DIFFRACTIVE OPTICAL ELEMENT AND MANUFACTURING METHOD OF THE SAME

Abstract: A diffractive element (2) that comprises a set of rectangular grating pixels (1) with a grating structure of grating period (D) and grating tilt (a), whilst at least some grating periods (1) have different grating period (D) and/or different grating tilt (a) and at least some grating pixels (1) are in direct contact with each other. The set of grating pixels (1) comprises grating pixels (1) generally of various dimensions (Lx) and (Ly), whilst the dimensions (Lx) and (Ly) of the grating pixels (1) with the same grating period (D) and the same grating tilt (a) are such that the lines of the grating structures of these adjacent grating pixels (1) with the same grating period (D) and the same grating tilt (a) continue on through their common boundary. Additionally, a method of creation of the diffractive element (2) is described herein.
Technical field

The invention relates to a diffractive element made up of a set of rectangular grating pixels with a grating structure having a grating period and grating tilt and in which at least some grating pixels have different grating periods and/or different grating tilts and at least some grating pixels are in direct contact with each other. The invention also relates to the method of creating a diffractive element.

Prior Art

Optical elements of the diffractive character are often used for security purposes and/or for the authentication of products, documents, securities, etc. They are often known as "security holograms" or as "security diffractive optically variable image devices"-security DOVIDs). Their fundamental characteristic is their inner microstructure with feature sizes typically comparable to the size of the wavelength or its multiples. A diffraction grating is a typical, and also basic, representative of such a structure.

A typical structure of a diffraction grating consists of a set of periodically repeating lines with a given spacing (period) and rotation angle (tilt).

A diffraction grating decomposes incoming white light into a spectrum of colours, and at the same time it changes the direction of its propagation. Light passing through or being reflected by the grating is perceived by an observer in various colour shades, depending on the angle of observation and/or angle of incidence.

If more grating structures are composed into a more complex image on the area, the observer can perceive reflected or transmitted light in the form of an image.

Such an image can be two-dimensional (similar to printed graphics) or three-dimensional (such as a stereoscopic image or hologram), whilst both types of
images can exhibit dynamic properties (i.e. graphic or holographic motives change), depending on the angle of incidence of incoming light and/or angle of observation.

To compose diffractive images by sophisticated combinations of various elementary diffraction gratings is a common method of creating such images. A set of graphic motives often serves as a model for such a composition, and such motives get converted into a diffractive pattern, often in the form of elementary gratings; so-called grating pixels.

This method of creation of diffractive images was introduced during the times of extensive growth of computer technologies and computer graphics which enabled the processing of large volumes of data at the level of individual graphic dots (graphic pixels). At the same time, methods of dot-oriented recording of diffractive images started to develop. One of such recording methods is, for example, the so-called dot-matrix recording technique, which records elementary grating pixels using interfering laser beams. Among other grating pixel recording methods belongs, for example, laser or electron beam lithography.

In the case of pixel-oriented recording methods, such as dot-matrix recording or direct recording using a laser or electron beam, the inner grating structure and positioning of individual lines within the recorded grating pixel becomes important when the pixel size decreases to under approx. 25 μm (1000 dpi), and particularly under approx. 10 μm (2500 dpi). As the pixel area decreases, the portion of that area near the pixel boundaries where the grating may not be recorded (exposed) fully increases. This may cause a reduction in the brightness of the diffractive image composed of the grating pixels. The boundaries represent a problem particularly for dot-matrix recording methods, where the grating is exposed less efficiently as a result of uneven distribution of the intensity in the recording laser beams, and/or as a result of diffractive effects at the boundaries of specifically shaped pixels. In addition to this, the reduction of the pixel area in the intent to increase resolution results in reduced number of grating lines, which is also accompanied by a reduction in intensity of the radiation from such a pixel in a
desired direction, or by an increase of angular scattering.

