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(71) Applicant: **PIXIUM VISION SA** [FR/FR]; 74 Rue du Faubourg Saint Antoine, 75012 Paris (FR).

(72) Inventors: **DURBAN, Bastien**; 38 bis rue Etienne Dolet, 75020 Paris (FR). **FLODERER, Jean-Baptiste**; 116 Boulevard de Menilmontant, 75020 Paris (FR). **DENEFLE, Maxime**; 1 rue Henri Clauteaux, 94370 Sucy en Brie (FR). **DETERRE, Martin**; 36, rue de Wattignies, 75012 Paris (FR).

(74) Agent: **VON STOSCH, Andreas** et al.; Prinzregentenstr. 22, 80538 München (DE).

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(54) Title: METHOD AND DEVICE FOR PROJECTING A PATTERN OF INTEREST ON A MODIFIED RETINAL AREA OF A HUMAN EYE

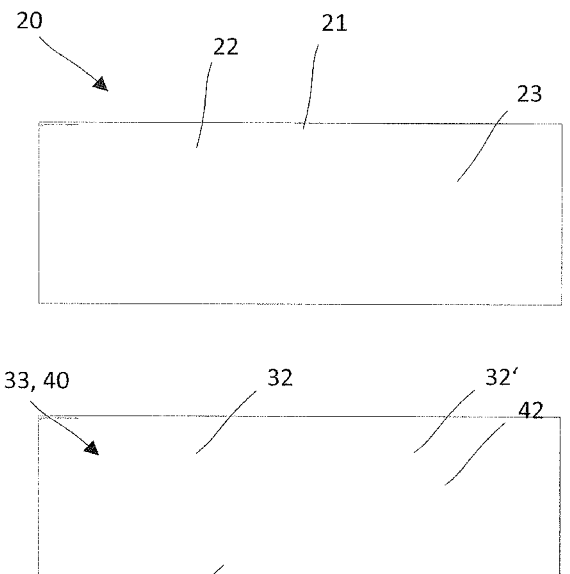

Fig. 3

(57) Abstract: The present invention pertains to a method for projecting a pattern of interest (6) on a modified retinal area (5) of a human eye, comprising the steps of providing a pulsed input light beam (20), modulation and dividing the pulsed input light beam (20) into a pulsed modulated light pattern of modulated pulsed sub-beams (40) based on a pattern of interest (6), wherein the modulated light pattern forms a pulsed output beam (4) reflecting the pattern of interest (6), wherein performing an individual pulse width modulation of a modulation duty cycle (32) of the modulated individual sub-beams (40) forming the output beam (4), and to correspondingly adapted device.

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Method and device for projecting a pattern of interest on a modified retinal area of a human eye

Technical Field

The invention relates to a method for projecting a pattern of interest on an area of a human retina that has been treated to restore its photosensitive characteristics, for instance via implantation of a retinal implant, and a corresponding device.

Technological Background

Retinal malfunction, particular caused by degenerative retinal diseases, is a leading reason for visual impairment or even blindness.

For at least partially restoring a patient's visual function, it is known to make use of modifications of a retinal area of the human eye, for instance by making use of a retinal implant or in other words retinal prosthesis. In this regard, several different types of retinal implants are known, which are based on different working principles.

Retinal implants have in common that they are usually placed subretinally, epiretinally, or suprachoroidally in the eye of the patient, such that they can replace in effect the damaged photoreceptors. In this regard, information about a visual scene is captured with a camera and then transmitted to an electrode array implanted in the retina.

Among common retinal implants, implants are known which comprise skin-penetrating wires. These wires introduce risks of infection and scarring. Thus, more modern implants use different wireless techniques, for instance by delivering power and visual information through inductive coils. Furthermore, it is known to deliver power inductively and visual information optically through the pupil of the eye, or to deliver both visual information and power optically.

A particularly beneficial type of wireless information transfer retinal implants is based on projecting stimulation patterns of preferably infrared light into the eye. When the gaze direction is such that some part of the implants is illuminated by part of the pattern, the implant converts that part of the signal to electrical current that stimulates the retina accordingly.

The retinal implant is an array composed of stimulation electrodes or pixels. Each pixel has one or several photodiodes that capture the light delivered from a visual processor and converts it into electrical current for stimulation.

Several implant arrays can be placed in the subretinal space, typically in or close to the foveal area.

Alternatively, an approach, known as optogenetics, has been proposed to treat the residual retinal cells to restore their photosensitive behavior by gene therapy.

In the following paragraphs of this patent, such a retinal area of the human eye that has been modified to restore photosensitive behavior through implantation of a retinal prosthesis or modification by optogenetics will be referred to as "modified retinal area".

For projecting light or a light beam, respectively, into a human eye, it is known to use a projector device, such as augmented reality goggles. A projector unit, for example projector otics, of the projector device projects a pulsed light beam onto and at least partially into the human eye. That is, the picture to be transmitted is transferred into the eye through its eye pupil and towards the retina.
Although it thereby is possible to provide the patient with an illuminated pattern of interest, the patient is merely able to sense a single light/dark contrast, as the irradiation is constant for each pulse of the pulsed light beam.

Summary of the invention

It is an object of the present invention to provide an improved method for projecting a pattern of interest on a modified retinal area of a human eye , and a corresponding device for projecting a pattern of interest on this modified retinal area.

The above object is solved by means of a method for projecting a pattern of interest on a modified retinal area of a human eye comprising the features of claim 1. Further preferred embodiments are presented in the dependent claims, the description and the figures.

