



Reconfigurable thz polarizer

Chigrin, Dmitry N.; Zhukovsky, Sergei; Lavrinenko, Andrei; Malureanu, Radu; Zalkovskij, Maksim

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- (71) Applicant: **DANMARKS TEKNISKE UNIVERSITET**
[DK/DK]; Anker Engelunds Vej 101 A, 2800 Kgs. Lyngby
(DK).
- (72) Inventor; and
- (71) Applicant : **CHIGRIN, Dmitry** [DE/DE]; Auf dem Felde
18, 58455 Witten (DE).
- (72) Inventors: **ZHUKOVSKY, Sergei**; Bagsværd Hovedgade
26, 2880 Bagsværd (DK). **LAVRINENKO, Andrei**; Lyn-
gborghave 26, 1. th, 3460 Birkerød (DK). **MALUREANU,**
Radu; Kollelevbakken 7A, tv., 2830 Virum (DK). **ZA-**
- LKOVSKIJ, Maksim**; Ulsøparken 2.2.3, 2660 Brøndby
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- (74) Agent: **GUARDIAN IP CONSULTING I/S**; Diplomvej,
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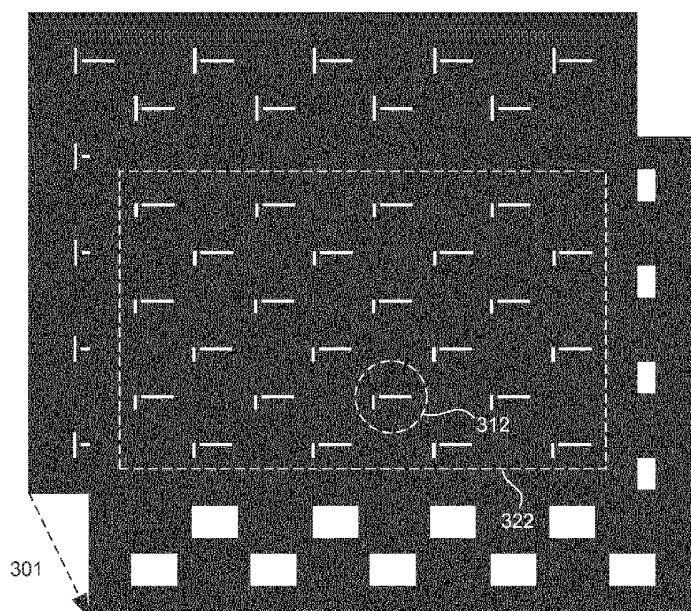


Fig. 3C

(57) Abstract: The present invention provides a polarizer. The polarizer comprises a first membrane having a first polarization region comprising a first plurality of membrane perforations; a second membrane having a second polarization region comprising a second plurality of membrane perforations; and a support structure to which the first and second membranes are attached, the support structure allowing a relative movement of the first membrane with respect to the second membrane, the relative movement enabling an at least partial overlap of one or more membrane perforations in the first plurality of perforations with one or more membrane perforations in the second plurality of perforations in a direction normal to the first polarization region or normal to the second polarization region, resulting in corresponding one or more openings in said direction.

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Reconfigurable THz polarizer

Technical field

The present invention relates to a polarizer for polarizing THz radiation.

Background of the invention

5 Terahertz (THz) radiation is very promising for many uses ranging from spectroscopy and communication to security and biomedical applications. However, to fully enable the use of THz radiation for these applications requires the ability to steer, focus and control THz waves in ways known from visible light frequencies. In other words, functional elements for THz optics, such as lenses, polarizers and phase transformers, are needed. Unfortunately,
10 such elements are largely missing at present because THz frequencies do not readily lend themselves to direct transfer of approaches known from either the microwave or the visible domain. For example, arbitrary polarization (linear, circular, elliptical) of visible and infrared light can easily be achieved using birefringent materials, Faraday rotation, and phase plates, whereas terahertz analogues of these devices would be excessively bulky. In this context, it
15 is worth noting that the spectral range of THz-radiation, which is located between microwaves and infrared light, is often referred to as the THz-gap, due to the lack of available technology in this range. Technologies for generation and manipulation of THz-radiation are indeed in their infancy. Therefore, in the field of THz-optical devices, maintaining high output intensity as compared to the input intensity is of utmost
20 importance, and much more critical than for any of the other above-mentioned adjacent frequency ranges. Unless otherwise stated in the present application, the term "THz" refers to electromagnetic waves within the ITU-designated band of frequencies from 0.3 to 3 terahertz (THz; $1 \text{ THz} = 10^{12} \text{ Hz}$). Wavelengths of radiation in the terahertz band correspondingly range from 1 mm to 0.1 mm (or 100 μm). Because the THz-band begins at
25 a wavelength of one millimeter and extends into shorter wavelengths, it is also referred to as the submillimeter band, and waves in the THz-regime are referred to as submillimeter waves.

As mentioned above, the present invention relates to the particular field of polarizing devices for THz-radiation. The polarization state of electromagnetic radiation may be
30 described by its location on the Poincaré sphere, wherein linear polarization states are located at the equator; circular polarization states are located at the poles; and elliptical polarization states are located anywhere else on the Poincaré sphere. That is, an elliptical

polarization state as referred to in this specification is neither located at the equator (linear polarizations) nor at any of the poles (circular polarizations) of the Poincaré sphere.

While simple THz-polarizing devices providing a linear polarization output exist, it is difficult to find useful circular polarizers, for not to speak about useful elements for producing an elliptical polarization state. In any case they are typically flawed with a low efficiency when considering the output intensity as compared to the input intensity. Even more challenging are devices allowing for adjusting the polarization output for a given THz-radiation input by reconfiguring the polarizer from providing one polarization state on the Poincaré sphere to another polarization state on the Poincaré sphere, wherein at least one of the polarization states is an elliptical polarization state, i.e. neither purely linear nor purely circular. Yet more challenging are reconfigurable devices allowing for a gradual and/or continuous change of the polarization state moving along a more or less arbitrary or predetermined path along the surface of the Poincaré sphere, the path including at least one elliptical polarization state.

It has been shown that metal membranes with certain fixed patterns of holes can provide a wide range of output polarizations. However, replacing one such fixed pattern device in a THz optical setup or system by another fixed pattern device is tedious and may require an even more tedious realignment of the optical setup/system. A reconfigurable polarizer for adjusting the polarization state of THz-radiation is therefore needed.

One object of the present invention is therefore to provide such a reconfigurable polarizer for adjusting the output polarization state of THz-radiation from a first polarization state to a second polarization state different from the first polarization state. A further object of the present invention is to provide such a reconfigurable polarizer, wherein at least one of the output polarization states is an elliptical polarization state. A yet further object of the present invention is to provide such a reconfigurable polarizer allowing for a gradual adjustment of the polarization state of THz-radiation via intermediate polarization states.

Summary of the invention

A first aspect of the present invention provides a polarizer for changing polarization of for instance THz radiation. The polarizer comprises:

- a first membrane having a first polarization region comprising a first plurality of membrane perforations,

- a second membrane having a second polarization region comprising a second plurality of membrane perforations, and
- a support structure to which the first and second membranes are attachable or attached, the support structure allowing a relative movement of the first membrane with respect to the second membrane, the relative movement enabling an at least partial overlap of one or more membrane perforations in the first plurality of perforations with one or more membrane perforations in the second plurality of perforations in a direction normal to the first polarization region or normal to the second polarization region, resulting in corresponding one or more openings in said direction.

Further, according to one aspect, a reconfigurable polarizer for use with an operational waveband over any subset of the terahertz band is provided, the polarizer being adapted for adjusting an output polarization from a first polarization state on the Poincaré sphere to a second polarization state on the Poincaré sphere different from the first polarization state, wherein the polarizer comprises a first membrane having a first polarization region comprising a first plurality of membrane perforations; a second membrane having a second polarization region comprising a second plurality of membrane perforations, wherein at least each member of the second plurality of membrane perforations has a primary branch shaped with an elongation in a primary direction, and a secondary branch shaped with an elongation in a secondary direction different from the primary direction; and a support structure to which the first and second membranes are attachable or attached, the support structure allowing a relative movement of the first membrane with respect to the second membrane, from a first position to a second position, at least one of the first and second positions enabling an at least partial overlap of one or more membrane perforations in the first plurality of perforations with one or more membrane perforations in the second plurality of perforations as seen in an axial direction normal to the first polarization region or normal to the second polarization region, resulting in corresponding one or more openings as seen in said axial direction, wherein a first shape of the one or more openings in the first position differs from a second shape of the one or more openings in the second position.

Most preferably, the first and second membranes are in close proximity to each other with an axial distance that is small as compared to the wavelength, i.e. well below 100µm, well below 10µm or even below 1µm. Most preferably, the first and second membranes are arranged essentially parallel to each other. Most preferably, the relative movement of the first and second membranes with respect to each is in lateral directions, essentially

perpendicular to the axial direction, or essentially parallel to the planes defined by the membranes.

The relative movement of the first and second membranes with respect to each other is adapted to induce a change in shape of the one or more openings, wherein at least in one position the contours of the openings are defined in combination by contours/edges of the first membrane perforations and contours/edges of the second membrane perforations. Each particular shape of the openings results in a corresponding output polarization state, which can be represented as a particular polarization state on the Poincaré sphere. Thereby, a change in output polarization state can be achieved. The reconfiguration of the polarizer from the first polarization state to the second polarization state is thus obtained by moving the first and second membranes with respect to each other, namely from the first position to the second position.

An important advantage of the reconfigurable polarizer according to the invention is that it can be adapted for a high efficiency when considering the output intensity as compared to the input intensity. Furthermore, this device may be adapted to allow for adjusting the polarization output for a given THz-radiation input by reconfiguring the polarizer from providing one polarization state on the Poincaré sphere to another polarization state on the Poincaré sphere, wherein at least one of the polarization states is an elliptical polarization state, i.e. neither purely linear nor purely circular. Furthermore, the device may be adapted to allow for a gradual change of the polarization state moving along any desired path and/or within any desired sub-surface of the Poincaré sphere, including any desired range of elliptical polarization states.

The first polarization region of the first membrane can cover substantially the entire membrane, or some fraction of it. Therefore, a fraction of an area of the first membrane in which there are perforations can also constitute a first polarization region. The same applies, *mutatis mutandis*, to the second polarization region.

The first and/or second membrane might be perforated in a central region and unperforated in a periphery region. The periphery region can be used for attaching the membrane to the support structure. An unperforated periphery region is less susceptible to damage or rupture while attached to or during the process of attaching it to the support structure.

The support structure allows relative movement of the first membrane with respect to the second membrane. Either the first or the second membrane may be fixed relative to the

support structure, or both may be movable. An advantage of fixing one membrane, either the first or second, is that fewer mechanical elements are needed.

The polarizer may comprise a third or even further membranes with corresponding polarization regions and pluralities of membrane perforations, each third or even further
5 membranes allowing overlaps as described for two membranes above. This can allow for desired polarization changes over a broader wavelength range.

In some embodiments, the first and/or second membranes are (easily) attachable and optionally also (easily) detachable. Embodiments in which the first and/or the second membrane are attachable allow the polarizer to be configured to operate optimally over a
10 broader wavelength range. The user of the polarizer (or suitable robotic equipment) replaces one or more membranes, selecting whichever one or more membranes give the desired polarizing effect. Optionally one or more further membranes, if present and if the support structure can support them (i.e. has appropriate support elements for attaching them to), can also be attachable and optionally also detachable.

15 In some embodiments, the movement of the first and second membranes (and optionally also further membrane or membranes, if present) can be performed by a suitably adapted electronic moving system, for instance one that includes an electronically actuated micrometer screw system. Such embodiments may allow for a more precise adjustment of
20 the relative position of the membranes with respect to one another. In some embodiments, a very fine adjustment that is not easily performed by a person may be necessary. In such cases, the electronic moving system is especially advantageous. Generally, such a system may, at least in some cases, also increase the speed at which the membranes are moved relative to each other into the desired configuration compared to what a person would be
25 capable of doing.

In some embodiments, the polarizer comprises:

- a detection system for measuring an output polarization of radiation transmitted through the first and second membranes, and
- 30 - a microprocessor configured to control the electronic moving system in response to the received polarization measurement.

Such embodiments allow the polarizer to automatically adjust the relative movement of the first and second membranes, typically with the purpose of reaching a desired target
35 polarization. If the microprocessor detects an output polarization different from the target

polarization, the microcontroller controls the electronic moving system to reconfigure the membranes in order to change the output polarization in the direction of the target polarization.

- 5 Embodiments of the polarizer depend on transmission of incoming light through the perforations and on non-transmission (for example absorption) outside at least some of the perforations. Preferably, the first polarization region comprises a first set of one or more non-transparent or absorptive materials, and the second polarization region comprises a second set of one or more non-transparent or absorptive materials.