Another parameter which can significantly affect the brightness of the observed diffractive image composed of the grating pixels is the relative position of the grating lines in the adjacent pixels. If the grating lines do not connect, i.e. they look shifted, reduced brightness of the resulting diffractive image occurs. Incident light, which diffracts on connected gratings, propagates towards the observer in-phase, i.e., light waves diffracted on the adjacent gratings are amplified (wave peaks are propagating jointly). Light diffracting on unconnected (shifted) adjacent gratings is attenuated, however, because the waves are not propagating in-phase (peaks and valleys of waves partially eliminate each other) and in extreme cases are propagating with opposite phases. Such an attenuation of the light waves becomes significant when the waves coming from the individual pixels propagate in the same direction (i.e. the grating structure has the same tilt and period) and the waves partially overlap due to the diffraction effects. These effects get larger as the grating pixel size gets smaller.

In a typical dot-matrix record, i.e. a record made by interfering laser beams focused on a small area, the position (or phase) of the grating lines inside the pixel is purely random. In order to control the phase of the grating lines, a very complex and extremely accurate recording device is required. The acquisition and operation of such a device for the recording of diffractive images would not be very economical, however. Nevertheless, devices allowing control of the phase of the grating lines have been built and are being used, mostly in the field of optical applications. A device called "Nanoruler" can be mentioned as an example (C.-H. Chang, C. Joo, Juan Montoya, Dr. Ralf Heilmann, „The MIT Nanoruler: A Tool for Patterning Nano-Accurate Gratings”). Although the phase of the grating structure is not being controlled during the dot-matrix type recording, i.e. it is random, this fact may actually be advantageously used in practice for the authentication of the recorded diffractive image, since two different dot-matrix recording systems would not expose grating pixels with the same position of the grating lines (see, for example, article "Identifying a dot-matrix hologram by the deviations of the fringe positions of its grating dots", Sheng Lih Yeh, Opt. Eng. 45, 075803, Jul 07, 2006).
In a direct, i.e. non-interference, method of recording by a laser or electron beam, the position of lines is controlled directly. Direct control allows creating grating structures in such a way, that they are continuous throughout the adjacent pixels, which maximises brightness of the recorded diffractive image. However, if the direct recording is limited by the ultimate resolution of positioning of the recording beam (typically in sub-micrometre down to nanometre range), the recording of the grating pixel may have its own limitations, if there is a requirement that grating lines in the adjacent pixels are continuous. If the pixels of a given size are distributed evenly on the diffractive image area, e.g. in a similar way as in a typical graphic bitmap, and if they are filled with a grating structure of the same type (for example, if they represent one graphic motive of the diffractive image), it is generally not guaranteed that the grating lines will be continuous. For certain parameters of the grating structure (tilt and period), the grating structure of the recorded pixels will be continuous, and for other parameters will not be continuous. This is due to the fact that the pixel shape, pixel area, distribution of pixels on the area, and ultimate recording resolution (address grid) are fixed. The consequences of the continuity or discontinuity of the grating lines will become evident from the radiation characteristics of the diffraction image constructed from a specific grating pixel.

A typical diffractive image consists of a series of graphic motives which differ particularly in colour and direction of radiation and which may be represented in a digital form of a bitmap, i.e. dots arranged in a regular rectangular grid. Pixels of a diffractive image are called grating pixels. When creating an image, the advantage of the pixel arrangement lies in the possibility that it can be generated by standard software graphic tools.

The inner structure of the grating pixel has a form of grating lines, the period and tilt of which determine basic radiation characteristics, i.e. colour and direction of radiation.

The ability to choose any combination of grating tilt and period has a substantial
effect on the number of options of the diffractive image design; the spectrum of colours and radiation angles can be almost continuous. This gives freedom to the graphic designer when designing a diffractive image and allows him to design images of better quality. In an analogy with conventional graphics-it is possible to design images when only 256 colour shades are available (so-called 8-bit graphics), or when more than 16 million of shades are available (so-called 24-bit graphics). The 24-bit graphics provide a higher quality of perception to the observer than the 8-bit graphics.

