a plurality of pixel regions and first, second and/or third zones are arranged in each of the pixel regions in such a manner that the colour value and colour brightness value defined for the respective pixel region are generated by the microstructure 4. Fig. 14b thus shows exemplarily a cut-out of such an image region having four pixel regions 350. Several zones 351, 352 and 353 are respectively provided in the pixel regions 350. The base elements arranged in the zones 351, 352 and 353 have a different spacing of the element face from the base face, namely the spacing 61, 62 and 63, as is also shown in the sectional depiction according to Fig. 14c. The section is identified in Fig. 14b with B-B'. The shaping and arrangement of the base elements 41 in the respective zone 351, 352 and 353 is preferably chosen here according to the previous embodiments according to Fig. 2a to Fig. 12.

Furthermore, in the embodiments of the microstructure 4 previously described using the Figures Fig. 2a to Fig. 14, it is also possible to additionally provide a hidden piece of information in the regions 31 and 32. For this purpose it is possible, for example, as illustrated using Fig. 15, to firstly form a microstructure 80 according to the above embodiments and then, in a second step, to slightly modulate the element faces and/or the base face of the microstructure by exposing a hologram 81 or writing a computer-generated hologram. The height of the element faces or base face is thereby slightly locally changed. This disrupts the interference and thus changes the colour of the microstructure, as is shown in the depiction below of Fig. 15, and therefore the modulation must also be small. Simultaneously, however, the image information of the hologram is stored to the microstructure 80, which is however accompanied by strong noise due to the low (slight) modulation. The strength of the modulation can be in the range +/- 50% of the height but is however preferably in the range +/- 20% and more preferably in the range +/- 10%. If only the element face or the base face is modulated, the colour effects of the microstructure are formed more strongly and are thus visible. The image information of the hologram is however very noisy, as mentioned above. If both planes are modulated, the disruption of the colour effects is stronger. The image information of the hologram is therefore less noisy. During viewing in ambient light, the hidden information is not visible or barely visible (due to the very low modulation). During illumination with a suitable laser light, the hologram appears. The optimal laser wavelength (λ) for the reconstruction of the hologram is twice the spacing (h) 61 times the refractive index (n) of the surrounding medium ($\lambda = 2*h*n$).

A further embodiment shown in Fig. 16 provides a modulation of the element face of the base element 41 and/or the base face 40 with a special grating structure. Thus, for example, in a region 361, the base face and the element face of the base face 41 are modulated with a diffractive structure 82 and, in a region 362, the base face 40 and the element faces of the base elements 41 are modulated with a diffractive structure 83. Here, the diffractive structures 82 and 83 differ in the orientation of their grating lines, as is indicated in Fig. 16. The grating structures can be linear, crossed or hexagonal. The grating periods of the gratings 82 and 83 is preferably chosen to be between 100 nm and 2000 nm, more preferably between 200 nm and 500 nm. The gratings 82 and 83 can be part of a design. In particular, the gratings 82 and 83 can be zeroth order polarisation gratings. Regions having a logo or background which is TE polarised can thus be provided, and other regions, e.g. the background of the logo or image, with the orthogonal TM polarisation. Here, TE refers to a transverse electrical wave (TE = transverse electric) and TM a transverse magnetic wave (TM = transverse magnetic). With respect to linear gratings, TE polarised light is understood to mean light in which the electrical field component is in parallel to the grating lines and TM polarised light is understood to mean that in which the electrical field component is perpendicular to the grating lines. The logo or image appears during viewing with a polarisation filter. Correspondingly, the regions 361 and 361 can thus be formed as a background region and pattern region, which only become visible during viewing through a polariser. As in the modulated hologram from Fig. 15, the modulation of the grating structure must be low, in particular in the range of +/- 50% of the height, however preferably in the range of +/- 20 % and more preferably in the range of +/- 10%. The modulation depth of the hologram or the diffraction grating is preferably smaller than 100 nm, particularly preferably smaller than 50 nm and more preferably smaller than 30 nm. The modulation thus only slightly disrupts the interference which generates the colour effect.

A further preferred embodiment combines the previously described microstructures, which generate colour effects, with refractive, achromatic micromirrors as described in, for example, DE 10 2008 046 128 A1.

Here, the base plane is defined by the micromirrors, i.e. the base plane changes from micromirror to micromirror. The depth of the microstructures on the micromirrors. i.e. the spacing 61 is preferably equal, so that the achromatic effect of the micromirrors is overlaid with the colour effect of the microstructures.

Fig. 17 shows this embodiment in a schematic side view. Here, a different base plane is respectively provided in different sub-regions 61, 62, 63, which is defined by the micromirrors, in particular by the micromirrors formed in DE 2008 046 128 A1. The element faces 411 of the base elements as well as the base face 40 are oriented in parallel to the respective base plane in each of the sub-regions 61, 62 and 63. Furthermore, the base planes in the regions 61, 62 and 63 are not arranged in parallel to one another but rather tilted with respect to one another, as shown in Fig. 17.

PATENTTIVAATIMUKSET

1. Koriste-elementti (2), jolloin koriste-elementissä (2) on mikrorakenne (4), joka tuottaa pintavalaisussa ja/tai läpivalaisussa optisen vaikutuksen, jolloin mikrorakenteen (4) ensimmäisellä alueella (31, 32) on pohjapinta (40) ja useita pohjaelementtejä (41), jotka kukin sisältävät pohjapintaan (40) nähden nousevan tai laskevan elementtipinnan (411) sekä elementtipinnan (411) ja pohjapinnan (40) väliin järjestetyn reunuksen (410), jolloin mikrorakenteen pohjapinta (40) määrittää koordinaattiakseleiden x ja y välillä ulottuvan pohjatason, jolloin pohjaelementtien (41) elementtipinnat (411) kulkevat vastaavasti oleellisesti yhdensuuntaisesti pohjatasoon nähden ja jolloin ainakin yhdellä tai useammalla ensimmäisen alueen (31, 32) ensimmäisellä vyöhykkeellä (333, 351) pohjaelementtien (41) elementtipinnat (411) ja pohjapinta (40) on sijoitettu toisistaan erilleen suunnassa, joka kulkee kohtisuorasti tukitasoon nähden koordinaattiakselin z suunnassa, ensimmäisellä etäisyydellä (61), joka on valittu siten, että erityisesti pohjapinnalta ja elementtipinnoilta pintavalaisussa heijastuvan valon interferenssin ja/tai erityisesti elementtipintojen ja pohjapintojen läpivalaisussa läpäisemän valon interferenssin johdosta kyseisellä yhdellä tai useammalla ensimmäisellä vyöhykkeellä (333, 351) muodostuu ensimmäinen väri, jossa mikrorakenne on muodostettu siten, että se muodostaa ensimmäisen värin ensimmäisessä diffraktiokertaluvussa, jossa pohjatason keskimääräinen peittyminen pohjaelementeillä (41) ensimmäisellä alueella on 30–70 % , edullisesti 40–60 % ja vielä edullisemmin noin 50 %, **tunnettu** siitä, että pohjaelementit (41) seuraavat toisiaan säännöllisesti ensimmäisellä alueella (31, 32), jossa pohjaelementit (41) on muotoiltu ja järjestetty ensimmäiselle alueelle (31, 32) siten, että saapuva valo taittuu taipumalla suorasta heijastuksesta tai suorasta läpäisystä tai nollannesta diffraktiokertaluvusta pohjaelementeillä (41) siten, että suorassa heijastuksessa tai suorassa läpäisyssä tai nollannessa diffraktiokertaluvussa tarkasteltaessa muodostuu toinen väri, joka täydentää ensimmäistä väriä.

2. Jonkin edellisen patenttivaatimuksen mukainen koriste-elementti (2), **tunnettu** siitä, että ainakin yhdellä tai useammalla ensimmäisen alueen (31, 32) toisella ja/tai kolmannella vyöhykkeellä (334, 352, 353) pohjaelementtien (41) elementtipinnat (411) ja pohjapinta (40) on sijoitettu toisistaan erilleen suunnassa, joka kulkee kohtisuorasti pohjatasoon nähden koordinaattiakselin z suunnassa, toisella tai kolmannella etäisyydellä (62, 63), joka poikkeaa ensimmäisestä etäisyydestä (61) ja on valittu siten, että erityisesti pohjapinnalta (40) ja

elementtipinnoilta (41) pintavalaisussa heijastuvan valon interferenssin ja/tai erityisesti elementtipintojen ja pohjapinnan läpivalaisussa läpäisemän valon interferenssin johdosta kyseisellä yhdellä tai useammalla toisella tai kolmannella vyöhykkeellä (334, 352, 353) muodostuu kolmas tai neljäs väri, joka eroaa ensimmäisestä tai toisesta väristä.

3. Jonkin edellisen patenttivaatimuksen mukainen koriste-elementti (2), **t u n n e t t u** siitä, että pohjaelementit (41) on muodostettu ja järjestetty ensimmäiselle alueelle (31, 32) siten, että vähintään 10 % saapuvasta valosta, erityisesti 20–90 % saapuvasta valosta, vielä edullisemmin 30–70 % saapuvasta valosta, taittuu nollannesta kertaluvusta taittuen erityisesti taipumalla, ja/tai pohjaelementit (41) on muodostettu ja järjestetty ensimmäiselle alueelle (31, 32) siten, että saapuva valo siroaa vähintään yhdessä suunnassa sirontakulman ollessa enintään 10 astetta ja erityisesti korkeintaan 30 astetta nollannen diffraktiokertaluvun ympärillä, ja/tai että vähintään yksi kunkin pohjaelementin (41) projektion sivusuuntainen jatkuminen pohjatasolla on 0,25–50 µm, edullisesti 0,75–10 µm, ja/tai että vähimmäisetäisyys vierekkäisten pohjaelementtien (41) välillä ei ole suurempi kuin 300 µm ja valitaan erityisesti niin, että se on 0,5–300 µm, edullisesti 0,5–50 µm.

