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(54) **DEVICE AND METHOD FOR PRODUCING A THREE-DIMENSIONAL OBJECT BY MEANS OF MASK EXPOSURE**

(75) Inventors: **Hendrik John**, Hunxe (DE); **Volker Schillen**, Düsseldorf (DE); **Ali El-Siblani**, Dearborn Heights, MI (US)

(73) Assignee: **Envisiontec GmbH**, Gladbeck (DE)

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(51) **Int. Cl.**
G06F 19/00 (2006.01)

(52) **U.S. Cl.** **700/98**; 700/120

(58) **Field of Classification Search** 700/95–98, 700/117–121

See application file for complete search history.

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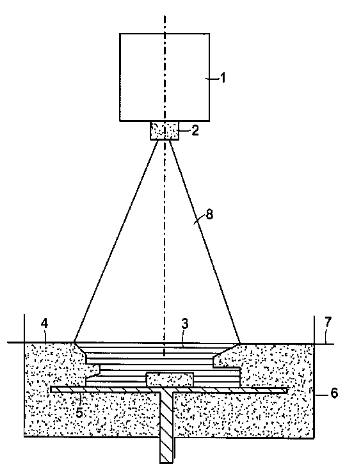
Primary Examiner—M. N. Von Buhr
(74) *Attorney, Agent, or Firm*—Hansen IP Law PLLC

(57) **ABSTRACT**

Device for producing a three-dimensional object by solidification of a material solidifiable under the action of electromagnetic radiation by means of energy input via an imaging unit comprising a predetermined number of discrete imaging elements (pixels), said device comprising a computer unit, an IC and/or a software implementation respectively with the ability of adjusting and/or controlling the energy input via a specific gray value and/or color value in a voxel matrix.

20 Claims, 8 Drawing Sheets



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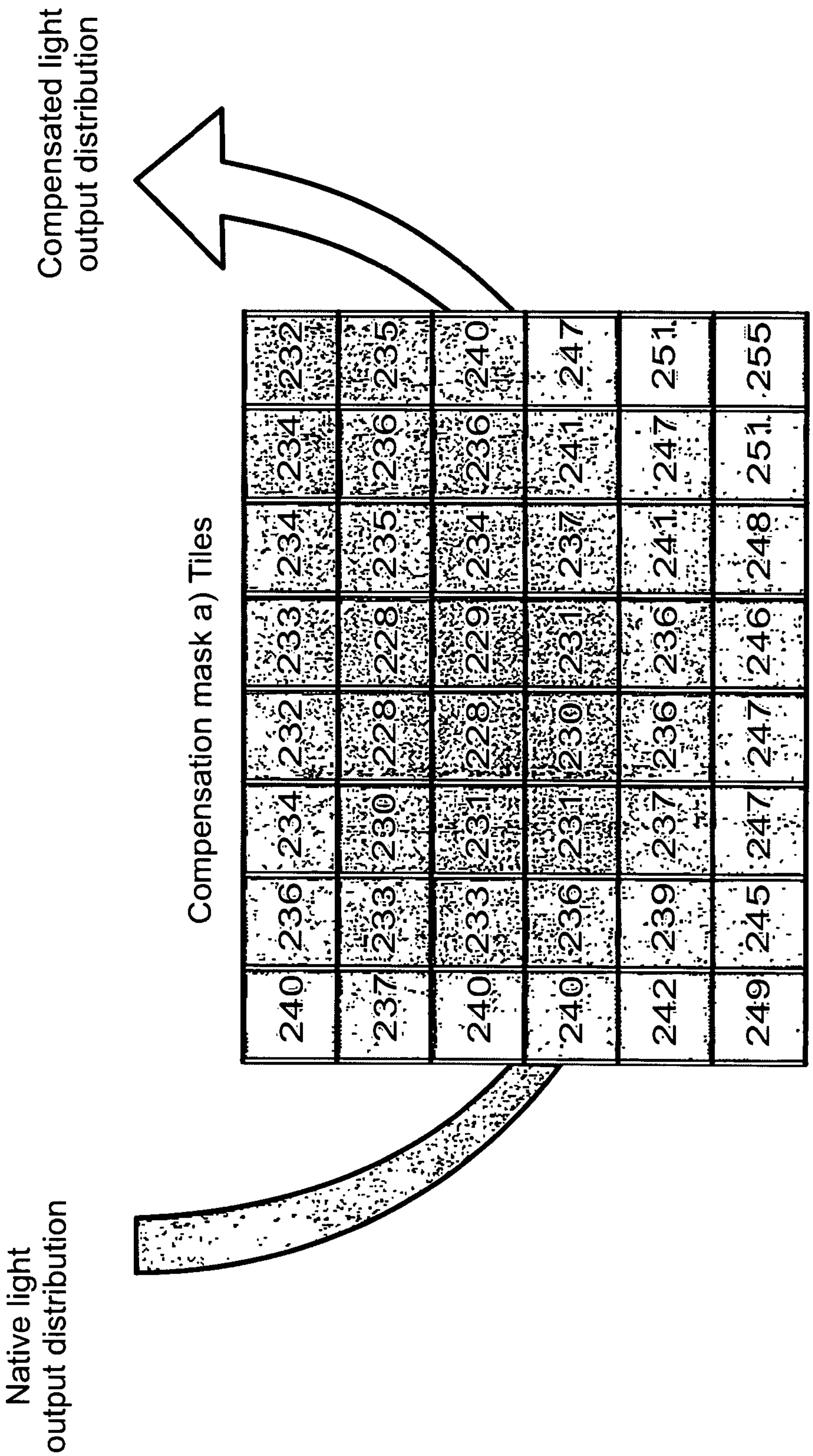

Compensated light output distribution
Compensation mask a) Tiles
Native light output distribution

