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(54) **MICROOPTICAL SYSTEM FOR THE FORMATION OF THE 3D IMAGE IN THE ZERO ORDER OF DIFFRACTION**

(57) The claimed microoptical system for visual control of products belongs mainly to the field of optical security technologies and is used to authenticate banknotes, documents, passports, IDs, plastic cards, securities, and brands.

The microoptical system consists of fragments of multilevel kinoforms and fragments of diffraction gratings of various periods and directions. In accordance with the claims, a method for synthesizing microoptical systems for forming 3D images in the zero diffraction order is described. Multilevel kinoform is used for the formation of 3D-images. A method for computing the microrelief of a microoptical system that forms a 3D image at diffraction angles smaller than 60° is proposed. At large diffraction angles the observer sees another 2D color image.

Microoptical systems are manufactured using electron beam technology and can be replicated using standard equipment for the manufacture of embossed holograms.

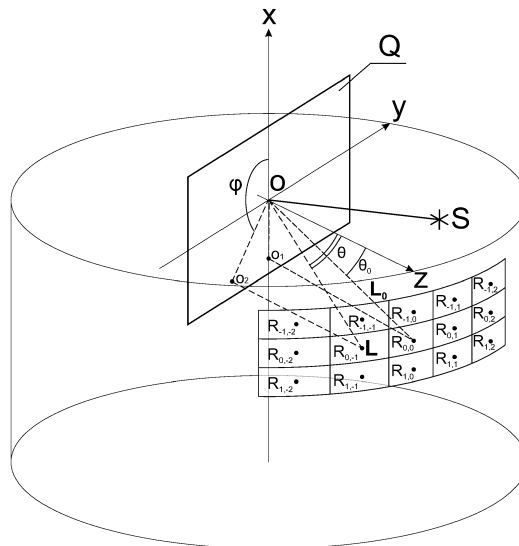


Fig. 1

EP 3 842 252 A1

Description

[0001] The claimed microoptical system for forming 3D images belongs to the field of optical security technologies, mainly to the so-called security tags used to authenticate banknotes, documents, passports, IDs, plastic cards, securities, and brands. Optical technologies allow both visual and instrumental control of the authenticity of optical security elements (Optical Document Security, Third Edition, Rudolf L. Van Renesse. Artech House, Boston, London, 2005). Devices for automated control of security elements have been developed (Eurasian patent for the method and device EA018419 (B1)). Of greatest interest are visual security features. Synthesis technologies for 2D, 2D-3D and 3D security holograms have been developed (Optical Document Security, Third Edition, Rudolf L. Van Renesse. Artech House, Boston, London, 2005).

[0002] Optical elements for the formation of 3D images were first used to protect VISA plastic cards against counterfeit back in 1984. The 3D dove holographic image of the hologram still adorns VISA plastic cards. Today, this hologram can hardly be called protective. Below we formulate the basic requirements to optical security elements for visual inspection.

- (1) The visual security feature should be easy to identify.
- (2) The optical element must be reliably protected from copying and counterfeit.
- (3) The optical element must allow mass replication.
- (4) The manufacturing technology of the original of optical security element should not be widely used.

[0003] The claimed microoptical system for forming a 3D image in the zero diffraction order meets all of the above requirements. The claimed invention uses multilevel kinoforms to form 3D images. Similar technical solutions are employed in patent EA018164(B1). In that patent, a flat optical element forms two 2D images when illuminated with white light. Images are controlled in the normal position of the optical element and when turned by 180°. Any optically recorded original produces identical images when observed at 0° and 180° turn angles. The use of multilevel kinoforms in invention EA018164(B1) ensures that images at 0° and 180° appear different. Such a visual feature is easy to control. In contrast to patent EA018164(B1), the claimed invention uses multilevel kinoforms to form a 3D image in the zero diffraction order.

[0004] The closest technical solution to the claimed invention by the combination of features (the prototype) is the "Optical variable security device" microoptical system (patent application US20070268536A1). This patent proposes a method of analog optical recording of optical security elements. To implement the method, 3D object must be created that is illuminated by coherent diffuse light. The interference pattern of the reference and scattered beam is recorded on a holographic photographic plate. Thus, the prototype uses analog optical technology to record the original optical security element. The technology of analog optical recording of holograms is widespread. Thus, for example, the hologram on a VISA card mentioned above is also recorded using optical technology. Optical recording equipment is relatively inexpensive. The main disadvantage of such holographic elements is their poor protection against counterfeit. In prototype the 3D image is formed in the first diffraction order, whereas in the claimed microoptical system it is formed in the zero diffraction order.

[0005] The aim of the present invention is to enhance the protective function of the tools used to authenticate banknotes, documents, passports, IDs, plastic cards, securities, and brands, and to reduce the availability of manufacturing technologies used to produce these security features. The task is solved by developing microoptical systems in the form of single-layer diffractive optical elements for the formation of 3D images in the zero diffraction order.

[0006] Unlike the prototype, the claimed invention uses the technology of computer synthesis of optical security features. Multilevel kinoforms are used to produce 3D images. The optical security element is a flat phase element whose microrelief forms a 3D image when the optical element is illuminated with white light. The accuracy of microrelief manufacture in terms of depth is 10 nm. For the manufacture of microrelief, electron beam lithography is used, which is knowledge intensive and not widespread.

[0007] In accordance with claim 1, a method for the synthesis of microoptical systems for the formation of 3D images in the zero diffraction order is described. The microoptical system is a single-layer reflective diffractive optical phase element. To synthesize an optical element, a 3D computer model is developed and 2D black-and-white frames K_n , $n=1\dots N$, and observing angles (φ_n, θ_n) are specified at which the observer sees frames K_n of the 3D image. The diffractive optical element is subdivided into elementary rectangular hogels G_{ij} , $i=1\dots L$, $j=1\dots M$, centered at the points (x_i, y_j) and with a size of no more than 100 μm . Each hogel G_{ij} is subdivided into two regions $G_{ij}^{(1)}$ and $G_{ij}^{(2)}$. Regions $G_{ij}^{(1)}$ are used to accommodate kinoforms forming a 3D image. For kinoforms in regions $G_{ij}^{(1)}$, the radiation patterns are formed as N rays emerging from the hogel G_{ij} at angles (φ_n, θ_n) , $n=1\dots N$, such that the beam intensity at an angle (φ_n, θ_n) is characterized by the brightness of the point with coordinates (x_i, y_j) of the n -th frame. The angles (φ_n, θ_n) specify the direction toward the point from which frame K_n is observed, $n=1\dots N$. The radiation pattern is used to compute the phase function of the multilevel kinoform $\Phi_{ij}(x, y)$, and multilevel kinoforms are produced in the regions $G_{ij}^{(1)}$. The regions $G_{ij}^{(2)}$ are partially or completely filled with diffraction gratings of different orientations with periods from 0.4 to 0.7 microns. When an optical element is illuminated with white light at diffraction angles of less than 60°, the observer sees different

frames of the 3D image K_n , $n=1...N$, at different angles (φ_n, θ_n) , and at diffraction angles greater than 60° , the observer sees another color image over the entire area of the optical element.