4. Jonkin edellisen patenttivaatimuksen mukainen koriste-elementti (2), **t u n n e t t u** siitä, että yhdellä tai useammalla ensimmäisestä, toisesta ja/tai kolmannesta vyöhykkeestä on sivusuuntaisia ulottuvuuksia, jotka ovat yhdensuuntaisia pohjakerroksen kanssa makroskooppisella alueella, erityisesti alueella 300 µm – 50 mm, ja näiden ensimmäisten, toisten ja/tai kolmansien vyöhykkeiden muodostuminen kuvioalueeksi ja/tai tausta-alueeksi saa aikaan optisesti havaittavissa olevan tiedon, ja/tai että yhdessä tai useammassa ensimmäisestä, toisesta ja/tai kolmannesta vyöhykkeestä vastaavien vyöhykkeiden peittymistä pohjaelementeillä vaihdellaan paikallisesti vastaavan vyöhykkeen värin kirkkauden vaihtelemiseksi paikallisesti ja/tai että yhden tai useamman ensimmäisen, toisen ja/tai kolmannen vyöhykkeen vähintään yksi sivusuuntainen ulottuvuus yhdensuuntaisesti pohjatasoon nähden on vähemmän kuin 300 µm, edullisesti 20–250 µm.

5. Turvadokumentti (1), jossa on jonkin edellisen patenttivaatimuksen mukainen koriste-elementti (2).

6. Menetelmä koriste-elementin (2) muodostamiseksi, jolloin menetelmässä koriste-elementtiin (2) lisätään mikrorakenne (4), joka tuottaa optisen vaikutuksen

pintavalaisussa ja/tai läpivalaisussa, ja jonka ensimmäisellä alueella (31, 32) on pohjapinta (40) ja useita pohjaelementtejä (41), jotka kukin sisältävät pohjapintaan (40) nähden nousevan tai laskevan elementtipinnan (411) ja elementtipinnan ja pohjapinnan väliin järjestetyn reunuksen (410), jolloin pohjapinta määrittää pohjatason ja pohjaelementtien (41) elementtipinnat (411) kulkevat vastaavasti oleellisesti yhdensuuntaisesti pohjatasoon nähden ja jossa ainakin yhdellä tai useammalla ensimmäisen alueen ensimmäisellä vyöhykkeellä pohjaelementtien (41) elementtipuolet (411) ja pohjapuoli (40) on sijoitettu erilleen toisistaan suunnassa, joka kulkee kohtisuorasti pohjatasoon nähden, ensimmäisellä etäisyydellä (61), joka on valittu siten, että erityisesti pohjapinnalta (40) ja elementtipinnoilta (411) pintavalaisussa heijastuvan valon interferenssin ja/tai erityisesti elementtipintojen (411) ja pohjapinnan (40) läpivalaisussa läpäisemän valon interferenssin johdosta kyseisellä yhdellä tai useammalla ensimmäisellä vyöhykkeellä muodostuu ensimmäinen väri, jossa mikrorakenne on muodostettu siten, että se muodostaa ensimmäisen värin ensimmäisessä diffraktiokertaluvussa ja jossa pohjatason keskimääräinen peittyminen pohjaelementeillä (41) ensimmäisellä alueella on 30–70 %, edullisesti 40–60 % ja vielä edullisemmin noin 50 %, jolloin pohjaelementit (41) seuraavat toisiaan säännöllisesti ensimmäisellä alueella (31, 32), jossa pohjaelementit (41) on muotoiltu ja järjestetty ensimmäiselle alueelle (31, 32) siten, että saapuva valo taittuu taipumalla suorasta heijastuksesta tai suorasta läpäisystä tai nollannesta diffraktiokertaluvusta pohjaelementeillä (41) siten, että suorassa heijastuksessa tai suorassa läpäisyssä tai nollannessa diffraktiokertaluvussa tarkasteltaessa muodostuu toinen väri, joka täydentää ensimmäistä väriä.