As described above, a fixed size of the grating pixel together with a fixed recording grid limits radiation options of the diffractive image composed of such periodically repeated pixels. Considering this, if the pixel size is further reduced (i.e. resolution of the image is increased), the number of combinations of the grating structures which can be recorded continuously is also reduced. In other words, the diffractive image may be composed effectively only with a lower number of different constructions of the grating pixel. This will result in further reduction of radiation options of the diffraction image. If a diffractive image includes variable graphic motives radiating into various observation angles, the transition between individual motives may appear to the observer as a coarse switching, i.e. the transition is not continuous. Furthermore, if the diffractive motives are composed of grating pixels whose lines are not connected continuously, the variable motives may appear to the observer as angularly overlapped and/or with reduced brightness.

Although the issues associated with connecting the grating lines can be solved without the use of the concept of grating pixels, the pixel arrangement of the diffractive image still has its advantages. It allows fast conversion of graphic motives in the form of graphic bitmaps created by standard graphic programs into the exposure data in the form of the grating pixels. Known diffractive elements typically comprise a set of grating pixels of fixed size in a given diffractive element, and differ only in the grating period and grating tilt.

The goal of the invention is to create a diffractive element and a method of creating such a diffractive element where the brightness of the resulting diffractive
image is not reduced, as is the case with the current state of the technology.

**Disclosure of the Invention**

The above-mentioned goal can be achieved by a diffractive element composed of a set of rectangular grating pixels comprising a grating structure defined by a grating period and grating tilt, where at least some gratings have different grating periods and/or different grating tilts and at least some grating pixels are in direct contact with each other. The essence of the invention lies in the arrangement of the set of grating pixels which includes grating pixels of different sizes, whilst the size of the grating pixels with the same grating period and the same tilt is such that the lines of the grating structure of adjacent grating pixels with the same grating period and grating tilt continue on through their common boundary.

In comparison with known diffractive elements consisting of grating pixels of fixed size, the diffractive element according to this invention allows grating lines of the grating structures of the adjacent pixels of a given grating period and a given grating tilt to always continue on through their common boundary by choosing different sizes of the grating pixels used. Thus the optimum size of the grating pixel used is determined for a given grating period and a given grating tilt, so that the lines of the grating structure of adjacent grating pixels always continue on through their common boundary.

According to a preferred embodiment, a set of grating pixels with a grating structure of the same grating period and the same grating tilt forms a pixel grid, whilst individual pixel grids are in direct contact with each other and/or there is empty space left between them and/or the empty space between them is filled with sub-pixels into which the individual grating pixels could be sub-divided.

In the invention, the diffractive element includes arrangements of the pixels not in only one given pixel grid, as it is typical for the conventional bitmap graphics or for the ordinary dot-matrix systems, but combines multiple different pixel grids for the purpose of increasing the options of the diffractive image design, brightness
maximisation by the elimination of potential discontinuities of the grating lines on boundaries of the adjacent pixels of the same type, and enhancement of the quality of the diffractive image radiation capabilities.

The above-described goal can also be achieved by a method of creating a diffractive element in which a set of rectangular grating pixels of dimensions Lx and Ly, comprising a grating structure of a grating period and a grating tilt, is created by a recording beam on a recording medium, whilst at least some grating pixels have different grating periods and/or different grating tilts and at least some grating pixels are in direct contact with each other. The substance of the invention is based on the arrangement in which the recording medium area is covered by a set of grating pixels of different sizes, whilst sizes of the grating pixels of the same grating period and the same tilt are determined retrospectively from the given grating period and grating tilt in such a way, that the lines of the grating structures of the adjacent grating pixels of the same grating period and the same grating tilt continue on through a common boundary of the grating pixels.

According to a preferred embodiment, the individual continuously-connected grating pixels comprising a grating structure of the same grating period and the same grating tilt are arranged into pixel grids that are recorded by a recording beam of a constant cross-section on a recording medium in such a way that they are in contact with each other and/or empty space is left between them and/or the empty space between them is filled with sub-pixels.