[0008] Claim 2 describes a microoptical system for generating 3D images in the zero diffraction order formed in accordance with the method described in claim 1. The microoptical system is a single-layer relief metallized phase reflecting diffractive optical element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods from 0.4 to 0.7 μm and of fragments of multilevel kinoforms such that the depth of the microrelief of the kinoform in each hogel G_{ij} , $i=1...L$, $j=1...M$ is given by the formula $h_{ij}(x,y) = \frac{1}{2}\Phi_{ij}(x,y)$.

[0009] Claim 3 describes a microoptical system for generating 3D images in the zero diffraction order formed in accordance with the method described in claim 1. The microoptical system is a single-layer relief partially demetallized reflective diffractive optical phase element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods from 0.4 to 0.7 μm and of fragments of multilevel kinoforms such that the depth of the microrelief of the kinoform of each hogel G_{ij} , $i=1...L$, $j=1...M$, is given by the formula $h_{ij}(x,y) = \frac{1}{2}\Phi_{ij}(x,y)$.

[0010] Claim 4 describes a microoptical system for generating 3D images in the zero diffraction order as described formed in accordance with the method described in claim 1. The microoptical system is a single-layer relief transparent reflective diffractive optical phase element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods from 0.4 to 0.7 μm and of fragments of multilevel kinoforms, such that the microrelief depth of the kinoform in each hogel G_{ij} , $i=1...L$, $j=1...M$, is given by the formula $h_{ij}(x,y) = \frac{1}{2}\Phi_{ij}(x,y)$.

[0011] The microoptical system described in claims 2-4 of the claims, produced in the form of hot stamping foil, holographic threads, stickers, laminates is designed to protect banknotes, documents, passports, IDs, plastic cards, securities, and brands.

[0012] The central point of the claimed invention is the use of flat optical phase elements - kinoforms. Each relief flat optical phase element is characterized by its phase function, and vice versa, given the phase function, one can calculate the microrelief of a flat phase optical element.

[0013] Let a flat optical element be located in the plane $z = 0$. The wave field $u(x,y,0-0)$ before the optical element and the wave field $u(x,y,0+0)$ after reflection from the optical element are related as follows:

$$u(x,y,0+0) = u(x,y,0-0) \cdot T(x,y). \quad (1)$$

[0014] The complex function $T(x,y)$ is the transfer function of a flat optical element. If $|T(x,y)| = 1$, then we call it a phase element. For a flat optical element, $T(x,y) = \exp(ik\Phi(x,y))$. The real function $\Phi(x,y)$ is called the phase function of a flat optical element. Computing the phase function $\Phi(x,y)$ of the optical element forming the given image $F(x,y)$ is a classical problem of flat optics. Scalar wave functions in the planes $z = 0$ and $z = f$ are known (Computer Optics & Computer Holography by A.V. Goncharsky, A.A. Goncharsky, Moscow University Press, Moscow, 2004) to be related by the following formula:

$$u(x,y,f) = \gamma \iint_G u(\xi,\eta,0-0) \exp(ik\Phi(\xi,\eta)) \exp\{ik \frac{(x-\xi)^2 + (y-\eta)^2}{2f}\} d\xi d\eta.$$

(2)

[0015] Here (ξ, η) are the Cartesian coordinates in the plane of the optical element, (x, y) are the Cartesian coordinates

in the focal plane $z=f$, $\gamma = \frac{k}{2\pi f}$, $k = \frac{2\pi}{\lambda}$, G is the region of the optical element, and f is the distance from the optical element to the focal plane. A distinguishing feature of the inverse problems considered is that in equation (1) we do not know the function $u(x,y,f)$, but only its modulus $|u(x,y,f)| = F(x,y)$. Thus the inverse problem reduces to determining the function $\Phi(x,y)$ from the equation

$$A\Phi = \left| \gamma \iint_G u(\xi,\eta,0-0) \exp(ik\Phi(\xi,\eta)) \exp\{ik \frac{(x-\xi)^2 + (y-\eta)^2}{2f}\} d\xi d\eta \right| = F(x,y). \quad (3)$$

[0016] Equation (2) is a nonlinear integral equation. Given function $F(x,y)$, it is necessary to find the phase function $\Phi(\xi,\eta)$. Efficient iterative methods were developed for solving the nonlinear equation (3). One of the most efficient methods for solving this problem was proposed in (L.B. Lesem, P.M. Hirsch, J.A. Jr. Jordan, The kinoform: a new wavefront

reconstruction device, IBM J. Res. Dev., 13 (1969), 105-155). The iterative method proposed by Lesem is known (Computer Optics & Computer Holography by A.V. Goncharsky, A.A. Goncharsky, Moscow University Press, Moscow, 2004) to have the following property. Let $\Phi_{n-1}(\xi, \eta)$ and $\Phi_n(\xi, \eta)$ be the values of function Φ at the $n-1$ and n -th iterations, respectively. Then the inequality

$$\|A\Phi_n - F\|^2 \leq \|A\Phi_{n-1} - F\|^2 \quad (4)$$

holds. Here $\|A\Phi_n - F\|^2$ and $\|A\Phi_{n-1} - F\|^2$ are the standard deviations of $A\Phi_n$ and $A\Phi_{n-1}$ from F , respectively. This property of the iterative process is called relaxation. The iterative Lesem's method described above allows one to compute the microrelief of an optical phase element given image $F(x, y)$. Such flat optical phase elements with microrelief depth not exceeding the wavelength are called multilevel kinoforms (A. Goncharsky, A. Goncharsky, and S. Durlevich, "Diffractive optical element with asymmetric microrelief for creating visual security features," Opt. Express 23, 29184-29192 (2015).). Multilevel kinoforms have high diffraction efficiency, but require sophisticated manufacturing techniques to produce. In the claimed invention, precision electron-beam technology (Computer Optics & Computer Holography by A.V. Goncharsky, A.A. Goncharsky, Moscow University Press, Moscow, 2004) is used to form the multilevel microrelief.