FIG. 1

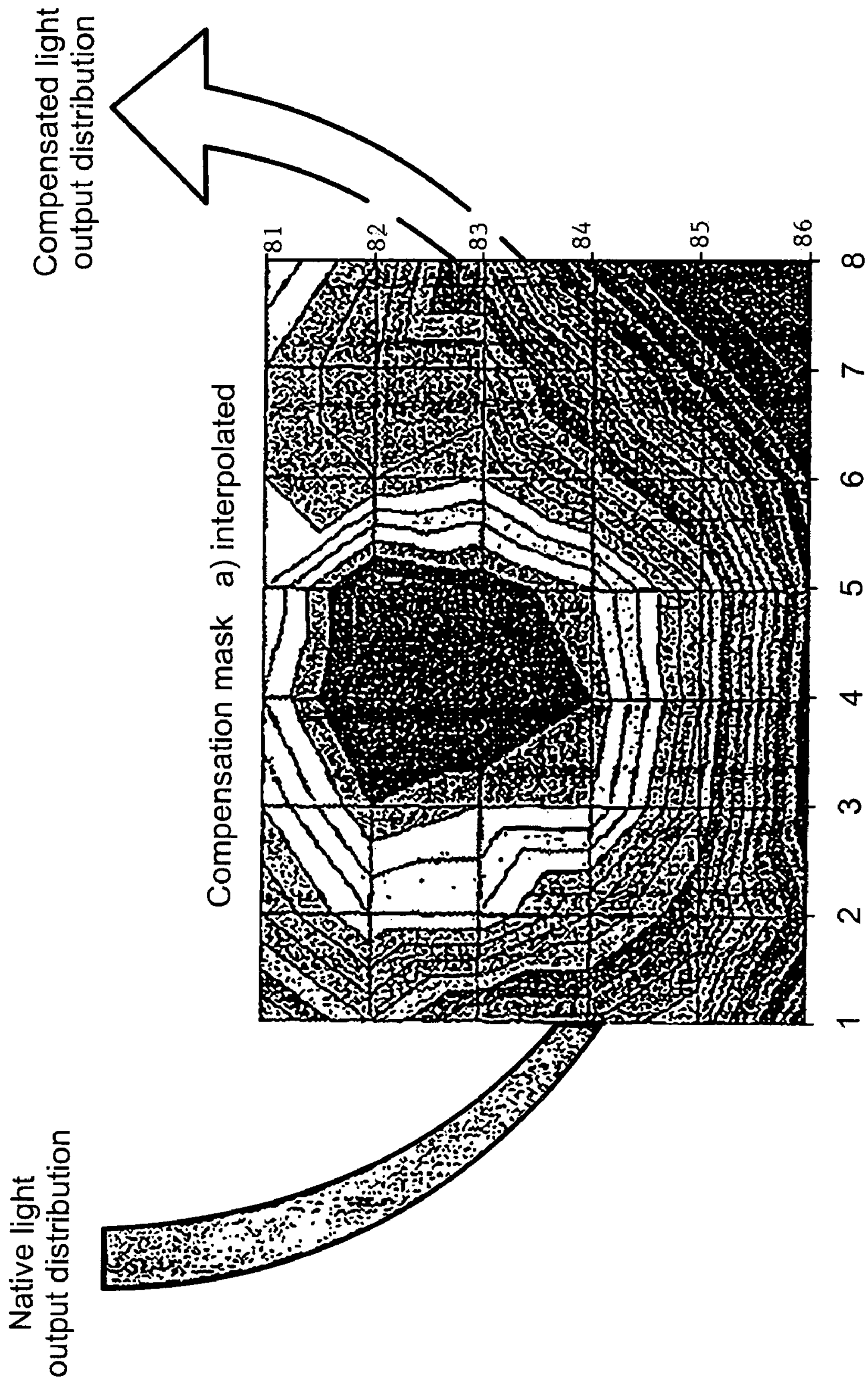
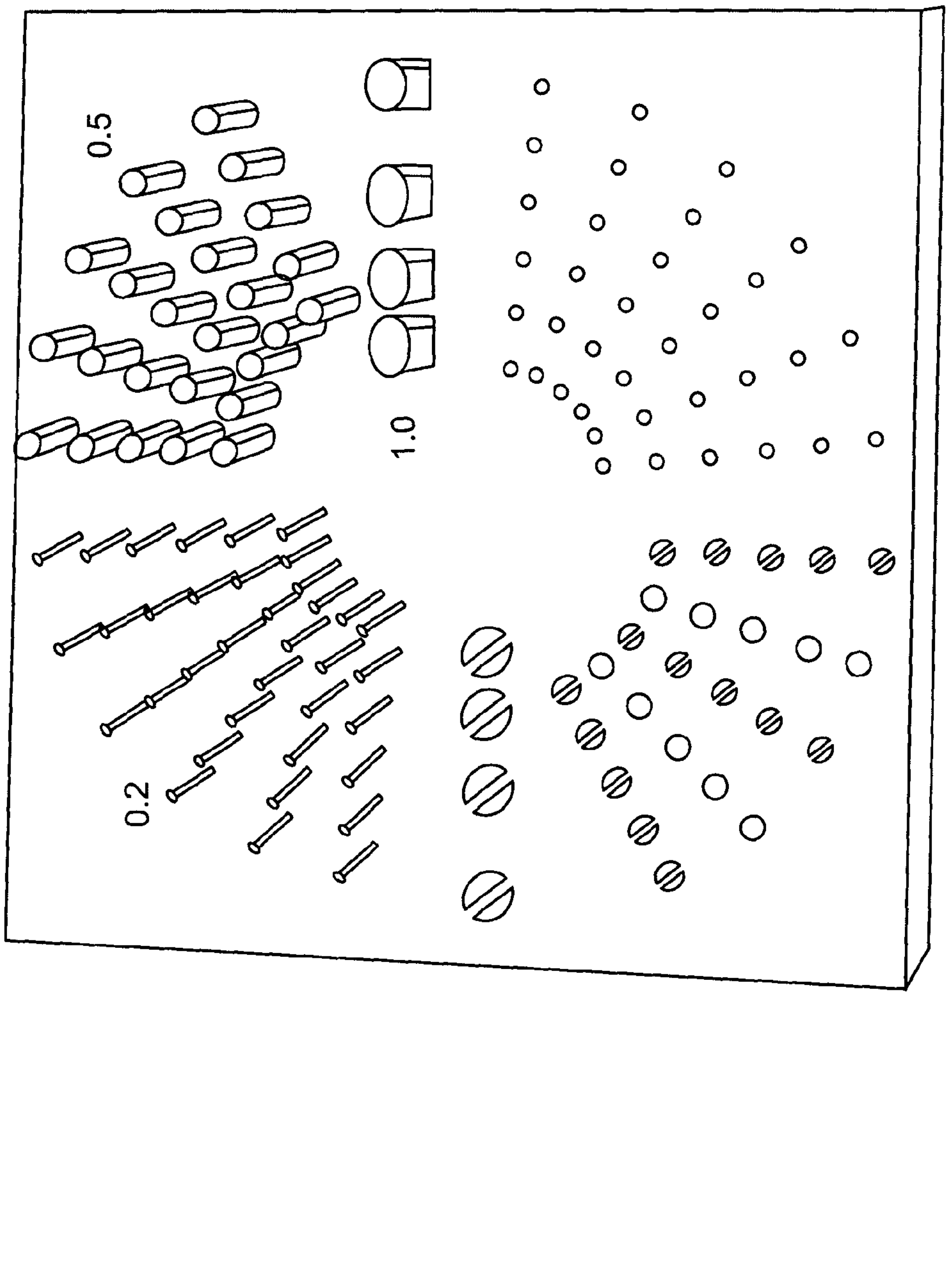
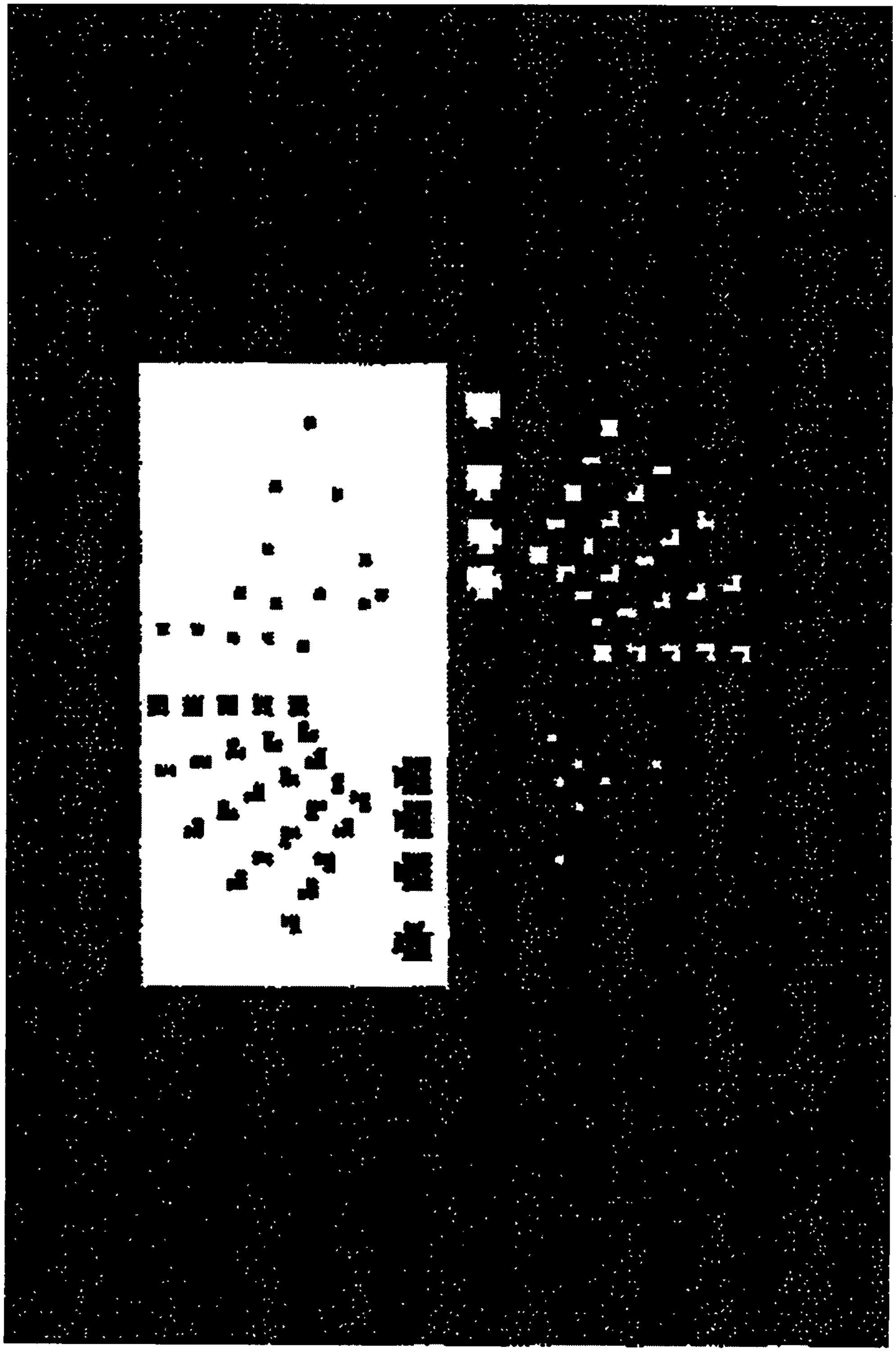