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Some embodiments are characterized as follows:

- within the first polarization region, the first membrane consists of one or more absorptive materials, and
- within the second polarization region, the second membrane consists of one or more

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In other words, within the first and second polarization regions, the first and second membranes are non-transparent or absorptive outside the perforations. This gives the highest degree of polarization.

- 20 The membranes can either be made entirely from a single material or material composition. Different regions of the membranes can be made of different materials, not unlike patchwork. From a fabrication perspective, a membrane having a polarization region which is made of a single material is more easily fabricated than a membrane consisting of several materials. As such, in many cases it is advantageous that each membrane's polarization
- 25 region is made of a single material or single material composition or material layer structure, uniformly across that polarization region. Polarization regions may make up only a fraction of their respective membranes, but fabricating not only the polarization regions, but the entire membranes in a single material or material composition or material layer structure is in some cases the simplest approach. In some embodiments, one or both
- 30 membranes might be transparent in one area and hardly transparent (for example, absorptive) in another area.

In principle, both solids and liquids can be used to form the membranes. However, solids are much more easily handled.

Within solids, metals are particularly advantageous because they can be hardly transparent for terahertz radiation in the range 1-20 THz at membrane thickness measuring only a few microns. It has also been found that membranes in which the polarization region is made of a single metal or alloy are relatively straightforward to fabricate, can be quite robust in terms of handling and environmental conditions, and can be made very uniform (such as an even thickness across the polarization region). The two or more membranes need not be made of the same material. One membrane can be made of one type of metal, while another membrane is made of a different metal.

Materials such as Ni, Cu, Al, Cr, Ti, Pt, Au, Ag, Pd are very suitable membrane materials.

It has been realized by the inventors that it is advantageous that the first polarization region and the second polarization region differ from a wire grid.

In some embodiments, the first plurality of membrane perforations forms a pattern. Alternatively, the second plurality of membrane perforations forms a pattern. Alternatively, the first plurality of membrane perforations forms a first pattern and the second plurality of membrane perforations forms a second pattern. In some embodiments, the first and second patterns are identical. This allows each perforation of the first plurality of perforations in the first membrane to overlap with a corresponding perforation in the second plurality of perforations in the second membrane. The individual perforations need not be identical.

The patterning of the perforations in the first and second membranes can for instance be a regular, square lattice or other periodic pattern, regular or pseudo-regular. Other types of patterns well understood by persons skilled in the art include: periodic pattern, periodic lattice, quasi-periodic pattern, quasi-periodic lattice.

It is known that a pattern may be comprised of "unit cells". The perforations may also be unit cells, such that the pattern is a pattern of unit cells. Each unit cell may be comprised of several elements. If these elements were considered as individual units, the pattern would not be regular. However, when considered as unit cells, the pattern is regular. The term "pattern" shall, unless otherwise specified, be construed as including patterns of unit cells each of which comprises more than one perforation.

The inventors have found that "T" shaped perforations in the first or second plurality of perforations are very suitable for polarizing radiation. "L" shaped perforations is another example of very suitable perforation shapes.

In some embodiments, the second polarization region comprises "T" shaped perforations, or at least perforations that resemble a "T". In some embodiments, the "T" is formed by a stem and a crossbar that are separated. The stem and crossbar are located close to each other, appearing as a "T". In some embodiments, the stem and cross bar form a "T"-like unit cell, and the pattern is a regular or pseudo-regular or periodic or quasi-periodic pattern or lattice of "T"-like unit cells.

Other perforations shapes include: "V", "II", and "X". Similar to the "T"-like unit cell described above, the "V", "II", and "X" shapes may also be comprised of separate perforations which together form a shape similar, respectively, to "V", "II", and "X".

Within each of the first or second polarization region, the perforations may all have the same shape and/or same size.

In some embodiments, the perforations in the first polarization region are large enough that an overlap between a first perforation in the first polarization region with a first perforation in the second polarization region results in an opening identical to the first perforation in the second polarization region. Identical membranes also achieve this, but in many cases, larger openings in the first membrane allow more flexibility.

In some embodiments, the pattern of the first plurality of perforations has a periodicity equal to a periodicity of the second plurality of perforations. This allows for the provision of a corresponding pattern of openings when the perforations of the first polarization region are aligned with perforations of the second polarization region.

Combining certain of the abovementioned properties can result in embodiments with the following property:

- a relative movement of the first membrane with respect to the second membrane provides one or more substantially T-shaped openings; and simultaneously or after a further relative movement of the first membrane with respect to the second membrane may provide one or more substantially L-shaped openings.

Preferably, the first and second plurality of perforations are arranged and dimensioned in such a way that the shift from "T" shape to "L" shape can be achieved by a linear relative movement.

Acting on the initially linearly polarized THz light, a wide range of output polarizations can be produced by one device, with minimal adjustments of relative movement of the first membrane with respect to the second membrane.

In some embodiments, the thickness of the membranes in the polarization region is thinner
5 than the wavelength of the light of interest. For many applications, these wavelengths correspond to THz radiation, i.e. radiation with a frequency in the interval 0.3 to 30 THz, such as in the interval 0.3 to 3 THz. Other relevant frequency intervals include: 0.3-10 THz, 0.3-50 THz, 0.3-100 THz, 1-10 THz, 1-50 THz, 1-100 THz, or even higher. The thicknesses of the membranes are dimensioned accordingly.

10 In some embodiments, the first and second polarization regions can be arranged to be parallel with respect to each other.

In some embodiments, the first and second polarization regions can be arranged at an angle with respect to each other.

15 In some embodiments, the first and second polarization regions are curved, having respective radii of curvature, which curvatures allows the first and second polarization regions to be moved relative to each other around a mutual center of rotation.

20 In some embodiments, a largest size of a membrane perforation in the first and/or second polarization regions is smaller than 1 millimeter, such as smaller than 100 microns, such as smaller than 10 microns, such as smaller than 5 microns, such as smaller than 2 microns, such as smaller than 1 micron, such as smaller than 800 nm, such as smaller than 600 nm, such as smaller than 500 nm.

25 In some embodiments, the second membrane furthermore comprises a third polarization region comprising a third plurality of membrane perforations, where at least one of the membrane perforations of the third plurality of membrane perforations differs in size or shape from a membrane perforation of the second plurality of membrane perforations. For
30 instance, the second plurality may comprise a regular pattern of "T"s having one set of dimensions defining it, and the third plurality comprises a regular pattern of "V"s or "X"s or "II"s or "L"s, or "T"s having dimension different from the dimensions of the "T"s in the second plurality. This allows a change in the frequency range in which the polarizer is most effective. For instance, the "T"s in the third plurality may be exactly twice the size (in each
35 dimension) of the "T"s in the second plurality. This allows the third plurality to polarize

radiation similarly to the second plurality, but at half the frequencies. In some embodiments, the first membrane is required to have a separate polarization region which is also scaled up corresponding to the scaling in perforation size between the second and third plurality of perforations.

- 5 In some embodiments, the first plurality of perforations and/or the second plurality of perforations comprise perforations (or unit cells) that are substantially symmetrical. Shapes such as "T", "II", "V", and "X" are examples of substantially symmetrical perforations, since each has at least one axis of symmetry.

- 10 In some embodiments, a smallest distance between perforations in the first plurality of membrane perforations is in the interval 15-1500 microns, allowing polarization conversion at frequencies in the interval 0.2-20 THz.

In some embodiments, a smallest distance between perforations in the second plurality of membrane perforations is in the interval 15-1500 microns, allowing polarization conversion at frequencies in the interval 0.2-20 THz.

- 15 In some embodiments where the first plurality of perforations are arranged in a periodic lattice, a corresponding lattice period is in the interval 15-1500 microns.

In some embodiments where the second plurality of perforations are arranged in a periodic lattice, a corresponding lattice period is in the interval 15-1500 microns.

- 20 In some embodiments, an absorption coefficient of at least one of the absorptive materials in the first set of materials exceeds 10^5 m^{-1} for at least one photon frequency exceeding 1 THz, and an absorption coefficient of at least one of the absorptive materials in the second set of materials exceeds 10^5 m^{-1} for at least one photon frequency exceeding 1 THz.

- 25 In some embodiments of the reconfigurable polarizer at least one of the first and second polarization states corresponds to an elliptical polarization, i.e. a polarization state which is neither purely linear nor purely circular. Thereby a highly flexible polarization device is achieved with improved radiation control in the terahertz range.

- 30 In some embodiments of the reconfigurable polarizer, the polarizer is further adapted to adjust the output polarization to at least a third polarization state on the Poincaré sphere by moving the first and second membranes to a third position. Thereby an even more flexible polarization device is achieved with improved radiation control in the terahertz range.

In some embodiments of the reconfigurable polarizer, the third polarization state corresponds to an elliptical polarization. Thereby yet further flexibility is added to the polarizer, which is useful for controlling terahertz radiation.

In some embodiments of the reconfigurable polarizer, the polarizer is further adapted to
5 adjust the output polarization gradually via intermediate polarization states, said gradual adjustment being achieved by a continuous or stepped movement via intermediate positions of the first and second membranes with respect to each other, said intermediate positions corresponding to the intermediate polarization states. The possibility of performing a gradual adjustment allows not only for switching between polarization states, but also for
10 tuning, and even fine-tuning of the output polarization provided by the device. Depending on the desired actuation mechanism for repositioning the first and second membranes with respect to each other, reconfiguring the polarizer for adjusting the output polarization may be achieved stepwise or in a continuous manner. A stepwise repositioning allows for a well-defined adjustment in predetermined steps, which may be useful if e.g. an incremental
15 and/or metered adjustment is desired. A continuous or quasi continuous repositioning is advantageous, if e.g. a fine-tuning of the output polarization is desired.

In some embodiments of the reconfigurable polarizer, at least one of the first, second, third, and intermediate states correspond to an elliptical polarization. As mentioned above, the inclusion of any desired polarization state in addition to purely linear and/or circular
20 polarizations opens up for a large range of terahertz radiation control with unprecedented reconfiguration flexibility and transmission efficiency of the polarization device.

Further according to one aspect of the invention, a method of controlling an output polarization state for a given input radiation within an operational waveband over any subset of the terahertz regime comprises: providing a first membrane, the first membrane
25 having a first polarization region comprising a first plurality of membrane perforations; overlaid in a first position on the first membrane, providing a second membrane having a second polarization region comprising a second plurality of membrane perforations, wherein at least each member of the second plurality of membrane perforations has a primary branch shaped with an elongation in a primary direction, and a secondary branch shaped
30 with an elongation in a secondary direction different from the primary direction, wherein at least one or more membrane perforations in the first plurality of perforations in combination with one or more membrane perforations in the second plurality of perforations define one or more openings having a shape as seen in an axial direction normal to the first polarization region or normal to the second polarization region; and transmitting the input
35 radiation through the openings so as to generate an output radiation having an output

polarization as determined by the shape of the openings, wherein said shape is determined by the relative position of the first and second membranes with respect to each other.

Thereby a highly flexible and efficient polarization technique is achieved allowing for easily obtaining any desired polarization state for the output radiation, including elliptic

5 polarization states. Most preferably, the shape of the openings is partly defined by contours/edges of the first membrane perforations, and partly by contours/edges of the second membrane perforations.

Further according to one embodiment a method of controlling an output polarization state further comprises the step of moving the first and second membranes with respect to each other to a second position, so as to modify the shape of the openings as seen in the axial direction, thereby adjusting the output polarization from a first polarization state corresponding to the first position to a second polarization state corresponding to the second position. Thereby a simple and cost effective technique for controlling/adjusting the polarization of the output radiation with a high degree of flexibility is achieved.

15 According to yet a further aspect of the invention relates to providing a method of producing a polarization device for operation in an operational waveband over any subset of the terahertz regime, wherein the method comprises: providing a first membrane, the first membrane having a first polarization region comprising a first plurality of membrane perforations; overlayed in a relative position with respect to the first membrane, providing a second membrane having a second polarization region comprising a second plurality of membrane perforations, wherein at least each member of the second plurality of membrane perforations has a primary branch shaped with an elongation in a primary direction, and a secondary branch shaped with an elongation in a secondary direction different from the primary direction, wherein at least one or more membrane perforations in the first plurality of perforations in combination with one or more membrane perforations in the second plurality of perforations define one or more openings having a shape as seen in an axial projection normal to the first polarization region or normal to the second polarization region, wherein said shape is determined by the relative position of the first and second membranes with respect to each other; and selecting the relative position of the first and second membranes with respect to each other according to a desired output polarization as determined by the shape of the openings. Most preferably, the shape of the openings is partly defined by contours/edges of the first membrane perforations, and partly by contours/edges of the second membrane perforations. Thereby, it is possible to easily and in a cost effective way to produce a polarization device for any desired output polarization specification, by merely combining two standard pre-fabricated membrane blanks in a

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certain relative position which respect to each other. Preferably, according to some embodiments, after tuning the output polarization to a desired polarization state on the Poincaré sphere, the the relative position of the two membranes with respect to each other is fixed, e.g. in a common mount or by attaching the mebranes to each other. Thereby, it is possible to easily and in a cost effective way to produce a polarization device for any desired fixed output polarization specification, by merely combining and fixing two standard pre-fabricated membrane blanks in a certain relative position which respect to each other.