Accordingly, in a first aspect, a method for projecting a pattern of interest on a modified retinal area of a human eye or a method of operating a device as described herein for projecting a pattern of interest is suggested, which comprises the steps of providing a pulsed input light beam, preferably comprising coherent light or incoherent light and/or preferably light having a wavelength in the near infrared field, and modulating and dividing the pulsed input light beam into a pulsed and modulated light pattern of modulated pulsed sub-beams based on the pattern of interest, wherein the modulated light pattern forms a pulsed output beam reflecting the pattern of interest. The method is characterized by the step of performing an individual pulse width modulation of a modulation duty cycle of the modulated individual sub-beams forming the output beam.

By the individual pulse width modulation of the individual sub-beams, an irradiation duration of each sub-beam can individually be controlled, as the modulation duty cycle of each sub-beam can be individually and separately adjusted. That is, for each period of the pulsed output beam, the irradiation duration at a retinal implant the output beam is directed to can be varied within the output beam, as each sub-beam may comprise an individual duty cycle. Hence, the photodiodes of the retinal implant may be exposed to different irradiation durations which in turn lead to different stimulation currents and/or different durations of stimulation of the retina. Thereby, a grey level perception on the projected pattern irradiated via the output beam may be achieved. With other words, thus, it may be possible to illuminate the retina with patterns that are converted into different perceived grey levels within one pulse period. Hence, a patient provided with an according photosensitive retinal implant may be able to sense or perceive at least a rudimentary grayscale image. The latter may improve or facilitate orientation of the patient and may increase the visual faculty.

A pattern of interest here may be based on a picture or image which is captured and which is to be projected, wherein the picture or image may comprise dark and bright zones, preferably pixels, comprising different brightness values.

Preferably, the modified retinal area may be provided via implantation of a retinal prothesis.

According to a further exemplary embodiment, the input light beam comprises a constant peak irradiance. Thereby, the irradiance hitting the retinal implant may be precisely identified, determined and/or calculated. Hence, both reliable operation of the retinal implant and prevention of damages at the retina due to an unknown excessive irradiance may be achieved.

Alternatively or in addition, the input light beam may comprise substantially the form of a pulse wave, as a such formed light beam may bear the advantage of a substantially constant irradiation during each duty cycle.

Preferably, the input light beam comprises a constant period.

According to another preferred embodiment, the input light beam comprises a constant duty cycle. Alternatively, the duty cycle of the input light beam is controlled.

Optimal adaption of a grayscale distribution inside the output beam may be achieved when, according to yet another preferred embodiment, a modulation period is synchronized with the period of the pulsed input light beam. With other words, a period of the pulse width modulation and hence of the sub- beams, which correspond to the modulation period, is synchronized with the period of the pulsed input light beam.

The method may be optimized in that, according to another preferred embodiment, a maximum individual modulation duty cycle of the individual sub-beams corresponds to the duty cycle of the pulsed input light beam.

To prevent damages at the retina due to an excessive irradiation, the duty cycle of the pulsed input light beam may preferably be equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 of the period of the pulsed input light beam, and/or a maximum possible duty cycle of the sub-beams may preferably be equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 of the period of the pulsed input light beam.

According to another preferred embodiment, the pattern of interest is obtained by capturing visual information, preferably an image, and dividing the captured visual information, preferably the captured image, into a pattern of pixels forming the pattern of interest, wherein the pixels at least reflect different brightness values if present within the visual information, preferably within the image.

Preferably an optional image processing of the captured image is performed prior to allocating the brightness values to pixels or regions of the processed image.

The above object is furthermore solved by means of a device for projecting a pattern of interest on a modified retinal area preferably comprising a retinal implant, of a human eye comprising the features of claim 7. Further preferred embodiments are presented in the dependent claims, the description, and the figures.

Accordingly, in a second aspect, a device for projecting a pattern of interest on a modified retinal area of a human eye is suggested, comprising a light source for providing a pulsed input light beam, preferably a light beam of preferably coherent light or incoherent light, preferably light having a wavelength in the near infrared field, and a modulation micromirror array for modulating and dividing the pulsed input light beam into a modulated light pattern of modulated pulsed sub-beams, wherein an orientation of each of the micromirrors of the micromirror array is individually controllable based on the pattern of interest, such that the sub-beams form a pulsed output beam reflecting the pattern of interest. The device further is formed and adapted to perform an individual pulse width modulation of the sub-beams forming the output beam by individually controlling a modulated duty cycle of the individual micromirrors.

By means of the device, the effects and advantages described with respect to the method above may be achieved.

According to a preferred embodiment, the device is further adapted such that a modulation period of the orientation control of the micromirrors is synchronized with the period of the pulsed input light beam.

For synchronization of the modulation by means of the micromirror array and the input light beam pulsing, a maximum individual modulation duty cycle of the micromirrors may preferably correspond to the duty cycle of the pulsed input light beam.

For prevention of damages at the retina caused by the output light beam, the duty cycle of the pulsed input light beam may preferably be set equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 to the period of the pulsed input light beam, and/or a maximum possible modulation duty cycle of the sub-beams may preferably be equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 to the period of the pulsed input light beam.

According to another preferred embodiment, the device may further comprise a camera for capturing visual information, preferably an image, and/or a processing unit for dividing the captured visual information, preferably the captured image, into a pattern of pixels forming the pattern of interest, wherein the pixels at least reflect different brightness values if present within the visual information, preferably within the image.