Compensated light output distribution
Compensation mask a) interpolated
81
82
83
84
85
86
1
2
3
4
5
6
7
8
Native light output distribution

FIG. 2



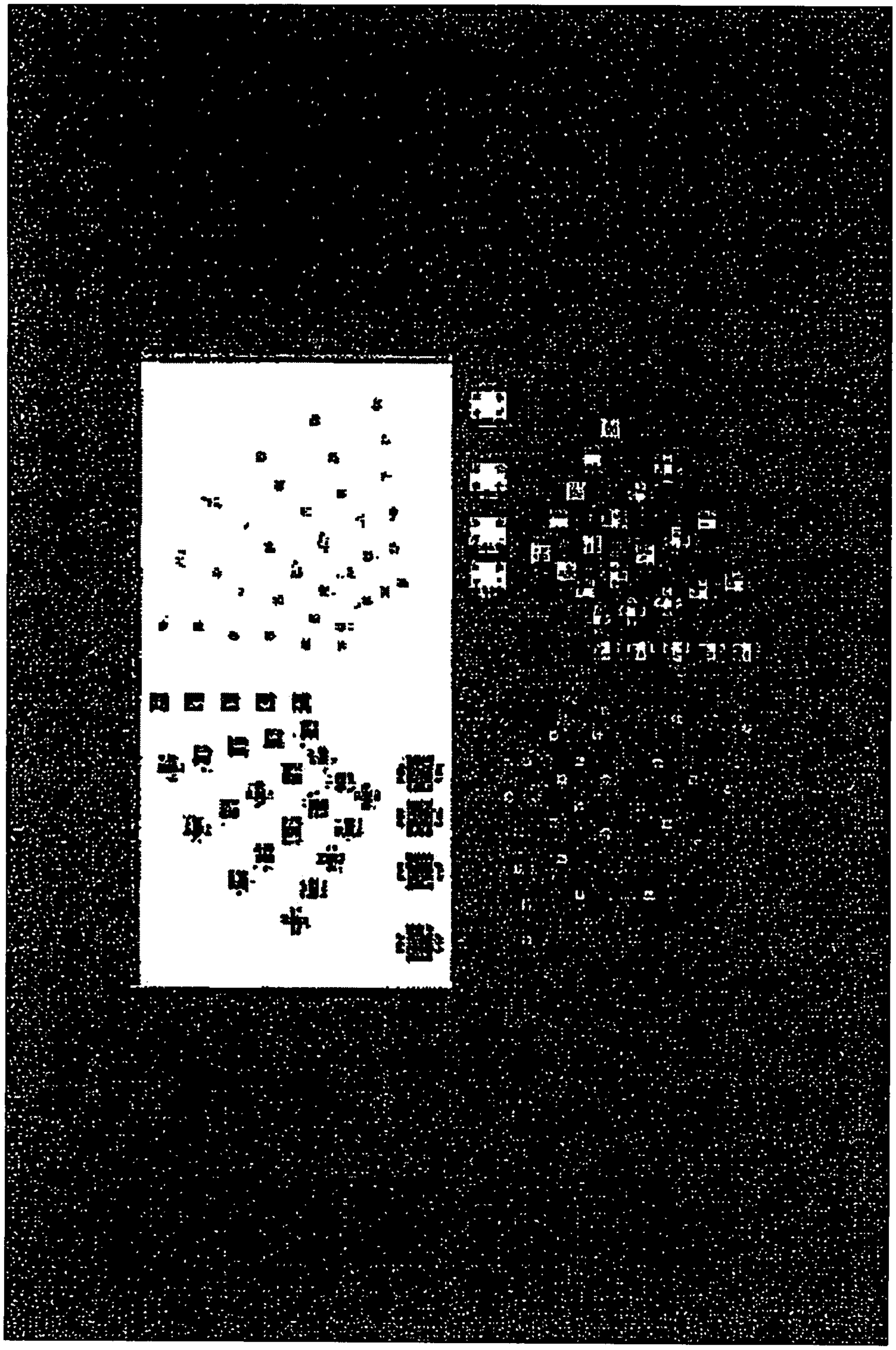
Geometry with differently sized holes and cylinders

FIG. 3



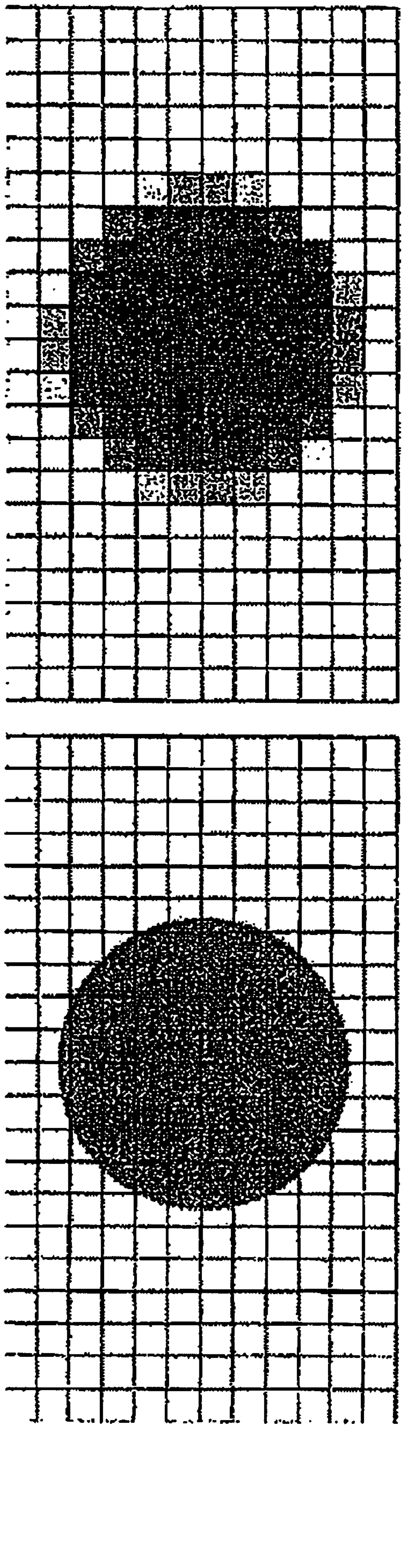
Generated bitmap with missing structures of the size 200 μm in diameter