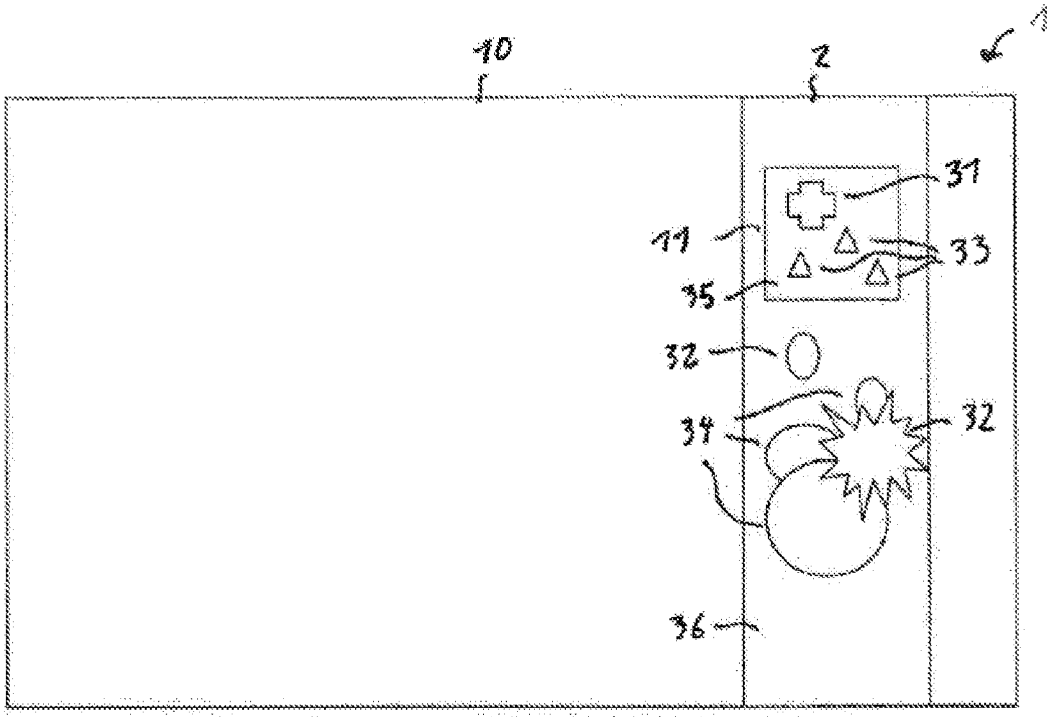


Fig. 1a

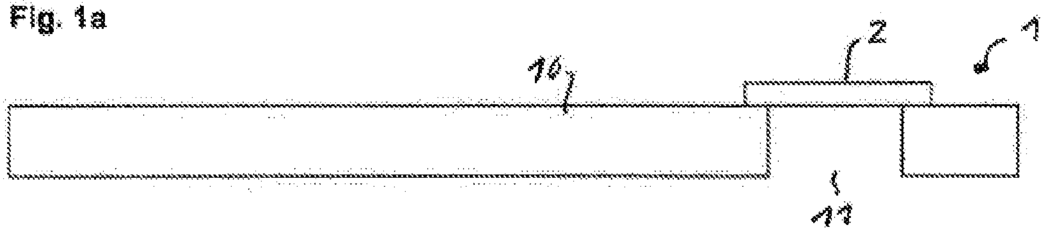


Fig. 1b

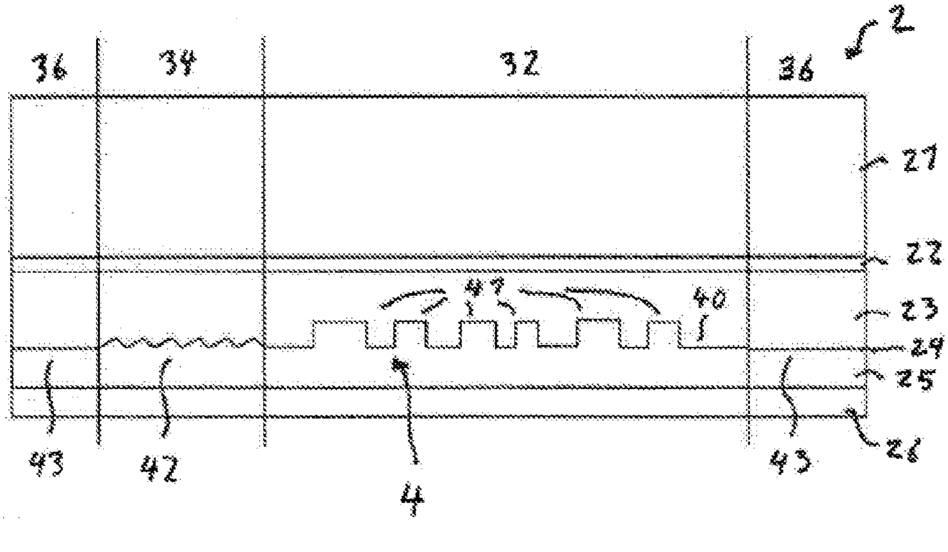


Fig. 1c

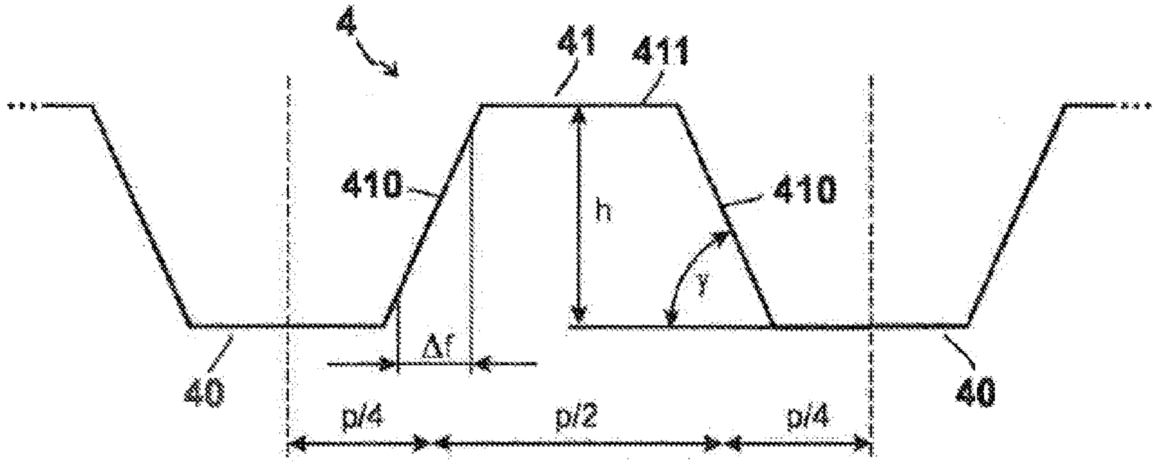


Fig. 1d

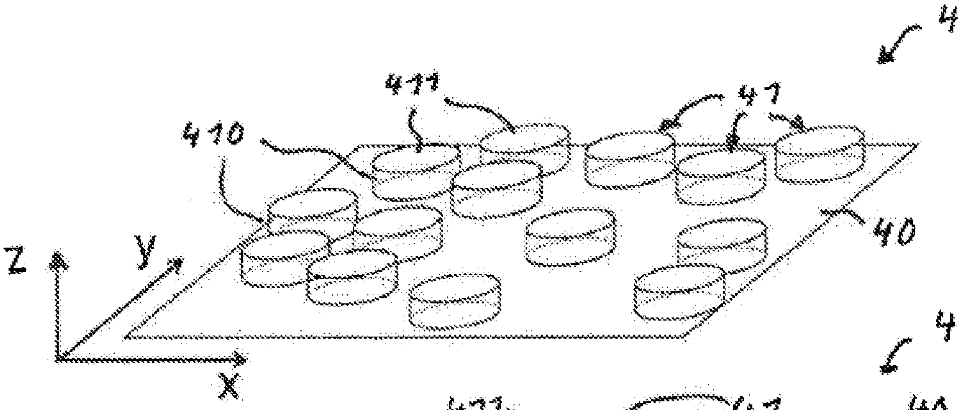


Fig. 2a

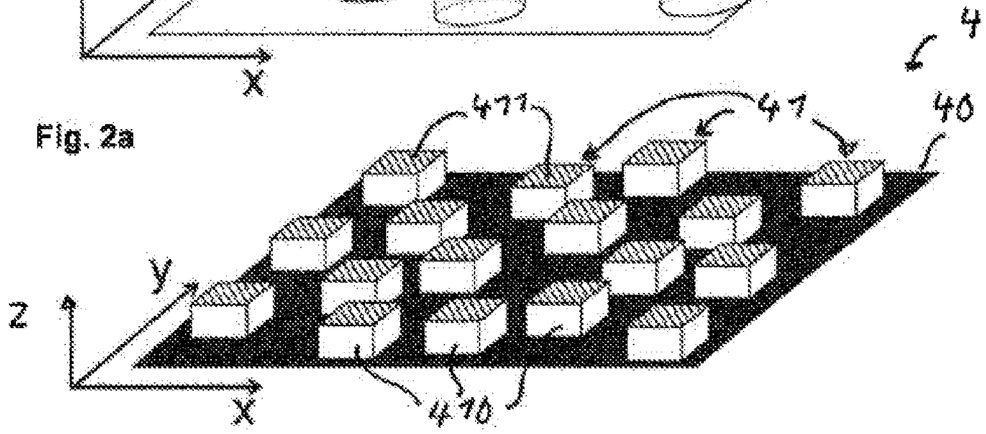


Fig. 2b

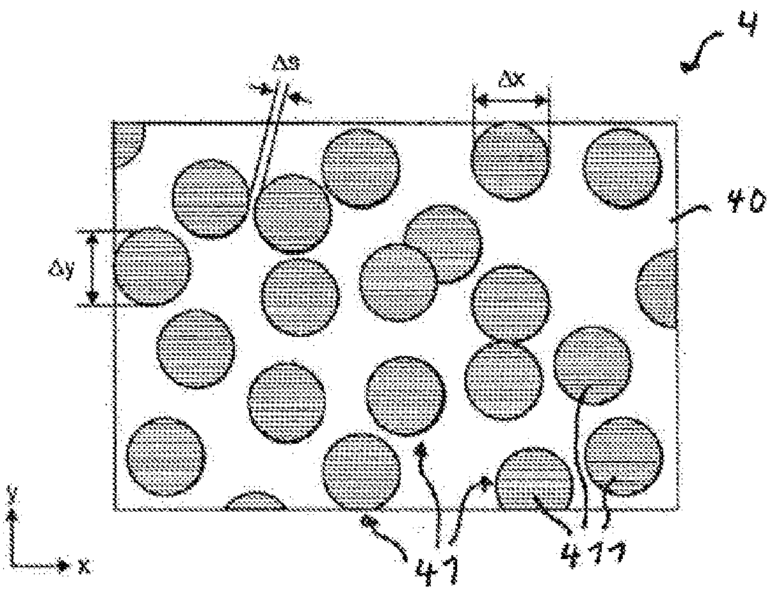


Fig. 2c

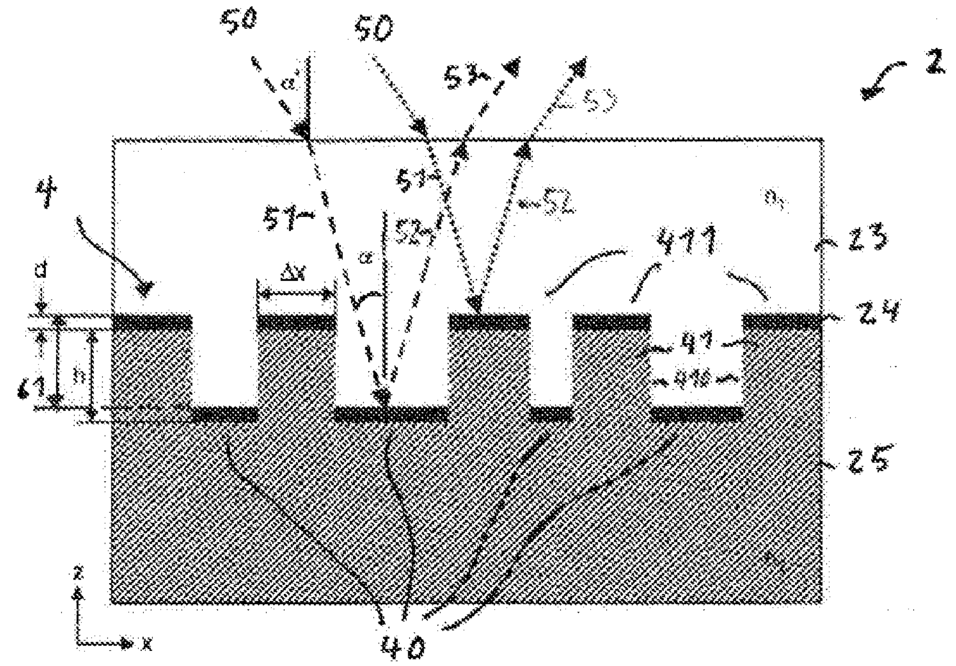


