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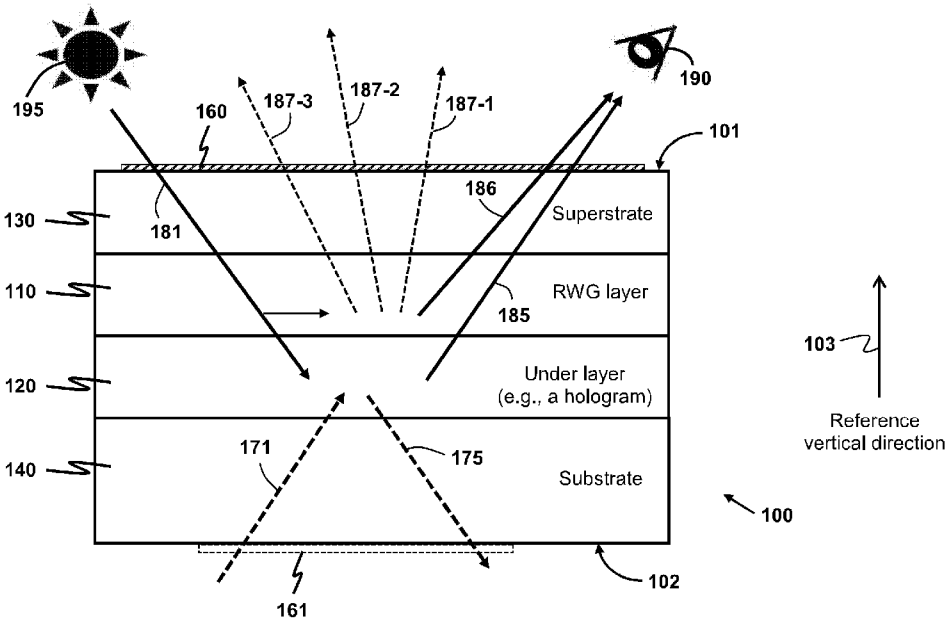


FIG.1

(57) Abstract: A multilayered optical security device (100) has a resonant waveguide grating (RWG) layer (110) on an under layer (120) having a hologram. The RWG layer (110) has plural RWGs (601-625) for generating one or more patterns. Each RWG (601-625) has the first and second RWG portions (301, 302), with diffraction gratings (320, 330) of different grating periods, for light coupling-in and coupling-out, respectively. Using the RWGs (601-625) minimizes interference to a holographic image generated by the under layer (120). This advantage is especially useful when the holographic image carries digital data such as in digital holographic encryption where an encrypted hologram is used in the under layer (120). The digital data may contain biometric information such as a fingerprint. In each RWG portion (301, 302) of an individual RWG (601-625), scattering elements (321, 331) in a grating (320, 330) are curved to thereby enhance an angular tolerance in azimuthal angle during observing the patterns by an observer while the individual RWG

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(601-625) is still selective in elevation angle.

Multilayered Optical Security Device

LIST OF ABBREVIATIONS

[0001] RWG Resonant waveguide grating

[0002] SRG Surface relief grating

FIELD OF THE INVENTION

[0003] The present disclosuregenerally relates to an optical security device having a multilayered structure for displaying an imageand one or more patterns. In particular, the present disclosure relates to such device having a RWG layer positioned above an under layer, whereby using the RWG layer avoids interfering the image, allowing substantially distortion-free transmission of the image from the under layer to an observer. The image may be a holographic image or even a holographically encrypted image.

BACKGROUND

[0004] A security hologram is often used as an anti-counterfeiting means for proving authenticity of an object attached with the security hologram. The security hologram and other optical security components have an advantage of being unaffected by electromagnetic-interference tampering and digital-data tampering. To enhance security, multiple security features may be embedded in an optical security device for enabling a person to verify authenticity of an object independently from different features. Furthermore, the features may offer multiple levels of security. For instance, some of the features are meaningful images visually verifiable by a human user, such as company logos, for achieving a normal security level, while remaining features are optical images carrying encrypted digital data recognizable by a specialized machine for achieving a high level of security. Incorporating multiple security features at different levels of security to the optical security device is challenging.

[0005] US 8,848,266 discloses a security element implemented as a multilayered film body for providing multiple security features. The security element has a volume hologram layer, in which a volume hologram is recorded, for providing a first optically variable information item. The security element has a replication layer, in the surface of which a SRG providing a second optically variable information item is molded and which is arranged above the volume hologram layer. However, the holographic image generated from the

volume hologram is interfered by the SRG, potentially modifying the holographic image when the holographic image is seen by an observer.

[0006] There is a need in the art for an optical security device implemented with a multilayered structure for providing multiple security features while reducing or avoiding interference introduced from one layer to another.

SUMMARY OF THE INVENTION

[0007] An aspect of the present disclosure is to provide a multilayered optical security device for displaying an image and one or more patterns.

[0008] The multilayered optical security device comprises an aperture, an under layer and a RWG layer. The aperture is arranged to face an observer such that the one or more patterns are viewable to the observer through the aperture. The aperture defines a top side of the device. The under layer, located below the top side, is used for generating the imageupon the under layer being illuminated. The RWG layer is located between the top side and the under layer. The RWG layer comprises a plurality of RWGs configured to generate the one or more patterns upon illuminated with an incident light beam received through the aperture. An individual RWG comprises a first diffraction grating and a seconddiffraction grating. The first and second diffraction gratings are attached to the waveguide. An individual diffraction grating has a grating period. The grating period is selected such that a first light beam having a preselected wavelength and a preselected propagation direction resonates with the individual RWG under the selected grating period,causing the first light beam to couple in or out of the individual RWG. Furthermore, this RWG structure becomesalmost transparent to a second light beam that is out of resonance,and allows the propagation of the second light beam without distortion, thus avoiding interference to the second light beam during the second light beam propagating through the individual RWG. It allows the incident light beam to transmit through the RWG layer to illuminate the under layer. It also avoids the RWG layer to interfere the image during transmission from the under layer to the aperture.

[0009] Preferably, the individual RWG comprises first and second RWG portions coupled together. The first RWG portion has the first diffraction grating, and the second RWG portion has the second diffraction grating. The first and second diffraction gratings have different grating periods for setting different resonance conditions for the first and second RWG portions such that the individual RWG filters a received portion of the incident light beam and generates an outgoing light beam having a predictable wavelength and leaving the individual RWG at a predictable exit angle from the RWG layer.

[0010] The respective diffraction grating of an individual RWG portion comprises one or two periodic arrangements of scattering elements. Preferably, an individual scattering element has a curved shape to thereby enhance an angular tolerance in observing the one or more patterns by the observer. The individual scattering element may be semi-circular, semi-elliptical or arc-shaped.

[0011] In certain embodiments, the first and second RWG portions are coupled together by sharing a common waveguide. The first RWG portion may be separated from the second RWG portion by a distance. Alternatively, the first and second RWG portions may be immediately adjacent to each other, and a first diffraction grating of the first RWG portion may touch a second diffraction grating of the second RWG portion.

[0012] Preferably, the waveguide and the two diffraction gratings of the individual RWG are dimensioned to provide single-mode optical propagation.

[0013] In certain embodiments, the plurality of RWGs is substantially-uniformly distributed over the RWG layer.

[0014] In certain embodiments, the device further comprises a polymer superstrate covering the RWG layer for isolating the RWG layer from the top side to thereby protect the RWG layer.

[0015] In certain embodiments, the device further comprises a substrate underneath the under layer for providing mechanical support to the under layer and the RWG layer. The substrate may be formed of a soft material, allowing the device to be flexible.

[0016] In certain embodiments, the under layer includes a hologram such that the image generated by the under layer is a holographic image. The holographic imagemay include one or more holographically encrypted images. In certain embodiments, at least one holographically encrypted image is embedded with biometric information data.

[0017] In certain embodiments, the under layer is formed with a phase-only hologram.

[0018] If the one or more patterns consist of a first number of plural patterns, the plurality of RWGs may be partitioned into the first number of subsets, where an individual subset of RWGs is used to create a respective pattern. Respective RWGs among different subsets of RWGs may be interlaced.