Brief descriptions of the drawings

10 Figure 1A illustrates schematically a first membrane for use in a polarizer in accordance with the present invention.

Figure 1B illustrates schematically a second membrane for use in a polarizer in accordance with the present invention.

15 Figure 2A illustrates schematically a side view of the first and second membranes of Figs. 1A and 1B at a certain relative position with respect to one another.

Figure 2B illustrates schematically a side view of the first and second membranes of Figs. 1A and 1B at another relative position with respect to one another.

Figure 2C illustrates schematically a side view of the first and second membranes of Figs. 1A and 1B at a certain relative position with respect to one another.

20 Figure 2D illustrates schematically a the second side view of the first and second membranes of Figs. 1A and 1B at another relative position with respect to one another.

Figure 2E illustrates first and second membranes arranged at an angle with respect to one another.

25 Fig. 3A illustrates the first and second membranes in a first overlapping configuration, producing a "T"-shaped perforation overlap.

Fig. 3B illustrates enlargement of the "T"-shaped perforation overlap shown in Fig. 3A.

Fig. 3C illustrates the first and second membranes in another overlapping configuration, producing an "L"-shaped perforation overlap.

Fig. 3D illustrates enlargement of the "L"-shaped perforation overlap shown in Fig. 3C.

Fig. 3E illustrates the first and second membranes in another overlapping configuration, producing an "I"-shaped perforation overlap.

Fig. 3F illustrates enlargement of the "I"-shaped perforation overlap shown in Fig. 3E.

5 Figure 4A illustrates the frequency dependence of the output polarization, in the form of Stokes parameters, when the openings are "T"-shaped as shown in Figs. 3A-3B.

Figure 4B illustrates the frequency dependence of the output polarization, in the form of Stokes parameters, when the openings are "L"-shaped as shown in Figs. 3C-3D.

10 Figure 4C illustrates the frequency dependence of the output polarization, in the form of Stokes parameters, when the openings are "I"-shaped as shown in Figs. 3E-3F.

Figure 4D illustrates the transformation of the output polarization, in the form of points on the Poincare sphere, for the gradual transformation from "T" to "L" shape at three fixed frequencies.

15 Figure 5A illustrates a second membrane having both "T"-shaped and "L"-shaped perforations.

Figure 5B illustrates a first membrane having a relatively large perforation.

Figure 5C shows a configuration of the membranes in Figure 5A and 5B.

Figure 5D shows a configuration of the membranes in Figure 5A and 5B in a configuration different from the one shown in Figure 5C.

20 Figures 6A-6D show membranes attached to frames for easier handling.

Figure 6E shows a reconfigurable polarizer in accordance with the invention.

Detailed description of selected embodiments

25 Fig 1A and 1B illustrate first and second membranes (121, 131) of a reconfigurable polarizer in accordance with an embodiment of the present invention. Such a reconfigurable polarizer is shown in Fig. 6E.

The first membrane 121 shown in Fig. 1A comprises a plurality of rectangular perforations 122 organized in a substantially regular, square lattice. The first membrane can be thought of as a screen. The membrane material is in this case Nickel (Ni).

Fig. 1B illustrates the second membrane 131, can be a "dimer membrane". This membrane also comprises a plurality of perforations 132, which in this example are substantially "T"-shaped. In this example, each "T" perforation 132 is composed of a "crossbar" perforation and a "stem" perforation, slightly separated from each other. Together, these form a unit cell. The "T"s are arranged in a regular pattern matching that of the perforations in the screen membrane. Fig. 3B illustrates the "crossbar" perforation 133a and the "stem" perforation 133b making up the "T" perforations, and the rectangular perforation 122.

Figs. 2A and 2B shows schematically a side view of the two membranes 121 and 131 placed near and parallel to each other. Here and in other figures, membrane thicknesses, distance between membranes, and perforation sizes are not necessarily to scale.

Line A-A is shown in Fig. 1A and defines a sectional view corresponding to a cut through a number of screen membrane rectangular perforations as shown in the figure. Line B-B is shown in Fig. 1B and defines a sectional view corresponding to a cut through a number of stems of "T"s of the dimer membrane.

In Fig. 2A, the membranes are placed in a certain configuration with respect to each other. The arrow illustrates schematically the amount of light that is able to pass through the combined openings, i.e. the overlap between the screen perforations and the dimer perforations. Fig. 2B illustrates the same sectional view, but with the two membranes having been displaced with respect to each other compared to the configuration in Fig. 2A. The new configuration results in a different shape of openings, i.e. a different shape of the overlap between the screen perforations and the dimer perforations. This causes a change in the polarization of light that passes through the two membranes, even at the same frequency. Examples of the polarizing effect are given later in this specification.

Figs. 2C and 2D show a different sectional view compared to Figs. 2A and 2C. Line C-C is shown in Fig. 1B and defines a sectional view corresponding to a cut through a number of crossbars of "T"s of the dimer membrane. In Fig. 2C, the membranes are placed in a certain configuration with respect to each other, and the rectangular perforations of the screen membrane and the crossbars of the dimer membrane overlap correspondingly, allowing a corresponding amount of light to pass through. The light at the output has a certain output polarization. The arrow illustrates schematically the amount of light that comes through the

openings. Fig. 2D illustrates the same sectional view, but the two membranes have been displaced with respect to each other, causing a change in the amount of light that can pass through the membranes. The output polarization of the light is also different.

Fig. 2E illustrates the membranes in a configuration in which the membranes are not parallel, but arranged with a certain angle θ with respect to each other. Such an embodiment provides a further degree of freedom that in some cases is advantageous.

These explanations of the figures above are schematic and serve only to illustrate the shapes of the "T"s and rectangles in the dimer and screen membranes, as well as indicate the effect of shifting the dimer and screen membranes relative to one another. Line 271 illustrates a normal to the first polarization region, and line 272 illustrates a normal to the second polarization region. The normal applied for the purpose of illustrating resulting openings is line 271, i.e. the normal of the first polarization region (which belongs to the first membrane 121). Note that the openings corresponding to perforation overlaps considered along the normal 272 of the second polarization region (which belongs to the second membrane 131) would be different.

Fig. 3A illustrates the screen and dimer membranes in a first overlapping configuration seen in a direction normal to both the screen membrane and the dimer membrane, which are parallel in this example. The rectangular perforations 122 of the screen membrane overlap entirely with the T-shaped perforations of the dimer membrane within a region 321, as shown in region 311 in Fig. 3A. The effective perforations, i.e. the openings, are therefore identical to the T-shapes of the dimer perforation. This is also an example showing that in some cases, the perforations of the screen membrane are larger than the dimer membrane perforations, whereby in certain relative positions of the membranes, an entire perforation in the dimer membrane "T" is revealed, resulting, as mentioned, in an opening identical to that provided by the dimer membrane perforation itself.

Area 311 is shown enlarged in Fig. 3B (although only including the outline of the perforations, not showing the membrane material as such, i.e. the black parts in Fig. 3A). The rectangular perforations 122 of the screen membranes overlap completely with the crossbars 133a and stems 133b of the T-shapes as described in relation to Fig. 3A, allowing the openings to have the "T" shape of the individual perforations in the dimer membrane.

Fig. 3C illustrates the overlap after the screen membrane and dimer membranes have been moved relative to each other by an illustrative amount shown by the vector 301. Now, some T-shaped perforations of the dimer membrane are now not screened at all, some are

screened entirely, and some are screened partially. This needs not be the case, but is a consequence of the particular layout of the perforations in this example.

Within a region 322 the effective perforations, illustrated within an area 312 inside the region 322, are substantially "L"-shaped. Note that in the present example, the screen and dimer membrane perforations are arranged in such a way that this shift is achievable by way of a linear relative movement of the membranes with respect to each other.

In the region 322, perforations of the screen membrane overlaps only parts of the "T"-shaped perforations of the dimer membrane. Fig. 3D shows the area 312 enlarged (except, similarly to Fig. 3B, only including the outline of the perforations, not showing the membrane material, i.e. the black parts in Fig. 3C). The stem 133b is entirely within rectangular perforation 122 of the screen membrane, whereas the crossbar 133a is partly screened, being partly covered by non-transparent material of the screen membrane. The result is a pattern of unit cells that are now "L"-shaped rather than "T"-shaped. As described previously, this has a profound effect on the polarizing effect of the polarizer, as will be illustrated later in the specification.

Note that the change in the polarizing effect that will be imposed on incoming light will be different inside the area 322 compared to outside it. If a uniform polarization change is desired, the area 322 should be sufficiently large compared to the size of the incoming light beam. This aspect will not be addressed in detail, since this is a matter of design and may be relevant in response to certain performance requirements, certain types of uses etc.

Fig. 3E illustrates the overlap after the screen membrane and dimer membranes have been moved relative to each other by another illustrative amount shown by the vector 311. In this configuration of the membranes, some T-shaped perforations of the dimer membrane are not screened at all, some are screened entirely, and some are screened partially. Within a region 323, the effective perforations, illustrated within an area 313, are substantially "I"-shaped. The rectangular perforations of the screen membrane overlap with the stem 133b of the "T"-shape inside the region 323. Fig. 3F shows the region 323 enlarged (except, similarly to Fig. 3B, only including the outline of the perforations, not showing the membrane material, i.e. the black parts in Fig. 3E). The stem 133b of the "T"-shape of the dimer membrane is entirely within the rectangular perforation, whereas the crossbar 133a is entirely outside the rectangular perforation 122 and therefore screened by the non-transparent or absorptive material of the screen membrane.

As mentioned, the inventors have realized that the "T", "L" and "I" perforations provide substantially different output polarizations, and the reconfigurable polarizer membranes allow the transition between them.

Figs. 4A, 4B, and 4C show, respectively, the polarization transformation capabilities of the
5 embodiments shown in Figs. 3A-3B, 3C-3D, and 3E-3F ("T", "L", and "I"-shaped), in the form of spectral dependencies of Stokes parameters. The X-axis is optical frequency in THz of incoming light.

For the "T"-shaped perforations in particular, a broad variety of polarization states are reached: output polarization changes from circular at frequency near 2 THz (the peak 411
10 where the Stokes V parameter reaches high values 421a of between 0.4 and 0.45) to linear at frequencies over 2.2 THz (412). In contrast, for the "L"-shaped perforations the output polarization are much closer to linear with (absolute) values of the Stokes V parameter less than 0.05 (421b). Further, for the "I"-shaped perforations the output polarization is almost linear at all frequencies with (absolute) values of the Stokes V parameter less than 0.005
15 (421c).

Fig. 4D further illustrates the polarization transformation capabilities by showing the output polarizations on the Poincare sphere as the openings shape is gradually reconfigured from "T"-shaped to "L"-shaped by gradually moving the screen membrane with respect to the dimer membrane, shifting the second plurality of perforations 131 with respect to the first
20 plurality 121. Figs. 3A-3F illustrate the definite states "T", "L" and "I" specifically. The location of the point on the Poincare sphere is determined by the values of the Stokes parameters and denotes the polarization of light: the poles 431a and 431b correspond to circular polarization of different handedness; the points on the equator 432 correspond to linear polarization of different orientation; all the remaining points correspond to elliptical
25 polarization. The lines 433a, 433b, and 433c correspond to three different frequencies 2.000 THz, 2.064 THz and 2.128 THz. It can be seen that potentially all points on the Poincare spheres, and hence all possible polarization states can be reached with the polarizer provided by the present invention.

Fig. 5A illustrates another dimer membrane 531 for an embodiment of the invention. Figure
30 5B illustrates a screen membrane 521 for use with the dimer membrane 531. The screen membrane 521 has one relatively large perforation 522. The dimer membrane 531 has two sets 511, 512 of perforations. One set 511 comprises "L"-shaped perforations. The other set 512 comprises "T"-shaped perforations.

Fig. 5C shows a configuration of the two membranes where the perforation 522 of the screen membrane overlaps with the "L"-shaped perforations of the set 511, and not with the "T"-shaped perforations 512, which are covered by the membrane. (The membrane material of the screen membrane 121 is shown in white as opposed to black in order to

5 make it easy to visually separate the dimer and screen membranes in the figure.)