[0017] The claimed microoptical system forms a new security feature for visual control - a 3D image that is visible to the observer in the zero diffraction order. The invention is illustrated by images, where Fig. 1 shows the formation scheme of 3D images; Fig. 2 shows a diagram for observing a 3D image visible to an observer at small diffraction angles; Fig. 3 shows a diagram for observing a 2D color image visible to an observer at large diffraction angles; Fig. 4 presents a computer-generated 3D model of the object; Fig. 5 shows a fragment of a sequence of 2D frames visible to the observer from different angles; Fig 6 shows a diagram of the partition of the region of a microoptical element into hogels G_{ij} ; Fig. 7 shows a variant of subdividing hogel G_{ij} into two regions $G^{(1)}_{ij}$ and $G^{(2)}_{ij}$; Fig. 8 shows the optical scheme for calculating the radiation pattern of the region $G^{(1)}_{ij}$ of each hogel G_{ij} ; Fig. 9 shows an example of the radiation pattern of hogel region $G^{(1)}_{ij}$; Fig. 10 shows a scheme for computing the phase function in hogel region $G^{(1)}_{ij}$; Fig. 11 shows a fragment of the microrelief of a multilevel kinoform; in Fig. 12 shows a variant of the hogel structure; and Fig. 13 shows an example of a 2D color image that is visible to an observer over the entire region of the microoptical element at large diffraction angles.

Fig. 1 shows the scheme of the formation of a 3D image by a flat reflective optical phase element. Fig. 1 shows a fragment of observing points (three horizontal rows with five points in each row). The centers of the observing points are indicated by the letters R. For optical elements forming a 3D image in the zero order, the number of frames is several hundreds. The optical element is located in the plane $Z = 0$. The radiation source S is located in the Oxz plane of the Cartesian coordinate system. The source is at an angle θ_0 to the Oz axis. The direction toward the zero order is denoted as Lo . The observer sees different 2D frames of a 3D image at different angles φ, θ . Here φ, θ are the angles in a spherical coordinate system. The angle θ is measured from the axis Oz , and φ is the azimuthal angle. Ray L in Fig. 1 is directed toward one of the observing points and has angular coordinates φ, θ . Let us assume that the angles (φ_n, θ_n) specify the directions toward the observing point of frame K_n , $n = 1 \dots N$.

Fig. 2 shows the observing scheme in the Oxz plane for small diffraction angles. The diffraction angle β in this case is $\beta = \theta - \theta_0$. A 3D image is observed at diffraction angles of less than 60° in the zero diffraction order. The angle θ_0 between the radiation source S and the normal to the plane of the optical element, which coincides with the Oz axis in the diagram, determines the zero-order diffraction by beam Lo .

Fig. 3 shows the observing scheme for a 2D image at large diffraction angles greater than 60° . When the optical element is tilted by angle α around the Oy axis then in the case of large diffraction angles $\beta = \theta - \theta_0$ the observer sees in place of the 3D image another 2D color image. The normal to the optical element in this case does not coincide with the Oz axis and is indicated by the dotted line.

The claimed method for forming 3D images allows the use of various 3D models. We chose a maximally simple 3D object to simplify the demonstration of the method for calculating the phase function of the diffractive optical element. Fig. 4 shows a 3D computer model of the object, which consists of the edges of a regular quadrangular pyramid. The edges are painted black.

Fig. 5 shows a fragment of 2D frames of a 3D object. Fig. 6 shows the scheme of the partition of an optical element into hogels - elementary regions G_{ij} . The size of the hogel does not exceed 100 microns, which is beyond the resolution of the human eye. Fig. 7 shows a variant of the scheme for partitioning a hogel into regions $G^{(1)}_{ij}$ and $G^{(2)}_{ij}$, which are colored in white and gray, respectively.

Fig. 8 shows the scheme of the formation of the radiation pattern of region $G^{(1)}_{ij}$ located in hogel G_{ij} . All rays emerging from the center of the hogel toward all observing points R participate in the formation of the radiation pattern. The number of rays coincides with the number of 2D frames of the 3D image and amounts to several hundreds. Let us denote the frames as K_n , $n=1 \dots N$. The beam intensity L_n in the direction (φ_n, θ_n) for each n , $n=1 \dots N$, is determined as follows. All images in frames K_n , $n=1 \dots N$ are monochromatic. The brightness of the point (x_i, y_j) in frame K_n is

measured in grayscale. The beam intensity L_n corresponds to the brightness of the point (x_i, y_i) on each frame K_n , that is, if the observer's eye is at a vantage point at angles (φ_n, θ_n) , then the region G_{ij} is visible as a point whose brightness corresponds to the brightness of the corresponding point (x_i, y_i) in frame K_n . As is evident from Fig. 8, the intersection point of the 1st, 2nd and 3rd planes is in the image in the frames, and the corresponding point in the intersection with the 4th plane is located in the background. The size of the hogel is not more than 100 microns and the eye sees this hogel as a point.

The radiation pattern of region $G^{(1)}_{ij}$ of each hogel is a set of N rays L_n emerging from the center of region $G^{(1)}_{ij}$ at the observing point of all 2D frames of the 3D image. Each ray L_n has a given intensity. By determining the intersection points of the rays L_n with the focal plane $z = f$ and setting the brightness at these points equal to the intensity of the rays L_n , we form the function $F(x, y)$ in equation (2). The parameter f can be set equal to the distance from the observer's eye to the optical element. The function $F(x, y)$ is an image consisting of N points of different intensities. Fig. 9 shows three functions $F(x, y)$ computed for regions $G^{(1)}_{ij}$ of three different hogels. The total number of hogels can amount to several hundred thousand. The function $F(x, y)$ is computed for region $G^{(1)}_{ij}$ of each hogel G_{ij} . The inverse problem (3) - (4) is then solved and the phase function $\Phi_{ij}(x, y)$, is determined for the region $G^{(1)}_{ij}$ of each hogel. The phase function is computed by equations (3) and (4) for the green wavelength $\lambda = 547$ nm. The microrelief depth $h_{ij}(x, y)$ of the optical element is uniquely determined by setting its phase function $\Phi_{ij}(x, y)$. Fig. 10 shows the scheme for computing the phase function in the hogel region $G^{(1)}_{ij}$. The hogel is located in the region G_{ij} in the $Z = 0$ plane. In the $Z = f$ plane the grayscale image $F(x, y)$ is located. For reflective optical elements with incidence angles close to normal the microrelief depth is determined by the formula $h_{ij}(x, y) = \frac{1}{2}\Phi_{ij}(x, y)$. Thus, the claim proposes a method for computing the phase function $F(x, y)$ of microoptical systems that form 3D images around the zero diffraction order. Given the phase function, a multilevel optical element can be manufactured that implements the method according to claim 1 (Computer Optics & Computer Holography by A.V. Goncharsky, A.A. Goncharsky, Moscow University Press, Moscow, 2004).

Fig. 11 shows a fragment of the microrelief of a multilevel kinoform in one of the hogels. The hogel size is less than 100 microns and the microrelief depth does not exceed 0.5λ .

Fig. 12 shows a variant of the structure of the hogel. Here, the region of multilevel kinoform occupies the region $G^{(1)}_{ij}$ of the hogel. In Fig. 12 the depth of the microrelief of the kinoform is proportional to the degree of darkening in the region $G^{(1)}_{ij}$. The remaining hogel area $G^{(2)}_{ij}$ is partially or completely filled with fragments of diffraction gratings of various periods and orientations, forming another 2D color image visible to the observer at large diffraction angles greater than 60° when illuminated with white light. Fig. 13 shows a variant of such a color image in false colors. Black and gray colors correspond to red and green, respectively, at a certain angle of inclination of the optical element.