FIG. 4



FillPath_Subsample_1.png

FIG. 5



Right: Raster graphic/bitmap, here with edge smoothing

Left: Presentation of a vector-based starting image of a cross-sectional structure to be imaged, with superposed raster (pixels are here presented as squares)

FIG. 6

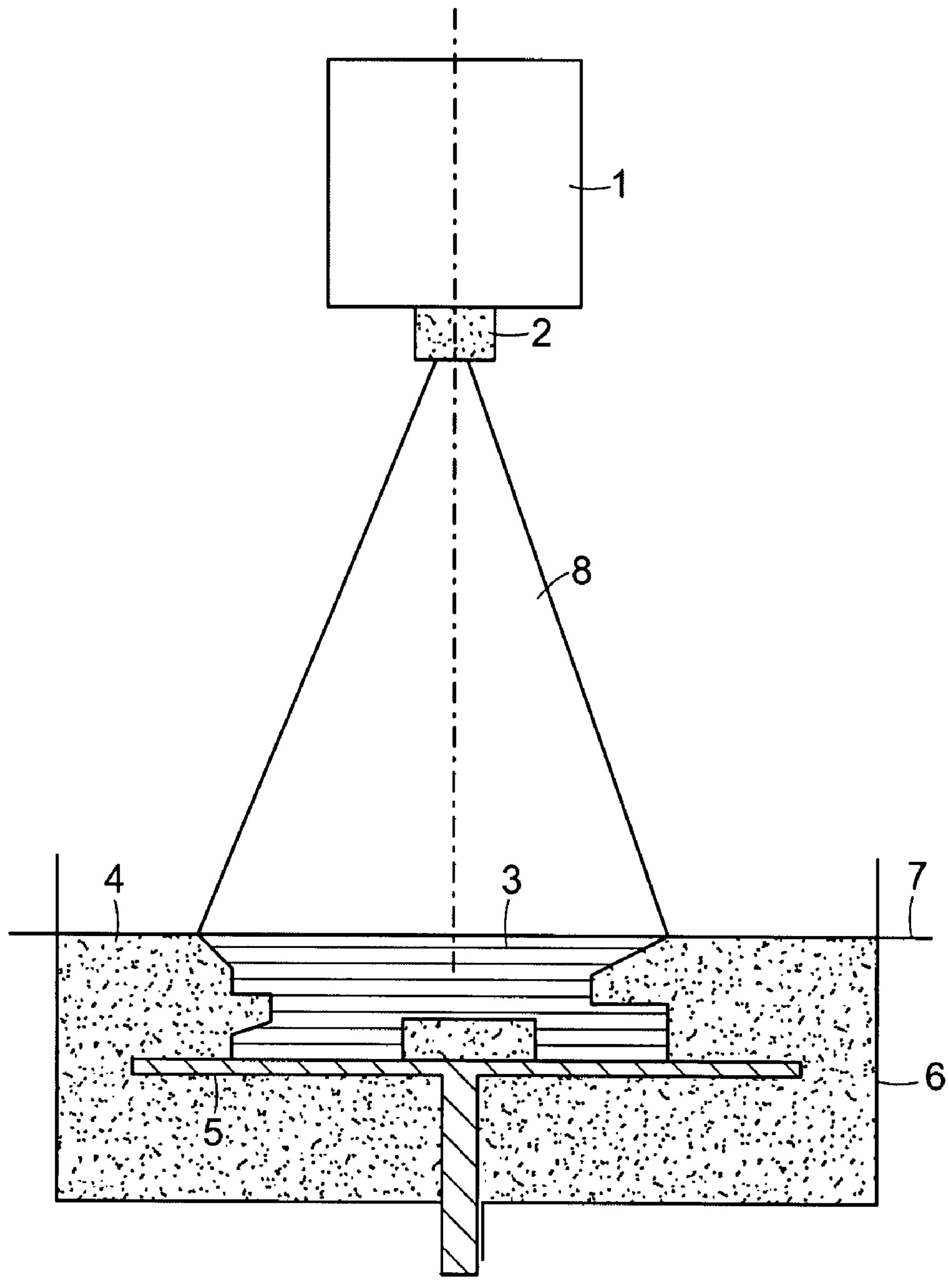


FIG. 7

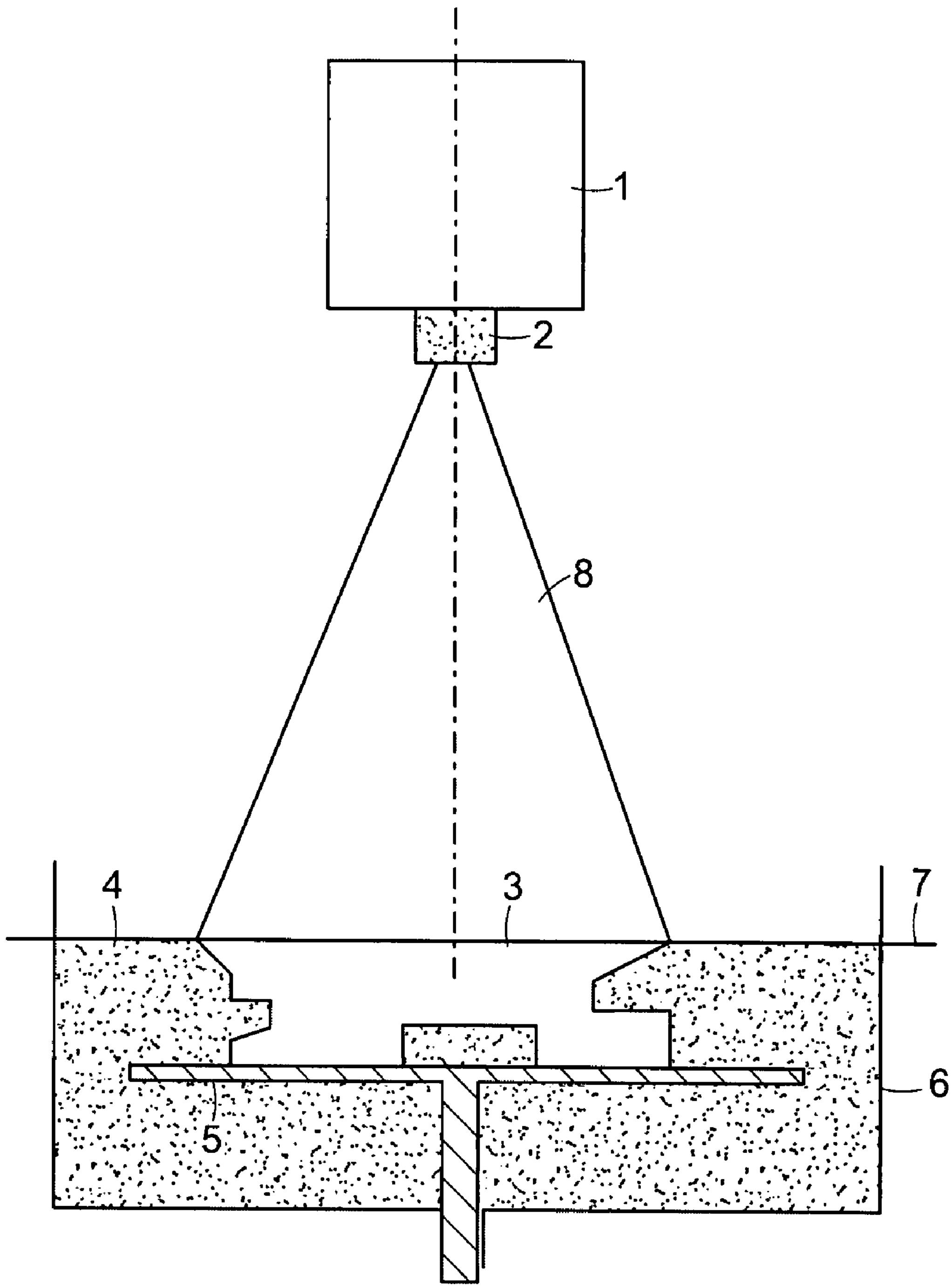


FIG. 8

DEVICE AND METHOD FOR PRODUCING A THREE-DIMENSIONAL OBJECT BY MEANS OF MASK EXPOSURE

The invention relates to a device for producing a three-dimensional object by solidification of a material, in particular a photopolymer, solidifiable under the action of electromagnetic radiation by means of energy input via an imaging unit comprising a predetermined number of discrete imaging elements (pixels). In particular, this invention relates to methods in which solidification is based on the exposure by means of a raster mask, with the smallest physical resolution in the mask given by the size of a pixel and the Spatial Light Modulator (SLM) technology being applied to the imaging unit.

BACKGROUND ART

The literature specifies highly varying methods for the construction of three-dimensional objects of "light-hardening" photopolymers, cf. "Automated Fabrication—Improving Productivity in Manufacturing" by Marshall Burns, 1993 (ISBN 0-13-119462-3).

Known possibilities are, inter alia, the exposure by

a) multimedia projector

b) LC display (reflexive, transmissive)

c) LED or laser diode line (which is moved over the area orthogonally to the line)

d) light valve technology (MEMS).

These methods are described in the following patents:

US Patent US005247180A "Stereolithographic Apparatus and Method of use" by Texas Instruments Inc., September 1993;

US Patent US005980813A "Rapid Prototyping using multiple materials" by SRI International, November 1999;

Utility model publication DE G 93 19 405.6 "Device for the production of a three-dimensional object (model) according to the principle of photo solidification" by the Research Center Informatics at the University of Karlsruhe, December 1993;

According to a similar method, the utility model publication DE 299 11 122 U1 "Device for producing a three-dimensional object", DeltaMed inter alia, June 1999 describes an application for the generation of micro-technical, three-dimensional components.

EP 1250997A (=US2002155189A) "Device for producing a three-dimensional object" by Envision Technologies GmbH, April 2002.

German Patent DE69909136T "Rapid Prototyping Device and Rapid Prototyping Method", July 2003 (equivalent: European Patent EP 1156922 "Rapid Prototyping Apparatus and Method of Rapid Prototyping", August 2003) of DICON AS Lystrup, Denmark.

WO 01/00390 A by HAP, Sitec Industrietechnologie and DELTAMED Medizinprodukte GmbH.

WO 2005/110722 A of Envisiontec GmbH.

With laser-based systems for photo-polymerization, the light output in the exposure point is provided by the energy setting of the laser beam, whereby the hardening depth of the solidifiable material, such as the photopolymer, can be controlled in that point.

For selective hardening, the laser beam is scanned over the cross-sectional area to be correspondingly hardened. The contours of the cross-sectional area to be hardened can be scanned by the laser beam as a curve.

A cross-sectional area is typically exposed at once with systems for photo-polymerization based on mask projection by means of projection systems, especially with the SLM technology. The white areas of the projected image harden the solidifiable material (normally a photopolymer); the black areas do not. The contours of the cross-sectional area to be hardened can only be presented in rasters; the resolution depends on the number of image points or, respectively, pixels and on the size of the projected image.

With the above mentioned WO 01/00390 A, the intensity of beams is controlled by controlling the permeability of the mask, wherein the intensity may be controlled via the selection of gray levels of a transmission LCD. An allocation by different intensities is, however, performed with respect to a layer only depending on whether solidified regions are underneath or not. There is no mentioning in WO 01/00390 of an adjustment and/or a control of an energy input in a voxel matrix as according to the present invention. The present invention deals with resolution and fine adjustment in a voxel matrix; while grey level gradation depending on whether an underneath hardened layer is absent or present for connection is not required in the present invention.