Accordingly, the openings are effectively the "L"-shaped perforations of the set 511. The polarizing effect of this configuration has some similarities with that of the configuration in Fig. 3C, which also has an area 322 of "L"-shaped perforations.

Fig. 5D shows the openings in a configuration in which the screen membrane has been

10 rotated relative to the dimer membrane, as illustrated by arrow 550. The perforation 522 of the screen membrane now reveals the "T"-shaped perforations 512 of the dimer membrane, but covers the "L"-shaped perforations 511. Accordingly, the openings correspond to the "T"-shaped perforations 512 of the dimer membrane. The polarizing effect of this configuration has some similarities with that of the configuration in Fig. 3A, which also has

15 an area 321 of "T"-shaped perforations. Similarly to Fig. 5C, the membrane material of the screen membrane 121 is shown in white as opposed to black in order to make it easy to visually separate the dimer and screen membranes in the figure.

The example in Figs. 5A-5D are only for illustrative purposes. The perforation 522 might have another shape or size, allowing it to cover and reveal a larger number of "T"- and "L"-

20 shaped perforations in different rotational configurations.

Figs. 6A and 6C illustrate, respectively, the dimer and screen membranes 131,121 attached to respective frames 631,621. The resulting dimer and screen polarizer frames 642,641 are easier to handle, control the shape of the membranes, and are used for attaching to a support structure. Figs. 6B and 6D show, respectively, side views of the polarizer frames

25 642,641. The frames 631,621 can for instance be made of silicon (Si).

Fig. 6E shows a reconfigurable polarizer 601 in accordance with the invention. It comprises the polarizer frames 642,641 attached to a support structure. The support structure comprises a holder 601 to which the polarizer frames are attached. The dimer polarizer frame 642 is rigidly attached to the holder 601 with fixed support elements 652. The screen

30 polarizer frame 641 is attached movably with screw mechanism 651 which allow a relative movement of the screen membrane relative to the dimer membrane.

Incoming light 661 passes through the openings formed by the configuration of the two membranes relative to each other. Output light 662 is illustrated with an arrow different in

shape and size from the arrow representing the incoming light. The different shape and size merely indicates the modification of the light that the reconfigurable polarizer imposes. By moving the screen polarizer frame 641 using the screw mechanism 651, the openings formed by the overlap in perforations of the two membranes change as illustrated previously. The result is a different intensity and/or spectrum and/or polarization of the output light.

Fig. 6E is only schematic. Furthermore, it only illustrates movability in one direction. The support structure 601 and support element 652 and screw mechanisms 651 may be designed in many ways, influenced for instance by the purpose of the reconfigurable polarizer. Depending on the design of the membranes, including the membrane perforations, it may also be necessary to provide movability in another direction.

The drawings of membranes in this specification shall be considered schematic. They shall not be construed as being to scale. Also, the number of, shape of, layout of, relative dimensions of, pattern of, and other properties of perforations and membranes in the drawings shall not be construed as limiting the scope of the claims to those embodiments.

Claims

1. A reconfigurable polarizer for use with an operational waveband over any subset of the terahertz band, the polarizer being adapted for adjusting an output polarization from a first polarization state on the Poincaré sphere to a second polarization state on the Poincaré sphere different from the first polarization state, the polarizer comprising:
 - a first membrane (121) having a first polarization region comprising a first plurality of membrane perforations (122);
 - a second membrane (131) having a second polarization region comprising a second plurality of membrane perforations (132), wherein at least each member of the second plurality of membrane perforations has a primary branch (133a) shaped with an elongation in a primary direction, and a secondary branch (133b) shaped with an elongation in a secondary direction different from the primary direction; and
 - a support structure (601,651,652) to which the first and second membranes are attachable or attached, the support structure allowing a relative movement (301,311) of the first membrane with respect to the second membrane, from a first position to a second position, at least one of the first and second positions enabling an at least partial overlap of one or more membrane perforations in the first plurality of perforations with one or more membrane perforations in the second plurality of perforations as seen in an axial direction normal (271) to the first polarization region or normal (272) to the second polarization region, resulting in corresponding one or more openings (311,312,313) as seen in said axial direction, wherein a first shape of the one or more openings (311, 312, 313) in the first position differs from a second shape of the one or more openings (311, 312, 313) in the second position.
2. A reconfigurable polarizer in accordance with claim 1, wherein the first polarization region comprises a first set of one or more non-transparent or absorptive materials, and the second polarization region comprises a second set of one or more non-transparent or absorptive materials.
3. A reconfigurable polarizer in accordance with claim 1, wherein
 - within the first polarization region, the first membrane consists of one or more absorptive materials; and
 - within the second polarization region, the second membrane consists of one or more absorptive materials.

4. A reconfigurable polarizer in accordance with claim 2 or 3, wherein the first set of materials comprises a metal and/or the second set of materials comprises a metal, such as Ni, Cu, Al, Cr, Ti, Pt, Au, Ag, Pd.
5. A reconfigurable polarizer in accordance with any of the preceding claims, wherein the first polarization region and the second polarization region differ from a wire grid.
6. A reconfigurable polarizer in accordance with any of the preceding claims, wherein the first plurality of membrane perforations forms a first pattern and/or the second plurality of membrane perforations forms a second pattern.
7. A reconfigurable polarizer in accordance with claim 7, wherein the first and second polarization regions can be arranged to be parallel with respect to each other.
8. A reconfigurable polarizer in accordance with claim 7, wherein the first and second polarization regions can be arranged at an angle with respect to each other.
9. A reconfigurable polarizer in accordance with any of the preceding claims, wherein the first and second polarization regions are curved, having respective radii of curvature, which curvatures allow the first and second polarization regions to be moved relative to each other around a mutual center of rotation.
10. A reconfigurable polarizer in accordance with any of the preceding claims, wherein the relative movement may provide one or more substantially T-shaped openings; and simultaneously or after a further relative movement of the first membrane with respect to the second membrane may provide one or more substantially L-shaped openings.
11. A reconfigurable polarizer in accordance with any of the preceding claims, wherein a largest size of a membrane perforation in the first and or second polarization regions is smaller than 1 millimeter.
12. A reconfigurable polarizer in accordance with any of the preceding claims, wherein the second membrane furthermore comprises a third polarization region comprising a third plurality of membrane perforations, where at least one of the membrane

perforations of the third plurality of membrane perforations differs in size or shape from a membrane perforation of the second plurality of membrane perforations.

13. A reconfigurable polarizer in accordance with any of the preceding claims, wherein
5 the first and/or second plurality of perforations are symmetrical in shape.

14. A reconfigurable polarizer in accordance with any of the preceding claims, wherein a
smallest distance between perforations in the first plurality of membrane
perforations is in the interval 15-1500 microns, allowing polarization conversion at
10 frequencies in the interval 0.2-20 THz.

15. A reconfigurable polarizer in accordance with claim 1, wherein an absorption
coefficient of at least one of the absorptive materials in the first set of materials
exceeds 10^5 m^{-1} for at least one photon frequency exceeding 1 THz, and an
15 absorption coefficient of at least one of the absorptive materials in the second set of
materials exceeds 10^5 m^{-1} for at least one photon frequency exceeding 1 THz.

16. A reconfigurable polarizer in accordance with any of the preceding claims, wherein at
least one of the first and second polarization states corresponds to an elliptical
20 polarization.

17. A reconfigurable polarizer in accordance with any of the preceding claims, wherein
the polarizer is further adapted to adjust the output polarization to at least a third
polarization state on the Poincaré sphere by moving the first and second membranes
25 to a third position.

18. A reconfigurable polarizer in accordance with claim 17, wherein the third polarization
state corresponds to an elliptical polarization.

19. A reconfigurable polarizer in accordance with any of the preceding claims, wherein
the polarizer is further adapted to adjust the output polarization gradually via
intermediate polarization states, said gradual adjustment being achieved by a
continuous or stepped movement via intermediate positions of the first and second
membranes with respect to each other, said intermediate positions corresponding to
35 the intermediate polarization states.

20. A reconfigurable polarizer in accordance with claim 19, wherein at least one of the first, second, third, and intermediate states correspond to an elliptical polarization.

21. Method of controlling an output polarization state of radiation within an operational waveband over any subset of the terahertz regime, the method comprising:

- providing a first membrane (121), the first membrane having a first polarization region comprising a first plurality of membrane perforations (122);
- overlaid in a first position on the first membrane, providing a second membrane (131) having a second polarization region comprising a second plurality of membrane perforations (132), wherein at least each member of the second plurality of membrane perforations has a primary branch (133a) shaped with an elongation in a primary direction, and a secondary branch (133b) shaped with an elongation in a secondary direction different from the primary direction, wherein at least one or more membrane perforations in the first plurality of perforations in combination with one or more membrane perforations in the second plurality of perforations define one or more openings (311, 312, 313) having a shape as seen in an axial direction normal (271) to the first polarization region or normal (272) to the second polarization region; and
- transmitting the input radiation through the openings (311, 312, 313) so as to generate an output radiation having an output polarization as determined by the shape of the openings, wherein said shape is determined by the relative position of the first and second membranes with respect to each other, and wherein the shape of the openings is partly defined by contours/edges of the first membrane perforations, and partly by contours/edges of the second membrane perforations.

22. Method of controlling an output polarization state according to claim 21, further comprising the step of:

- moving the first and second membranes with respect to each other to a second position, so as to modify the shape of the openings (311, 312, 313) as seen in the axial direction, thereby adjusting the output polarization from a first polarization state corresponding to the first position to a second polarization state corresponding to the second position.

23. Method of producing a polarization device for operation in an operational waveband over any subset of the terahertz regime, the method comprising:

- providing a first membrane (121), the first membrane having a first polarization region comprising a first plurality of membrane perforations (122);
- 5 - overlaid in a relative position with respect to the first membrane, providing a second membrane (131) having a second polarization region comprising a second plurality of membrane perforations (132), wherein at least each member of the second plurality of membrane perforations has a primary branch (133a) shaped with an elongation in a primary direction, and a secondary branch (133b) shaped with an elongation in a secondary direction different from the primary direction, wherein at least one or more membrane perforations in the first plurality of perforations in combination with one or more membrane perforations in the second plurality of perforations define one or more openings (311, 312, 313) having a shape as seen in an axial projection normal (271) to the first polarization region or normal (272) to the second polarization region, wherein said shape is determined by the relative position of the first and second membranes with respect to each other; and
- 10 - selecting the relative position of the first and second membranes with respect to each other according to a desired output polarization as determined by the shape of the openings (311, 312, 313), wherein the shape of the openings is partly defined by contours/edges of the first membrane perforations, and partly by contours/edges of the second membrane perforations.