Brief description of the drawings

The present disclosure will be more readily appreciated by reference to the following detailed description when being considered in connection with the accompanying drawings in which:

Figure 1 schematically shows a device for projecting a pattern of interest on a photosensitive modified retinal area of a human eye;

Figure 2 schematically shows a detailed view of the pattern of interest of figure 1 being an illuminated region of the modified retinal area;

Figure 3 schematically shows a pulsed input light beam comprising the shape of a pulsed wave and a corresponding modulated pulsed sub-beam;

Figure 4 schematically shows another input light beam having substantially the form of a pulse wave and corresponding micromirror pulsing for three different micromirrors, resulting in three different sub- beams; and

Figure 5 shows schematically an example for zones of the pattern of interest projected at a retinal implant via the sub-beams of figure 5.

Detailed description of preferred embodiments

In the following, the invention will be explained in more detail with reference to the accompanying figures. In the Figures, like elements are denoted by identical reference numerals and repeated description thereof may be omitted in order to avoid redundancies.

Figure 1 schematically shows a device 1 for projecting a pattern of interest 6 on a modified retinal area 5 of a human eye. The device 1 comprises a light source 2 which provides a pulsed input light beam 20 comprising light having a wavelength in the near infrared field.

The input light beam 20 is directed onto a modulation micromirror array 3 comprising a plurality of micromirrors 3 which can individually be operated such that an orientation of each of the micromirrors 30 can individually be adjusted and/or controlled. The modulation micromirror array 3 according to this specific embodiment is provided in form of a per se known digital micromirror device.

By means of the micromirror array 3, the input light beam 20 is reflected thereby forming an output beam 4. The output beam 4 consists of a plurality of sub-beams 40, into which the input beam 20 is divided when hitting on the individual micromirrors 30 of the micromirror array 3. The orientation of the micromirrors 30 is individually adjusted, such that a pattern of interest 6 which is to be projected onto a modified retinal area 5 are reflected by the plurality of sub- beams 40.

In this regard, the pattern of interest 6 is based on an image captured by a camera (not shown) which has been processed into a digital pattern of pixels, wherein the pixels comprise a grayscale value corresponding to a brightness value of the respective region of the image. Such data processing is per se known.

That is, only those micromirrors 30 which corresponds to a pixel comprising a brightness value above a predetermined threshold value are controlled to reflect the input light beam 20, wherein micromirrors 30 corresponding to pixels comprising a brightness value below the predetermined threshold value are oriented such that they do not contribute to forming the output beam 4.

Optionally, the retinal area 5 may comprise a retinal implant, preferably a photosensitive retinal implant.

Hence, the output beam 4 substantially reflects the pattern of interest 6. When the output beam 4 hits the modified retinal area, only those parts of the modified retinal area 5 comprising the retinal implant are illuminated by means of the output beam 4 or in particular the sub- beams 40, which reflect the pattern of interest at the retinal implant. Consequently, only those photosensitive diodes of the retinal implant convert light into electric current, which are arranged in the projected pattern of interest 6. A person comprising the retinal implant, thus, can perceive the pattern of interest 6.

Figure 2 schematically shows a detailed view of a pattern of interest 6 being an illuminated region of the modified retinal area 5.

The input light beam 20 is pulsed having a waveform comprising the shape of a pulsed wave, as can be taken for instance from figure 3. The light beam 20 is pulsed by means of the light source 2 in that it comprises a constant irradiation 23, which is irradiated during each duty cycle 22 in each period 21 of the wave of the light beam 20.

Accordingly, as the output beam 4 is essentially based on the input beam 20, also the output beam 4 is pulsed, wherein a period of the output beam 4 and also a duty cycle of the output beam 4 generally corresponds to the period 21 and the duty cycle 22 of the input light beam 20. Hence, the pattern of interest 6 comprises an even irradiation over its entire surface, as depicted in figure 2.

In order to achieve the ability to provide also grayscale information into the output beam 4, the device 1 is furthermore formed and adapted to perform a pulse width modulation individually for each of the sub- beams 40. The latter is achieved by individually controlling a modulation duty cycle 32 of each of the individual micromirrors 30.

With other words, the time each of the micromirrors 30 is oriented in a position such that it reflects the input light beam 20 and thereby providing a sub- beam 40 contributing to the output beam 4 may be individually set different for each micromirror 30 depending on the corresponding grayscale level of the pixel in the pattern of interest 6 correlated to the respective micromirror 30.

In this regard, the pulse width modulation is performed, such that for each micromirror pulsing cycle, the modulation duty cycle 32 may individually adjusted. That is, when a camera keeps constantly capturing images, a change in the brightness level of a pixel may lead to a change of the modulation duty cycle 32. Hence, when the brightness level increases, also the modulation duty cycle 32 is correspondingly increased, or vice versa.

Preferably, as shown in figure 3, a modulation period 31 of the micromirror pulsing 33, which corresponds to an output beam period 41, is synchronized with the period 21 of the input light beam 20. Moreover, optionally, a maximum possible modulation duty cycle 32 of the micromirrors 30 is set to correspond to the constant duty cycle 22 of the input light beam 20.

Thereby, it may be achieved that no operation of micromirrors 30 is performed, when the light source 2 does not provide irradiance. This may hence safe operation power of the device 1.