[0018] The claimed microoptical system for forming 3D images uses multilevel kinoforms. The main difference between the claimed microoptical system from that proposed in patent EA018164(B1) is that in the claimed invention a 3D rather than 2D image is formed. The claimed microoptical system for forming 3D images in the zero diffraction order has the following differences from the prototype US20070268536A1.

(1) In the known microoptical system (the prototype), a 3D image is formed in the first diffraction order. In the claimed microoptical system such an image is formed in the zero diffraction order.

(2) Unlike the prototype, which uses optical recording of the original, in the claimed invention the microoptical system is computer-synthesized. The optical element consists of fragments of multilevel kinoforms. A method is proposed for computing the microrelief of an optical element forming a given 3D image.

(3) Controlled visual feature includes the control of a 3D image at low diffraction angles and the control of a 2D color image at large diffraction angles.

(4) For the formation of microrelief the claimed invention uses precision electron beam lithography. This technology is not common, it is not widely available. All this allows the range of technologies to be narrowed down that make it possible to produce the claimed microoptical systems, thereby ensuring their reliable protection against counterfeit.

(5) The technology of mass replication of the claimed microoptical systems is easily available and ensures low cost of microoptical systems in the case of mass replication.

[0019] The following example of a specific implementation of the invention confirms that it can be worked without limiting its scope.

[0020] To provide an example, the original of a microoptical system for the formation of 3D images in the zero diffraction order was computed and manufactured. A 3D image consists of the edges of a regular quadrangular pyramid. The microoptical system is a 28×28 mm² flat reflective optical phase element. The original of the flat reflective optical element was synthesized using electron beam technology.

[0021] Multilevel kinoforms were used for the formation of 3D images. A 28×28 mm² flat optical element was subdivided into elementary regions - 70×70 μm² sized hogels G_{ij} , $i=1 \dots L$, $j=1 \dots M$ as in Fig. 6. The total number of hogels

was 160000. Regions $G_{ij}^{(1)}$ containing kinoforms were $50 \times 50 \mu\text{m}^2$ squares in the centers of the hogels. The rest area of the hogels ($G_{ij}^{(2)}$ regions) was filled by gratings with grating frequencies $0.4 \mu\text{m}$ and $0.5 \mu\text{m}$. The number of frames N was 825 (55 frames in a row $\times$ 15 rows). The microrelief of the flat optical element in regions $G_{ij}^{(1)}$ was computed in each hogel at a given wavelength $\lambda = 547 \text{ nm}$. To compute the phase function in the $G_{ij}^{(1)}$ region of each hogel, a 500×500 grid was used to solve inverse problem (2) - (3). The phase function $\Phi_{ij}(x, y)$ for $G_{ij}^{(1)}$ region, $i=1 \dots L$, $j=1 \dots M$, of each hogel can be computed with a common personal computer.

[0022] To manufacture the microrelief of the microoptical system, an electron beam lithography system with a resolution of $0.1 \mu\text{m}$ was used, which corresponds to a resolution of 254000 dpi. A positive electron resist was used to record the microstructures of the microoptical system. Further the original master shim of diffractive optical element was made using standard electroforming process. The master shim was used to produce microoptical systems in the form of metallized and transparent stickers using standard equipment for the production of embossed holograms. To manufacture transparent stickers, transparent material with a high reflection coefficient was used. At diffraction angles smaller than 60° the observer sees 3D image in the zero diffraction order. At diffraction angles greater than 60° the observer sees another 2D color image formed by gratings as shown in Fig. 13. The microrelief was computed for the wavelength of $\lambda = 547 \text{ nm}$, which corresponds to green light, however, even when illuminated with white light, the quality of the images so formed remains good. For testing, mobile phone flashlight was used as a point source of white light. The testing of the manufactured samples demonstrated the high efficiency of the technical solutions proposed in the application.

[0023] The microoptical system as per claims 2-4 made in the form of hot stamping foil, holographic threads or stickers, is meant to protect banknotes, documents, passports, IDs, plastic cards, securities, and brands.

Claims

1. The method of synthesis of microoptical systems for forming 3D images in the zero diffraction order distinctive in that the microoptical system is a single-layer reflective diffractive optical phase element whose synthesis involves the formation of a 3D computer model and setting black and white 2D frames K_n , $n=1 \dots N$ and the viewing angles (φ_n, θ_n) at which the observer sees frames K_n of the 3D image; the diffractive optical element is partitioned into rectangular hogels G_{ij} , $i=1 \dots L$, $j=1 \dots M$ with the sizes no greater than 100 microns and centered at the points (x_i, y_j) , with each hogel G_{ij} partitioned into two regions $G_{ij}^{(1)}$ and $G_{ij}^{(2)}$, with regions $G_{ij}^{(1)}$ used to accommodate kinoforms forming a 3D image; the radiation patterns are formed in regions $G_{ij}^{(1)}$ represented by N rays emerging from the hogel G_{ij} at angles (φ_n, θ_n) , $n=1 \dots N$, so that the beam intensity at an angle (φ_n, θ_n) is equal to the brightness of the point with coordinates (x_i, y_j) in the n -th frame, the radiation pattern is used to compute the phase function $\Phi_{ij}(x, y)$ of the multilevel kinoform and produce the multilevel kinoform in regions $G_{ij}^{(1)}$, whereas the region $G_{ij}^{(2)}$ is partially or completely filled with diffraction gratings of various orientations with periods ranging from 0.4 to $0.7 \mu\text{m}$; when the optical element is illuminated with white light at diffraction angles smaller than 60° the observer sees different frames K_n , $n=1 \dots N$ of the 3D image at different angles (φ_n, θ_n) , and at diffraction angles greater than 60° the observer sees a different color image over the entire area of the optical element.
2. The microoptical system formed by the method according to claim 1 for generating 3D images in the zero diffraction order, which is a single-layer relief metallized reflective diffractive optical phase element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods ranging from 0.4 to $0.7 \mu\text{m}$ and fragments of multilevel kinoforms, with the kinoform microrelief depth in each hogel G_{ij} , $i=1 \dots L$, $j=1 \dots M$ determined by the formula $h_{ij}(x, y) = \frac{1}{2} \Phi_{ij}(x, y)$.
3. The microoptical system formed by the method according to claim 1 for generating 3D images in the zero diffraction order, which is a single-layer relief partially demetallized reflective diffractive optical phase element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods ranging from 0.4 to $0.7 \mu\text{m}$ and fragments of multilevel kinoforms, with the kinoform microrelief depth in each hogel G_{ij} , $i=1 \dots L$, $j=1 \dots M$ determined by the formula $h_{ij}(x, y) = \frac{1}{2} \Phi_{ij}(x, y)$.
4. The microoptical system formed by the method according to claim 1 for generating 3D images in the zero diffraction order, which is a single-layer relief transparent reflective diffractive optical phase element on a detachable or non-detachable polymer base, consisting of fragments of diffraction gratings with periods ranging from 0.4 to $0.7 \mu\text{m}$ and fragments of multilevel kinoforms, with the kinoform microrelief depth in each hogel G_{ij} , $i=1 \dots L$, $j=1 \dots M$ determined by the formula $h_{ij}(x, y) = \frac{1}{2} \Phi_{ij}(x, y)$.
5. Microoptical system according to claims 2-4 made in the form of hot stamping foil, holographic threads, stickers, laminates is designed to protect banknotes, documents, passports, IDs, plastic cards, securities, and brands.