Fig. 1A

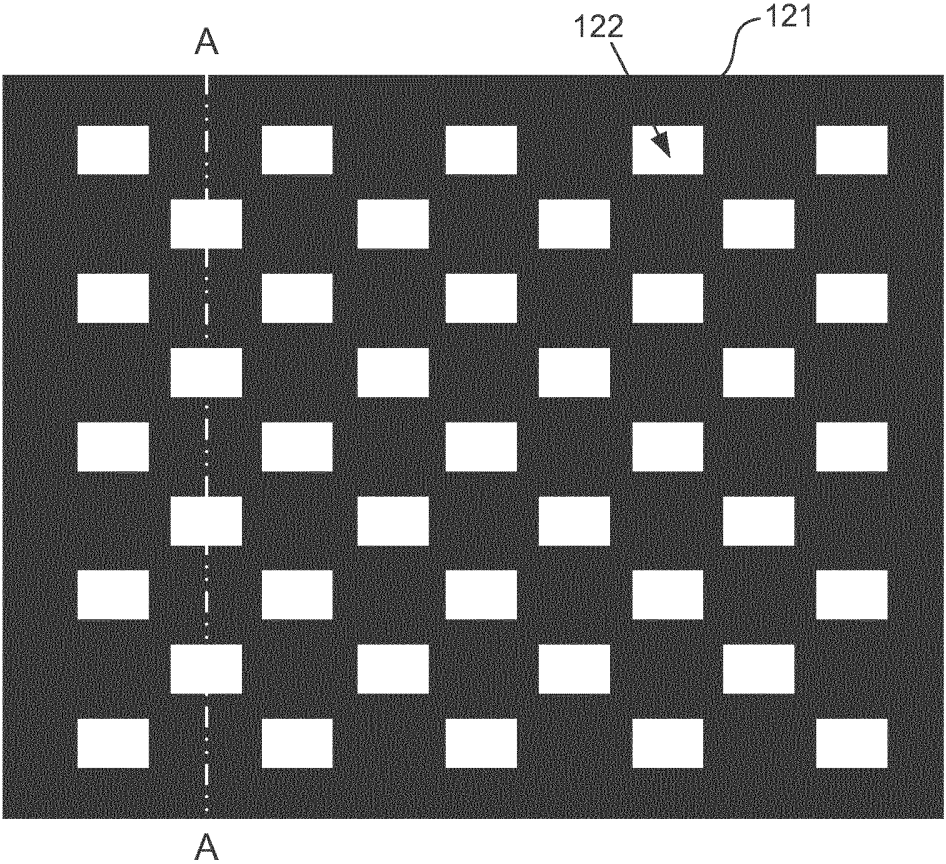
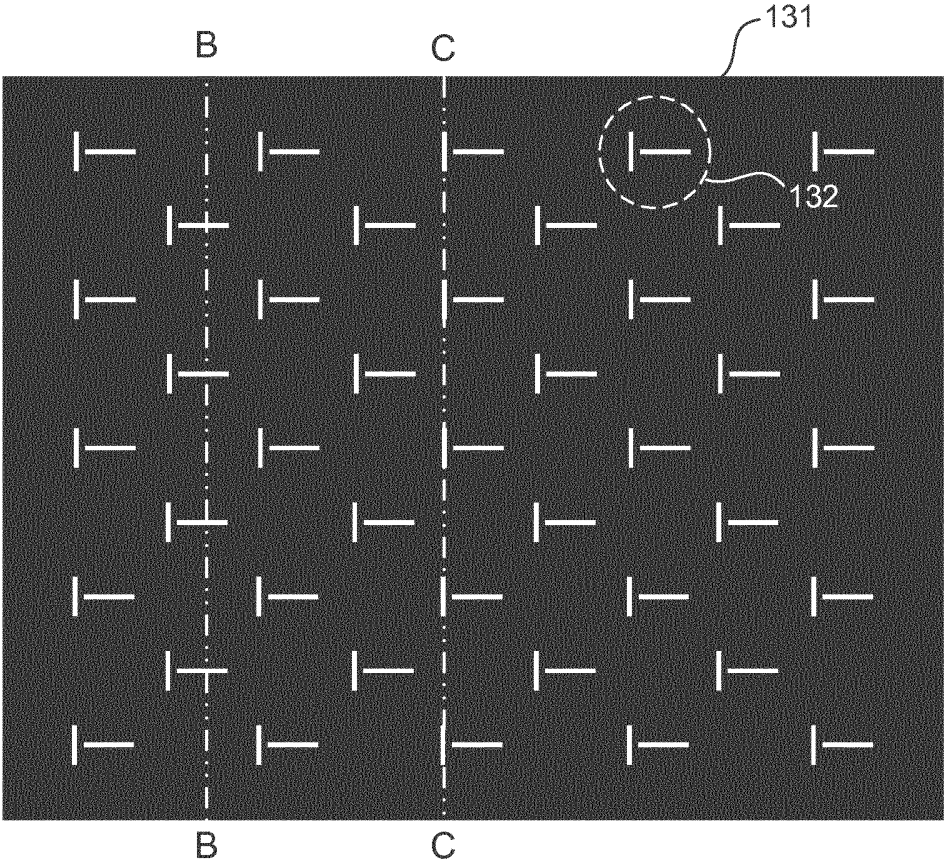


Fig. 1B



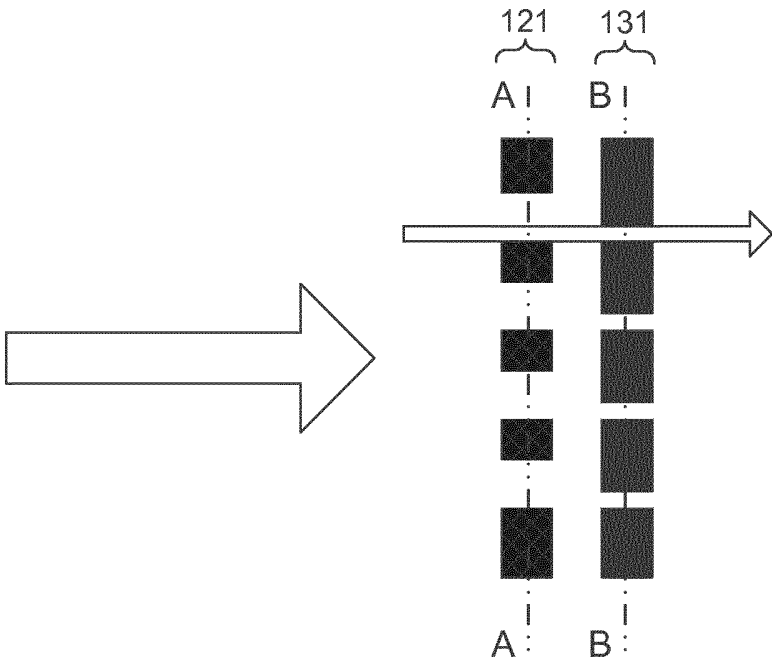


Fig. 2A

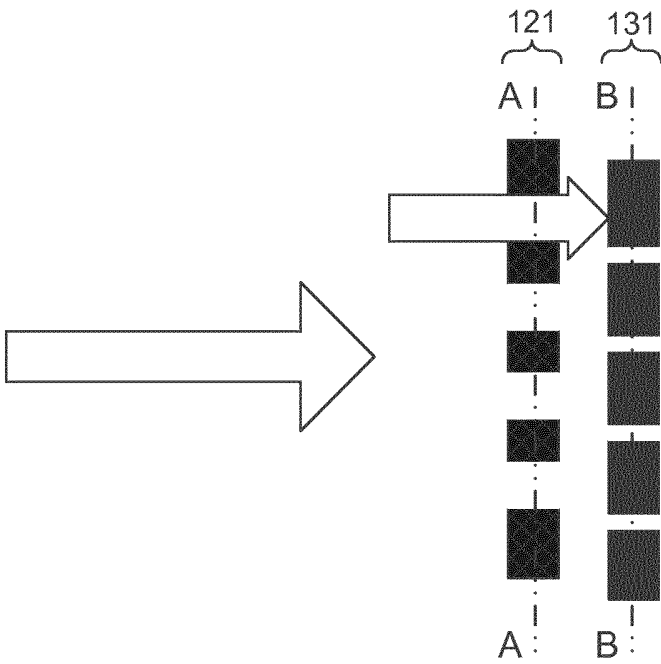


Fig. 2B

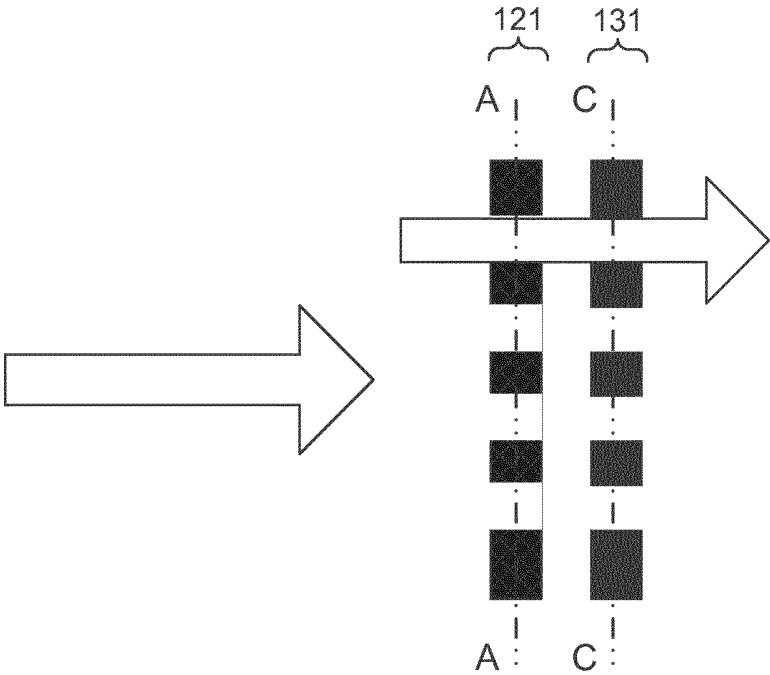


Fig. 2C

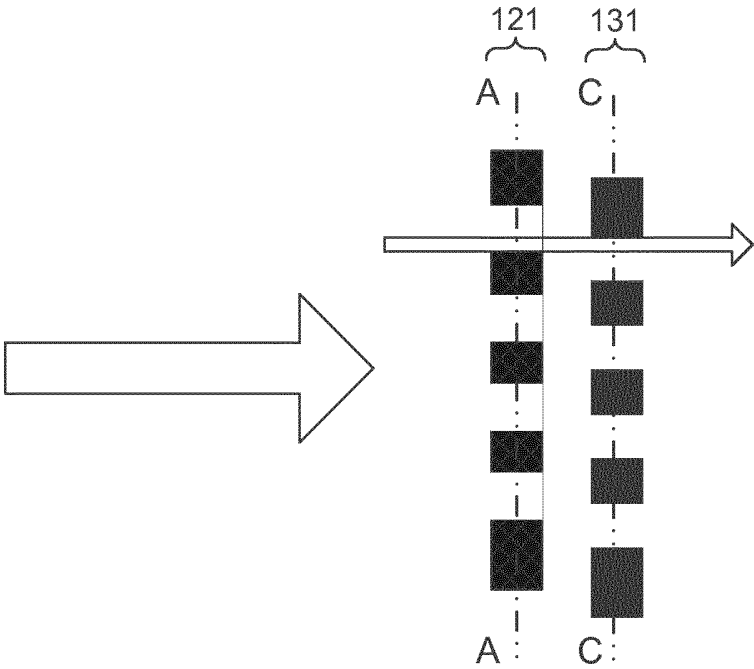


Fig. 2D

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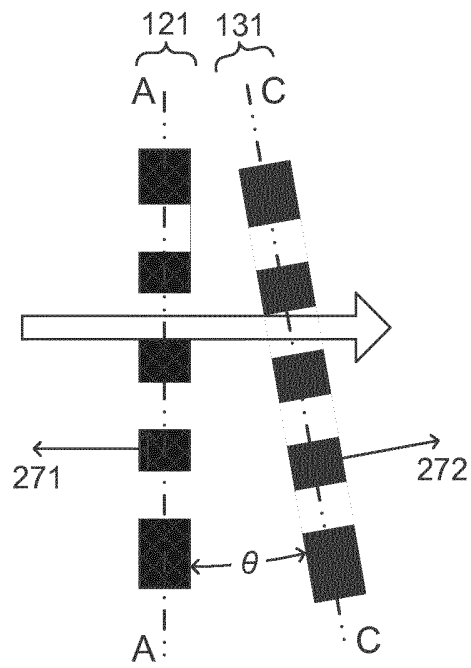