In WO 2005/110722 A, a multiple exposure is carried out on the subpixel level for improving the resolution along the outside and inside contours of the cross-sectional areas of the object to be generated, said exposure consisting of a sequence of a plurality of images offset on the subpixel level in the image/building plane, wherein a separate mask/bitmap is generated for every offset image. A gray level adjustment is taken into account for the contour pixels obtained by the subpixel offset. There is neither any mentioning in WO 2005/110722 A of an adjustment and/or a control of an energy input in a voxel matrix as according to the present invention.

Neither WO 01/00390 A nor WO 2005/110722 show how the resolution and the fine adjustment in the image plane can be improved, and how native inhomogeneities of the light source can be balanced better.

OBJECT OF THE INVENTION

It is the object of the invention to improve device and method for the production of a three-dimensional object by solidification of a material solidifiable under the action of electromagnetic radiation, by means of energy input via an imaging unit comprising a predetermined number of discrete imaging elements (pixels) so that a higher precision, higher resolution and fine adjustment and/or a higher homogeneity of the system will be realized.

SOLUTION OF THE PROBLEM

In a first embodiment, the invention provides a device for the production of a three-dimensional object by solidification of a material solidifiable under the action of electromagnetic radiation by means of energy input via an imaging unit comprising a predetermined number of discrete imaging elements (pixels), said device comprising a computer unit, an IC and/or a software implementation respectively with the ability of adjusting and/or controlling the energy input via a specific gray value and/or color value.

It has been found to be particularly advantageous to selectively adjust and/or control the energy input via a specific grey value and/or color value in a voxel matrix. Further preferably, a raster mask (bitmap) is used without pixel shift.

In the present invention, the term voxel matrix means a rastered arrangement of solidified voxels (volume pixels), wherein a voxel images an image point of a pixel matrix, and the hardening depth per voxel depends on the energy input per image point.

In a preferred development of the first embodiment, the capability for adjusting and/or controlling a specific gray value and/or color value can be advantageously provided specifically and individually per pixel.

In a second embodiment, the invention further provides a device for the production of a three-dimensional object by means of solidification of a material solidifiable under the action of electromagnetic radiation by means of energy input via a raster imaging unit comprising a predetermined number of discrete imaging elements (pixels) arranged as a dot, a line or as a matrix, wherein the imaging unit composes the image from the pixels and thus forms a raster mask (bitmap), wherein the imaging unit is designed such that at least one part of the pixels can be allocated to more than two energy levels for a variable energy input. Also in this second embodiment, it has been found to be particularly advantageous to selectively adjust and/or control the energy input via a specific grey value and/or color value in a voxel matrix. Further preferably, a raster mask (bitmap) is used without pixel shift.

The allocation is suitably provided by the supply or, respectively, provision of more than two energy levels per bitmap and preferably specifically per pixel. In a preferred development of the second embodiment, the design of the imaging unit can be advantageously such that the allocation or, respectively, the classification of pixels into the more than two energy levels can be provided specifically and individually per pixel.