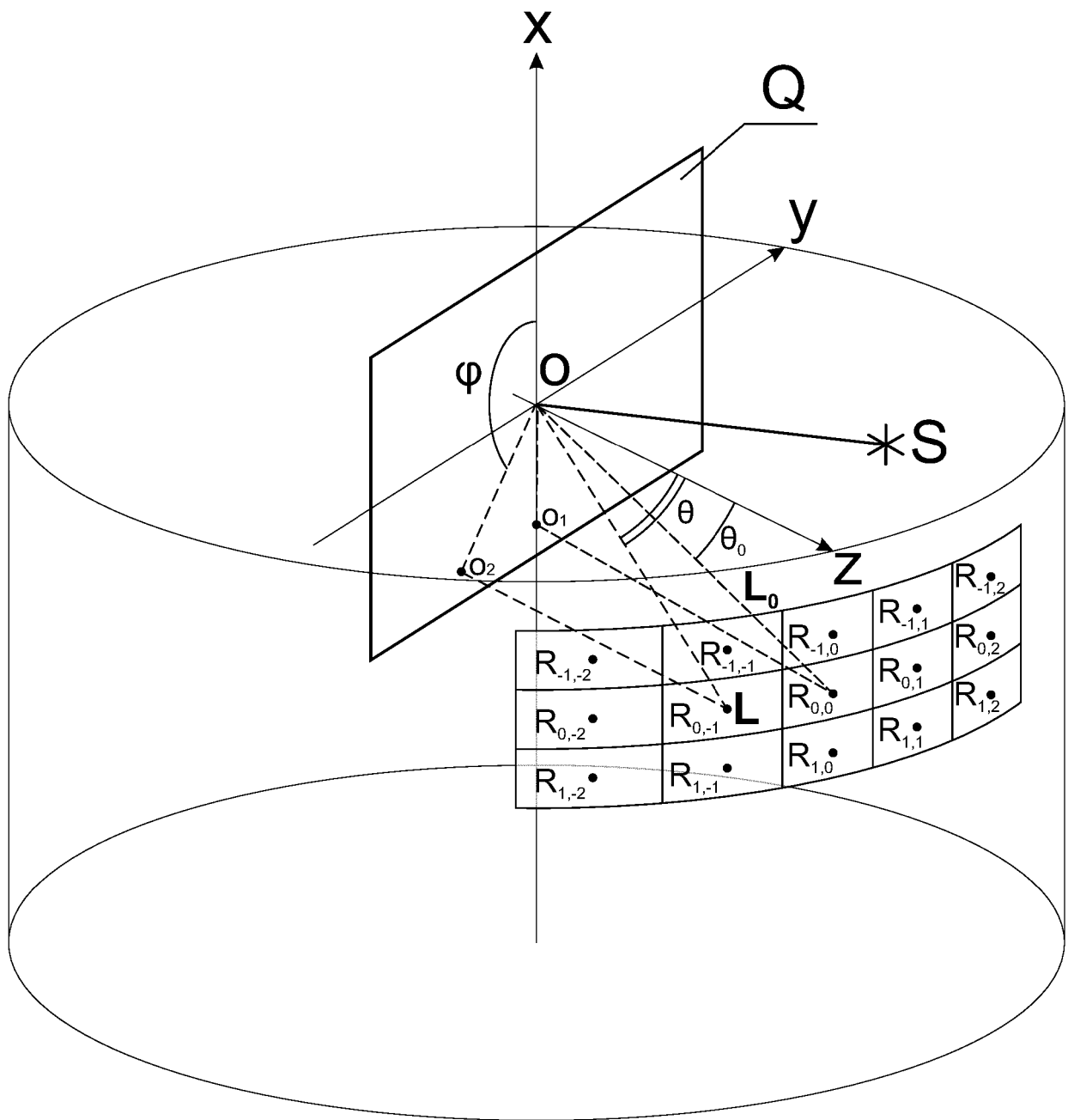


Fig. 1

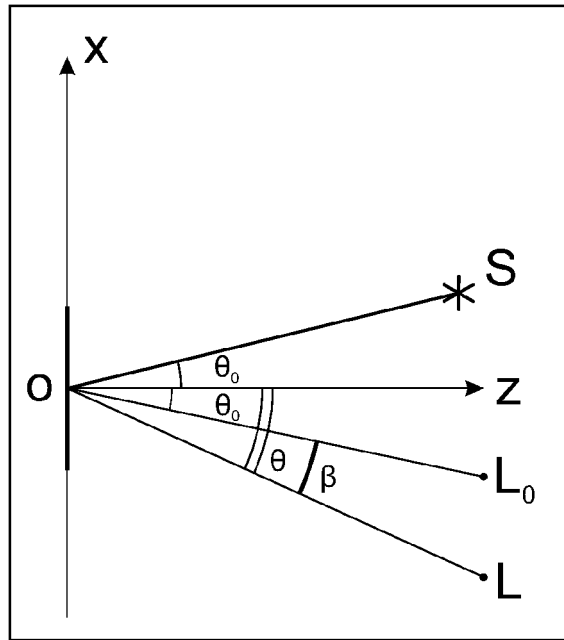


Fig. 2

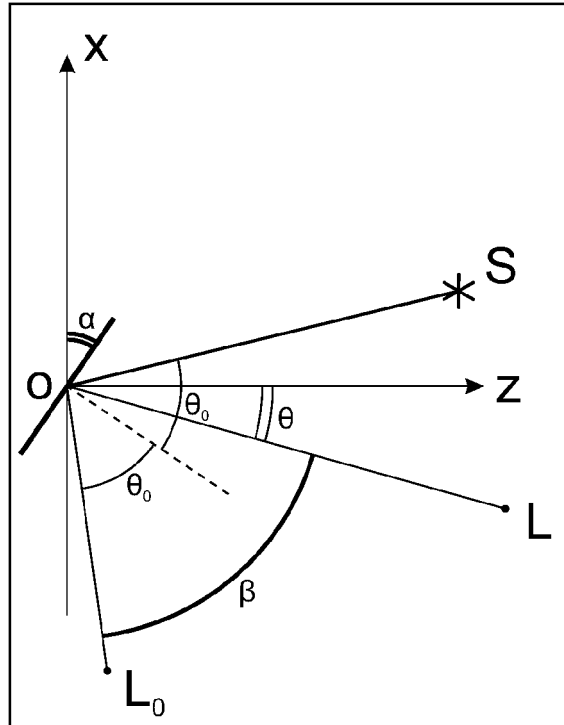


Fig. 3

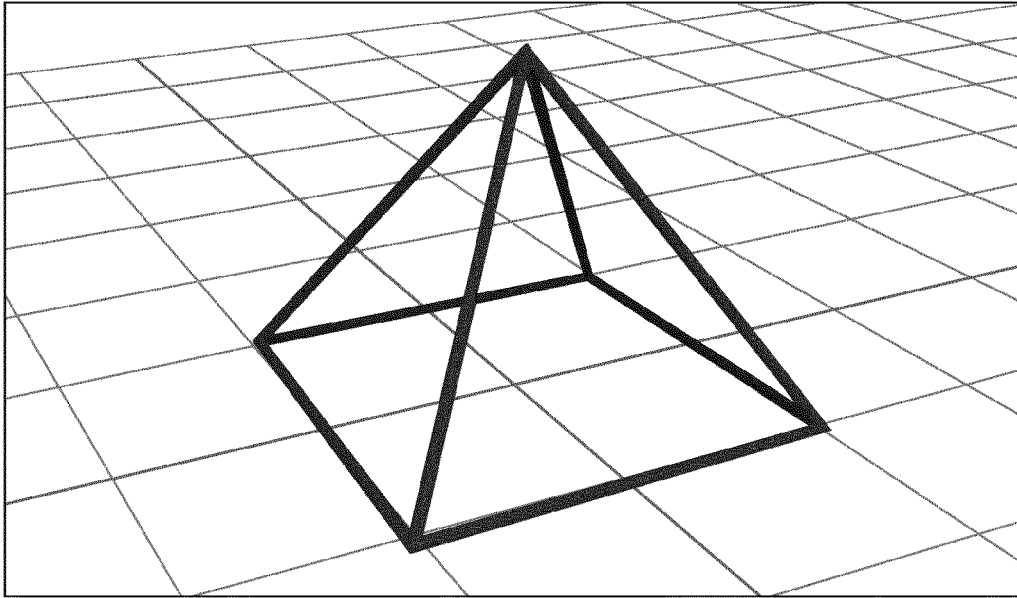


Fig. 4

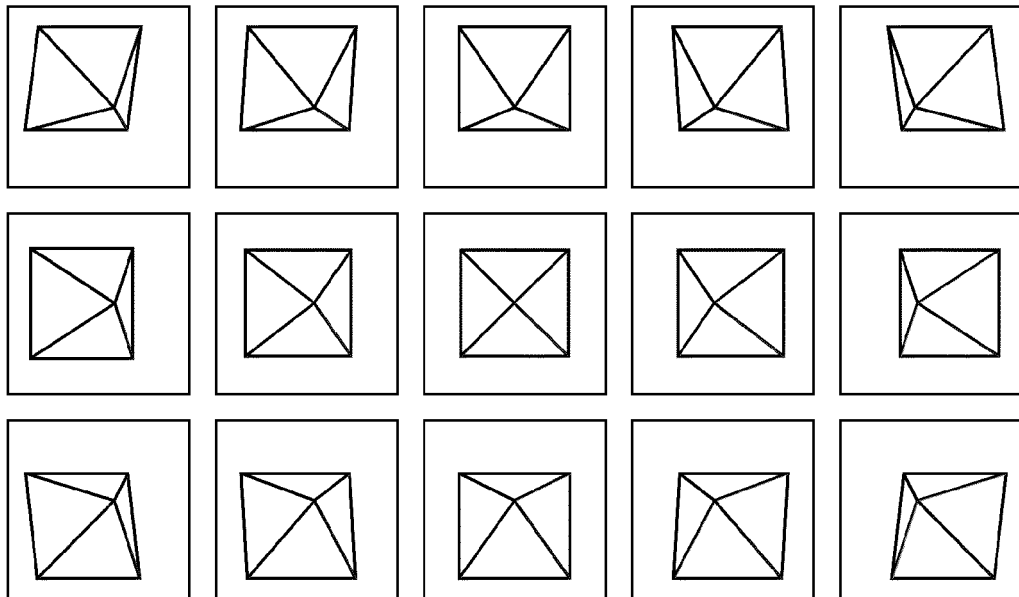


Fig. 5

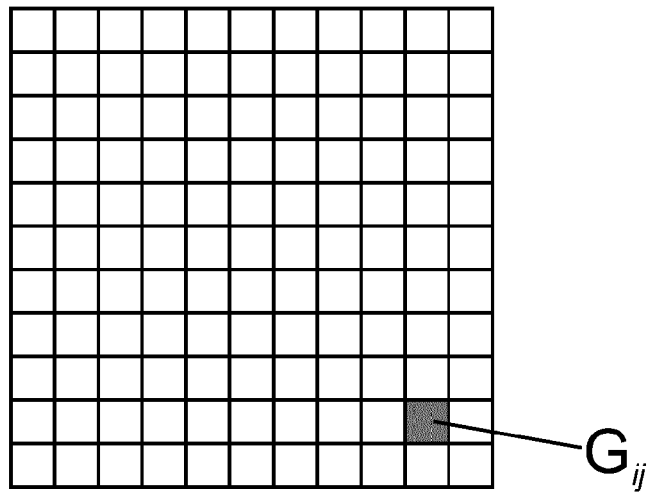


Fig. 6

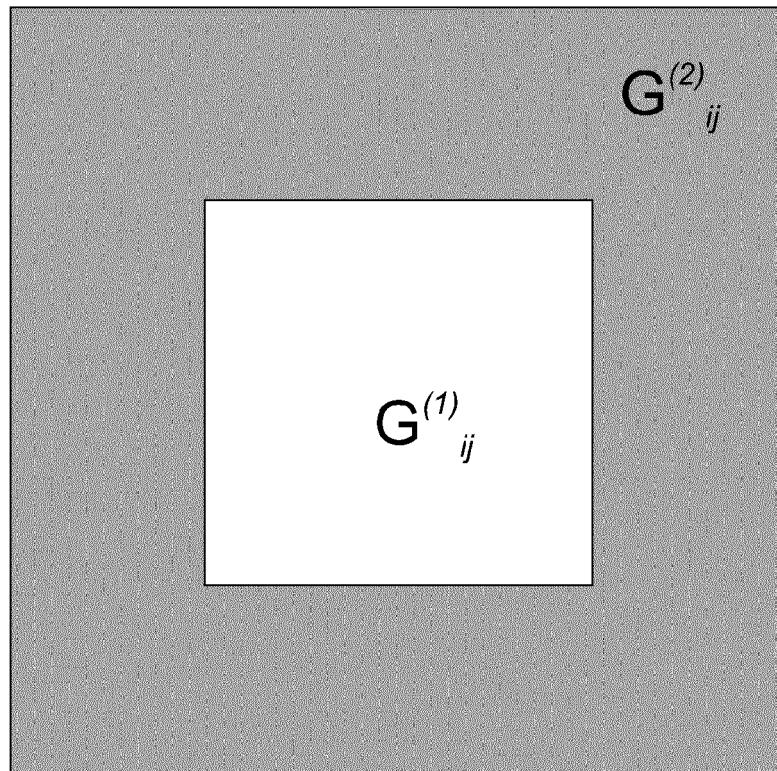


Fig. 7

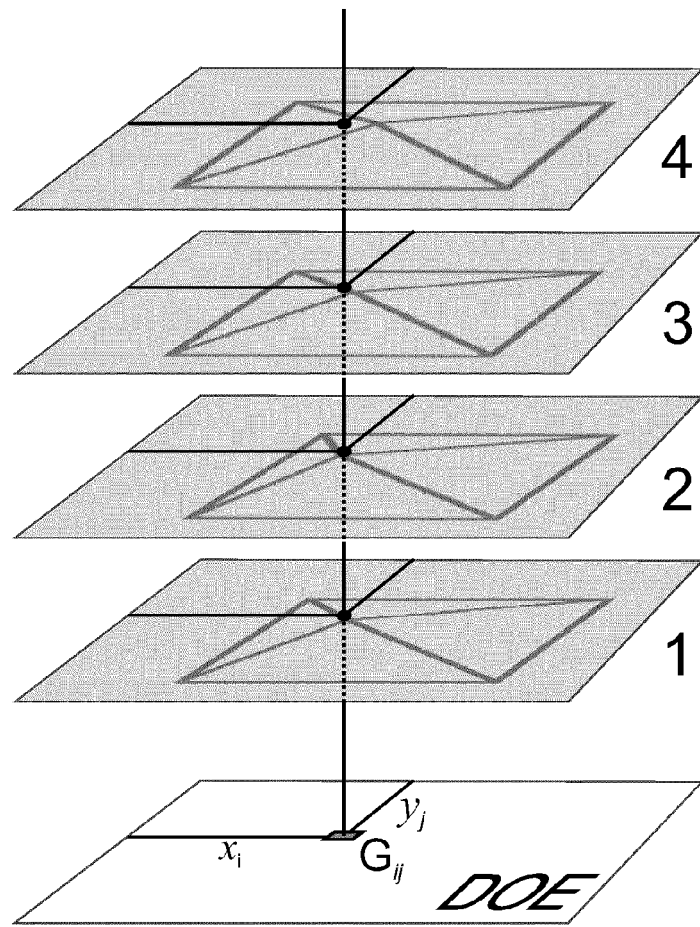


Fig. 8

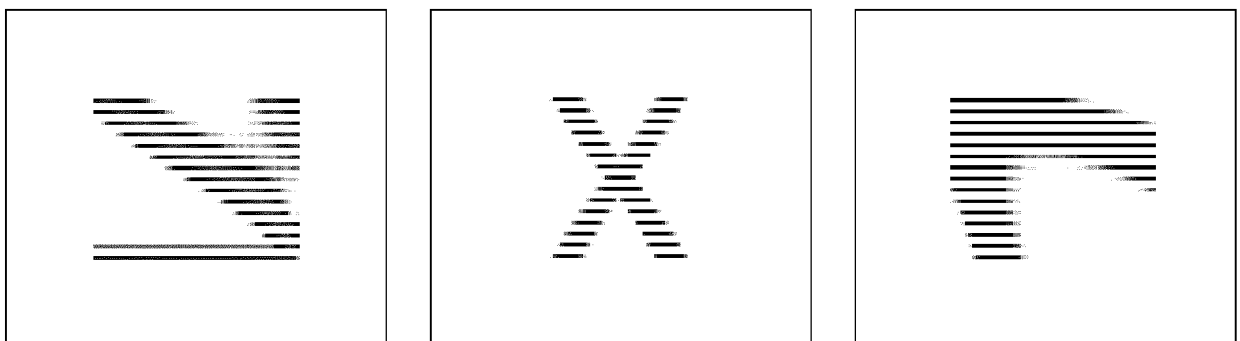


Fig. 9

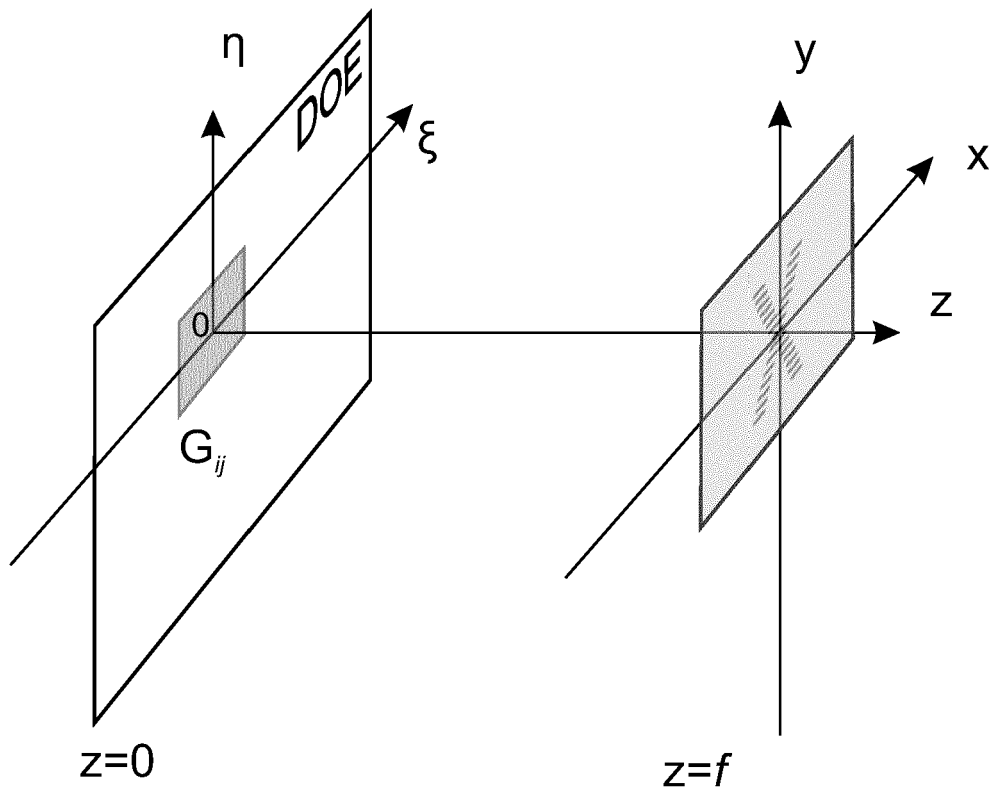


Fig. 10

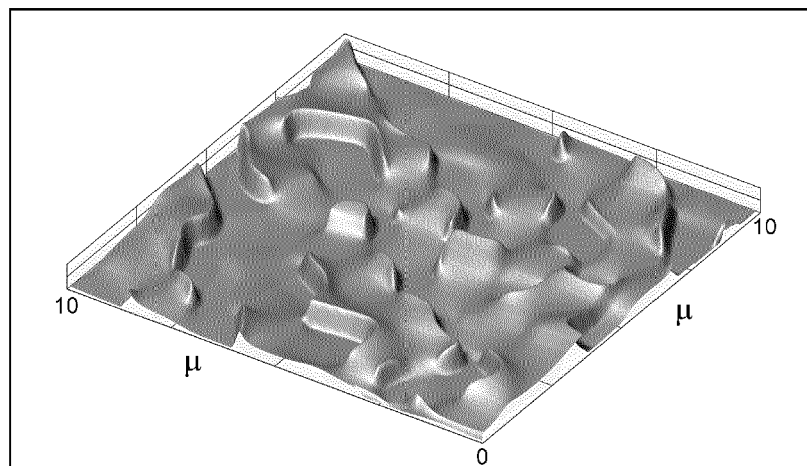


Fig. 11