Fig. 2E

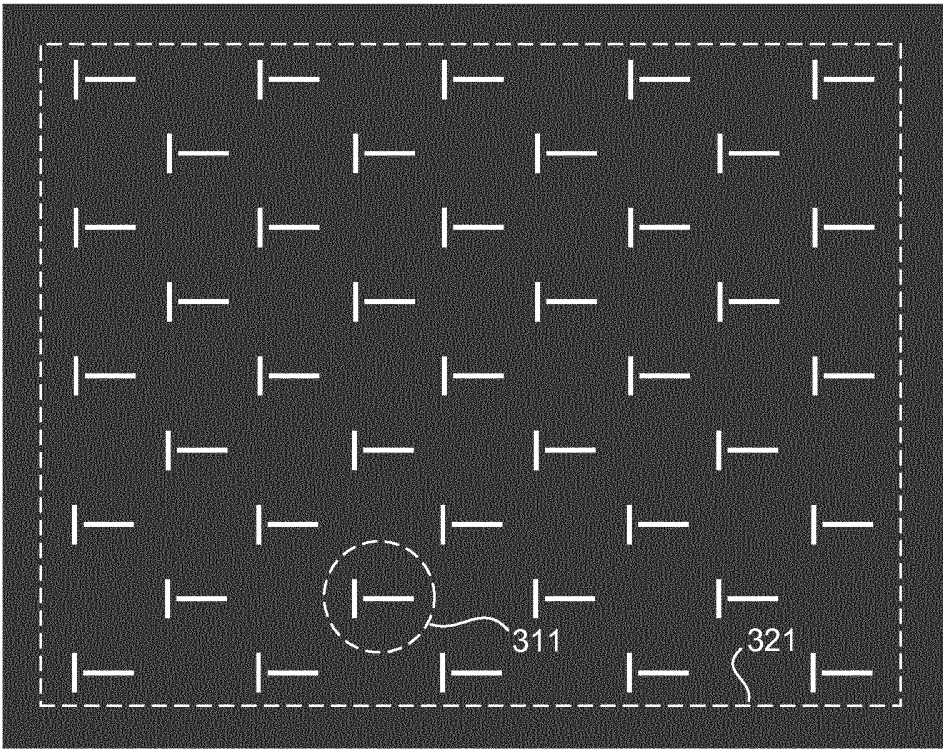


Fig. 3A

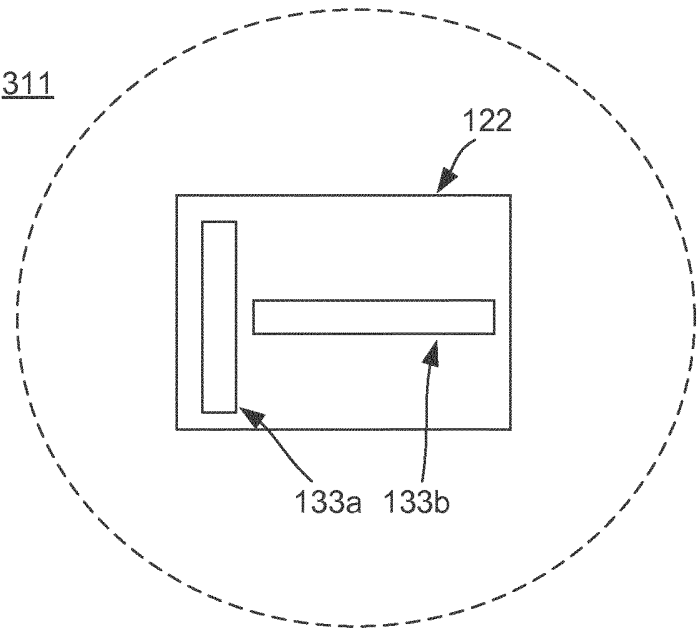


Fig. 3B

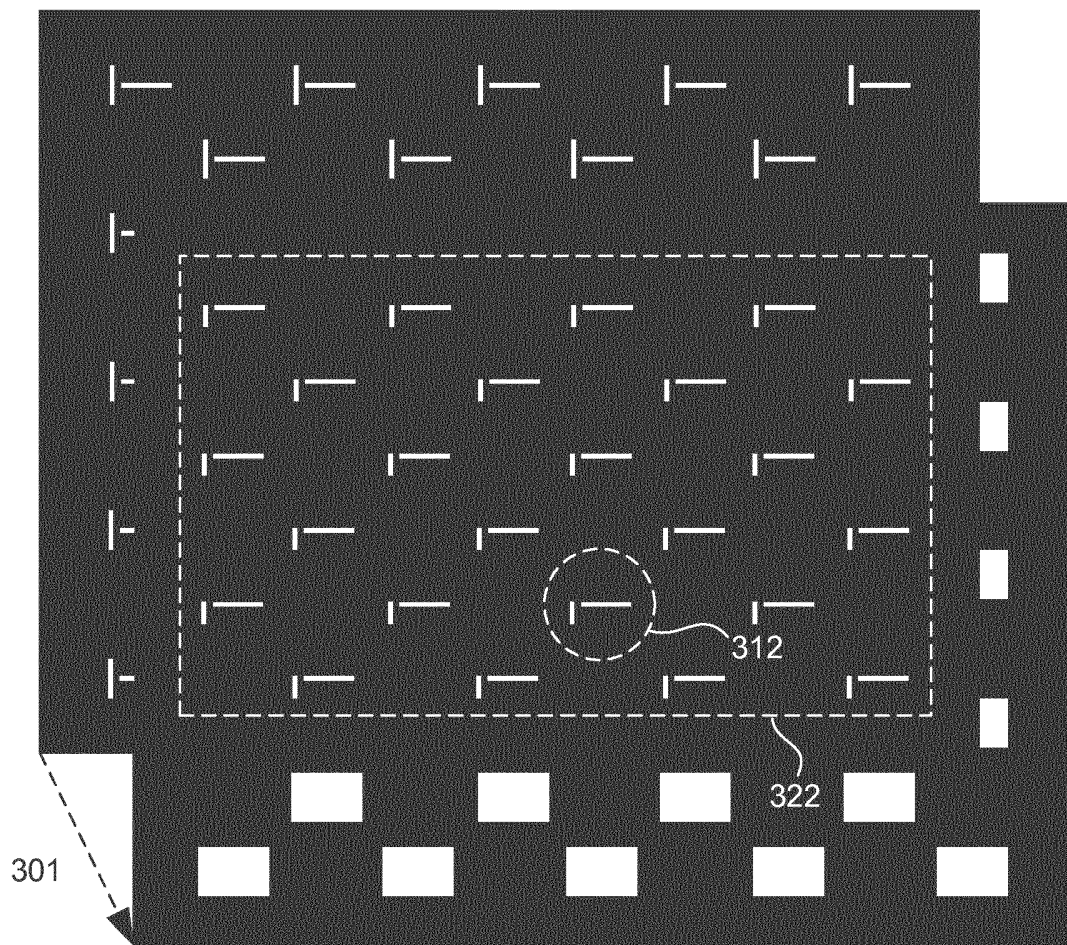


Fig. 3C

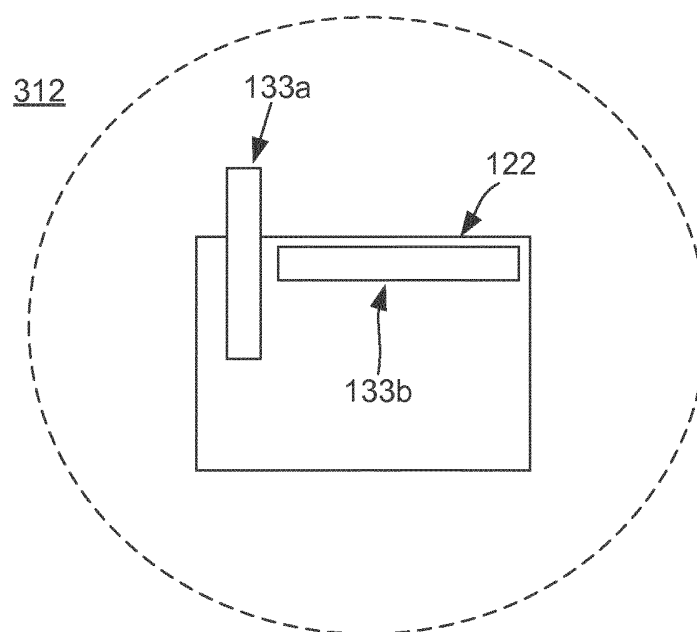


Fig. 3D

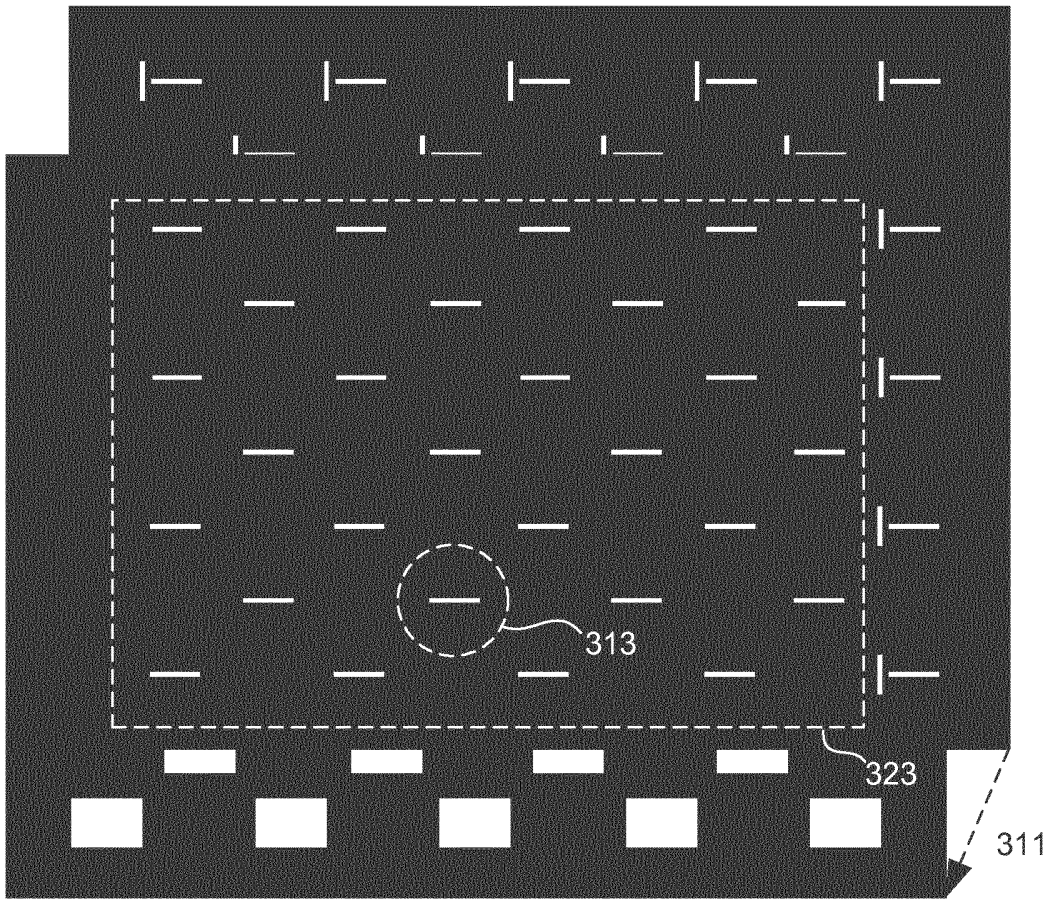


Fig. 3E