The more than two energy levels preferably include:

a1) ON and OFF states, by an essentially complete energy transmission (white) or, respectively, by an essentially complete energy blocking without energy transmission (black), in transmissive systems (especially with light valves); or

a2) ON and OFF states, by an essentially complete energy reflection into the optical axis (white in the projection image) or, respectively, by an essentially complete reflection out of the optical axis into an optical absorber (black in the projection image), in reflexive systems (in particular in a Digital Micromirror Device [DMD] or a Liquid Crystal on Silicon [LCoS] for digital light processing [DLP]); and additionally

b1) a predetermined, desired number of gray levels, or

b2) a predetermined, desired number of color values. The color values can represent a color tone and/or a color density or, respectively, intensity.

In accordance with the invention, the adjustment or setting via color values in comparison with gray values can be particularly advantageous because a significantly better fine adjustment will then be possible, specifically in relation to the photopolymer correspondingly used.

In a preferred development of the first and second embodiments, the imaging unit of the device can be included in a projection unit. The imaging unit is typically designed such that the number of pixels is constant and is arranged in the plane in a mutually spatially fixed manner.

In a preferred development of the first and second embodiments, the imaging unit can be the device of the type of an emitting dot, an emitting line or an emitting matrix. A resolution improvement is particularly achieved when the imaging unit comprises a Spatial Light Modulator (SLM) or light valves in MEMS technology or LEDs.

The present invention furthermore provides a method for the production of a three-dimensional object by means of solidifying a material solidifiable under the action of electromagnetic radiation by means of energy input via an imaging unit comprising a predetermined number of discrete imagining elements (pixels), wherein the light output for solidification of the material is controlled for at least a part of the pixels via a defined gray value and/or color value. Due to this measure, the depth of penetration of the electromagnetic radiation for solidifying the material can be advantageously set significantly finer and variable and precisely per pixel by selectively adjusting and/or controlling the energy input via a specific grey value and/or color value in a voxel matrix, preferably a raster mask (bitmap) being used without pixel shift.

Information on gray value and/or color value can be stored in the raster image (bitmap) per image point (pixel).

In a preferred embodiment of the method according to the invention, the exposure mask or, respectively, the image will be projected by means of a projection unit into the building plane for the solidification of the material.

In a preferred embodiment of the device and the method according to the invention, a compensation mask is generated with gray values for the entire projection image on the basis of the measured native light output distribution, said compensation mask causing, in a superposition to the bitmap generated for the solidification, a homogeneous distribution of the light output over the entire projection image. The homogeneity of the light output distribution will thus be considerably improved. When the measurement of the native light output distribution occurs in the projection image of the building plane, the generation of the compensation mask can occur independently of the bitmap generated in the building process and thus involves not only exposed but also unexposed surfaces.

In a preferred embodiment of the method according to the invention, the gray values in the compensation mask are interpolated between the measuring points, thus a more uniform gray value distribution is achieved over the entire compensation mask.

In a particularly preferred embodiment of the device and the method according to the invention, it is determined which pixels are overlapped how much by the graphics. Depending on the result of this determination, a correspondingly weighted gray value or a specific color value will be allocated pixel—specifically. Due to this measure, the resolution can be significantly improved for very fine structures. Alternatively or additionally, these measures take into account antialiasing in rastering a contour line, thus eliminating or, respectively, reducing the so-called aliasing artifacts in the edge/contour areas which develop with the rastering of vector graphics—here of the cross-sectional structure to be exposed. According to the invention, multiple exposure and/or a subpixel offset is not desired in this case.

In another, particularly preferred embodiment of the device and the method according to the invention, different areas of various area expansion will be identified in a cross-sectional image which was generated for solidification. The pixels of the respectively identified areas are allocated or provided with uniform gray values and/or color values so that gray value and/or color value extend over the corresponding areas. Thus, for example, larger area structures can be darkened according to their expansion, whereas smaller area structures are radiated lighter. Thus, a uniform hardening depth will be obtained over the entire cross-sectional image and thus over the entire area to be exposed.

In a preferred embodiment of the device and the method according to the invention, increased hardening of selected areas will occur through the single or multiple exposure of a voxel matrix, by providing a corresponding gray value/color value allocation within the voxel matrix. The hardening depth in the selected areas, which are allocated without or with a lower grey value/color value, is preferably several-fold, i.e. at least the three-fold, preferably at the least the four-fold, and further preferred by at least the five-fold of the hardening depth of the remaining areas.

In a preferred embodiment of the device and the method according to the invention, information regarding the gray value and/or the color value per image point (pixel) is calculated online on a current basis for each raster image (bitmap).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically shows a concept of the present invention concerning gray value or color value adjustment on a macroscopic level according to an embodiment using simple tiling by compensation mask;

FIG. **2** schematically shows another concept of the present invention concerning gray value or color value adjustment on a macroscopic level according to another embodiment, wherein interpolation is used between individual measuring points to generate a compensation mask.

FIG. **3** schematically shows a geometry of a model for a three-dimensional object comprising differently sized holes and cylinders, as a basis for the generation of a bitmap;

FIG. **4** schematically shows a comparison example of generating a bitmap without pixel-precise grey value or color value adjustment or control of the invention;

FIG. **5** schematically shows an example of generating a bitmap with pixel-precise grey value or color value adjustment or control on a microscopic level according to an embodiment of the present invention, the adjustment or control depending on a degree of overlapping of raster pixels by the vector graphic;

FIG. **6** shows, on the left-hand presentation, a vector-based starting image of a cross-sectional structure to be imaged, with superimposed raster (pixels are here represented as squares); on the right-hand presentation the generated bitmap based on raster graphic is shown, here with edge smoothing according to an embodiment of the present invention obtained by grey value or color value adjustment on a microscopic level depending on whether, and by which extend, pixels are crossed over by the graphics such that they are provided with a correspondingly weighted gray value;

FIG. **7** shows schematically a basic device which can be used for generating a three-dimensional object according to the present invention; wherein the three-dimensional object is built in the form of layers in this embodiment; and

FIG. **8** shows schematically a basic device which can be used for generating a three-dimensional object according to the present invention; wherein the three-dimensional object is built in this embodiment independent from layers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS AND THE ADVANTAGES OF THE INVENTION

Device and method according to the invention allow to improve the homogeneity of the light output distribution. Specifically, light output control by means of gray levels and/or color values on the macroscopic level or specifically at the pixel level on the microscopic level can improve the imaging performance by a bitmapping that determines a voxel matrix. Imaging losses can be reduced which are caused by a pure ON/OFF (BLACK/WHITE) raster. The resolution performance in the building plane is improved without having to increase the resolution of the imaging unit. Thus, the quality of the constructed component will be improved overall with regard to surface smoothness, accuracy of details, and tolerances.

Particularly in projection systems with SLM technology, the light output distribution over the image surface can be significantly improved (versus a conventional inhomogeneous distribution of possibly up to 50% in absolute terms). Accordingly, compared with the state of the art, the dependence or, respectively, the influence is reduced by means of the invention, with regard to a) the light source used; b) the optical system for coupling the light energy (specifically to the SLM) and c) the vignetting of the projection optics.

Even if the properties of the light source will change over time, this can be corrected according to the invention so that variable errors and changing homogeneity distributions can be compensated. If desired, even constant errors—which can be caused by the optical system for coupling the light energy to the SLM and the projection optics—can be prevented with the invention by compensating any homogeneity deviations.

If desired, with the concept according to the invention, the problem can also be dealt with that the light intensity varies depending on the size of the exposed area structure (higher light intensity with larger, contiguous areas, lower light intensity with small, filigree area structures) which is why—without the measure according to the invention—the inhomogeneity of the light output distribution in the projected image can result in corresponding deviations in the hardening depth of the photopolymer and thus in errors/deviations, imprecisions in the component upon the application of mask projection by means of the SLM technology.