[0019] In certain embodiments, the device further comprises an additional aperture located on a bottom side opposite to the top side for viewing the image.

[0020] Other aspects of the present disclosure are disclosed as illustrated by the embodiments hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** depicts a multilayered optical security device in accordance with an exemplary embodiment of the present disclosure.

[0022] FIG. **2**depicts an exemplary RWG layer used in the disclosed device, where the RWG layer is formed with a plurality of RWGs, each RWG having first and second RWG portions coupled together preferably with different grating periods, the first and second RWG portions being used for light coupling-in and coupling-out, respectively.

[0023] FIG. **3**depicts three embodiments of the RWG.

[0024] FIG. **4**depicts simulation results of intensity distribution of light coupled-out of the RWG against elevation angle and azimuthal angle for demonstrating an advantage of offering greater angular tolerance in pattern observation by an observer by using an arc-shaped RWG over a linear RWG.

[0025] FIG. **5**depicts, for illustration purpose, a scheme of embedding a dedicated pattern into the RWG layer.

[0026] FIG. **6**shows experimental results demonstrating minimal interference introduced by RWGs to light beams and holographic images in comparison to SRGs.

[0027] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DETAILED DESCRIPTION

[0028] As used herein in the specification and appended claims, the term “avoid” or “avoiding” refers to any method to partially or completely preclude, avert, obviate, forestall, stop, hinder or delay the consequence or phenomenon following the term “avoid” or “avoiding” from happening. The term “avoid” or “avoiding” does not mean that it is necessarily absolute, but rather effective for providing some degree of avoidance or prevention or amelioration of consequence or phenomenon following the term “avoid” or “avoiding”.

[0029] A hologram is a physical recording of an interference pattern which uses diffraction to reproduce a three-dimensional light field, resulting in a holographic image that retains the depth, parallax, and other properties of the original scene. As used herein, “a holographic image” is an image generated by a hologram. A holographic image may be a two- or three-dimensional image. The holographic image can be used as a security feature.

[0030] As used herein, “a pattern” is a two-dimensional image. Examples of a pattern include a two-dimensional design, a visually-recognizable mark, a line-art picture, etc. The

line-art picture may have a solid background or a transparent background. The pattern can also be used as a security feature.

[0031] Occasionally, "elevation angle" and "azimuthal angle" are used in describing a pointing direction from a reference point on an optical security device to an observer of a pattern or an image such as a holographic image. The pointing direction is also related to a viewing direction of the observer. In simple words, the elevation angle is related to the up-down viewing direction of the observer while the azimuthal angle is related to the viewing direction projected on the horizontal plane.

[0032] Disclosed herein is a multilayered optical security device having a multilayered structure for displaying an image and one or more patterns.Herein in the present disclosure, the aforesaid image and an individual pattern are regarded as two different entities. The image is a general image, and may be a natural image, an artificial image, a two-dimensional image, a three-dimensional image (such as a holographic image), etc. The multilayered structure has a RWG layer onan under layer such that the imagegenerated by the under layer is required to pass through the RWG layer. As demonstrated hereinafter, using the RWG layer has a useful advantage of avoiding interfering the image, allowing substantially distortion-free transmission of the image from the under layer to an observer to be achievable. This advantage is especially useful if the imagecarries digital data.

[0033] The disclosed multilayered optical security device is illustrated with the aid of FIG. **1**, which depicts an exemplary multilayered optical security device **100**.

[0034] In the device **100**, various layers are allowed to be illuminated by an incident light beam **181** arrived through an aperture **160** for producing an image and one or more patterns. The aperture **160**generally means an opening for allowing light to pass through, and may simply be a transparent window. The aperture **160** also allows various light beams **186**, **187-1:3** carrying the one or more patterns to pass through such that the one or more patterns are viewable by an observer **190**. The image mayor may notbe viewable through the aperture **160** depending on different realizations of the device **100**. If the image is viewable through the aperture **160**, the image is carried by a light beam **185**. The observer **190** means an object for receiving the one or more patterns and optionally the image. The observer **190** may be, for example, a human observer, an imaging sensor, or a specialized machine for imagingand decoding the image and one or more patterns. The light beams **186**, **187-1:3**propagate in different directions for angularly multiplexing the one or more patterns. Note that the aperture **160** is arranged to face the observer **190**. Furthermore, the aperture **160** defines a top side **101**and a bottom side **102**of the device **100**. The aperture **160** is located on the top

side **101**. The bottom side **102** is opposite to the top side **101**. A reference vertical direction **103** is defined as a pointing direction from the bottom side **102** to the top side **101**. Herein in the specification and appended claims, positional and directional words such as "above," "below," "higher," "upper," "lower," "top," "bottom" and "horizontal" are interpreted with reference to the reference vertical direction **103**.

[0035] The device **100** comprises a RWG layer **110** and an under layer **120**. The under layer **120** is located below the top side **101** while the RWG layer **110** is located between the top side **101** and the under layer **120**.

[0036] The under layer **120** generates the imagewhen the under layer **120** is illuminated.Of particular importance to security applications, the under layer **120** may contain a hologram such that the image generated by the under layer **120** is a holographic image. Structural details and manufacturing methods of the hologram can be found in the art, e.g., in US 6,141,123. Hereinafter various advantages of the disclosed device **100** are elaborated by considering the specific case that the under layer **120** includes the hologram for generating the holographic image. The advantages carry over to any general image unless otherwise stated.

[0037] Apart from illuminating the under layer **120** from the incident light beam **181** arrived from the aperture **160** located on the top side **101**, it is possible that the hologram of the under layer **120**is intended to be illuminated by a second incident light beam **171**traveled from the bottom side **102**to the under layer **120**through an optional additional aperture **161**. Besides being reflective, the hologram may be transmissive. Hence, the holographic image generated by the hologram may travel towards the top side **101** (e.g., carried by the light beam **185**) or towards the bottom side **102** (e.g., carried by a light beam **175**). Hereinafter the advantages of the disclosed device **100** are elaborated by assuming that the under layer **120** is illuminated from the top side **101** and the holographic image travels from the under layer **120** towards the top side **101**. The advantages carry over to other combinations of illumination direction and holographic-image traveling direction.

[0038] The RWG layer **110** is used for generating the one or more patterns while allowing a portion of the incident light beam **181** to pass through to reach the under layer **120**. FIG. **2** depicts a schematic showing an exemplary construction of the RWG layer **110**. The RWG layer **110** comprises a plurality of RWGs **601-625**configured to generate the one or more patterns upon illuminated. Note that although 25 RWGs **601-625**arranged in a rectangular array are shown in FIG. **2** for illustrating the RWG layer **110**, the present disclosure is not limited to this number of RWGs and this form of arrangement, any number

of RWGs distributed over the RWG layer **110** in any manner, e.g., in a circular arrangement, may be used. The RWGs **601-625**have a similar structure. Take the RWG **617**as a representative RWG for illustration.

[0039] The RWG **617**comprises a waveguide **310**, a first diffraction grating **320**and a second diffraction grating **330**. The first and second diffraction gratings **320**, **330** areattached to the waveguide **310**. The waveguide **310**is formed by a substantially-transparent dielectric having a refractive index higher than a surrounding environment in the vicinity of the waveguide **310**. The first diffraction grating **320**is obtained by periodically arranging plural scattering elements **321**on one side or both sides of the waveguide **310**. Similarly, the second diffraction grating **330** has periodically-arranged scattering elements **331** disposed on one side or both sides of the waveguide **310**. In FIG. **2**, the first diffraction grating **320**is illustrated with two periodic arrangements of scattering elements **321**respectively located on two opposite sides of the waveguide **310**, and each of the two periodic arrangements of scattering elements **321** forms a corrugated structure. It is similar for the second diffraction grating **330**. Note that the RWG **617**has an orientation along a direction **205**. The orientation of the RWG **617**is perpendicular to the scattering elements **321**in the first diffraction grating **320**, or to the scattering elements **331** in the second diffraction grating **330**.