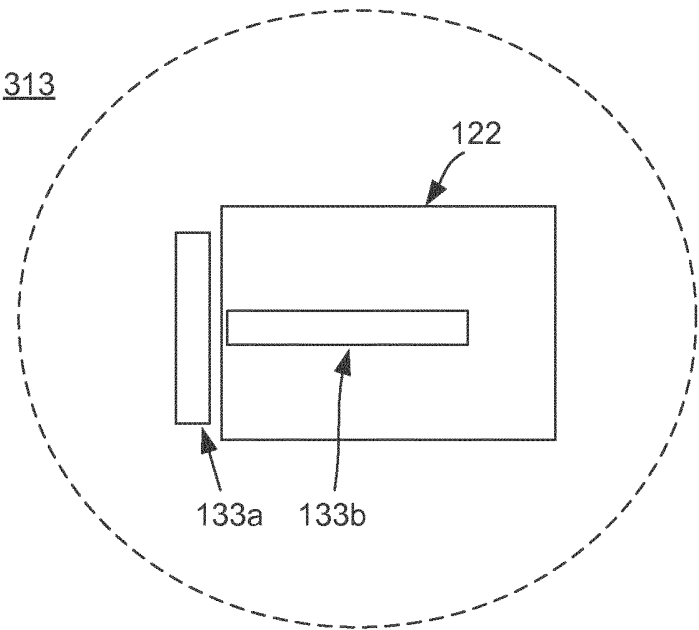


Fig. 3F

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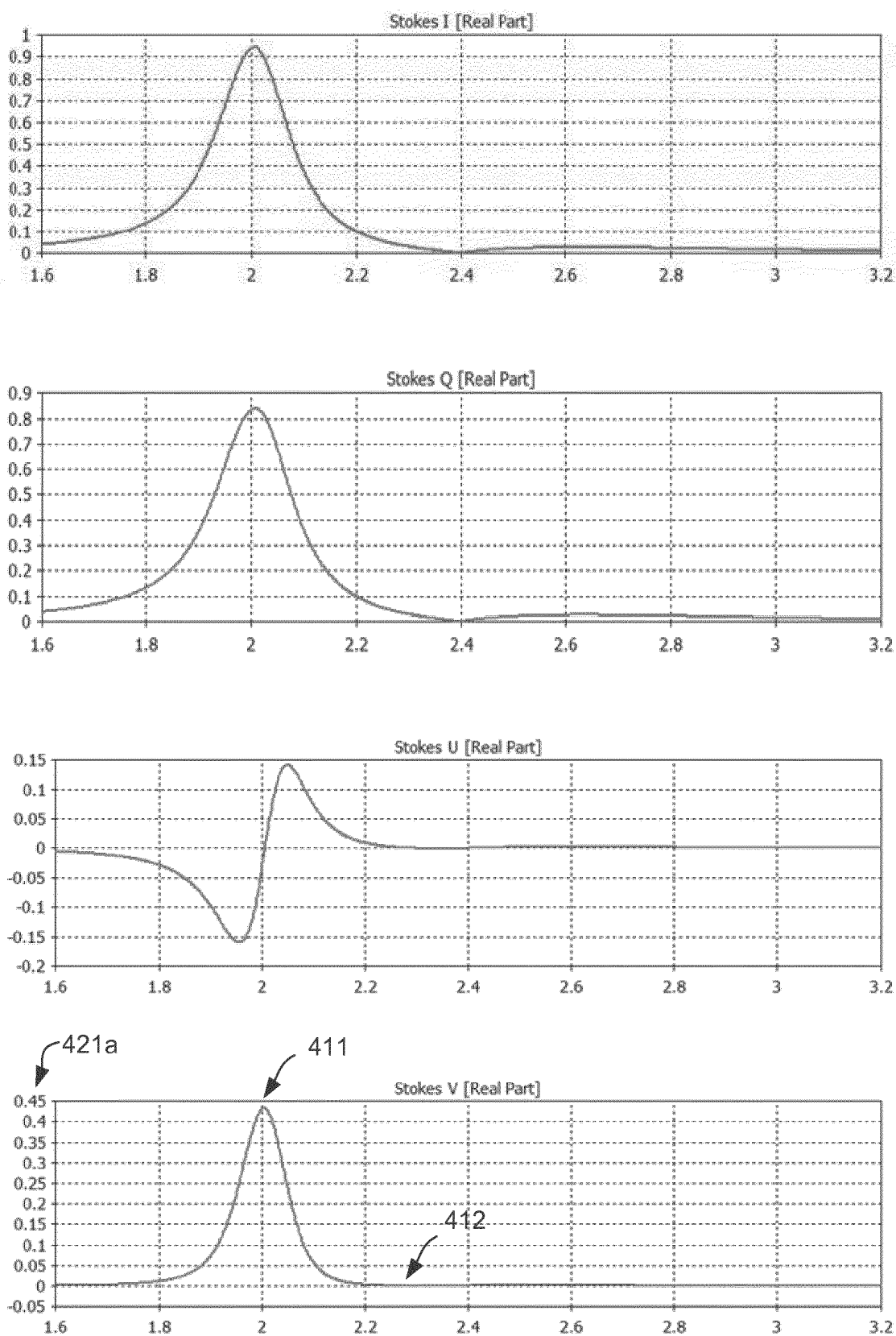


Fig. 4A

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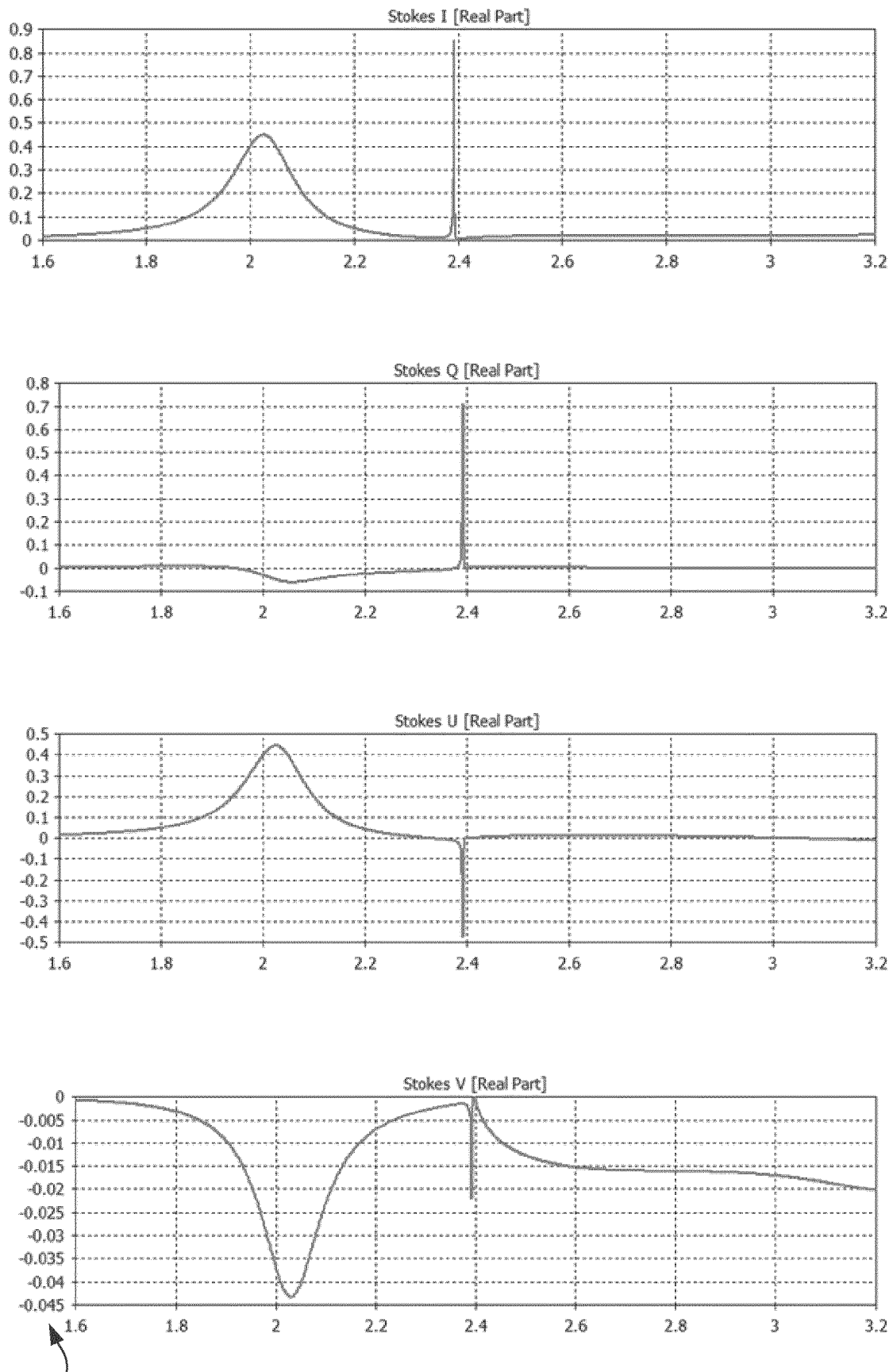
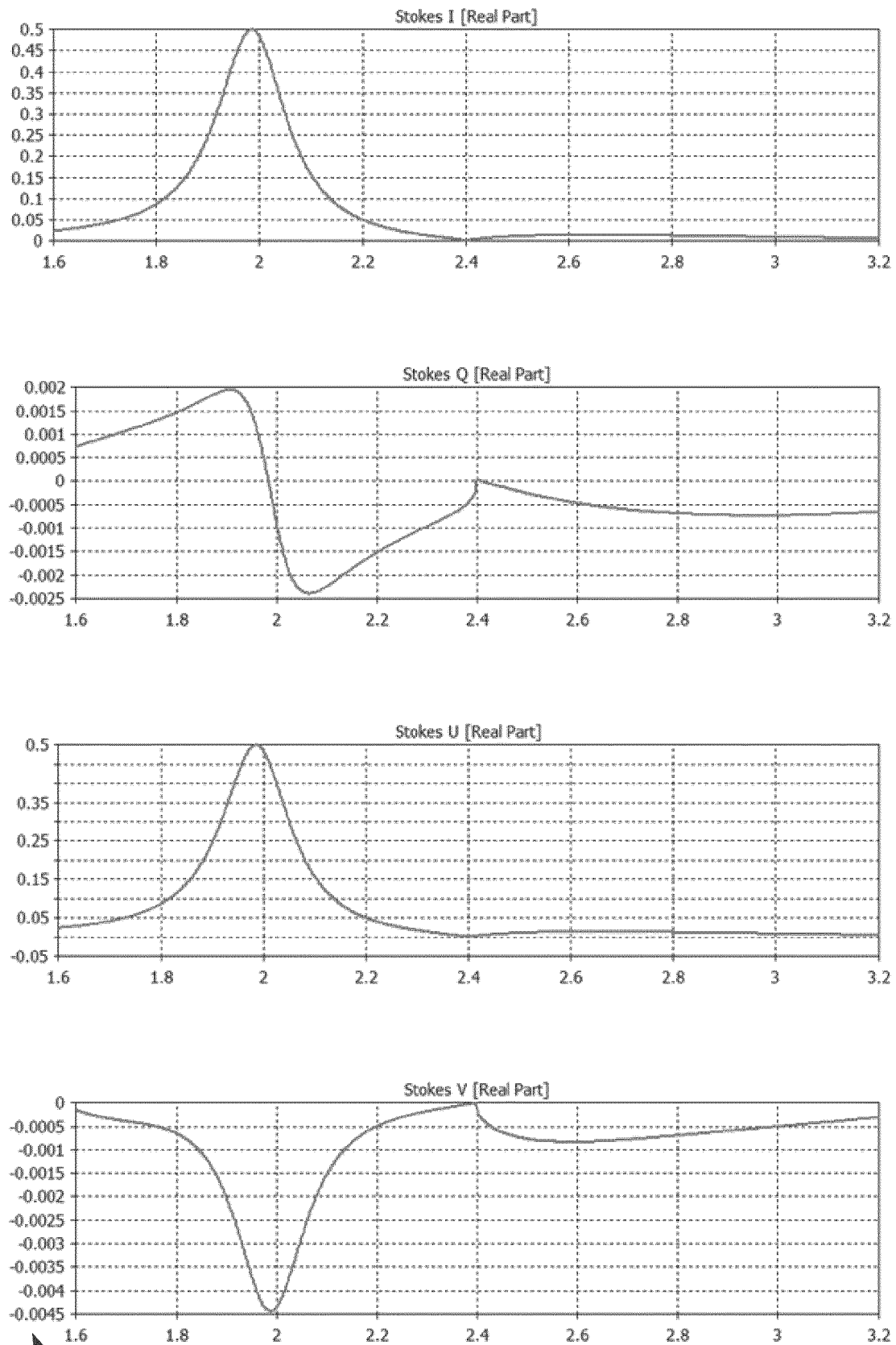