Fig. 3a

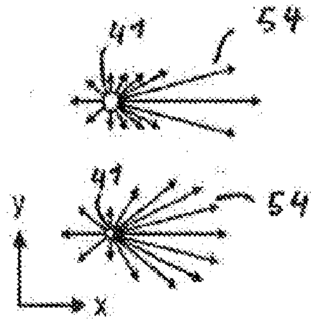


Fig. 3b

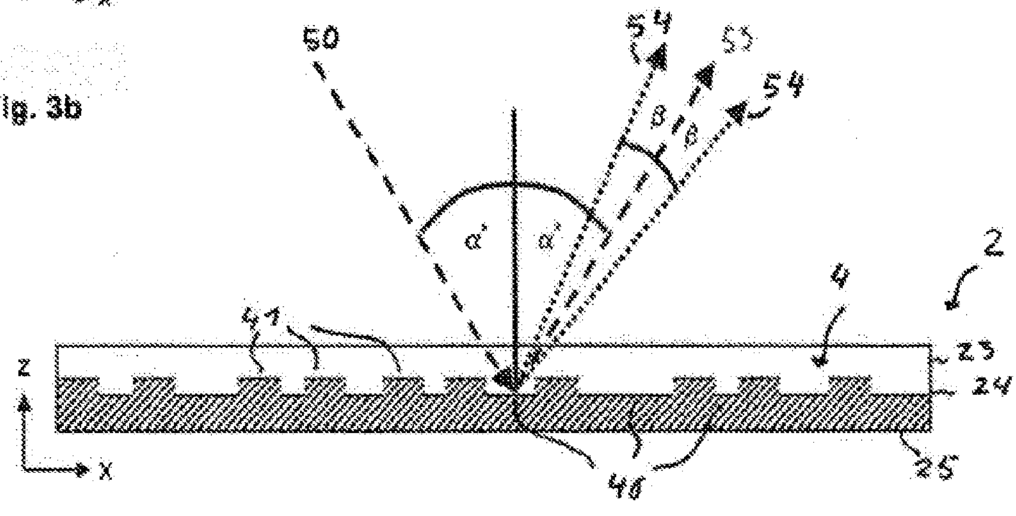


Fig. 3c

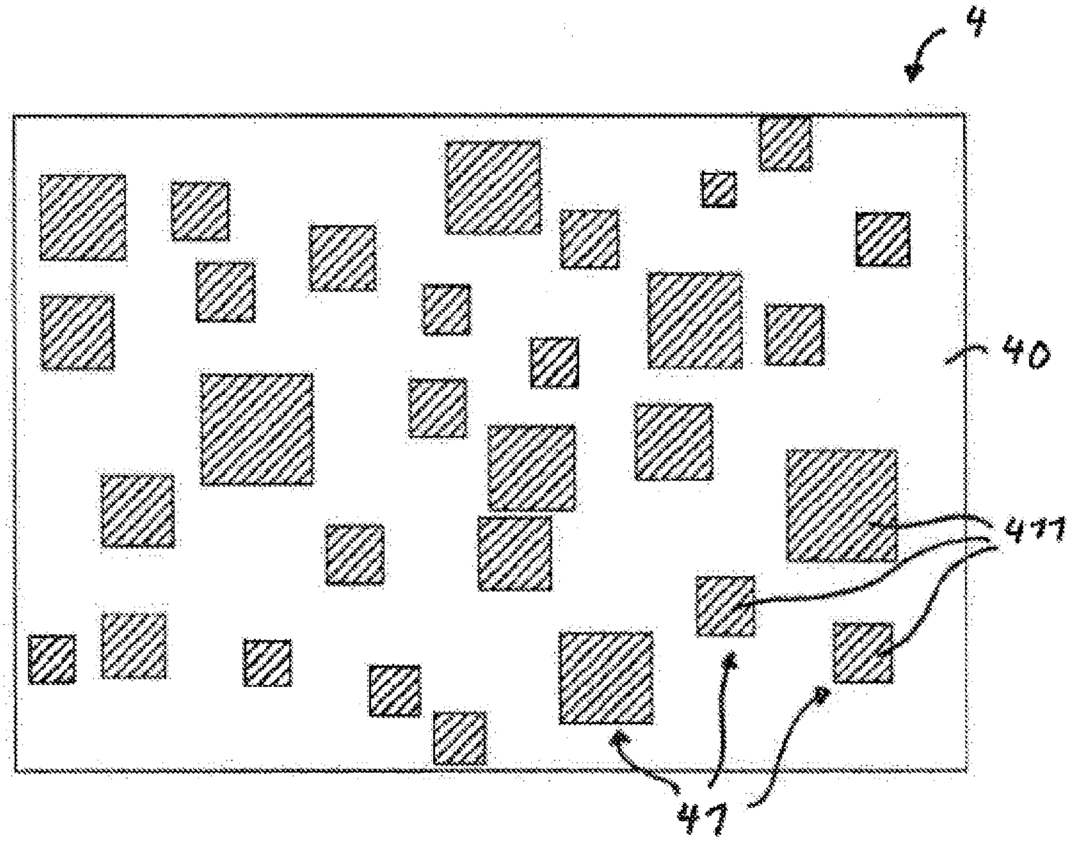


Fig. 4

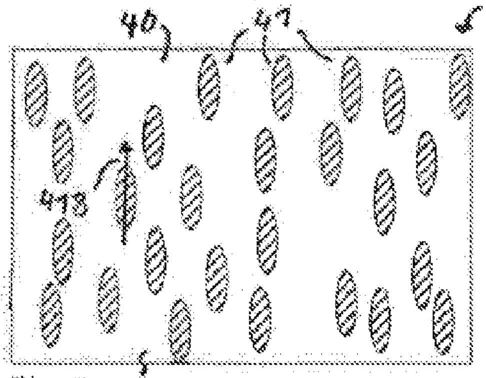


Fig. 5a

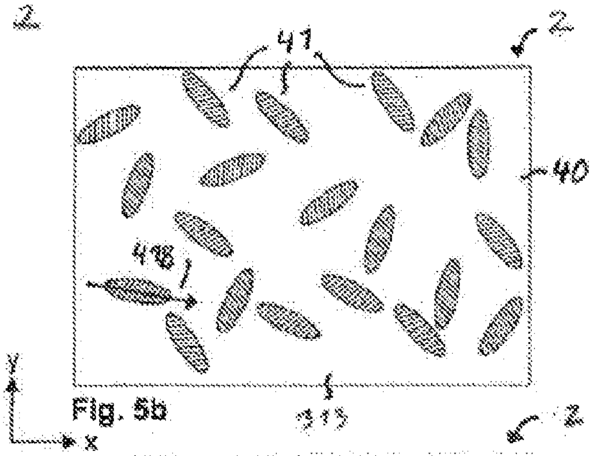


Fig. 5b

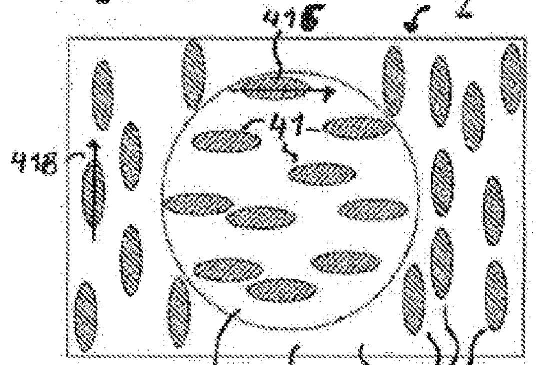


Fig. 5c

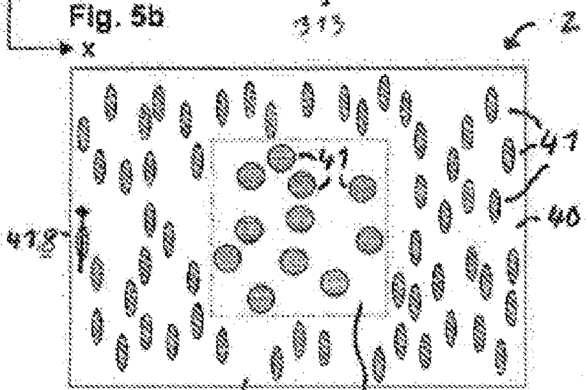


Fig. 5d

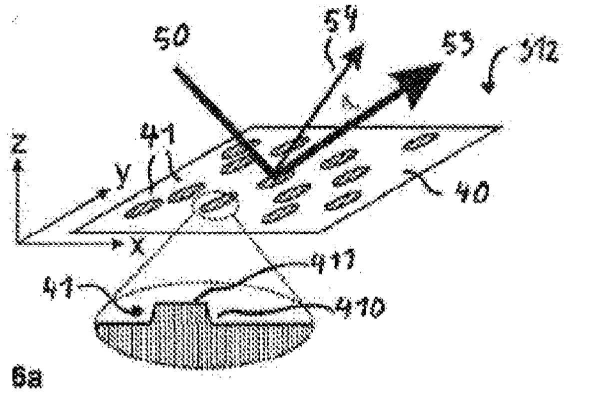