[0040] The first and second diffraction gratings **320**, **330** are located on different portions of the waveguide **310**. Define a first waveguide portion **311**as a first portion of the waveguide **310** on which the first diffraction grating **320** is laid. Similarly, define a second waveguide portion **312**as a second portion of the waveguide **310** on which the second diffraction grating **330** is laid. For convenience, define a first RWG portion **301** and a second RWG portion **302** as mutually non-overlapping portions of the RWG **617** such that the first RWG portion **301** has the first waveguide portion **311** and the first diffraction grating **320**, and such that the second RWG portion **302** has the second waveguide portion **312** and the second diffraction grating **330**. Note that the first and second RWG portions **301**, **302** are coupled together. In particular, the first and second waveguide portions **311**, **312** are linked together for achieving coupling.

[0041] Each of the first and second diffraction gratings**320**, **330**is characterized by a grating period, which is a separation between adjacent scattering elements. The grating period determines a resonance condition of the RWG **617**. The grating period and orientation can be selected such that an incoming light beam **380**specifically prepared to have a first preselected wavelength λ_1 and arrive at a first preselected (elevation) angle $\theta_{in}$with respect to the waveguide **310**resonates with the RWG **617**, causing the incoming light beam **380**to

couple-in the RWG **617**and propagate along the waveguide **310**in the waveguide mode as an in-waveguide light beam **383**. The grating period and orientation can also be selected such that an outgoing light beam **381**having the wavelength λ_1 and leave at a second preselected (elevation) angle θ_{out} with respect to the waveguide **310**resonates with the RWG **617**, causing the in-waveguide light beam **383**to couple out of the RWG **617**and form the outgoing light beam **381**. Mathematical formulas for determining the grating period from λ_1 and θ_{in} or θ_{out} can be found in the art, for example, in EP 3,205,512 and in G. QUARANTA, G. BASSET, O. J. F. MARTIN and B. GALLINET, "Recent Advances in Resonant Waveguide Gratings," *Lasers & Electronics Reviews*, 30 July 2018. Note that since the RWG **617**is usually used to interact with the incoming light beam **380**in the visible and near-infrared spectrum, the waveguide **310**and the first and second diffraction gratings**320**, **330**are usually dimensioned in nanoscale, and are implemented as nanostructures.

[0042] Without loss of generality and for the purpose of illustrating the disclosed device **100**, assume that the first RWG portion **301** is configured to couple-in the incoming light beam **380** and the second RWG portion **302** is configured to couple-out the in-waveguide light beam **383** to form the outgoing light beam **381**.Consider that the incoming light beam **380** (viz., a received portion of the incident light beam **181**) is incident on the first RWG portion **301** at an incident angle, viz., θ_{in}. If the wavelength and incident angle of the incoming light beam **380** meet the resonance condition of the first RWG portion **301** and if the last-mentioned wavelength satisfies the resonance condition of the second RWG portion**302**, then the first RWG portion **301** couples-in the incoming light beam **380** to form the in-waveguide light beam **383** propagating from the first waveguide portion **311** to the second waveguide portion **312**, at which the in-waveguide light beam **383** is coupled-out from the second RWG portion **302** with a predetermined exit angle, viz., θ_{out}, to form the outgoing light beam **381**.

[0043] Conversely, ifthe incoming light beam **380**does not meet any one of the resonance conditions of the first and second RWG portions **301**, **302**, the incoming light beam **380** does not interact with the RWG **617** and simply bypasses the RWG **617**to form a bypassed light beam **382**. As a result, it avoids interfering the incoming light beam **380** that is out of resonance with the RWG **617** when the incoming light beam **380** propagates through the RWG **617**.

[0044] The presence of resonance condition(s) in the RWG **617** is advantageously used in the disclosed device **100**. The incident light beam **181**, which usually has multiple spectral

contents and arrives at the device **100** from different directions, can at least partially transmit through the RWG layer **110** to illuminate the under layer **120**. Furthermore, it is difficult or almost impossible for light beams carrying the holographic image to resonate with the RWGs **601-625** of the RWG layer **110**, avoiding the RWG layer **110** to interfere the holographic image during transmission from the under layer **120** to the aperture**160**. The holographic image receives minimal or negligible interference from the RWG layer **110**. Generally, the RWG layer **110** becomes almost transparent out of resonance and allows the propagation of the holographic image without distortion. This advantage is of particular importance if the holographic image carries digital data, such as a holographically encrypted image in digital holographic encryption.(The holographically encrypted image is generated by an encrypted hologram in the under layer **120**.) Nearly distortion-free reproduction of the holographic image is required in successful decryption of the encrypted data in the holographic image. As the holographic image may be received by a machine to decode digital data embedded in the holographic image, nearly distortion-free reproduction of the holographic image increases "a channel capacity" of an optical channel between the under layer **120** and the machine, allowing more digital data to be embedded in the holographic image.

[0045] Denote the grating period of the first diffraction grating **320** as a first grating period **323**, and that of the second diffraction grating **330** as a second grating period **333**. If the first and second grating periods **323**, **333** take on the same value, the RWG **617** basically becomes a conventional RWG as described in the paper of G. QUARANTA, G. BASSET, O. J. F. MARTIN and B. GALLINET.As a result,multiple values of $\lambda_1$may induce resonance in the RWG **617** and also the values of θ_{in} or θ_{out} affect each other. This result may not be preferable in certain applications of the device **100**.

[0046] In a preferred embodiment, the first and second grating periods **323**, **333** are selected to be different in order to set the resonance condition. As a result, with a suitable choice of other RWG parameters such as the waveguide dielectric refractive index, gratings depth, etc., it becomes feasible to configure the RWG **617** to resonate at only one value of wavelength. The net effect is that the RWG **617** filters a received portion of the incident light beam **181** and generates the outgoing light beam **381** having a predictable wavelength and leaving the RWG **617** at a predictable exit angle from the RWG layer **110**.

[0047] FIG. **6**experimentally demonstrates the minimal interference introduced by RWGs to light beams and holographic images in comparison to using SRGs. In picture **710a**, a first slab implemented with a layer of RWGs is placed on a text, and a clear image of the text without noticeable distortion is seen. In picture **710b**, a second slab having a layer of SRG is

also placed on the text, but a blurred image is observed. A holographic image **750** generated by a bare hologram is used as a reference for comparing resultant holographic images **720a**, **720b** when the hologram is placed below the RWG layer and the SRG layer, respectively. It is shown that the holographic image **720a**after passing through the RWG layer is sharper and clearer than the holographic image **720b**after passing through the SRG layer.

[0048] In the device **100**, a pattern is generated from a certain plurality of RWGs in the RWG layer **110**. Respective RWGs in the aforementioned plurality of RWGs are designed to have respective values of λ_1, θ_{in} and θ_{out}. These values are obtained according to the positions of a light source **195** and the observer **190**, and also the color distribution of the pattern. Note that θ_{in} and θ_{out} are elevation angles. The positions of the light source **195** and the observer **190** also provide information on azimuthal angles thereof. Grating periods and orientations of these respective RWGs are thus determined. Generally, orientations of the respective RWGs are adjusted to align with the intended or expected azimuthal anglethat the observer **190** views the pattern.

[0049] The first and second RWG portions **301**, **302** are coupled together by setting up an optical path to link the first and second waveguide portions **311**, **312** together. Practically, the first and second RWG portions **301**, **302** are coupled together by sharing the waveguide**310**. FIG. **3**depicts two embodiments of arranging the first and second RWG portions **301**, **302** in sharing the common waveguide**310**. In a first realization **617a**of the RWG **617**, the first RWG portion**301** is separated from the second RWG portion**302**by a distance**410**, which may be chosen to be shorter or longer than lengths of the first and second RWG portions **301**, **302**. Between the first and second RWG portions **301**, **302**, there is no grating to modify the propagation of the in-waveguide light beam **383**. In a second realization **617b**of the RWG **617**, the first and second RWG portions **301**, **302** are immediately adjacent to each other, and in particular, the first diffraction grating **320** touches the second diffraction grating **330**.