Fig. 4B

10/15



421c

Fig. 4C

11/15

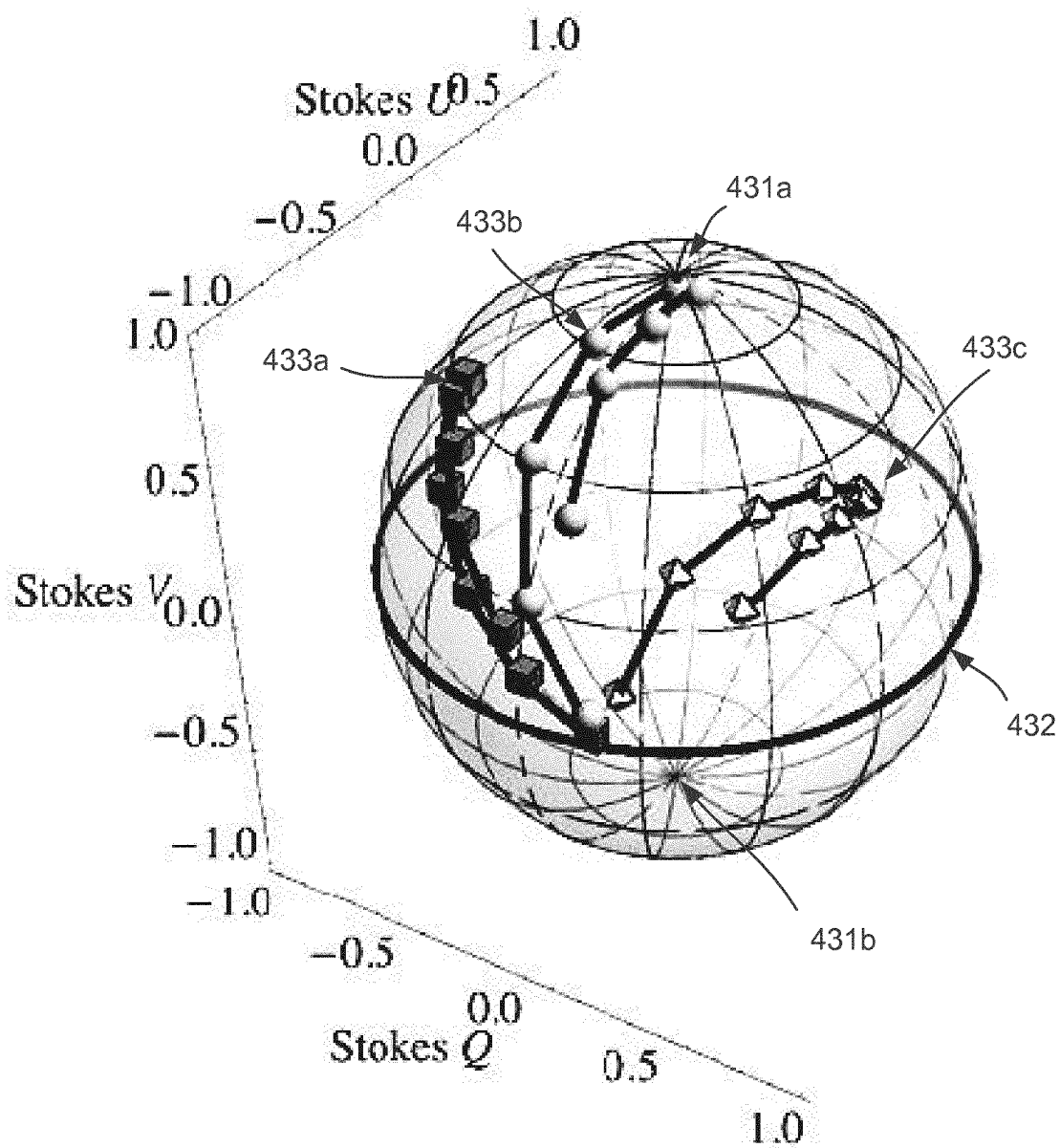


Fig. 4D

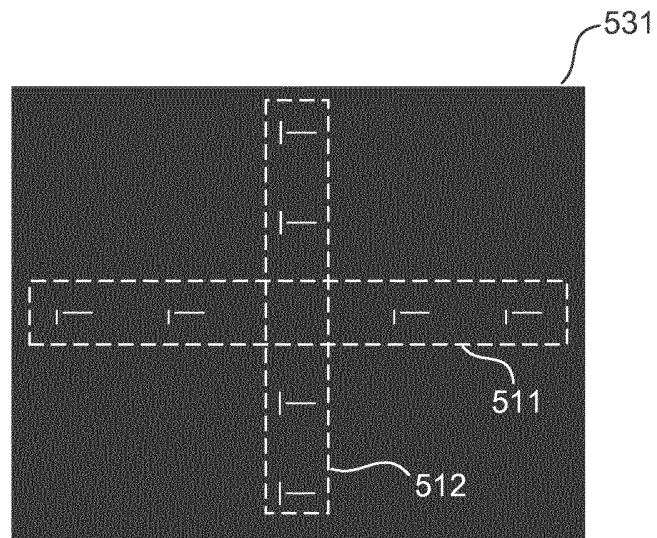


Fig. 5A

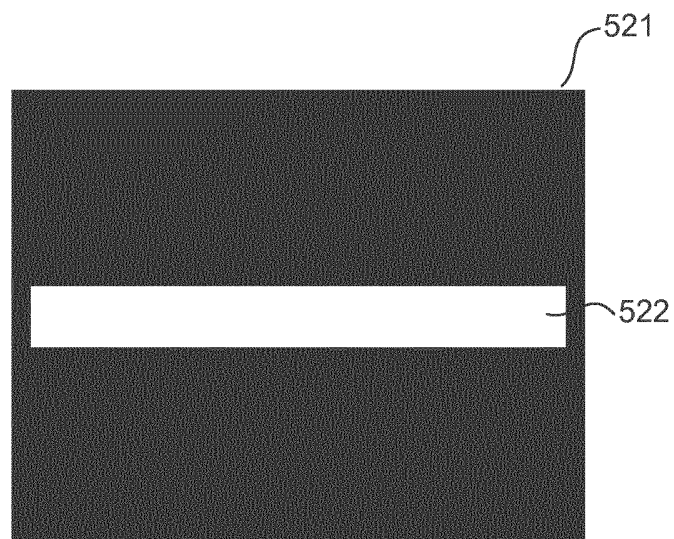


Fig. 5B

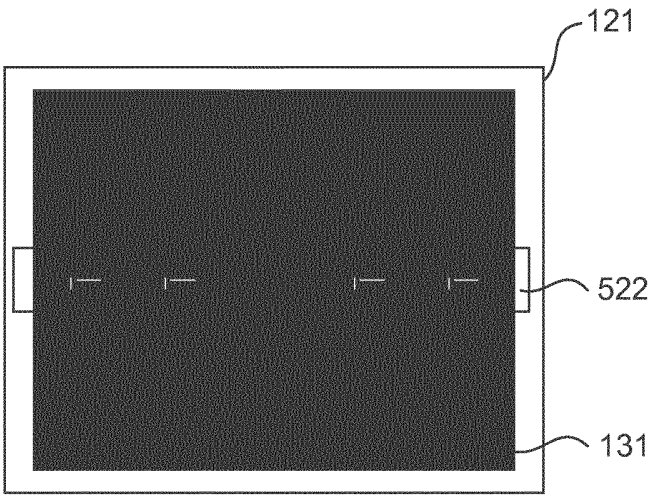


Fig. 5C

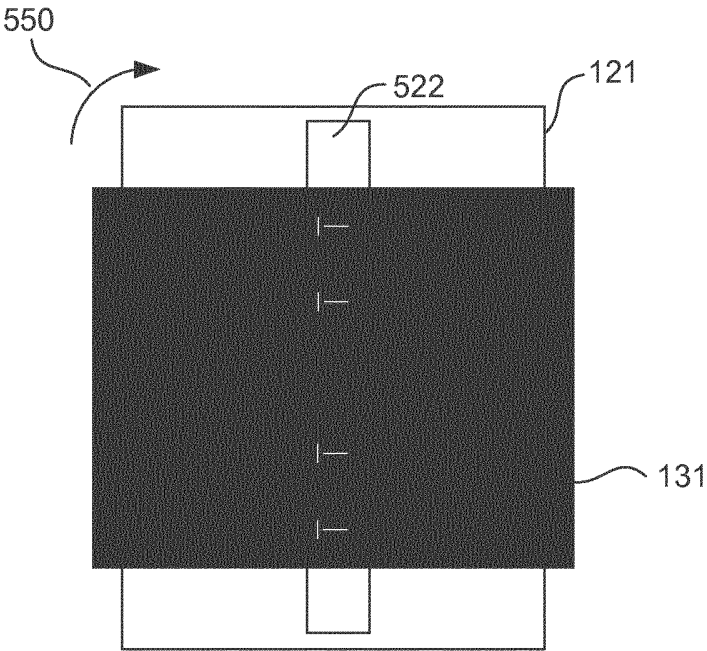
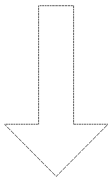


Fig. 5D

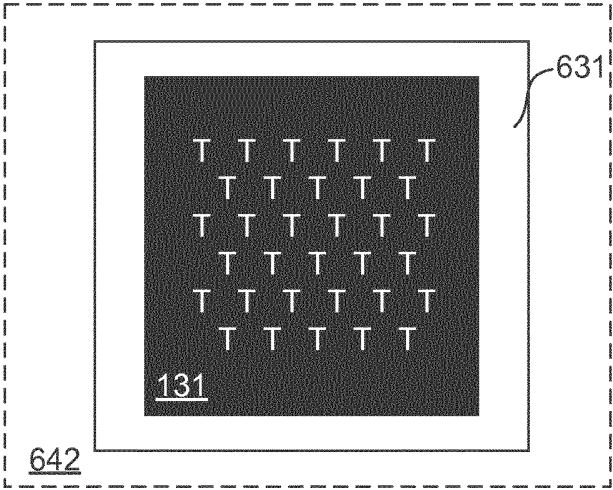


Fig. 6A

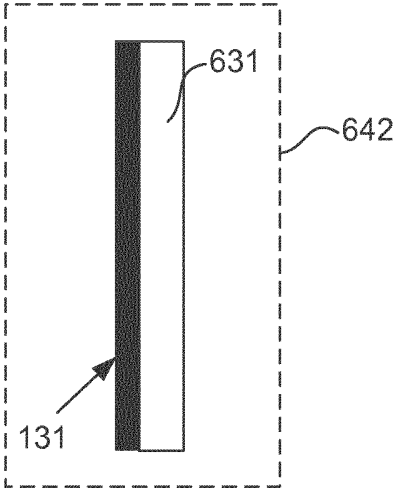


Fig. 6B

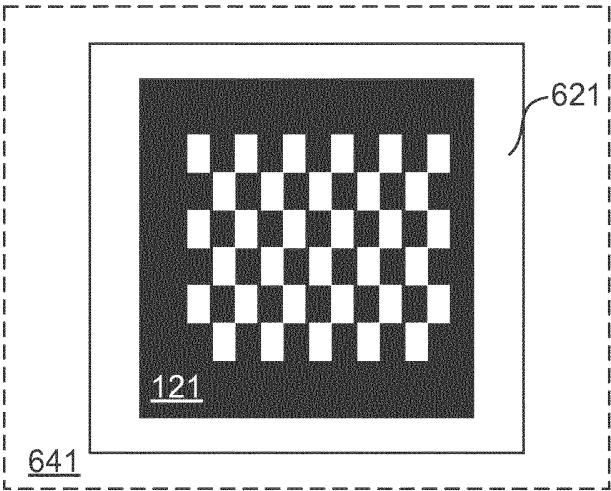


Fig. 6C

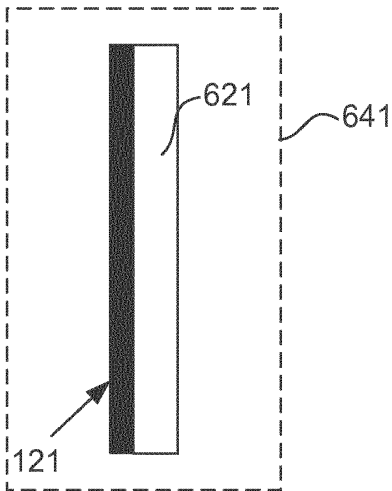


Fig. 6D

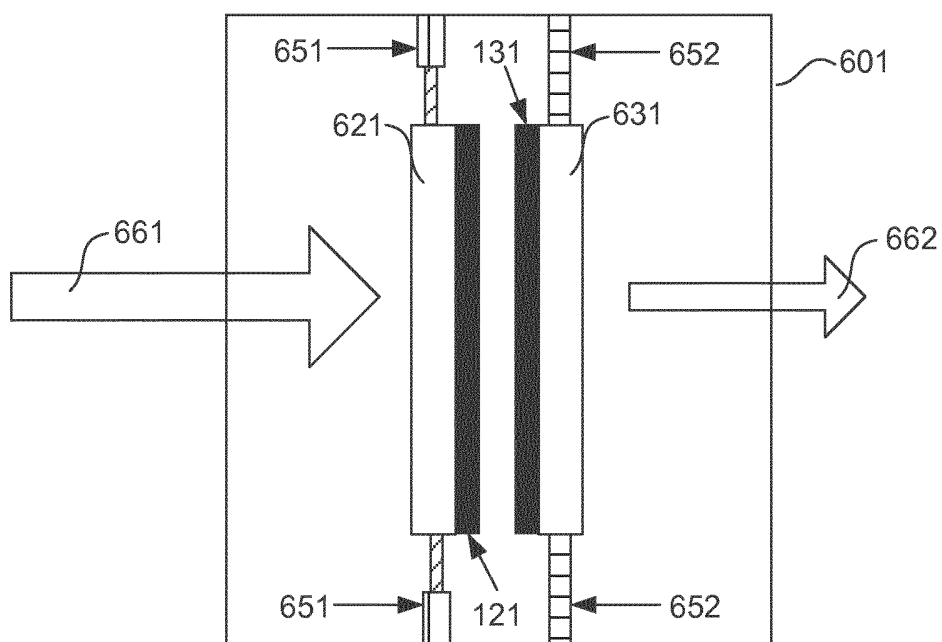


Fig. 6E

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/079230

A. CLASSIFICATION OF SUBJECT MATTER

INV. G02B5/30 G02B27/28 H01Q15/24
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)

G02B H01Q

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.
A	EP 2 595 245 A1 (THALES SA [FR]) 22 May 2013 (2013-05-22) paragraphs [0003], [0007], [0037] - [0040]; figures 4a-4c -----	1-23
A	US 2012/327502 A1 (ZHELUDEV NIKOLAY IVANOVICH [GB] ET AL) 27 December 2012 (2012-12-27) paragraphs [0003], [0004], [0120] - [0121]; figures 1,17a,17b -----	1-23
A	US 6 693 605 B1 (CROUCH DAVID D [US] ET AL) 17 February 2004 (2004-02-17) column 1, lines 7-12; figures 4,5 column 4, line 59 - column 5, line 22 column 7, line 56 - column 8, line 57 ----- -/-	1-23



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

26 February 2016

Date of mailing of the international search report

23/03/2016

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

Casse, Martin

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/079230

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/054067 A1 (HEIKENFELD JASON C [US] ET AL) 27 February 2014 (2014-02-27) paragraphs [0003], [0029] - [0031] -----	1-23
A	JP 2004 117703 A (OSAKA IND PROMOTION ORG) 15 April 2004 (2004-04-15) abstract; figures 1-5 -----	1,21,23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/079230

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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			FR 2982999 A1 24-05-2013
			JP 2013110742 A 06-06-2013
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