Fig. 6a

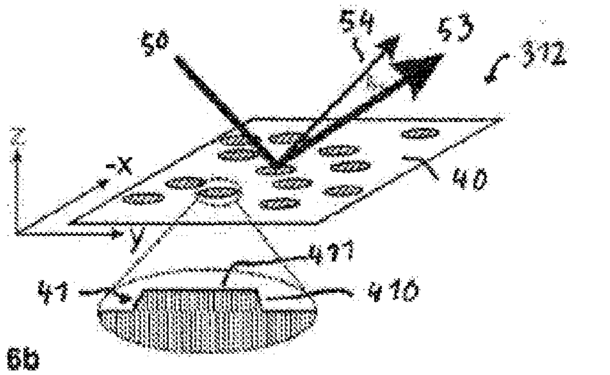


Fig. 6b

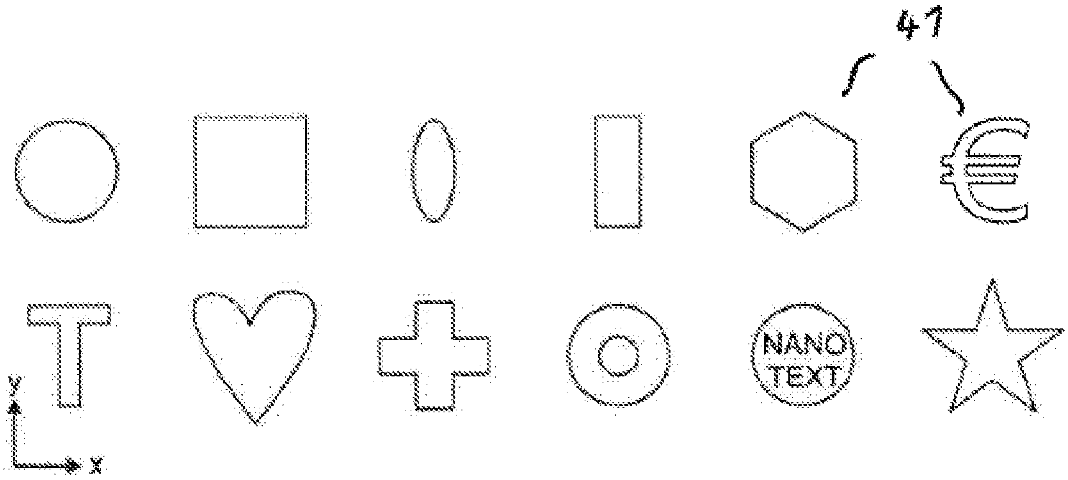


Fig. 7

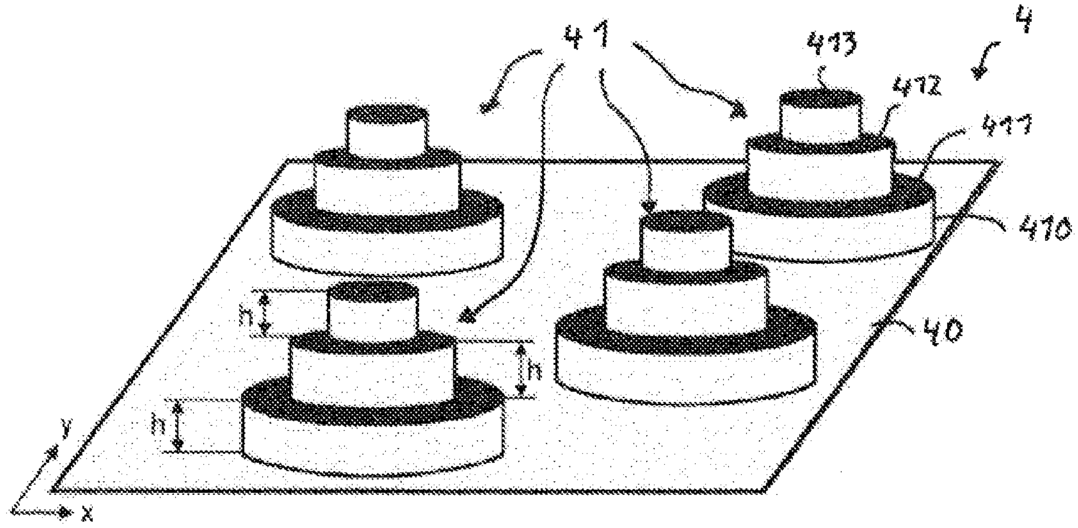
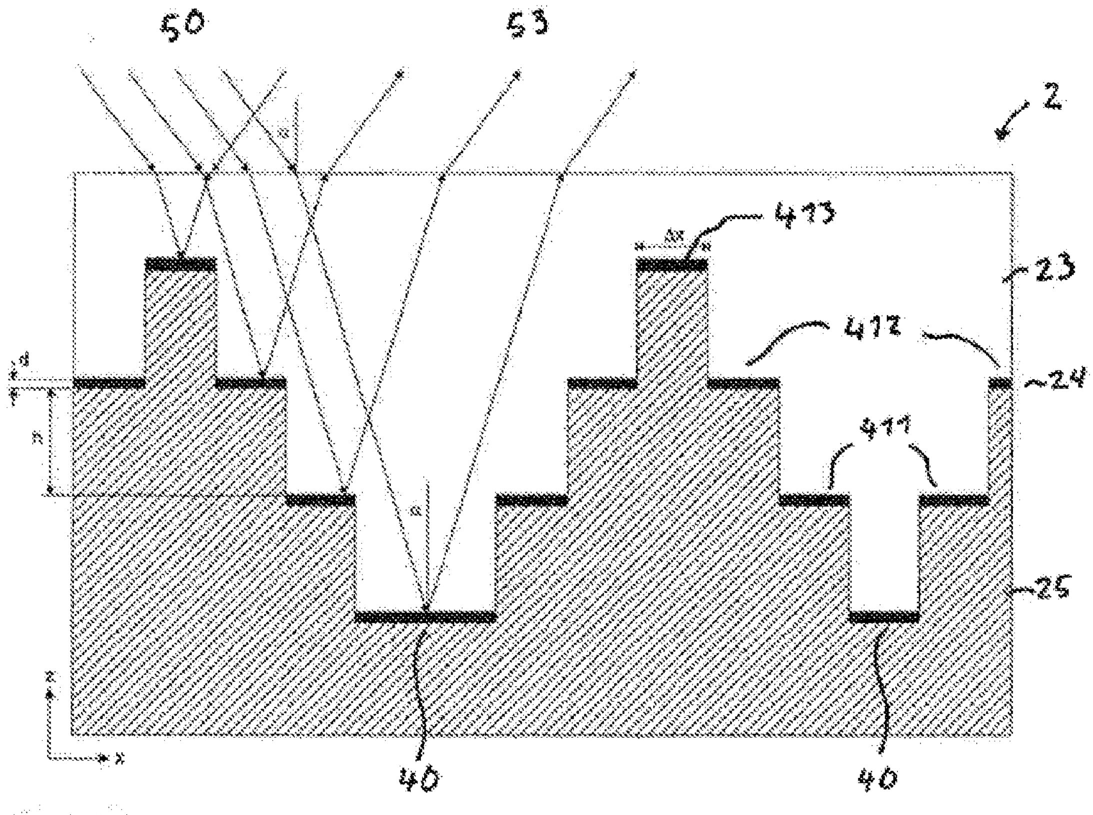

41
413
4
412
411
410
40
h
h
h
y
x

Fig. 8a


50
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α
413
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412
d
24
h
411
α
25
z
x
40
40