[0050] As mentioned above, the first and second waveguide portions **311**, **312** have a common refractive index higher than the refractive index of surrounding environment. By taking into account the refractive index difference, preferably, the first and second waveguide portions **311**, **312** and the first and second diffraction gratings **320**, **330** are dimensioned to provide single-mode propagation along the first and second waveguide portions **311**, **312**(or the waveguide **310**) for an advantage of enhancing spectral/angular selectivity in generation of the one or more patterns.

[0051] The RWG **617**is similar to the one disclosed in EP 3,205,512. Manufacturing methods disclosed in EP 3,205,512 may be adopted to fabricate the RWG layer **110** of the disclosed device **100**.

[0052] Conventionally, the first and second diffraction gratings **320**, **330** are realized as linear gratings. A linear grating is a grating whose scattering elements are linear. A RWG using linear gratings is referred to as a linear RWG. A linear RWG has a small angular width in azimuth in generating an outgoing light beam, such that the observer **190** is easy to miss the generated pattern if the observer **190** slightly shifts his or her left-right viewing direction. As a result, the linear RWG provides a low value of angular tolerance for the observer **190** to observe the one or more patterns. The inventors have observed that if the scattering elements are made to be curved, the angular tolerance is increased.

[0053] Refer to FIG. **2**. In the RWG **617**, preferably, each of scattering elements **321**, **331** in the first and second diffraction gratings **320**, **330**has a curved shape so as to enhance an angular tolerance in observing the one or more patterns by the observer **190**. As examples, an individual scattering element may be semi-circular, semi-elliptical, or arc-shaped. FIG. **3**additionally depicts a third realization **617c** of the RWG **617** (denoted as the RWG **617c** for simplicity). The RWG **617c** has scattering elements **321**, **331** that are arc-shaped, i.e. in a shape of an incomplete ring. The RWG **617c** is referred to as an arc-shaped RWG. Note that an orientation of the RWG **617c** is given by an orientation direction **405**, obtained as a central axis of the RWG **617c** with a direction from the first RWG portion**301** (for light in-coupling) to the second RWG portion**302** (for light out-coupling).

[0054] FIG. **4**plots simulation results of intensity distribution in the far field of light coupled out from the RWG layer **110** against different elevation anglesθ and azimuthal anglesφ for a linear RWG (shown in graph **510**) and an arc-shaped RWG (shown in graph **520**). Consider regions **511** and **521** on the graphs **510** and **520**, respectively. The region **511** is a collection of (θ, φ)-pairs each giving an intensity that is at least 50% of the highest intensity for the linear RWG. The region **521**is the corresponding one for the arc-shaped RWG. It is shown that the arc-shaped RWG provides a wider range of φ under a constant θ than the linear RWG does. The result shows that the arc-shaped RWG provides a greater angular tolerance in azimuthal angle during pattern observation than the linear RWG does, but the generated pattern is still selective in elevation angle. This observation demonstrates the advantage of using curved scattering elements in forming the first and second gratings of the RWG.

[0055] FIG. **5**depicts a scheme of embedding a dedicated pattern **680** into the RWG layer **110**. Consider an example that the RWG layer **110** has an array of RWGs**601-625**. Each of the RWGs **601-625** is intended to produce an outgoing light beam in a particular direction (specified by an elevation angleθ and an azimuthal angleφ), and the outgoing light beam carries "a pixel" of the pattern **680**. For example, the RWG **611** reproduces a pixel **681**. If the RGW layer **110** is intended to produce the designated pattern **680** only, all the RWGs**601-625** are designed by determining particular grating periods and orientations of diffractiongratings and exit angles (including elevation angles and azimuthal angles) of outgoing beams such that a continuity condition of propagation vector is satisfied, that is, all pattern pixels can be seen under preselected illumination or observation angle. Multiple colors may be added to the designated pattern **680** by setting different grating periods for different RWGs**601-625**. Pattern observation at multipleazimuthal angles may be realized by varying periods and orientations of different RWGs**601-625**with respect to illumination and observation angles.

[0056] If it is desired that multiple patterns are embedded in the RWG layer **110** for display at different observation angles through angular multiplexing, and if there are a first number of such patterns to be displayed, the plurality of RWGs**601-625**may be partitioned into the first number of subsets. An individual subset of RWGsis used to create a respective pattern.

[0057] In one embodiment, respective RWGs in each subset are clustered together such that the respective RWGs in an individual subset form a contiguous region on the RWG layer **110**. For illustration, consider an example that two patterns are required to be generated. The plurality of RWGs**601-625** is divided into two subsets. The first subset has the RWGs**601-615**. The second subset consists of the RWGs**616-625**. In another embodiment, respective RWGs among different subsets of RWGs are interlaced. Consider again the aforementioned example. In one arrangement, the first subset contains the RWGs**601-605**, **611-615**, **621-625**, and the second subset has the RWGs**606-610**, **616-620**. Note that row-wise interfacing of the RWGs **601-625** is adopted in this arrangement. Similarly, column-wise interlacing may also be used. In another arrangement, RWGs that are adjacent are assigned to different subsets. For instance, the first subset contains the RWGs **601**, **603**, **605**, **607**, **609**, **611**, **613**, **615**, **617**,**619**,**621**, **623**, **625** while the second subset contains the RWGs **602**, **604**, **606**, **608**, **610**, **612**, **614**, **616**, **618**, **620**, **622**, **624**.

[0058] As mentioned above, apart from being distributed as a rectangular array, the plurality of RWGs**601-625** may be arranged in any form on the RWG layer **110**, e.g.,

arranged along one or more circles, along mesh lines, as hexagonal grids, as a chessboard, or randomly, according to resolution requirements. The plurality of RWGs**601-625** may be substantially-uniformly distributed over the RWG layer **110**, or unevenly distributed.

[0059] Other implementation details of the disclosed device **100** are illustrated as follows.

[0060] In certain embodiments, the under layer **120** is formed with a hologram such that a holographic image generated therefrom includes one or more holographically encrypted images.The under layer **120** is therefore formed with an encrypted hologram. Optionally, the under layer **120** is formed with a phase-only hologram. In certain embodiments, biometric information data, such as a fingerprint, a palm shape and a shape of vein, are embedded in at least one holographically encrypted image generated from the under layer **120**.

[0061] Methods for fabricating the under layer **120** having an encrypted hologram can be found in the art, e.g., in US 2006/0078113 and US 9,798,290. In general, a hologram that generates a holographically encrypted imageupon illuminated can be obtained by encoding an image with an encryption mask. The holographically encrypted image is decryptable by overlaying the device **100** with a specific decryption mask under illumination of a coherent light beam. The decryption mask may be put on the top side **101**, and the incident light beam **181** is formed with decryption information. After the incident light beam **181** passes through the RWG layer **110**, which advantageously avoids interfering the incident light beam **181**, coherence of the incident light beam **181** is not destroyed such that encrypted data embedded in the encrypted hologram can be successfully decrypted, thereby generating a decrypted holographic image. In one embodiment, the encrypted hologram is transmissive such that the decrypted holographic image is carried by the light beam **175** towards the bottom side **102**. An imaging sensor may be conveniently located at the bottom side **102** to receive the decrypted holographic image, which contains plain data without encryption. Note that alternatively, the decryption mask may be put on the bottom side **102** with coherent light illumination, and the imaging sensor is then put on the top side **101** for receiving the decrypted holographic image.

[0062] In certain embodiments, the device **100** further comprises a superstrate **130** covering the RWG layer **110** for isolating the RWG layer **110** from the top side **101** to thereby protect the RWG layer **110**. The superstrate **130** is transparent, and may be formed by polymer.

[0063] In certain embodiments, the device further comprises a substrate **140** underneath the under layer **120** for providing mechanical support to the under layer **120** and the RWG

layer **110**. The substrate **140** may be formed of a soft material, allowing the device to be flexible. Alternatively, it is also possible that the substrate **140** is made of a hard material.