In figure 3, two subsequence micromirror pulsing cycles for an individual micromirror 30, and hence for a sub- beam 40 are shown. The first shown modulation duty cycle 32 is smaller than the second shown modulation duty cycle 32′, wherein the irradiance 42 is constant for each modulation duty cycle 32, 32′. Hence, a patient comprising the retinal implant will perceive the respective zone of the image to become brighter.

As can be furthermore seen in this figure, both modulation duty cycles 32, 32′ are shorter than the duty cycle 22. Hence, the patient perceives a brightness level lower than a maximum possible perceivable brightness. For safety reasons, the duty circle 22 is limited to 30% of the period 21, thereby preventing damages at the retina due to an excessive irradiation.

In order to provide a redundant safety system, also the duty cycle 32 of the micromirrors 30 is limited to be 30% of the period 21 or the modulation period 31, respectively. Hence, in case the light source erroneously emits a constant light beam, the maximum possible duty cycle of the output beam 4 is limited to the duty cycle 32 of the micromirrors 30. Hence, even if the safety setting for the light source 2 fails, it can be achieved that no excessive irradiance hits the retina. Moreover, also if the micromirrors 30 fail to pulse and/or are stuck in an "ON" position, the source pulsing forbids to have a pulse duration of the output light beam 4 higher than the source pulse duration, that is than duty circle 22.

Figure 4 shows an exemplary embodiment of a waveform of an input light beam 20 having substantially the form of a pulse wave comprising a constant source irradiance 23, a constant duty cycle 22 of the pulse 24, and a constant period 21.

Below the wave form of the input light beam 20, micromirror pulsing 33, 33′, 33′′ for three different micromirrors 30 is shown, resulting in three different sub- beams 40, 40′, 40″.

The micromirror pulsing 33, 33′, 33″ distinguish from each other in that their duty cycles 32, 32′, 32″ of the corresponding pulses 34, 34′, 34′′ differ.

That is, the radiant power of each of the sub- beams 40, 40′, 40″ distinguished from the others, wherein the first sub- beam 40 comprises a lower radiant power than the second and the third sub- beams 40′, 40″, and the second sub- beam 40′ comprises a lower radiant power than the third sub- beam 40″.

Consequently, when for instance a first zone 61 of the pattern of interest 6 is irradiated with sub- beams corresponding to sub- beam 40, a patient comprising the retinal implant perceives a darker greyscale value than in a second zone 62 irradiated with sub- beams corresponding to sub- beam 40′, and a third zone 63 irradiated with sub- beams corresponding to sub- beam 40″, wherein the latter comprises the brightest grayscale value.

An example for the above-mentioned zones 61, 62, 63 of the pattern of interest 6 projected at a modified retinal area 5 comprising retinal implant can be taken from figure 5.

Hence, by the above described device 1 and a corresponding method, it is possible to provide a patient comprising a photosensitive retinal implant with patterns that have different grey levels.

Moreover, by the aforementioned, power consumption for performing the method and/or for operation of the device 1 can be reduced and/or optimized, since the light source can be switched off between pulses and therefore consume less energy between pulses and thus reduce power consumption.

It will be obvious for a person skilled in the art that these embodiments and items only depict examples of a plurality of possibilities. Hence, the embodiments shown here should not be understood to form a limitation of these features and configurations. Any possible combination and configuration of the described features can be chosen according to the scope of the invention.

List of reference numerals

1	Device
2	light source
20	input light beam
21	period
22	duty cycle
23	irradiance
24	pulse
3	micromirror array
30	micromirror
31	modulation period
32	modulation duty cycle
33	micromirror pulsing
34	pulse
4	output beam
40	sub-beam
41	output beam period
42	irradiance
5	modified retinal area 6 pattern of interest
61	first zone
62	second zone
63	third zone

Claims

1. Method for projecting a pattern of interest (6) on a modified retinal area (5) of a human eye, comprising:

   - Providing a pulsed input light beam (20),
   - Modulating and dividing the pulsed input light beam (20) into a pulsed and modulated light pattern of modulated pulsed sub-beams (40) based on a pattern of interest (6), wherein the modulated light pattern forms a pulsed output beam (4) reflecting the pattern of interest (6),

   characterized by

   performing an individual pulse width modulation of a modulation duty cycle (32) of the modulated individual sub-beams (40) forming the output beam (4).

2. Method according to claim 1, wherein the input light beam (20) comprises a constant peak irradiance (23), and/or the input light beam (20) comprises substantially the form of a pulse wave, and/or the input light beam (20) comprises a constant period (21), and/or the input light beam (20) comprises a constant duty cycle (22) or the duty cycle (22) of the input light beam (21) is controlled.

3. Method according to any one of the preceding claims, wherein a modulation period (31) is synchronized with the period (21) of the pulsed input light beam (20).

4. Method according to any one of the preceding claims, wherein a maximum individual modulation duty cycle (32) of the individual sub-beams (4) corresponds to the duty cycle (22) of the pulsed input light beam (20).

5. Method according to any one of the preceding claims, wherein the duty cycle (22) of the pulsed input light beam (20) is equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 to the period (21) of the pulsed input light beam (20), and/or a maximum possible modulation duty cycle of the sub-beams (40) is

equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 to the period (21) of the pulsed input light beam (20).

6. Method according to any one of the preceding claims, wherein the pattern of interest (6) is obtained by capturing visual information, preferably an image, and dividing the captured visual information into a pattern of pixels forming the pattern of interest (6), wherein the pixels at least reflect different brightness values if present within the visual information.