By means of the gray level control and/or the color value control, the light output distribution can be adjusted over the overall image (gray mask compensation), i.e. a macro-adjustment, but as well as on a pixel level, i.e. a micro-adjustment, but without changing the native condition of the light source and/or the imaging optics. Micro-adjustment is best done selectively, i.e. depending on the cross-sectional structure to be imaged, and during the generation of the bitmap of the cross sectional area for the voxel matrix currently produced.

Furthermore, a significantly better fine adjustment of the energy input can be achieved by means of the measure of allocating at least a part of the pixels more than two energy levels, providing, particularly in addition to the normal ON and OFF states (white/black), additional energy levels by a predetermined number of gray levels, preferably by a predetermined number of color values.

By means of the invention, operating conditions, particularly the hardening depth, also can be largely kept constant over the entire cross-sectional imaging structure, or can be specifically selectively manipulated for the purpose of overexposure or underexposure of selected areas, which will result in an improvement of the quality of the constructed component. A better resolution and a better fine adjustment will be achieved especially if the following are comprised as parameters for overexposure or underexposure:

- degree of overlapping of the raster pixels by the vector graphic; and/or
- size of the area of the cross-sectional image.

Also, deviations can be compensated which are caused e.g. by aging of the light source or other optical errors.

The gray level control and/or the color value control can be technically performed most suitably entirely by software. A computer unit such as a CPU, an IC and/or a software implementation respectively with the corresponding function can be used as suitable elements for this purpose. The system can thus be used very flexibly and for all mask projection systems based on SML technology.

Another major advantage is that the selective, pixel-precise light output adjustment can be provided, independent of the exposure time, by the gray level and/or color level control. Thus, the exposure time can advantageously remain constant for all bitmaps.

The invention will be described in more detail on the basis of further exemplary embodiments with reference to the attached Figures; however, the invention is by no means limited to the described embodiments and examples and drawings but can instead comprise any variations and modifications within the scope of the claims.

FIG. **7** shows schematically a basic device for generating a three-dimensional object **3** by hardening of a photo-hardening material **4** by means of mask projection **8**, wherein the projection unit **1** with imaging optics **2** is provided above basin **6** being filled with photo-hardening material **4** and hardens the object **3** on a support plate **5** which can be moved in vertical direction within the basin **6**.

In the illustrated embodiment, the building of the three-dimensional object **3** is carried out in layers. However, the building can be alternatively carried out independently from layers. Other design options are possible. For example, the hardening process can be carried out continuously without layers; discontinuously (either with same or different or variable layer thicknesses); partially continuously and partially discontinuously (discontinuously either with same or different or variable layer thicknesses); or in a combination of various possibilities. As an example, FIG. **8** schematically shows an illustrative embodiment as an alternative to the device shown in FIG. **7**, where same reference signs denote corresponding components but where the three-dimensional object **3** is built independent from any layers.

The device and process according to the present invention is particularly suitable for building a three-dimensional object independent from layers.

With a method based on photo-polymerization, the light radiation necessary for hardening will be projected into the processing plane. Exposure will be effected by means of a multimedia projector. The image is here composed of individual image points (pixels) to a so-called bitmap. The bitmap mask will be formed by a Spatial Light Modulator, wherein the pixels are arranged in a mutually spatially fixed manner in the plane. A currently typical, exemplary resolution for such semiconductor elements is SXGA+, 1400×1050 pixels.

Gray Level Control/Macro-Adjustment

Macro-adjustment concerns the balancing of native deviations in the light output distribution over the entire image area, which are caused by the optical system or, respectively, its error, by means of a gray or color mask compensation.

For this, multiple measuring values are recorded uniformly distributed over the entire image surface, and a compensation mask of gray values or color values is calculated, said compensation mask being laid over or superposed on each individually projected bitmap mask.

Due to this method, the homogeneity is improved at least by a factor of two.

The measurements can be either manually recorded or determined via a sensor matrix.

Simple tiling can be used with the compensation mask (FIG. **1**) as one embodiment of the compensation mask; as another embodiment, the compensation gray values or color values between the individual measuring points can be interpolated (FIG. **2**) and thus a compensation mask can be generated with soft/continuous transitions between the individual measuring points.

Gray Level Control/Micro-Adjustment

Micro-adjustment concerns obtaining the most faithful image of the cross-sectional area to be projected with the maximum precision and to also keep the exposure and hardening parameters over the structure to be exposed either constant or to influence them specifically and pixel-precisely by gray-value or color-value controlled overexposure or underexposure.

Application Examples:

Pixel-Precise Adjustment of Gray Values with Structures Smaller than 3×3 Pixels to be Exposed in the Imaging Plane

With a structural size of 1.5×1.5 pixels, it can happen here that—due to an unfavorable pixel/bitmap distribution or, respectively raster with a purely black/white conversion—either only one pixel or even 3×3 pixels are switched white. With yet smaller structures in 1 pixel size, a complete loss of the structure to be imaged in the bitmap can even occur.

To prevent this, each pixel is allocated a corresponding gray value depending on the degree of overlapping by the structure to be imaged. This comes to bear especially in the contour area of the structure.

The principle is here presented on the basis of a structure which comprises small holes as well as small cylinders of various sizes (diameter 200, 500 and 1000 μm) (FIG. **3**), from whose cross-sectional areas one bitmap mask will be generated respectively.

From the resolution of the raster—here 1280×1024 pixels—and the size of the structural field—here 317.5×254 mm—a pixel size of 248 μm will result.

It should be noted that the smallest structure is here smaller than one pixel!

By means of two different bitmapping strategies, the improvement through gray value or color value adjustment will be shown:

Bitmapping Strategy with Purely Black/White Pixels

- The inside area of the contour is filled with pixels.
- Outside contours (mass on the inside) are filled with white pixels.
- Inside contours (hollow space on the inside) are filled with black pixels.
- Pixels touch the contour line only if the pixel is at least 50% covered over by the inside area.

The bitmap thus generated (FIG. **4**) shows clearly missing structures of the size 200 μm in diameter.

The reason is that with these structures, which do not appear in the bitmap, no pixel will be covered by more than 50%, depending on their position in the raster.

Dimensions:

Original diameter	Bitmap presentation "hole"		Bitmap presentation "cylinder"	
200 μm	1 pixel	248 μm	1 pixel	248 μm
500 μm	2 pixels	496 μm	2 pixels	496 μm
1000 μm	4 pixels	992 μm	4 pixels	992 μm

Bitmapping Strategy with Pixel-Precise Gray Value Adjustment:

- The inside area of the contour is filled with pixels.
- Outside contours (mass on the inside) are filled with "light" pixels.

Inside contours (hollow space on the inside) are filled with "dark" pixels.

The pixel lightness or, respectively, its gray value depends on the degree of overlapping by the inside area.

The thus generated bitmap (FIG. **5**) will render all structures/geometries visible. The 200 μm cylinders are too dark and the 200 μm holes are too light. The reason for it is that, no pixel will appear overlapped at 100% and thus no pixel will be presented 100% white (with outside contours) or 100% black (with inside contours), depending on the position of the contours in the pixel raster.

Dimensions:

Original diameter	Bitmap presentation "hole"		Bitmap presentation "cylinder"	
200 μm	~1 pixel	~248 μm	~1 pixel	~248 μm
500 μm	~2 pixels	~496 μm	~2 pixels	~496 μm
1000 μm	~4 pixels	~992 μm	~4 pixels	~992 μm

Smoothing the Outside and Inside Contours of the Structures to be Exposed

Here, the antialiasing effect already known in digital image processing will be utilized.

A known problem of rasterization is the alias effect. If a gray value depth of more than 1 bit is available for the raster graphics to be generated, this effect can be reduced by means of "edge smoothing" (antialiasing). Different B/W filter methods are available for this.