[0064] The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A multilayered optical security device for displaying an imageand one or more patterns, the device comprising:
   an aperture arranged to face an observer such that the one or more patterns are viewable to the observer through the aperture, the aperture defining a top side of the device;
   an under layer below the top side for generating the imageupon the under layer being illuminated; and
   a resonant waveguide grating (RWG) layer located between the top side and the under layer, the RWG layer comprising a plurality of RWGs configured to generate the one or more patterns upon illuminated with an incident light beam received through the aperture, an individual RWG comprising a waveguide and first and second diffraction gratingsboth attached to the waveguide, an individual diffraction grating having a grating period, wherein the grating period is selected such that a first light beam having a preselected wavelength and a preselected propagation direction resonates with the individual RWG under the selected grating period,causing the first light beam to couple in or out of the individual RWG while avoiding interference to a second light beam that is out of resonance with the individual RWG during the second light beam propagating through the individual RWG, thereby avoiding the RWG layer to interfere the image during transmission from the under layer to the aperture.

2. The device of claim 1, wherein the individual RWG comprises first and second RWG portions coupled together, the first RWG portionhavingthe first diffraction grating, the second RWG portion having the second diffraction grating, the first and second diffraction gratings having different grating periods for setting different resonance conditions for the first and second RWG portions such that the individual RWG filters a received portion of the incident light beam and generates an outgoing light beam having a predictable wavelength and leaving the individual RWG at a predictable exit angle from the RWG layer.

3. The device of claim 1, wherein theindividual diffraction gratingcomprises one or two periodic arrangements of scattering elements, an individual scattering element having

a curved shape to thereby enhance an angular tolerance in observing the one or more patterns by the observer.

4. The device of claim 3, wherein the individual scattering element is semi-circular, semi-elliptical or arc-shaped.

5. The device of claim 2, wherein the first and second RWG portions are coupled together by sharing the waveguide.

6. The device of claim 5, wherein the first RWG portion is separated from the second RWG portion by a distance.

7. The device of claim 5, wherein a first diffraction grating of the first RWGportion touches a second diffraction grating of the second RWG portion.

8. The device of claim 1, wherein the waveguide and the two diffraction gratingsof the individual RWG are dimensioned to provide single-mode optical propagation.

9. The device of claim 1, wherein the plurality of RWGs is substantially-uniformly distributed over the RWG layer.

10. The device of claim 1 further comprising:
    a polymer superstrate covering the RWG layer for isolating the RWG layer from the top side to thereby protect the RWG layer.

11. The device of claim 1 further comprising:
    a substrate underneath the under layer for providing mechanical support to the under layer and the RWG layer.

12. The device of claim 11, wherein the substrate is formed of a soft material, allowing the device to be flexible.

13. The device of claim 1, wherein the under layer includes a hologram such that the image is a holographic image.

14. The device of claim 13, wherein the hologram is a phase-only hologram.

15. The device of claim 13, wherein the holographic imageincludes one or more holographically encrypted images.

16. The device of claim 15, wherein at least one holographically encrypted image is embedded with biometric information data.

17. The device of claim 1, wherein the one or more patterns consist of a first number of plural patterns, and wherein the plurality of RWGs is partitioned into the first number of subsets, an individual subset of RWGs being used to create a respective pattern.

18. The device of claim 17, wherein respective RWGsamong different subsets of RWGsare interlaced.

19. The device of claim 1 further comprising:

an additional aperture located on a bottom side opposite to the top side for viewing the image.

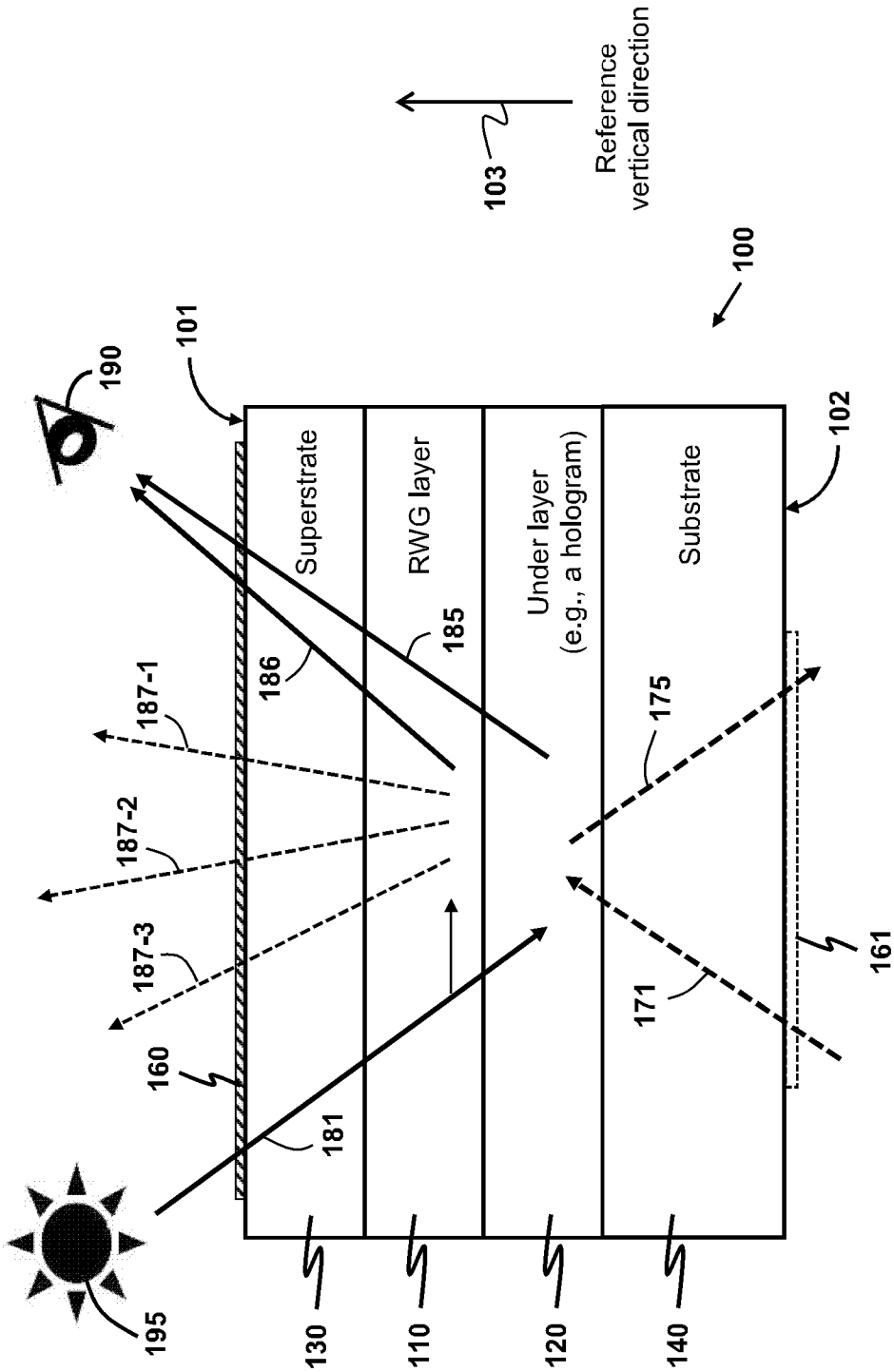

Reference vertical direction
103
100
101
190
Superstrate
RWG layer
Under layer (e.g., a hologram)
Substrate
102
186
185
187-1
187-2
187-3
175
160
181
171
161
195
130
110
120
140