7. Device (1) for projecting a pattern of interest (6) on a modified retinal area (5) of a human eye, comprising

   - a light source (2) for providing a pulsed input light beam (20),
   - a modulation micromirror array (3) for modulating and dividing the pulsed input light beam (20) into a modulated light pattern of modulated pulsed sub-beams (40), wherein an orientation of each of the micromirrors (30) of the micromirror array (3) is individually controllable based on a pattern of interest (6), such that the sub-beams form a pulsed output beam (4) reflecting the pattern of interest (6),

   characterized in that
   the device (1) is formed and adapted to perform an individual pulse width modulation of the sub-beams (40) forming the output beam (4) by individually controlling a modulation duty cycle (32) of the individual micromirrors (30).

8. Device (1) according to the preceding claim, being further adapted such that a modulation period (31) of the orientation control of the micromirrors (30) is synchronized with the period (21) of the pulsed input light beam (20).

9. Device according to any one of claims 7 or 8, wherein a maximum individual modulation duty cycle (32) of the micromirrors (30) corresponds to the duty cycle (22) of the pulsed input light beam (20).

10. Device (1) according to any one of claims 7 to 9, wherein the duty cycle (22) of the pulsed input light beam (20) is equal to or smaller than 0.5, preferably 0.4,

particularly preferably 0.3 to the period (21) of the pulsed input light beam (20), and/or a maximum possible modulation duty cycle (32) of the sub-beams (40) is equal to or smaller than 0.5, preferably 0.4, particularly preferably 0.3 to the period (21) of the pulsed input light beam (20).

11. Device (1) according to any one of the preceding claims, further comprising a camera for capturing visual information, preferably an image, and/or a processing unit for dividing the captured visual information into a pattern of pixels forming the pattern of interest (6), wherein the pixels at least reflect different brightness values if present within the visual information.