Pitch $\Delta x$ and Ay of the recording grid and the cross-section of the recording beam depend on the type and capabilities of the recording device, and, if the device allows, they are chosen for the recording of a grating structure, i.e. grating lines of one type of the grating pixels, such that the grating lines, recorded in such a recording grid and with such a beam cross-section, are differentiable. The pitch and size of the beam in directions x or y are typically smaller than one-half of the grating period projected in direction x or y, respectively.
In another advantageous embodiment, the minimum possible dimension \( L_x \) of the grating pixel in direction \( x \) shall be determined from the relation \( L_x = \frac{D}{\sin(a)} \) and minimum possible dimension \( L_y \) of the grating pixel in direction \( y \) from the relation \( L_y = \frac{D}{\cos(a)} \), where

\[ D = \text{grating period} \ [\mu m] \]
\[ a = \text{grating tilt} \ [\text{degrees, } ^\circ] \]

if the determined minimum possible dimensions \( L_x \) and \( L_y \) of the grating pixel are not integer-divisible by the pitch of the recording grid, i.e. by chosen step of positioning \( \Delta x \), \( \Delta y \) of the recording grid in directions \( x \) and \( y \), respectively, the dimensions \( L_x \) and \( L_y \) of the grating pixel are rounded to the nearest integer multiples of the recording grid pitch, i.e. the chosen step of positioning \( \Delta x \), \( \Delta y \) of the recording beam in directions \( x \) and \( y \), respectively,

and grating pixel dimensions adjusted in this manner \( L_{x upr} \) and \( L_{y upr} \) are used to retrospective determination of the adjusted grating period \( D_{upr} \) and adjusted grating tilt \( a_{upr} \),

if the adjusted value of grating period \( D_{upr} \) and grating tilt \( a_{upr} \) do not differ from the original grating period and/or original grating tilt by more than the predetermined permitted deviation, the adjusted dimensions \( L_{x upr} \) and \( L_{y upr} \) of the grating pixel represent the final dimensions of the grating pixel, and

if the adjusted values of grating period \( D_{upr} \) and grating tilt \( a_{upr} \) differ from the value of the grating period and/or grating tilt by more than the permitted deviation, the minimum possible dimension \( L_x \) of the grating pixel is being increased by integer multiples in direction \( x \) and/or minimum possible dimension \( L_y \) of the grating pixel is being increased by integer multiples in direction \( y \), until the value of grating period \( D_{upr} \) and grating tilt \( a_{upr} \) achieve values within the boundaries of the predetermined deviation, i.e. with given accuracy.
Grating lines forming the grating structure with period $D_{\text{upr}}$ and tilt $\alpha_{\text{upr}}$ are then written into the grating pixel of dimension $L_{\text{xupr}}$, $L_{\text{yupr}}$, using a recording beam of a constant cross-section and recording grid with pitch $\Delta x$, $\Delta y$.

In another advantageous embodiment, the record of different grating pixels into a recording medium can be made by a recording beam of different cross sections, whilst for the same grating pixels the recording beam cross-section is constant.

**Brief Description of Drawings**

The diffractive element according to the invention will be described in detail with references to the attached drawings. Fig. 1 shows a grating pixel with a grating structure. Fig. 2 shows a pixel-oriented record with pixels arranged into one specific pixel grid, as is typical for conventional bitmap graphics or for ordinary dot-matrix systems according to the currently known state of the art. Figs. 3 and 4 show examples of a design of a diffractive element according to the invention.

**Description of preferred embodiments**

Fig. 1 presents an example of an implementation of grating pixel 1, whose grating structure has grating period $D$ and grating tilt $\alpha$. The set of such grating pixels 1 forms diffractive element 2. In the case of known implementations (see Fig. 2), the diffractive element 2 comprises a set of grating pixels 1 with fixed dimensions $L_x$ and $L_y$. The problem is that in the case of fixed sizes of grating pixels 1 the lines of the grating structures of adjacent grating pixels 1 with the same grating period $D$ and the same grating tilt $\alpha$ may not always continue on through their common boundary, as shown on Fig. 2 in detail 3.