FIG.1

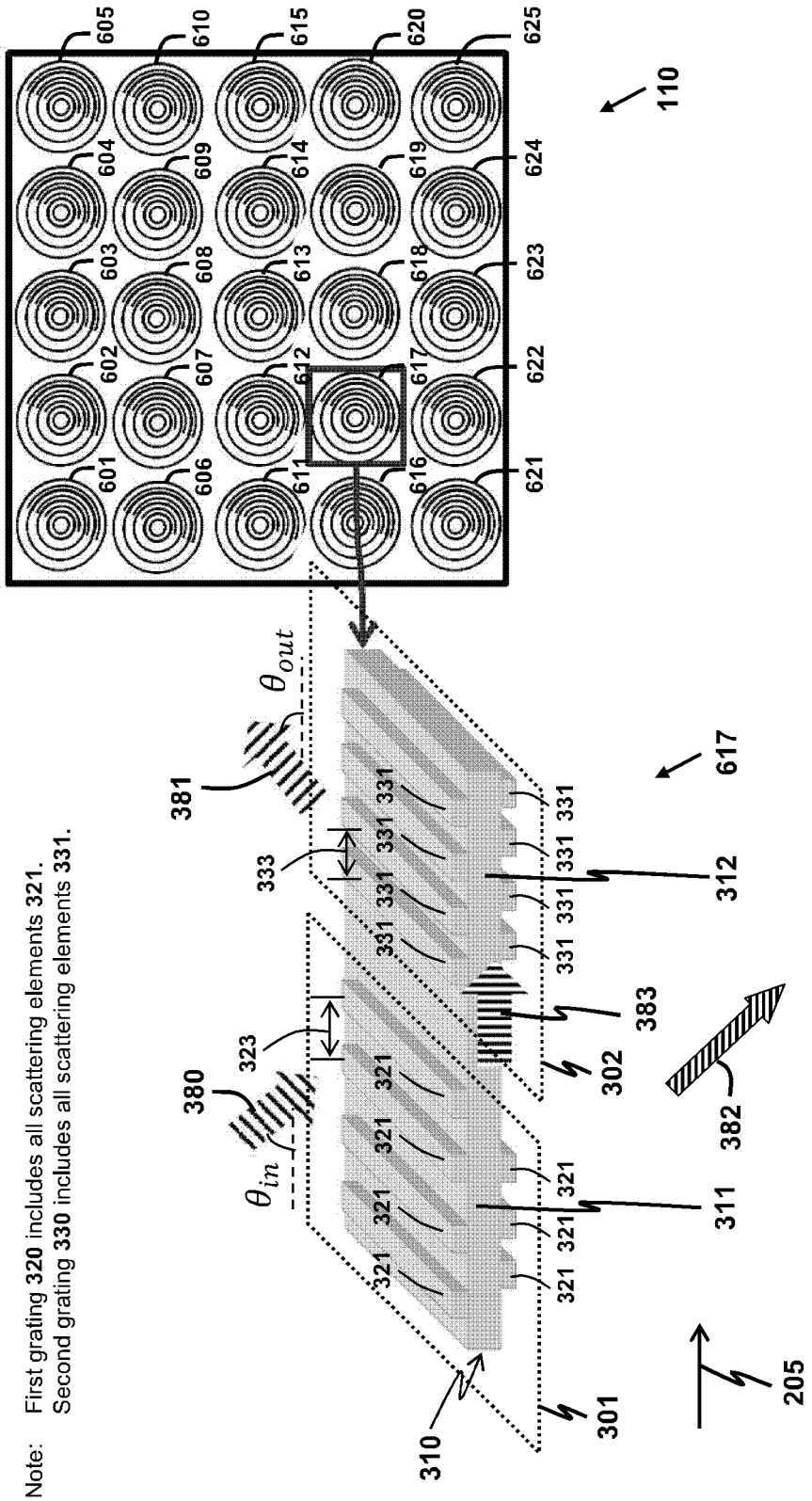

605
610
615
620
625
604
609
614
619
624
603
608
613
618
623
602
607
612
617
622
601
606
611
616
621
110
θ_{out}
381
333
331
312
617
383
302
380
323
321
θ_{in}
382
311
310
301
205
Note: First grating 320 includes all scattering elements 321.
Second grating 330 includes all scattering elements 331.