With antialiasing of the bitmap output, the so-called aliasing artifacts, an effect of aliasing, will be removed which occur in the raster of a vector graphic (here the cross-sectional structure to be exposed (FIG. **6**).

When drawing a line, only horizontal and vertical lines can be drawn without any problem whose line thickness is a multiple of the pixel space and whose starting and end point lies on a pixel. If a line is somewhat inclined, aliasing artifacts will inevitably occur. The same also happens with all round/free forms. The effect will become all the more pronounced, the coarser the resolution.

In antialiasing of vector graphics, it is taken into account which pixels are crossed over how much by the graphics; and they are provided with a correspondingly weighted gray value. The pixels are here usually viewed as squares. The more of the pixel surface is covered by the graphics, the lighter the gray value of the pixel will be adjusted. Special software filters are used for implementation.

By this method, the hardening behavior of the material will finally also be accordingly influenced, and a higher precision is thus achieved in the final component.

The imaging imprecision of the projection optics and the photopolymer can additionally exercise a deep pass filter function which can result, on the one hand, in a further smoothing effect of the component surface, but, on the other hand, also in a more imprecise component or, respectively, in a loss of detail.

Controlling the Hardening Depth by Means of the Gray Level Control as a Function of the Cross-Sectional Structure to be Imaged/Component Geometry to be Imaged

Hardening Depth with Large Surface Structures Versus Filigree Cross-Sectional Structures

With larger structure areas, more light output per area is available than with filigree structures; this phenomenon results in different hardening in xy-extension (beyond the contour) and z-extension (depth).

If, for example, a 10 mm×10 mm large surface is exposed once, it will harden e.g. to a thickness of 130 μm; however, with the same exposure time, a structure of 2 mm×10 mm will harden only 100 μm. If the component is now built for example in 100 μm layers or in a corresponding voxel matrix, it may happen that, in the filigree portion, the generated solidified material will not enter into sufficient chemical bonding through overexposure (130 μm depth hardening up to 30% into the preceding layer), that the hardened material will be separated in this portion, and that the component is defective. This phenomenon is particularly critical with filigree supporting structures.

Based on special algorithms, structures of different area expansions will be identified in the cross-sectional image and will be allocated pixel-precisely to corresponding gray values to obtain a uniform hardening depth (Z) and extension (XY) over the entire structural area to be exposed (larger area structures will here be darkened according to their extension).

Higher Green Compact Hardness with Massive Structures/Higher Material Accumulations Within One Component

With some components, there are volume portions with an accumulation of material whose wall thickness on the one hand exceeds the maximum possible hardening depth of the material in post-hardening or which are in a position within the component not reached by light energy or only to a limited extent in the post-hardening process.

Already during the generating process, such volume portions can achieve a higher green compact hardness by being specifically overexposed. This can be carried out by corresponding gray value or color value allocations in a voxel matrix, wherein the hardening depth in Z preferably exceeds a normal hardening depth several-fold.

For all applications described above, the bitmap mask/exposure mask can contain information on black/white, gray value, and or color information by which the exposure energy will be controlled. The individually described embodiments and examples can be combined in any way with each other.

The invention claimed is:

1. A device for producing a three-dimensional object from a solidifiable material comprising:

an imaging unit comprising a predetermined number of discrete imaging elements;

an imaging unit controller configured to control the discrete imaging elements, wherein each of the discrete imaging elements corresponds to a location on an exposed surface of the solidifiable material and projects electromagnetic radiation based on a corresponding scaled intensity value onto the corresponding location on the exposed surface of the solidifiable material, each scaled intensity value is based on a corresponding compensation light intensity value selected from the group consisting of a measured light intensity value and a light intensity value interpolated from measured light intensity values, each measured light intensity value is determined by measuring a light intensity at a selected location of the exposed surface of the solidifiable material, and each scaled intensity value is selected from the group consisting of a gray scale value and a color value.

2. The device of claim **1**, wherein the imaging unit controller receives data comprising a voxel matrix, and the voxel matrix includes the scaled intensity values corresponding to each location on the exposed surface of the solidifiable material.

3. The device of claim **1** wherein the imaging unit controller comprises at least one selected from the group consisting of a computer, an integrated circuit, and software.

4. The device of claim **1**, wherein the exposed surface of the solidifiable material comprises a plurality of regions, each region includes a plurality of the locations on the exposed surface of the solidifiable material, and the compensation light intensity value within each region is constant across all of the locations within the region.

5. The device of claim **4**, wherein the plurality of regions comprises a first subset of regions having a first exposed surface area and a second subset of regions having a second exposed surface area, the first exposed surface area is greater than the second exposed surface area, and the compensation light intensity value for the first subset of regions is greater than the compensation light intensity value for the second subset of regions.

6. The device of claim **1**, wherein each compensation light intensity value corresponds to one of the locations on the exposed surface of the solidifiable material and one of the discrete imaging elements.

7. The device of claim **1**, wherein the compensation light intensity values define a compensation mask.

8. The device of claim **1**, wherein when the imaging unit projects electromagnetic radiation having the scaled intensity values to each of the locations on the exposed surface of the solidifiable material corresponding to the scaled intensity values, a homogeneous light distribution among each of the locations is obtained.

9. The device of claim **1**, wherein the imaging unit controller determines a degree of overlap between each of the locations on the exposed surface of the solidifiable material and a graphic depicting the three-dimensional object, and each of the discrete imaging elements projects electromagnetic radiation onto the surface of the solidifiable material based on the corresponding compensation light intensity value and the corresponding degree of overlap with the graphic depicting the three-dimensional object.

10. The device of claim **1**, wherein the imaging unit is included in a projection unit.

11. The device of claim **1**, wherein the imaging unit is a spatial light modulator.

12. The device of claim **1**, wherein the imaging unit comprises light valves.

13. The device of claim **1**, wherein the imaging unit comprises light emitting diodes.

14. A method of producing a three-dimensional object from a solidifiable material, comprising:

projecting electromagnetic radiation to each location in a plurality of locations on an exposed surface of the solidifiable material based on a scaled intensity value corresponding to the locations, wherein each scaled intensity value is based on a corresponding compensation light intensity value selected from the group consisting of a measured light intensity value and a light intensity value interpolated from measured light intensity values, each measured light intensity value is determined by measuring a light intensity value at a selected location of the exposed surface of a solidifiable material, and each scaled intensity value is selected from the group consisting of a gray scale value and a color value.

15. The method of claim **14**, further comprising measuring a plurality of light intensity values at selected locations on the exposed surface of the solidifiable material to obtain the measured light intensity values.

16. The method of claim **15**, further comprising interpolating between the measured light intensity values to obtain the interpolated light intensity values.

17. The method of claim **14**, wherein the exposed surface of the solidifiable material comprises a plurality of regions, each region includes a plurality of the locations on the exposed surface of the solidifiable material and the compensation light intensity value within each region is constant across all of the locations within the region.

18. The method of claim **17**, wherein the plurality of regions comprises a first subset of regions having a first exposed surface area and a second subset of regions having a second exposed surface area, the first exposed surface area is greater than the second exposed surface area, and the compensation light intensity value for the first subset of regions is greater than the compensation intensity value for the second subset of regions.

19. The method of claim **14**, further comprising determining a degree of overlap between each of the locations on the exposed surface of the solidifiable material and a graphic depicting the three-dimensional object, wherein the projecting step comprises projecting electromagnetic radiation onto the locations on the exposed surface of the solidifiable material based on the corresponding compensation light intensity value and the corresponding degree of overlap with the graphic depicting the three-dimensional object.

20. The method of claim **14**, further comprising providing voxel matrix data, wherein the voxel matrix data includes the scaled intensity values corresponding to each location on the exposed surface of the solidifiable material.

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