Fig. 8b

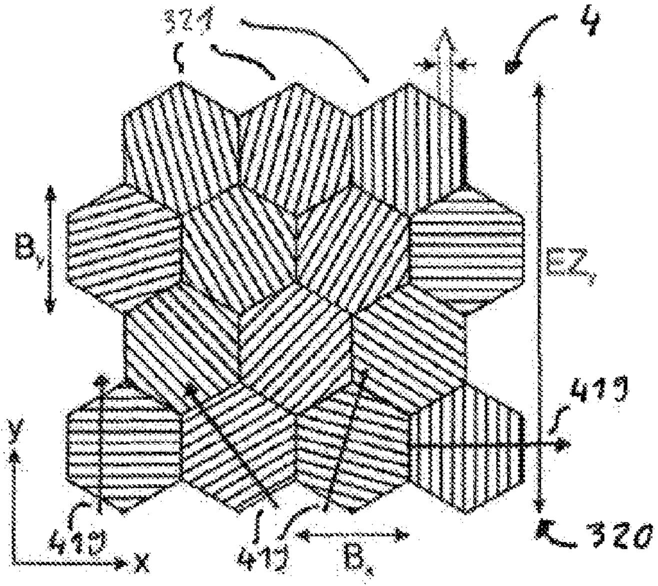


Fig. 9a

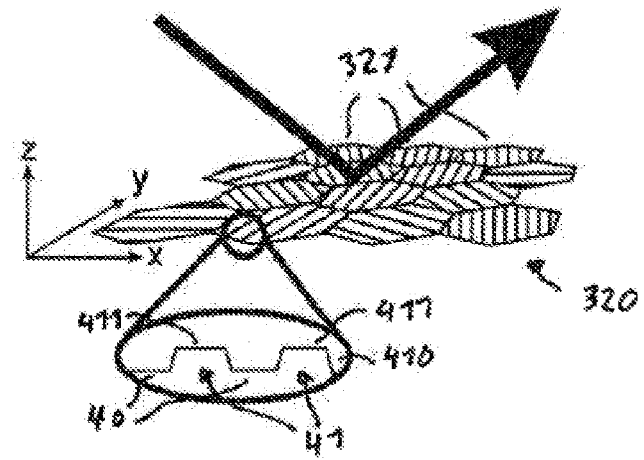


Fig. 9b

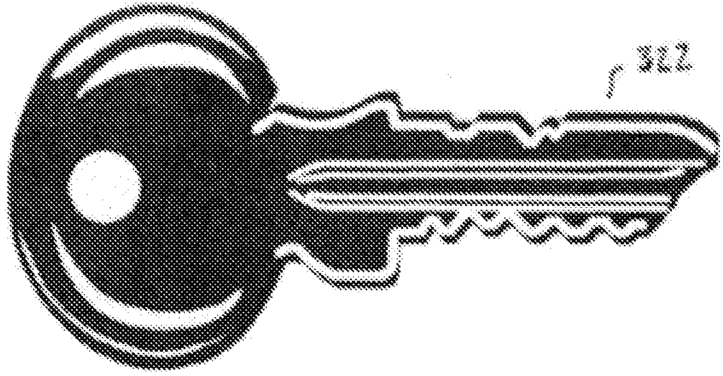
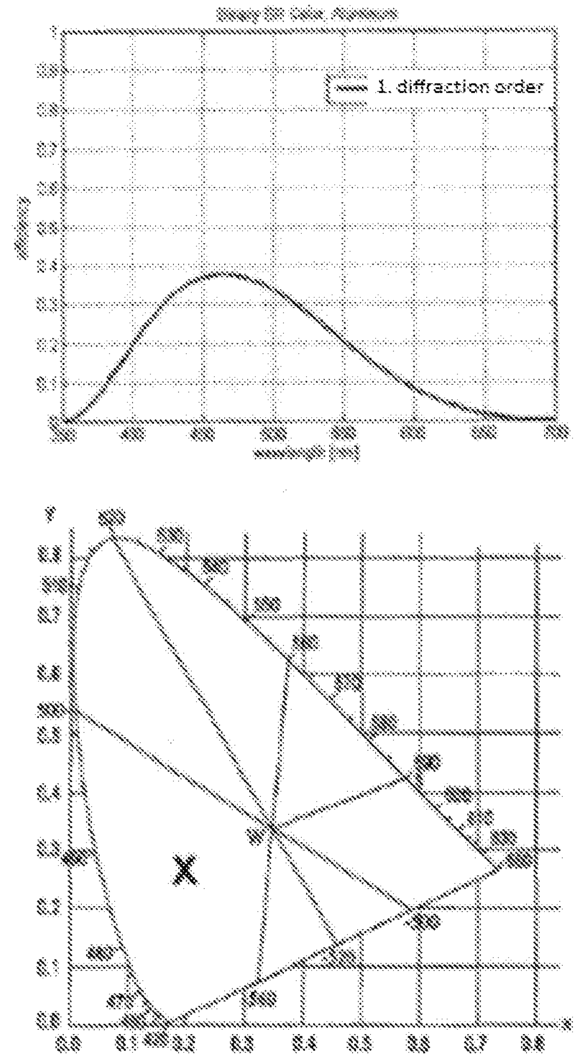


Fig. 10a



The CIE 1931, 2° observer chromaticity diagram.