Fig. 4 presents an example of a very simple diffractive element 2 according to the invention. The diffractive element 2 shows letter A on a background. The area of the letter A on diffractive element 2 is filled with a set of grating pixels 1 with dimensions $L_{x1}$ and $L_{y1}$ and with grating period $D_{1}$ and grating tilt $\alpha_{1}$, whilst the background is filled with grating pixels 1 of different dimensions $L_{x2}$ and $L_{y2}$ and
with different grating period $D_2$ and grating tilt $a_2$. The use of dimensions $Lx_1$ and $Ly_1$ of pixels 1 to fill the letter A, and different dimensions $Lx_2$ and $Ly_2$ of pixels 1 to fill the background, enables the adjustment of the sizes of pixels 1 to the particular grating period $D$ and grating tilt $a$ in such a way that, within the given group of grating pixels 1, the lines of the grating structures of the adjacent grating pixels 1 of the same grating period $D$ and the same grating tilt $a$ always continue on through their common boundary. This would not always be possible if the fixed size of grating pixels 1 were used, as is used in the current state of technology.

Fig. 3 presents a detail of another example of an embodiment of diffractive element 2 according to the invention. Diffractive element 2 comprises three pixel grids 4. Grating pixels 1 with a grating structure of the same grating period $D$ and the same grating tilt $a$ are always used within one pixel grid 4. The size of grating pixels 1 is tailored to the given grating period $D$ and grating tilt $a$ in such a way, that the lines of grating structures of the adjacent grating pixels 1 of the same grating period $D$ and grating tilt $a$ continue on through a common boundary.

Individual pixel grids 4 are connected in some locations, whilst empty spaces 5 are left between them in other locations. Free places 5 between individual pixel grids 4 could also be filled with sub-pixels. The sub-pixels are created by sub-dividing grating pixels 1 of given grating period $D$ of and grating tilt $a$ into smaller parts. Therefore, sub-pixels of grating pixels 1 belonging to two different adjacent pixel grids 4 could occur in empty spaces 5. In the case of a diffractive image, for example, the sub-pixels usually follow the boundary of the graphic motive.

The grating structure forms a diffraction grating that decomposes incident white light into a colour spectrum and, at the same time, changes the direction of its propagation. An observer who observes diffractive element 2 perceives light passed through or reflected by the grating in various colour shades, depending on the angle of observation or angle of incidence.

Typically, when more complex diffractive images are created, one particular motive of such an image is composed of grating pixels 1 of one type (grating pixel
of a certain size, grating period \( D \) and grating tilt \( a \), i.e. grating pixel \( 1 \) is populated across the area delimited by the graphic motive. Generally, the adjacent motive of the diffractive image is composed of different types of grating pixels \( 1 \).

The process of filling the motives of the diffractive image with grating pixels \( 1 \) can be done in multiple ways.

The first example of filling the motives of the diffractive image with grating pixels \( 1 \) assumes that grating pixels \( 1 \) will be filling the given motive area coarsely, i.e. fineness of boundaries of the motive will be given by the size of grating pixel \( 1 \). The adjacent motive will continue the filling process using a different type of grating pixels \( 1 \) and generally with different fineness. At the locations where different grating pixels \( 1 \) do not fit each other completely, spaces between motives will remain unfilled. In such a case, however, the individual graphic motives of the diffractive image may be represented by simple graphic bitmaps.

Another example of filling the diffractive image motives with grating pixels \( 1 \) assumes that grating pixel \( 1 \) is trimmed on the motive boundaries in such a way that the motive boundary is filled with the desired fineness. Individual motives can still be defined by graphic bitmaps; however, their trimming on motive boundaries requires working with grating pixels \( 1 \) at their inner level, which exceeds the capabilities of standard graphic tools.