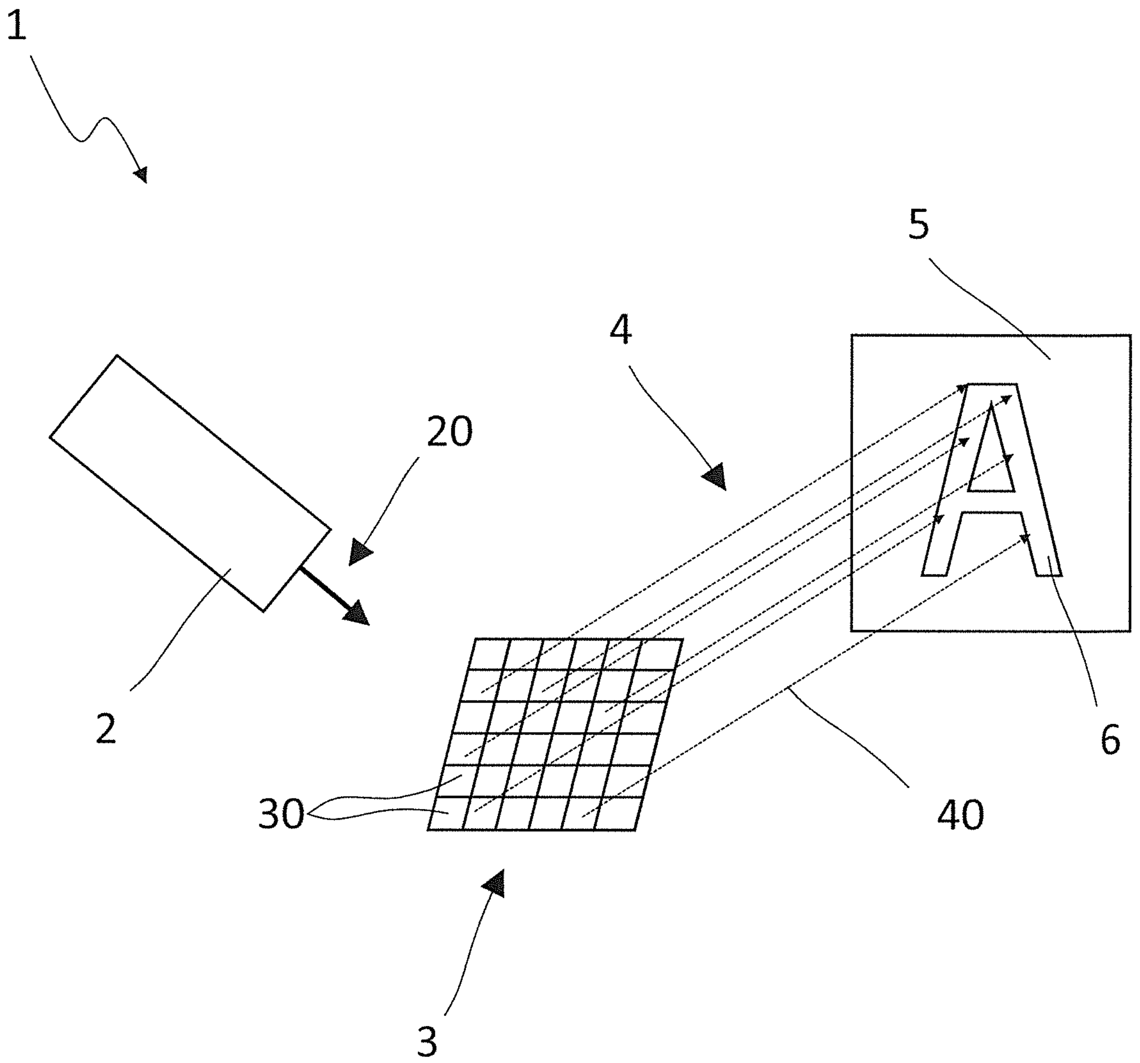


Fig. 1

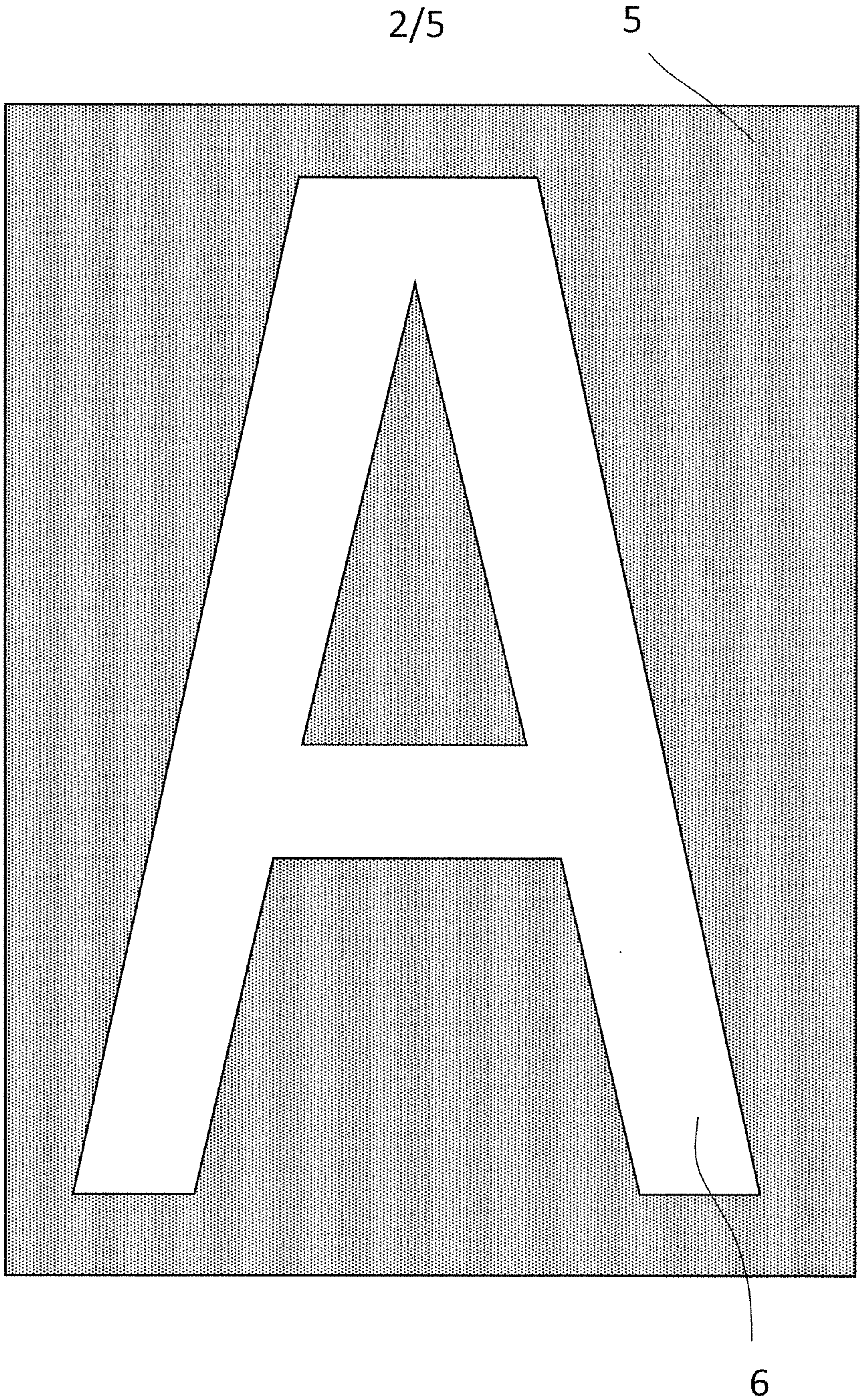