FIG.2

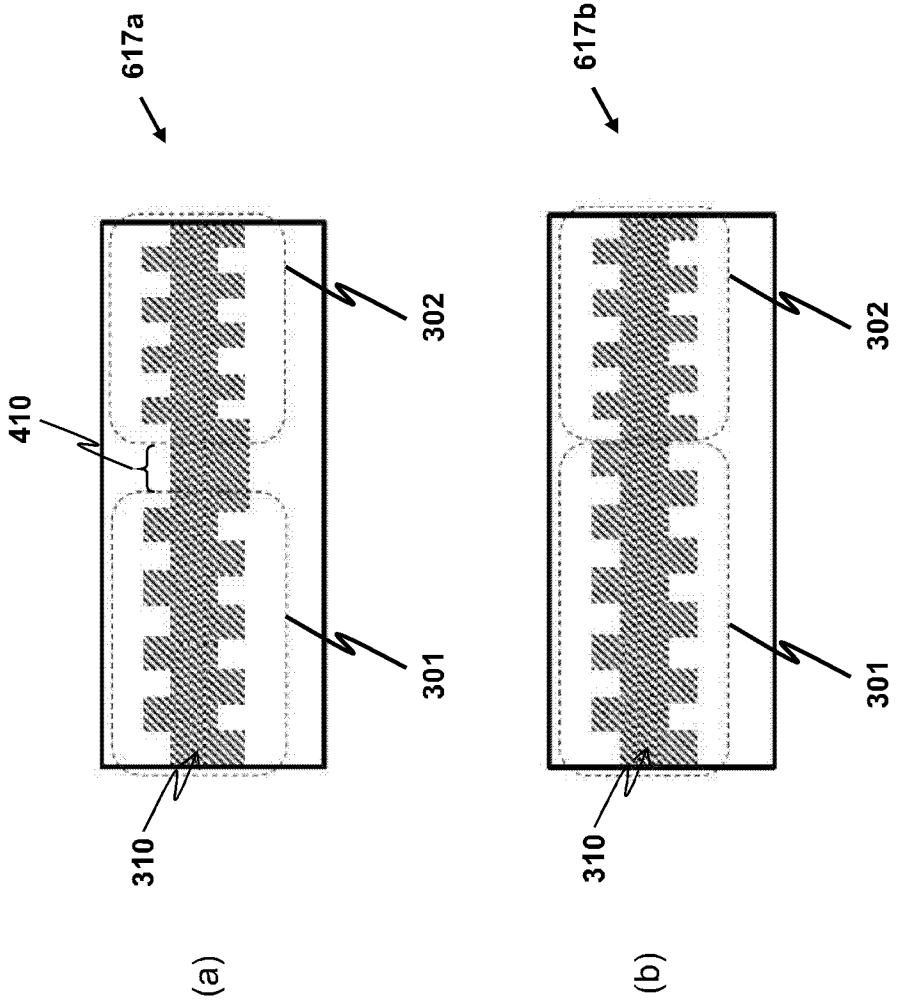


FIG.3

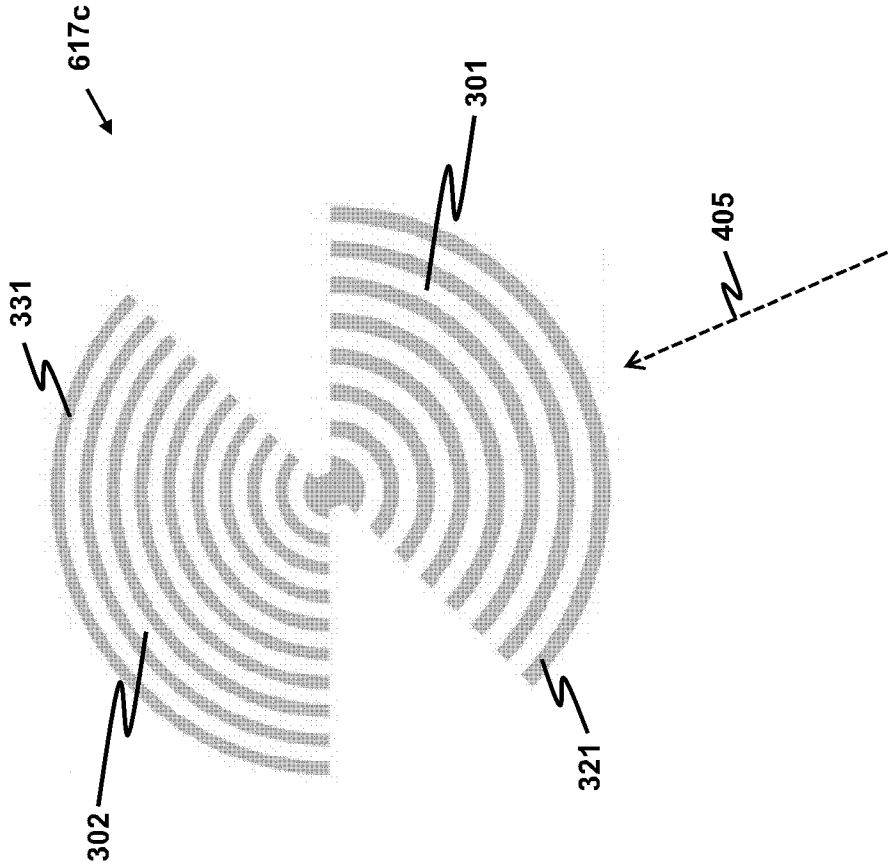


FIG.3 (cont.)

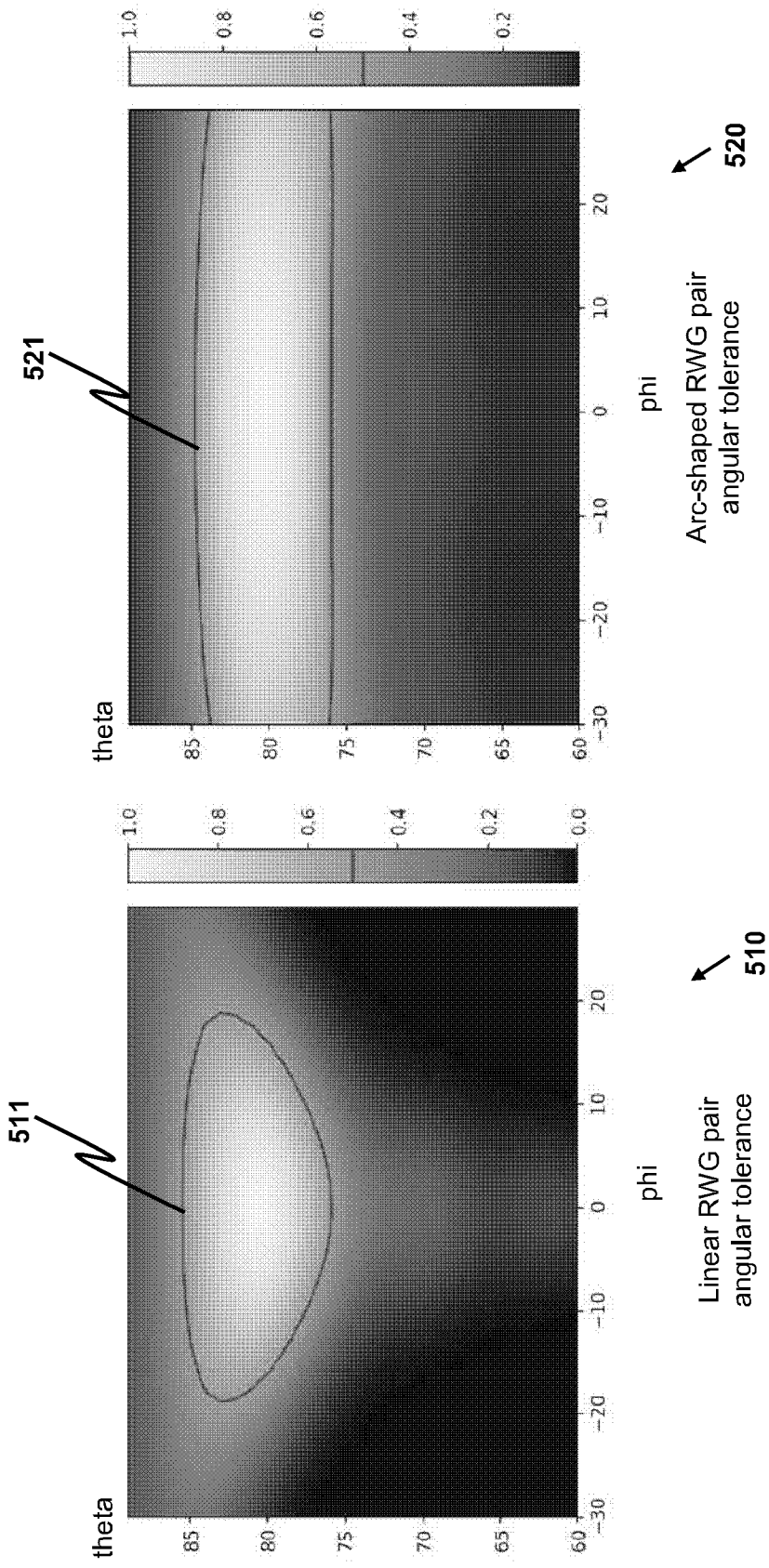

511
theta
phi
Linear RWG pair
angular tolerance
510
521
theta
phi
Arc-shaped RWG pair
angular tolerance
520