Fig. 10b

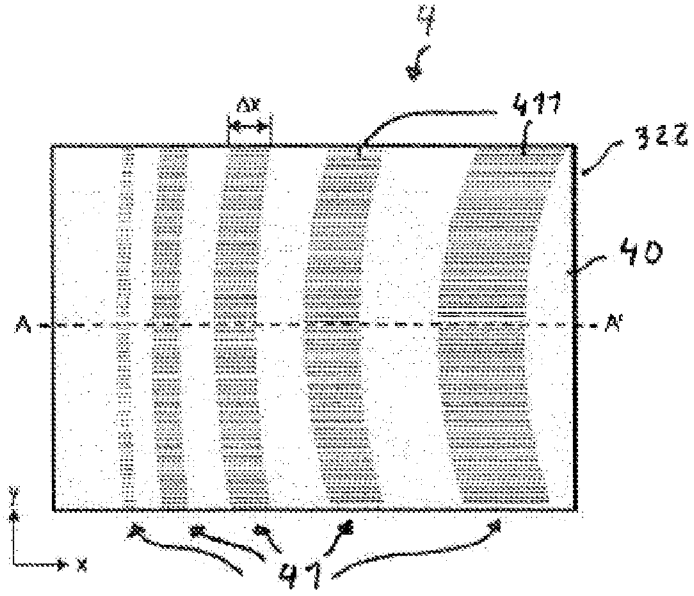


Fig. 11a

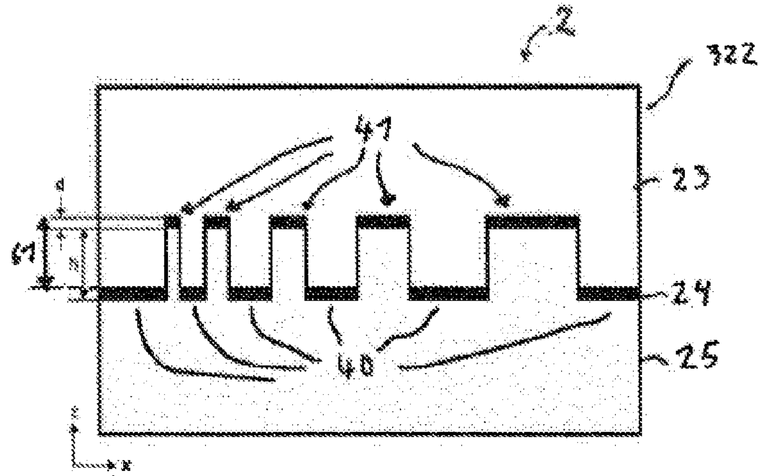


Fig. 11b

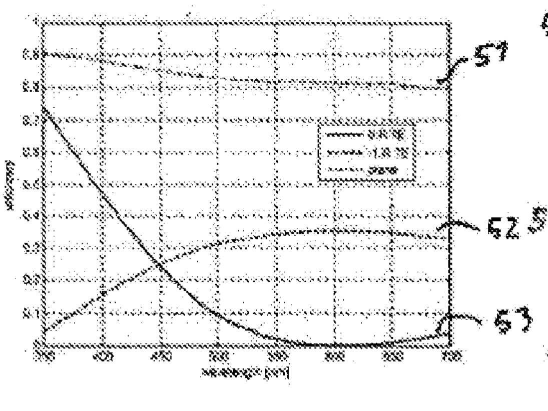


Fig. 11c

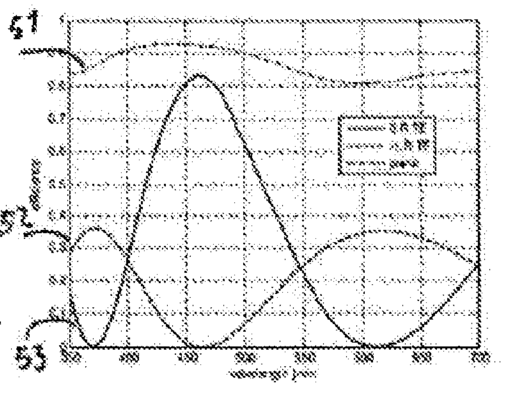


Fig. 11d

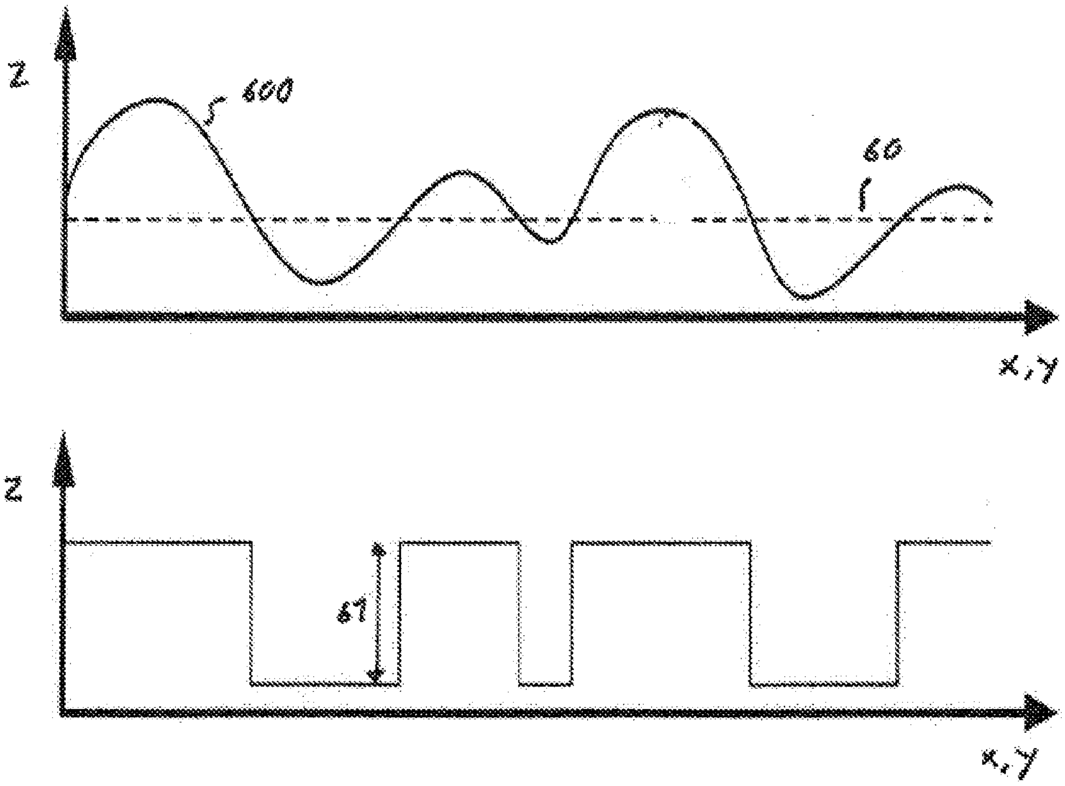


Fig. 12a

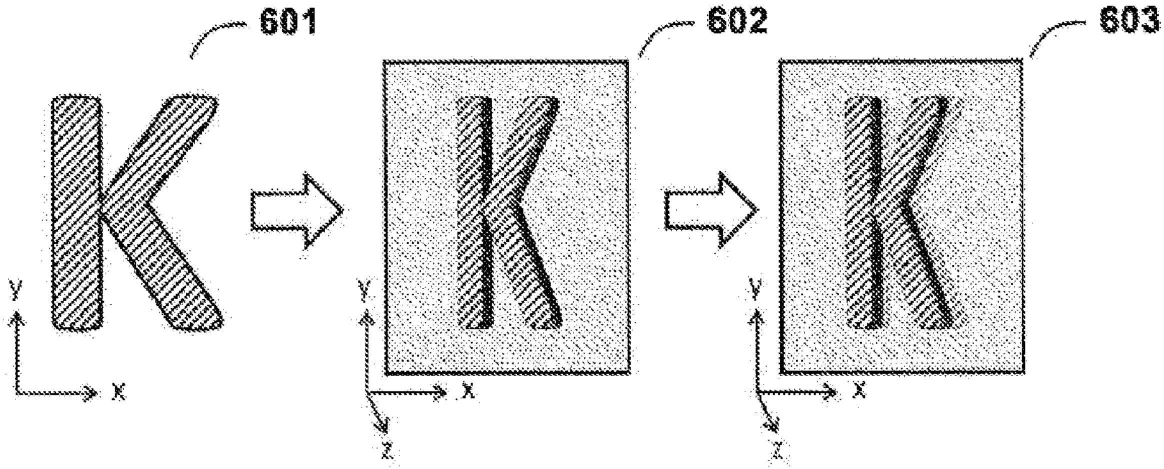


Fig. 12b

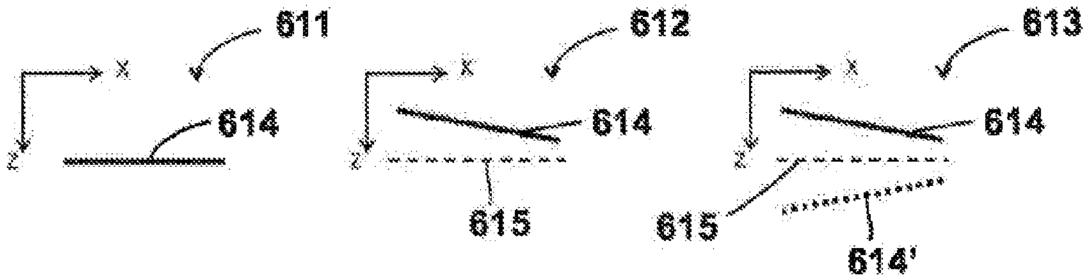


Fig. 12c

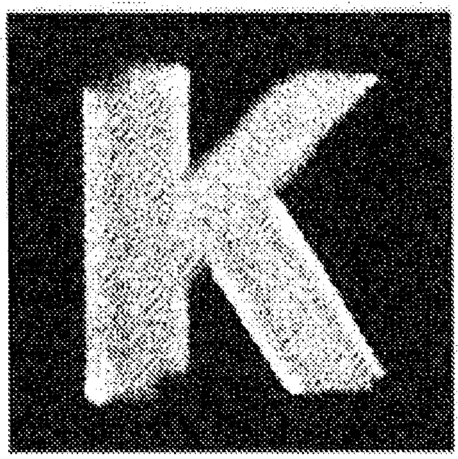


Fig. 12d