The last example of filling the diffractive image motives with grating pixels \( 1 \) assumes that grating pixel \( 1 \) is divided internally into several parts, into so-called sub-pixels, that represent a specific segment of its inner structure. Filling the diffractive image motive with the respective grating pixels \( 1 \) is performed at the level of grating sub-pixels, which ensures a higher fineness of the boundaries than filling the motive with un-divided grating pixels \( 1 \). At the same time, the grating sub-pixels may be represented by the graphic pixels. This method of combining grating pixels \( 1 \) into a diffractive image represents a compromise between the above-described examples; whilst from a graphic standpoint, it is solvable fully at the level of a bitmap.
The design of grating pixel 1 is based on the requirements for basic parameters of the grating, i.e. grating period D and grating tilt \( \alpha \). These two parameters can be chosen completely arbitrarily (more precisely, with defined tolerances; e.g. ± 0.1° for maximum angle deviation and ± 1% for maximum deviation from the grating period D), depending on the radiation characteristics that have to be achieved by the resulting diffraction element 2.

Other important input parameters for a design of grating pixel 1 include characteristics of the recording device that is used for recording the gratings. In particularly, this includes the ultimate resolution of the positioning of the recording laser or electron beam. The design assumes that the positioning of the recording beam is performed in a rectangular grid (in directions x and y), whilst minimum pitch of grid \( \Delta x \) and \( \Delta y \) is given by the smallest positioning step (ultimate resolution) or its multiples. The grid pitch values in directions x and y are generally different.

The size of the spot of the recording laser or electron beam is not important here. The spot needs to be sufficiently small so that the grating lines could be resolved. Also, the shape of the spot cross-section can be arbitrary, e.g. round, elliptic, rectangular, etc. Further, it is also assumed that the nominal size and shape of the spot does not change during the recording of the grating lines within one type of grating pixel 1.

The essence of the method for the creation of diffractive element 2 is based on a process of creating a set of rectangular grating pixels 1 of various dimensions \( L_x \) and \( L_y \) and grating structures with various grating periods D and various grating tilts \( \alpha \) on a recording medium, such as photoresist or electron resist using, for example, a laser or electron recording beam. The dimensions of the grating pixels with the same grating period D and the same grating tilt \( \alpha \) are such integer multiples of recording pitches \( \Delta x \) and \( \Delta y \) in the respective directions, that, according to the example of the embodiment, the grating lines contained in the adjacent grating pixels 1, will be recorded by a recording beam of a constant
cross-section in a recording grid of pitches $\Delta_x$ and $\Delta_y$ in such a way, that they
would continue on through a common boundary of grating pixels.

In the course of recording, individual adjacent grating pixels containing a grating
structure of the same grating period $D$ and the same grating tilt $a$ are arranged in
pixel grids that are recorded by the recording beam of a constant cross-section
on the recording medium in such a way that they are in direct contact with each
other and/or there is empty space left between them and/or the empty space
between them is filled with sub-pixels.

A procedure for how to design a grating pixel is explained in detail on a particular example below.

First, minimum possible dimension $L_x$ of grating pixel in direction $x$ shall be
determined from relation

$$L_x = \frac{D}{\sin a}$$

and minimum possible dimension $L_y$ of the grating pixel in direction $y$ from
relation

$$L_y = \frac{D}{\cos a},$$

where

$D =$ grating period [$\mu\text{m}$]

$a =$ grating tilt [degrees, °],

if the found minimum possible dimensions $L_x$ and $L_y$ of grating pixel are not
integer-divisible by the pitch of the recording grid or by the chosen positioning step
$\Delta_x$, $\Delta_y$ of the recording beam in respective directions $x$ and $y$, dimensions $L_x$ and
$L_y$ of the grating pixel shall be rounded to the nearest integer multiples of the
recording grid pitch or chosen step of positioning $\Delta_x$, $\Delta_y$ of the recording beam in
respective directions $x$ and $y$.

The dimensions of grating pixel adjusted by such a manner $L_{x\text{upr}}$ and $L_{y\text{upr}}$, will be used for the retrospective determination of the adjusted grating period $D_{\text{upr}}$
and grating tilt $a_{\text{upr}}$. 
If the adjusted values of grating period $D_{\text{upr}}$ and grating tilt $a_{\text{upr}}$ do not differ from the original grating period $D$ and/or original grating tilt $a$ by more than the predetermined permitted deviation, the adjusted dimensions $L_{x\text{upr}}$ and $L_{y\text{upr}}$ of grating pixel 1 represent the final dimensions of grating pixel 1.