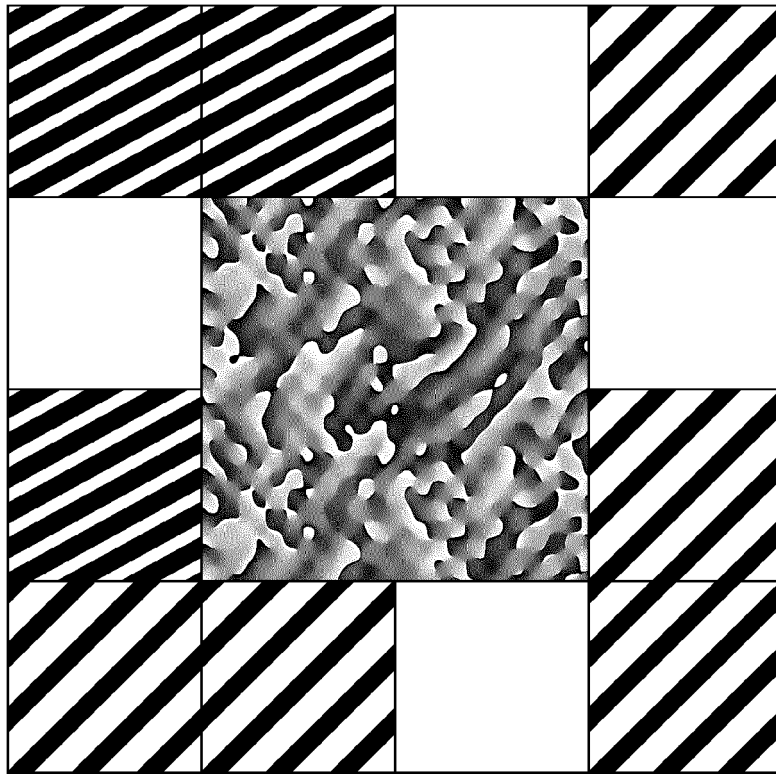


Fig. 12

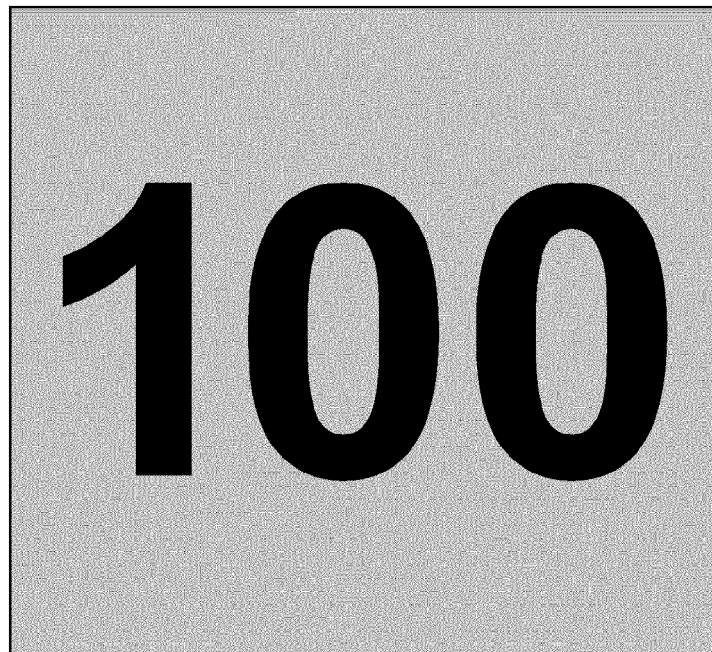


Fig. 13



EUROPEAN SEARCH REPORT

Application Number
EP 19 21 9414

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EA 2017 00161 A1 (LLC COMPUTER HOLOGRAPHY CENTRE [RU]) 28 February 2018 (2018-02-28) * claim 1 *	1-5	INV. B42D25/328
A	RU 190 048 U1 (CENT COMPUTER HOLOGRAPHY LLC) 17 June 2019 (2019-06-17) * paragraph [0009]; figure 3 *	1	
			TECHNICAL FIELDS SEARCHED (IPC)
			B42D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 17 March 2020	Examiner Langbroek, Arjen
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

 1
EPO FORM 1503 03.82 (P04C01)

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EP 19 21 9414

5

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17-03-2020

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EA 201700161	A1	28-02-2018	NONE

RU 190048	U1	17-06-2019	NONE

15

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Patent documents cited in the description

- EA 018419 B1 [0001]
- EA 018164 B1 [0003] [0018]
- US 20070268536 A1 [0004] [0018]

Non-patent literature cited in the description

- **RUDOLF L. VAN RENESSE**. Optical Document Security. Artech House, 2005 [0001]
- **A.V. GONCHARSKY ; A.A. GONCHARSKY**. Computer Optics & Computer Holography. Moscow University Press, 2004 [0014] [0016] [0017]
- **L.B.LESEM ; P.M.HIRSCH ; J.A.JR. JORDAN**. The kinoform: a new wavefront reconstruction device. *IBM J. Res. Dev.*, 1969, vol. 13, 105-155 [0016]
- Diffractive optical element with asymmetric microrelief for creating visual security features. **A. GONCHARSKY ; A. GONCHARSKY ; S. DURLEVICH**. *Opt. Express*. 2015, vol. 23, 29184-29192 [0016]