Fig. 2

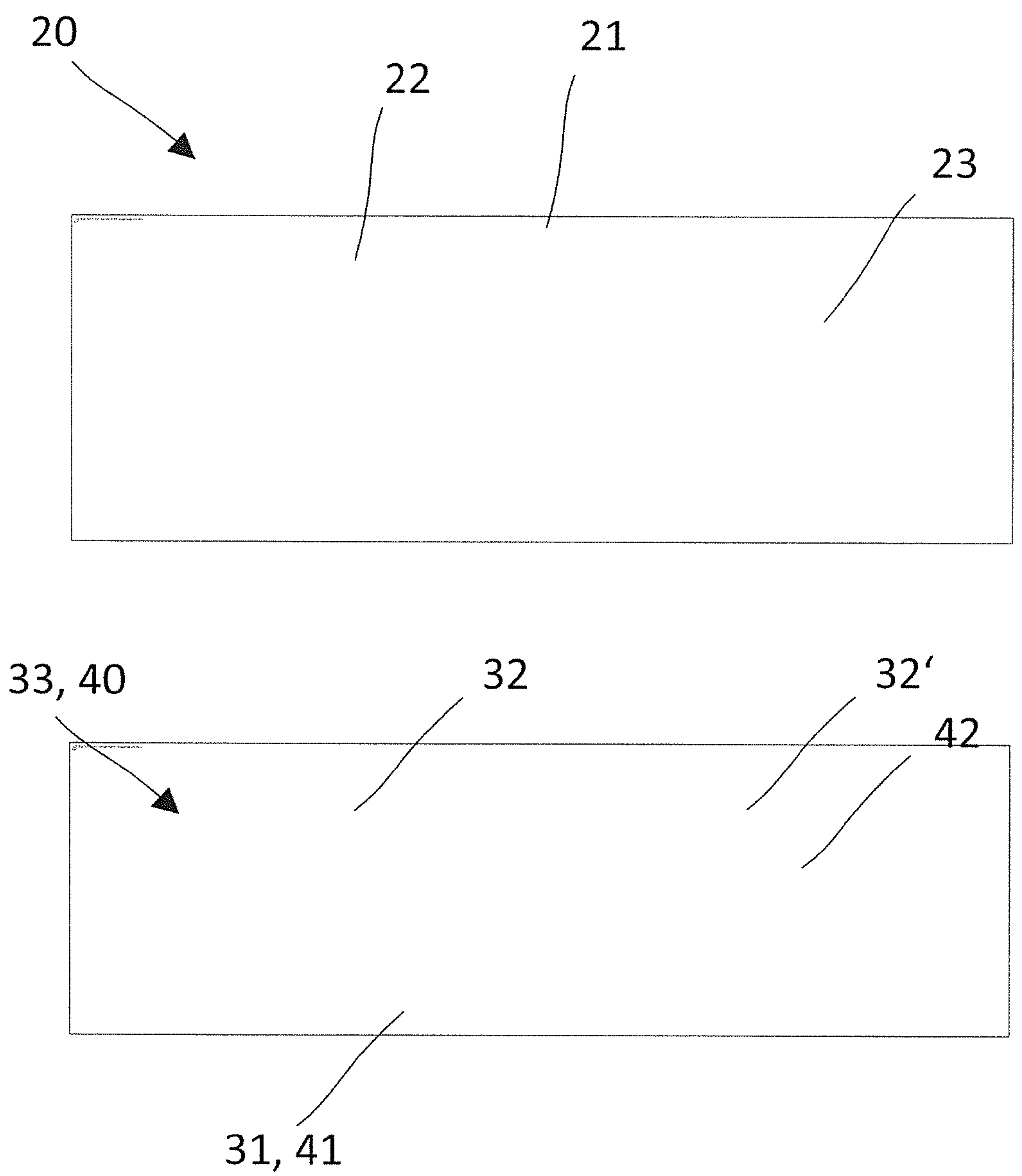
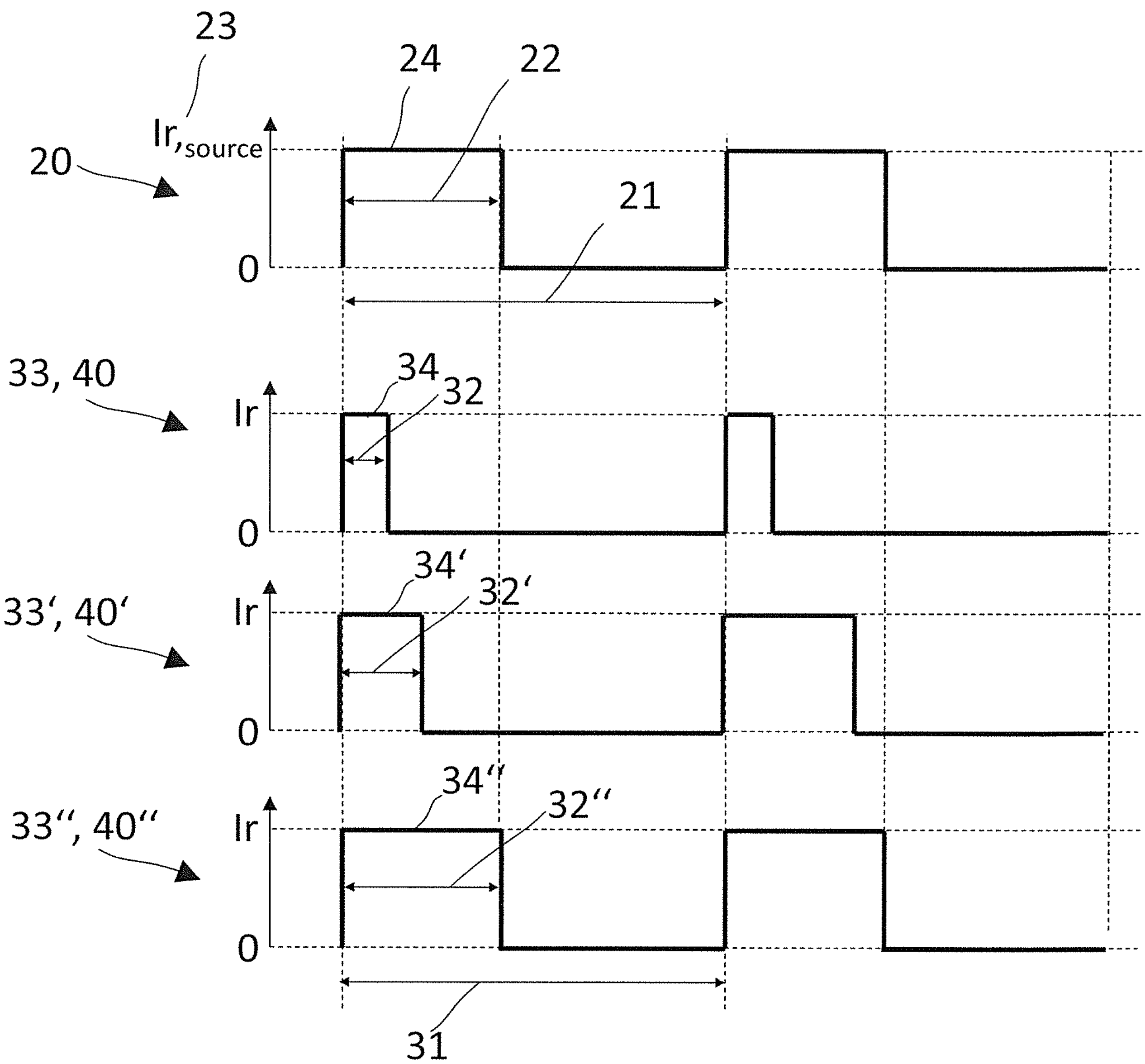