FIG.4

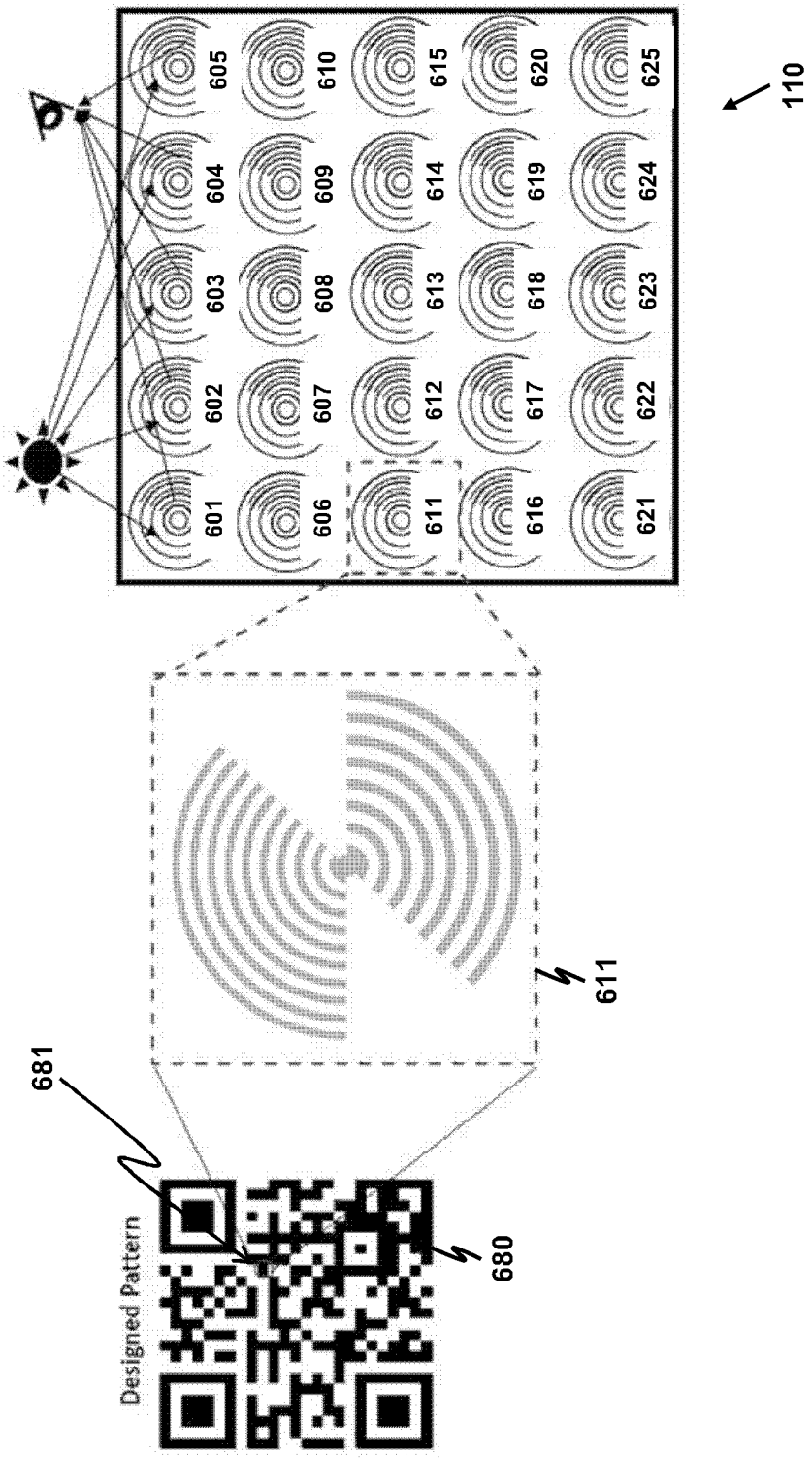

110
601
606
611
616
621
602
607
612
617
622
603
608
613
618
623
604
609
614
619
624
605
610
615
620
625
611
681
680
Designed Pattern

FIG.5

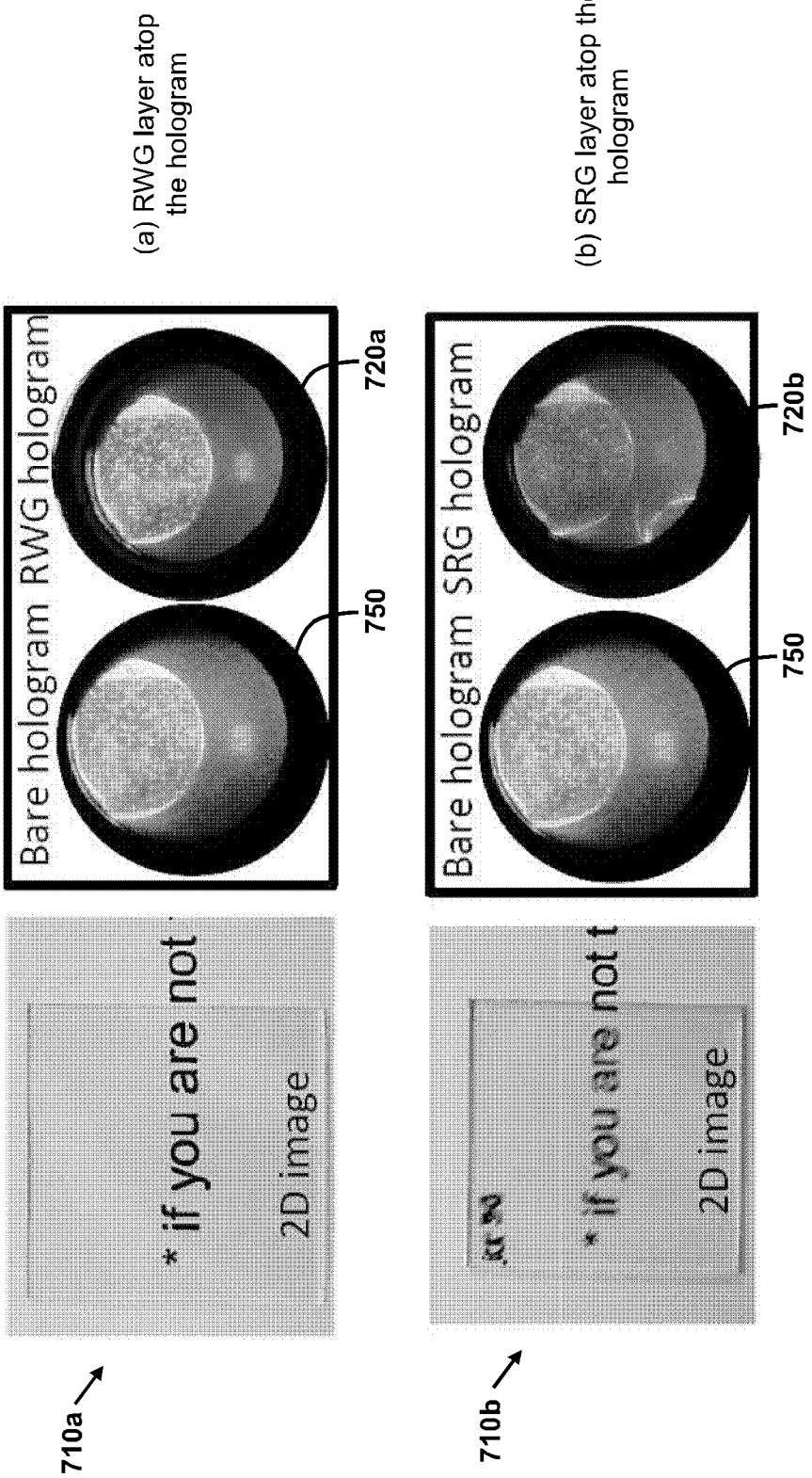

(a) RWG layer atop the hologram
Bare hologram RWG hologram
720a
750
* if you are not
2D image
710a
(b) SRG layer atop the hologram
Bare hologram SRG hologram
720b
750
* if you are not
2D image
710b

FIG.6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/105230

A. CLASSIFICATION OF SUBJECT MATTER

B42D 25/351(2014.01)i; B42D 25/328(2014.01)i; B42D 25/30(2014.01)i; B42D 25/435(2014.01)i; G03H 1/28(2006.01)i; G03H 1/02(2006.01)i; G02B 5/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B42D; G03H; G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS, VEN, CNTXT, WOTXT, EPTXT, USTXT: securit+, authentic+, anti, prevent+, counterferi+, fak+, forger+, resonant +, grating+, raster+, rwg?, hologra+, imag+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	EP 3205512 A1 (CSEM CENT SUISSE ELECTRONIQUE & MICROTEC) 16 August 2017 (2017-08-16) description, paragraphs 36-119, and figures 1a-9	1-19
Y	US 2019009609 A1 (OBERTHUR FIDUCIAIRE SAS) 10 January 2019 (2019-01-10) description, paragraphs 293-500, and figures 1-37D	1-19
Y	WO 2015096859 A1 (SUISSE ELECTRONIQUE MICROTECH) 02 July 2015 (2015-07-02) description, paragraphs 43-92, and figures 1-13	1-19
Y	CN 201619321 U (LU X) 03 November 2010 (2010-11-03) description, paragraphs 11-13, and figures 1-4	1-19
A	CN 207704754 U (SHANGHAI GUANZHONG OPTICAL TECHNOLOGY CO) 07 August 2018 (2018-08-07) the whole document	1-19

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 2021	**27 April 2021**
Name and mailing address of the ISA/CN **National Intellectual Property Administration, PRC** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China** Facsimile No. **(86-10)62019451**	Authorized officer **CHEN,Yajuan** Telephone No. **(86-10) 62085757**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2020/105230

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				CN	108883652	B	05 January 2021
				KR	20180098397	A	03 September 2018
				CN	108883652	A	23 November 2018
				RU	2726715	C2	15 July 2020
				RU	2018123343	A3	17 February 2020
				WO	2017114801	A1	06 July 2017
				EP	3397501	B1	04 November 2020
				FR	3046110	A1	30 June 2017
				BR	112018013384	A2	04 December 2018
				ID	201812611	A	30 November 2018
				HK	1260119	A0	13 December 2019
WO	2015096859	A1	02 July 2015	CN	105899983	A	24 August 2016
				EP	3087421	B1	31 July 2019
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				EP	3087421	A1	02 November 2016
				US	9946019	B2	17 April 2018
				JP	2017503203	A	26 January 2017
				JP	6392876	B2	19 September 2018
CN	201619321	U	03 November 2010	None			
CN	207704754	U	07 August 2018	None			