If the adjusted value of grating period $D_{\text{upr}}$ and/or grating tilt $a_{\text{upr}}$ differs from the value of grating period $D$ and/or grating tilt $a$ by more than the permitted deviation, the minimum possible dimension $L_x$ of the grating pixel 1 is increased by integer multiples in direction $x$ and/or minimum possible dimension $L_y$ of the grating pixel 1 is increased by integer multiples in direction $y$, until the values of grating period $D_{\text{upr}}$ and grating tilt $a_{\text{upr}}$ achieve values within the boundaries of the predetermined deviation.

The recording grid shall be sufficiently fine so that the individual grating lines can be distinguished reasonably. In addition, the size or shape of the recording beam cross-section shall be sufficiently small, so that the grating lines can be distinguished upon completion of the recording process. It is necessary that the beam size is smaller than grating period $D$, i.e. smaller than $D/\sin(a)$ in direction $x$ and smaller than $D/\cos(a)$ in direction $y$.

If the limitations of the recording device (size of the cross-section of the recording beam and, namely, the minimum chosen step of positioning $\Delta x$, $\Delta y$ of the recording beam in directions $x$ and $y$), and tolerances on the period $D$ and tilt $a$ of the grating acceptable for the graphic designer are taken into consideration, then the parameters of the spacing of the pixel grid can be found such that the grating lines are continuous, which is important for the maximization of the brightness of diffractive element 2, and thus its quality.

By the correct choice of dimensions $L_x$ and $L_y$ of the grating pixel 1, the desired radiation characteristics of the part of diffractive element 2 that is filled with these repeating grating pixels 1 can be achieved. Another part of diffractive element 2 may be filled with grating pixel 1 of a different grating period $D$ and different grating tilt $a$, and in general of a different size, which is chosen such that the grating lines
of the adjacent grating pixels 1 are continuous and keep the optimum radiation characteristics of this part of the diffractive motive.

However, grating pixel 1, as it was designed according to the invention, may not keep in its square or rectangular form. The boundary of grating pixel 1 can be changed arbitrarily (e.g. into a staircase shape), but such that, when pixels are periodically copied across an area in a matching manner, the step period is equal to its original dimensions Lx, Ly or a multiple of these dimensions. The structure of the grating lines, designed originally for a square or rectangular grating pixel 1 does not change; the only change is in the shape of the pixel boundary. The change of the boundary of grating pixel 1 may be advantageous either in view of the recording technology or specific shapes of the borders that may be used as identification or authentication elements of the producer.
CLAIMS

1. A diffractive element (2) comprising a set of rectangular grating pixels (1) with a grating structure of a grating period (D) and grating tilt (a), whilst at least some grating pixels (1) have different grating period (D) and/or different grating tilt (a) and at least some grating pixels (1) are in direct contact with each other, characterised in that the set of grating pixels (1) comprises grating pixels (1) generally of various dimensions (Lx) and (Ly), whilst the dimensions (Lx) and (Ly) of the grating pixels (1) of the same grating period (D) and the same grating tilt (a) is such that the lines of the grating structures of these adjacent grating pixels (1) of the same grating period (D) and the same grating tilt (a) will continue on through their common boundaries.

2. A diffractive element (2) according to the claim 1, characterised in that the set of grating pixels (1) with a grating structure of the same grating period (D) and the same grating tilt (a) forms a pixel grid (4), whilst individual pixel grids (4) are in direct contact with each other and/or empty space (5) is left between them and/or the empty space between them is filled with sub-pixels, into which individual grating pixels can be sub-divided.