Fig. 3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34''
33'', 40''
32''
Ir
0
31

Fig. 4

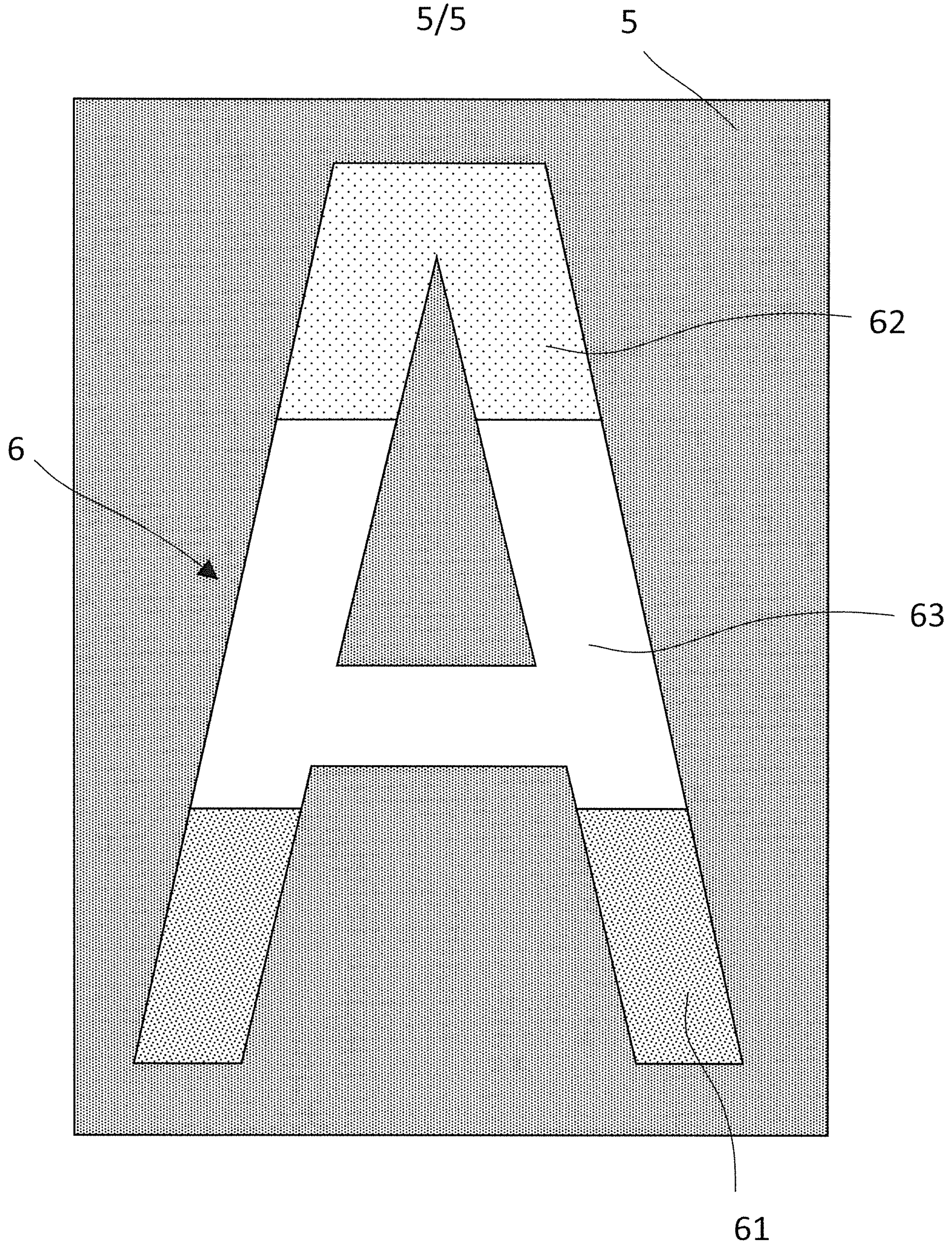

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/057967

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B3/00
ADD.

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)
A61B 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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/234187 A1 (LEE VINCENT [US]) 20 August 2015 (2015-08-20) abstract; claim 4; figures 1,8A paragraphs [0054], [0058], [0059] -----	1-11
X	US 2003/181957 A1 (GREENBERG ROBERT J [US] ET AL) 25 September 2003 (2003-09-25) abstract; claims 2,8,17 paragraphs [0053], [0054] -----	1-11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
18 December 2019	13/01/2020

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/057967

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