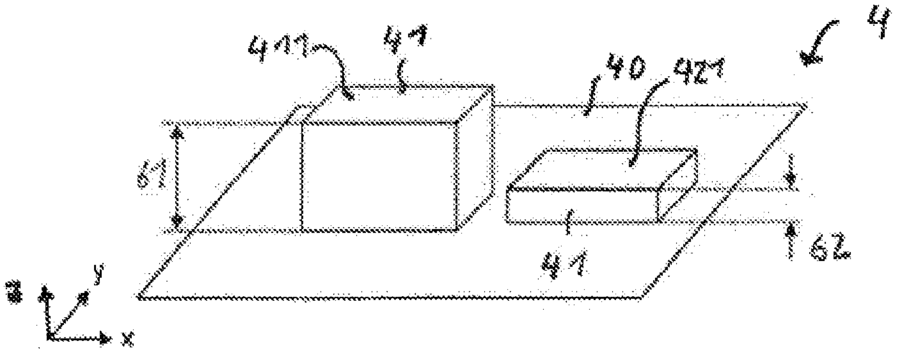


Fig. 13a

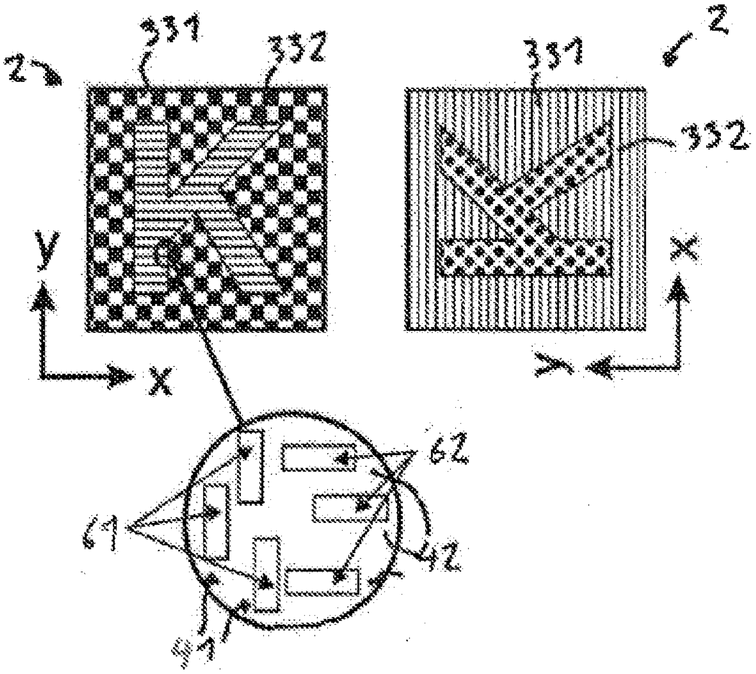


Fig. 13b

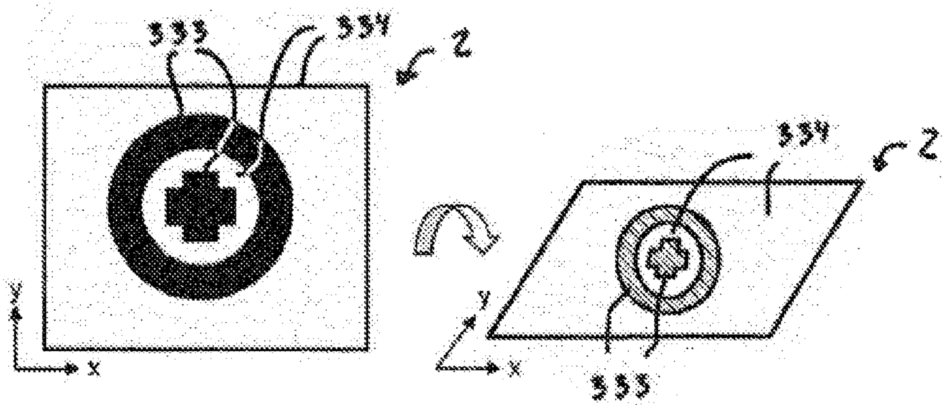


Fig. 13c

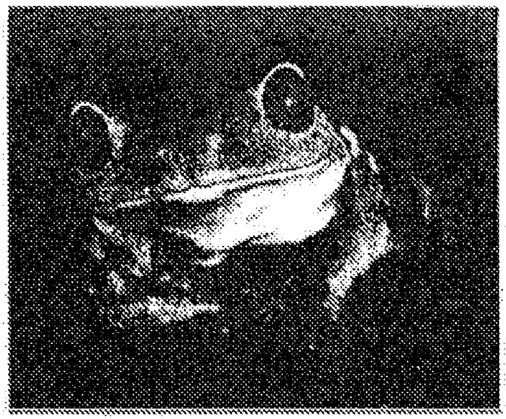


Fig. 14a

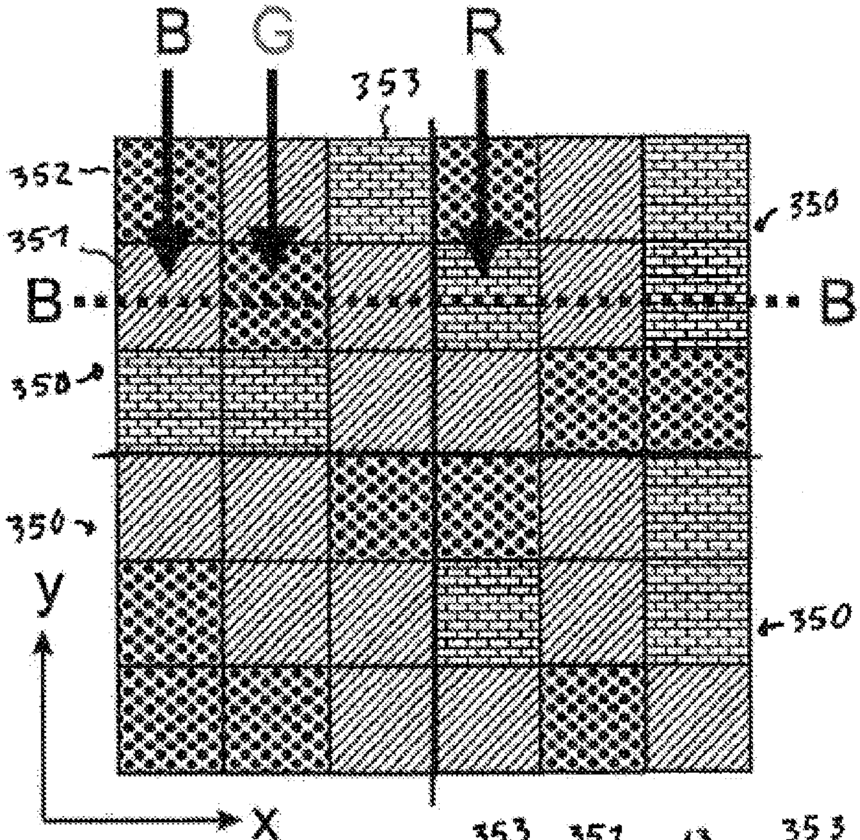


Fig. 14b

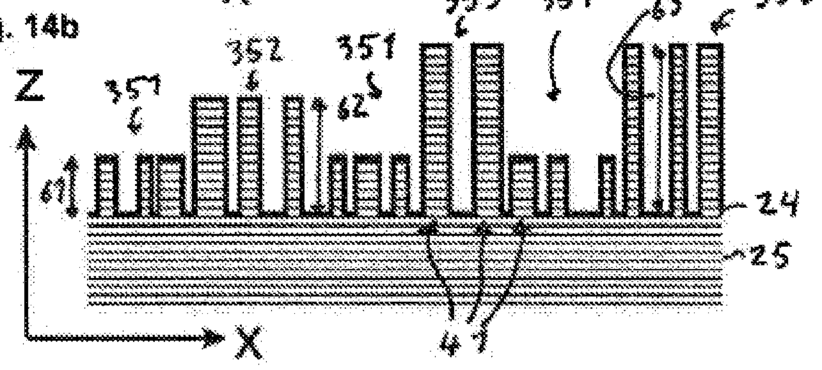


Fig. 14c

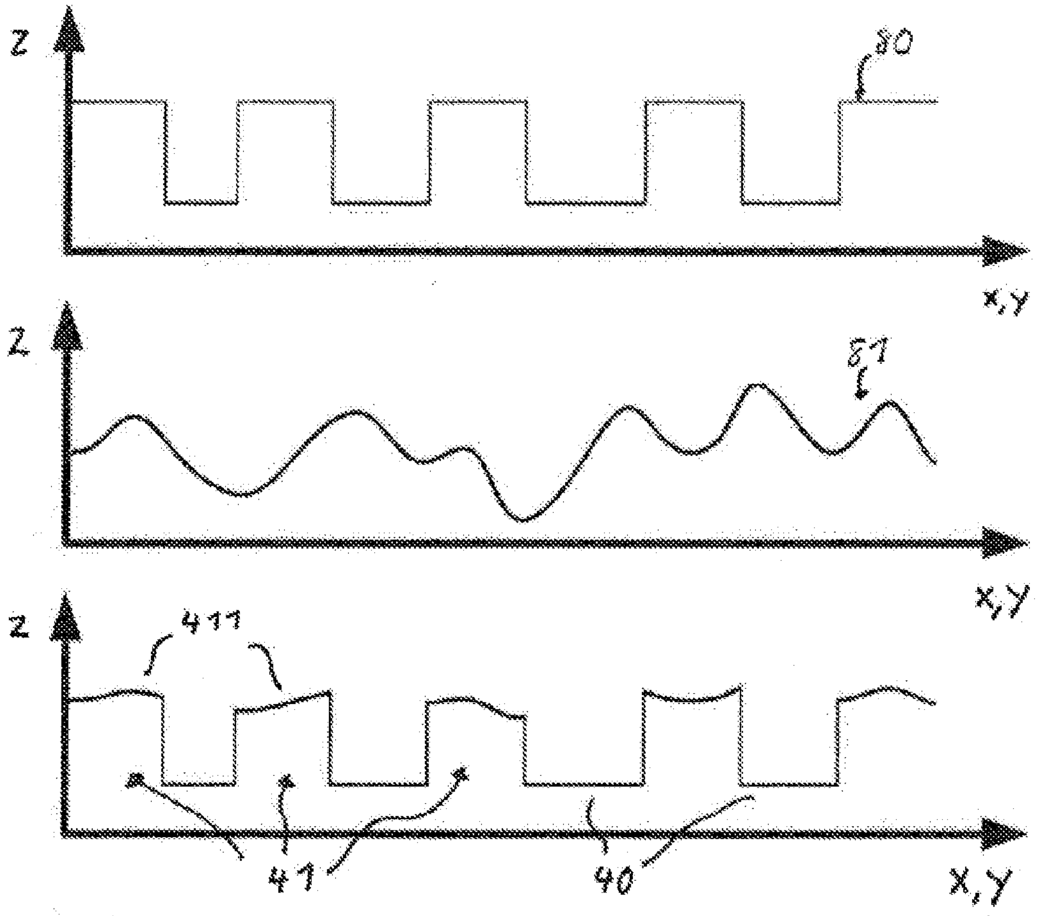


Fig. 15

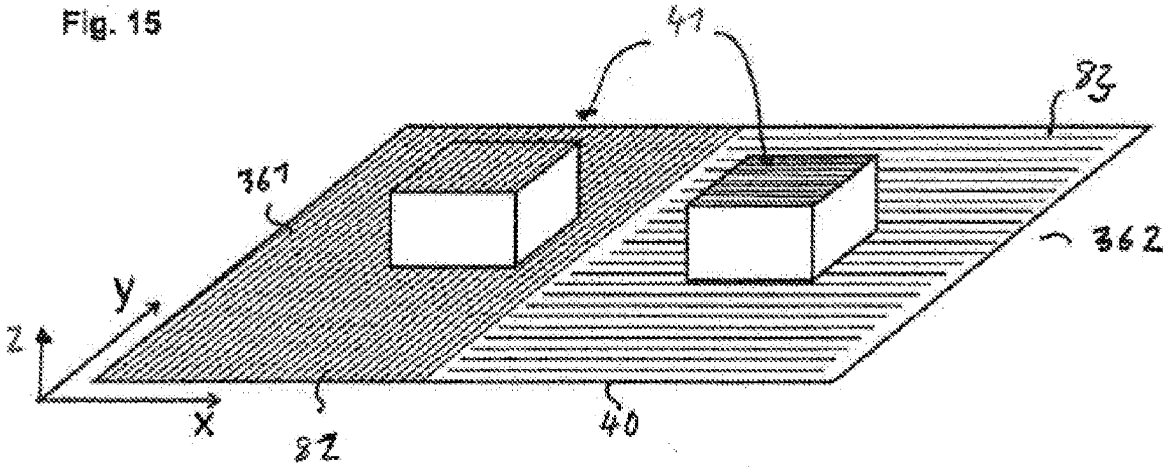


Fig. 16

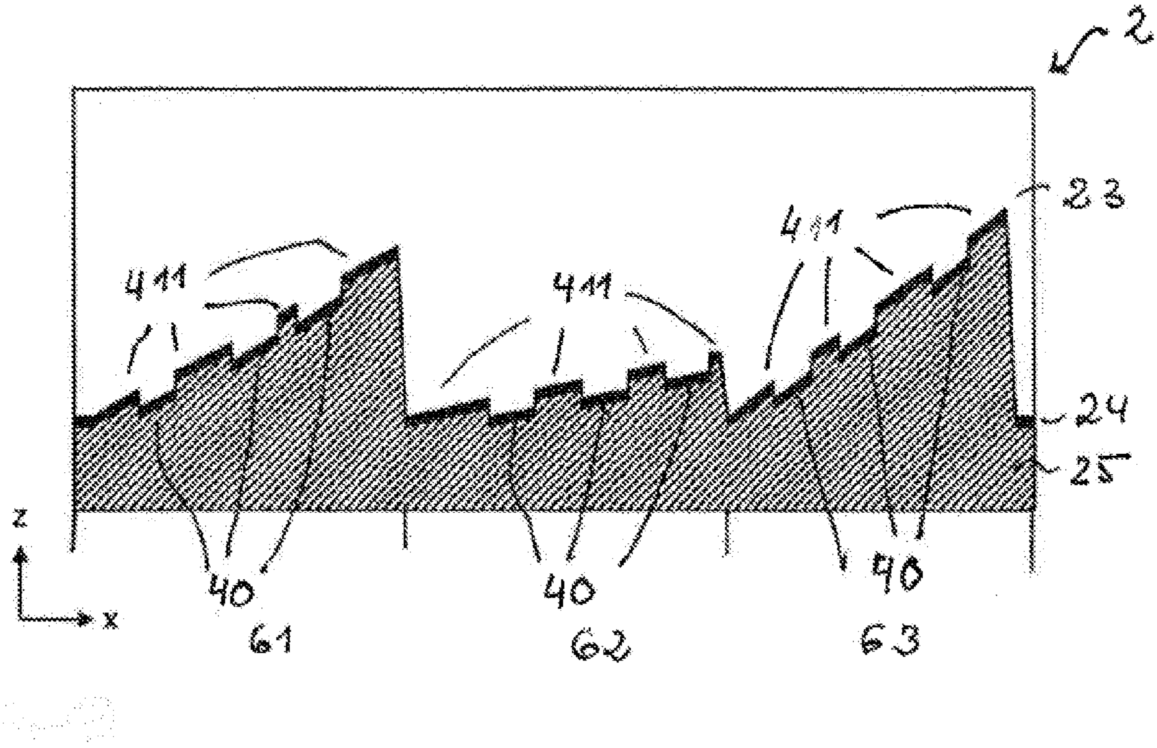


Fig. 17