3. A method of creation of a diffractive element (2), in which a set of rectangular grating pixels (1) with dimensions (Lx) and (Ly) with a grating structure of a grating period (D) and grating tilt (a) is created on a recording medium using a recording beam, whilst at least some grating pixels (1) have different grating period (D) and/or different grating tilt (a) and at least some grating pixels (1) are in direct contact with each other, characterised in that the recording medium area is populated with a set of grating pixels (1) generally of different dimensions (Lx) and (Ly), whilst dimensions (Lx) and (Ly) of grating pixels (1) with the same grating period (D) and the same grating tilt (a) is determined retrospectively from the given grating period (D) and grating tilt (a) so that the lines of the grating structures of adjacent grating pixels (1) with the same grating period (D) and the same grating tilt (a) continue on through the common boundary of those grating pixels (1).
4. The method according to claim 3, characterised in that the individual grating pixels (1) in contact with each other and having the same grating period (D) and the same tilt (a) are arranged in pixel grids (4) that are recorded on a recording medium by a recording beam of a constant cross section in such a way that the pixel grids (4) are in direct contact with each other and/or empty spaces (5) are left between them and/or the empty spaces between them are filled with sub-pixels.

5. The method according to claims 3 or 4, characterised in that the minimum possible dimension (Lx) of the grating pixel (1) is determined in direction (x) from the relation Lx = D/sin(a) and the minimum possible dimension (Ly) of the grating pixel (1) is determined in direction (y) from the relation Ly = D/cos(a), where

\[ D = \text{grating period} \hspace{1mm} [\mu\text{m}] \]
\[ a = \text{grating tilt} \hspace{1mm} [\text{degrees, } ^\circ], \]

if the found minimum possible dimensions (Lx) and (Ly) of the grating pixel (1) are not integer-divisible by the pitch values of the recording grid or by chosen steps \( \Delta \chi \), \( \Delta y \) of the positioning of the recording beam in respective directions (x) and (y), the dimensions (Lx) and (Ly) of the grating pixel (1) are rounded to the nearest integer multiples of the pitch values of the recording grid or the chosen steps \( \Delta \chi \), \( \Delta y \) of the positioning of the recording beam in respective directions (x) and (y), and such adjusted dimensions Lxupr and Lyupr of the grating pixel (1), are used for retrospective determination of the adjusted values of the grating period Dupr and grating tilt aupr,

if the adjusted values of the grating period Dupr and grating tilt aupr do not differ from the original grating period (D) and/or original grating tilt (a) by more than the predetermined permitted deviation, the adjusted dimensions Lxupr and Lyupr of the grating pixel (1) represent the final dimensions of the grating pixel (1), and

if the adjusted values of the grating period Dupr and/or grating tilt aupr differ from the values of the grating period (D) and/or grating tilt (a) by more than the permitted deviation, the minimum possible dimension (Lx) of the grating pixel (1) is
being successively increased by its integer multiples in direction (x) and/or the minimum possible dimension (Ly) of the grating pixel (1) by its integer multiples in direction (y), until the values of the period Dupr and tilt aupr of the grating achieve values within limits of the predetermined deviation or a given accuracy.

6. The method according to any of the claims 3 to 5, characterised in that the different grating pixels (1) can be recorded on a recording medium using a recording beam of different cross-sections, whilst for identical grating pixels (1) the cross-section of the recording beam is constant.
Fig. 2
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B42D15/00 G02B5/18

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

B42D 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)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>A</td>
<td>WO 2005/071444 A2 (GI ESECKE &amp; DEVRI ENT GMBH [DE]; Dichtl Marius [DE]) 4 August 2005 (2005-08-04) col umn 3, lines 16-23; figures 9a, 9b page 14, line 21 - page 15, line 19; figures 2a, 2b page 20, line 22 - page 22, line 7</td>
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<td>X</td>
<td>DE 102 26 115 AI (GI ESECKE &amp; DEVRI ENT GMBH [DE]) 24 December 2003 (2003-12-24) paragraphs [0047] - [0063]; figures 2, 3, 4, 7</td>
<td>1-4,6</td>
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search: 25 October 2013

Date of mailing of the international search report: 06/11/2013

Name and mailing address of the ISA:

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel: (+31-70) 340-2040
Fax: (+31-70) 340-3016

Authorized officer:

Hambach, Dirk
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