(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
02 August 2024 (02.08.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/156795 A1

(51) International Patent Classification:
G02B 1/00 (2006.01) *G02B 13/00* (2006.01)

(21) International Application Number:
PCT/EP2024/051750

(22) International Filing Date:
25 January 2024 (25.01.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/481,480 25 January 2023 (25.01.2023) US

(71) Applicant: **NIL TECHNOLOGY APS** [DK/DK]; Haldor Topsøes Alle 1, 2800 Kongens Lyngby (DK).

(72) Inventors: **VESTERGAARD, Thorlak**; Haldor Topsøes Alle 1, DK-2800 Kongens Lyngby (DK). **NIELSEN, Theodor**; Haldor Topsøes Alle 1, DK-2800 Kongens Lyngby (DK). **QUAADE, Ulrich**; Haldor Topsøes Alle 1, DK-2800 Kongens Lyngby (DK).

(74) Agent: **FISH & RICHARDSON P.C.**; Highlight Business Towers, Mies-van-der-Rohe-Str. 8, 80807 Munich (DE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title:** APPARATUS INCLUDING A LENS CONFIGURATION HAVING STACKED METASURFACES, AND METHODS FOR FABRICATING THE SAME

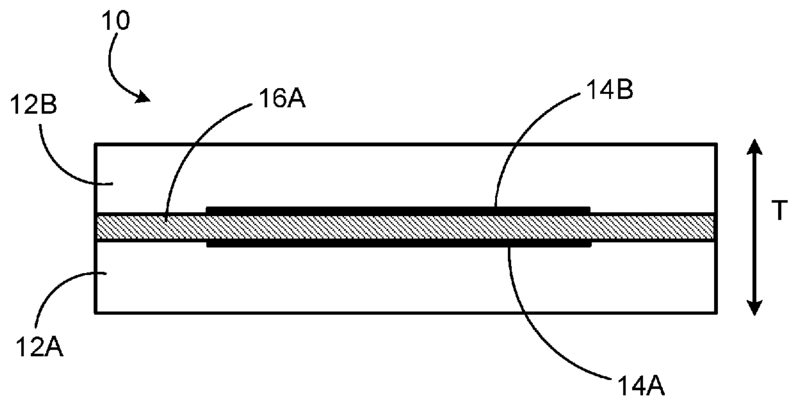

FIG. 1

(57) **Abstract:** An example apparatus includes a lens arrangement. The lens arrangement includes a first substrate having a first metasurface thereon, and a second substrate having a second metasurface thereon. The first and second metasurfaces are stacked and face one another, the first and second metasurfaces being separated from one another by an adhesive that attaches the first and second substrates to one another. Methods of fabricating the lens arrangements also are disclosed.

WO 2024/156795 A1

APPARATUS INCLUDING A LENS CONFIGURATION HAVING STACKED METASURFACES, AND METHODS FOR FABRICATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] The present application claims the benefit of priority of U.S. Provisional Patent Application No. 63/481,480, filed on January 25, 2023, the contents of which are incorporated herein by reference in their entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to lens configurations having stacked metasurfaces.

BACKGROUND

[0003] Meta-optical elements (MOEs) are examples of optical elements that employ a flat optic technology. An MOE has a metasurface that includes distributed small subwavelength structures (e.g., nanostructures or other meta-atoms) arranged to interact with light in a particular manner. The meta-atoms can, individually and/or collectively, interact with light waves to change a local amplitude, a local phase, or both, of an incoming light wave. MOEs can be used, for example, in optical applications to take advantage of the internal properties given by a tailored phase function, compared to classic, curved refractive lenses.

SUMMARY

[0004] The present disclosure describes apparatus that include a lens configuration having stacked metasurfaces, as well as methods for fabricating the lens configuration.

[0005] In one aspect, for example, the present disclosure describes an apparatus that includes a lens arrangement. The lens arrangement includes a first substrate having a first metasurface thereon, and a second substrate having a second metasurface thereon. The first and second metasurfaces are stacked and face one another, the first and second metasurfaces being separated from one another by an adhesive that attaches the first and second substrates to one another.

[0006] Some implementations include one or more of the following features. For example, in some instances, the first and second substrates are composed of a glass material, and the adhesive is a polymer glue. In some implementations, the first and second substrates are composed of a borosilicate glass. In some implementations, the adhesive is optically clear at an infra-red operating wavelength.

[0007] In some implementations, the first metasurface faces the second metasurface, with only the adhesive between them, wherein there is no air gap present between the first and second metasurfaces. In some implementations, a total combined thickness of the lens arrangement including the first and second substrates, the first and second metasurfaces and the adhesive, is 100 microns (μm) or less. In some implementations, a total combined thickness of the lens arrangement including the first and second substrates, the first and second metasurfaces and the adhesive, is 10 microns or less. In some implementations, a total combined thickness of the lens arrangement including the first and second substrates, the first and second metasurfaces and the adhesive, is 1 micron or less.

[0008] In some application the lens arrangement further includes an aperture, which, in some cases, is composed of a layer of black chrome or structured resist applied to one of the metasurfaces or one of the substrates.

[0009] In some implementations, the lens arrangement further includes a third substrate having a third metasurface thereon, the third substrate being attached by additional adhesive to the second substrate. In some cases, the third metasurface faces the second substrate the third metasurface faces the second substrate, with only the additional adhesive between them.

[0010] The present disclosure also describes a method that includes applying adhesive over a surface of a first substrate having a metasuface thereon. The first substrate is attached to a second substrate having a second metasurface thereon such that the first and second metasurfaces are stacked and face one another, the first and second substrates being attached to one another by the adhesive, and the first and second metasurfaces being separated from one another by the adhesive.

[0011] Some implementations include one or more of the following features. For example, in some instances, the first and second substrates are composed of a glass material, and the adhesive is a polymer glue, wherein, after attaching the first and second substrates to one another, the first metasurface faces the second metasurface, with only the adhesive between them, and wherein there is no air gap present between the first and second metasurfaces.

[0012] In some implementations, the method includes thinning at least one of the first or second substrates. The thinning can include, for example, etching, grinding and/or polishing. In some instances, the method includes thinning at least one of the first or second substrates until a total combined thickness of the first and second substrates, the first and second metasurfaces and the adhesive, is 10 microns or less.

[0013] In some implementations, the lateral alignment accuracy between the first and the second metasurfaces is better than 50 µm, 20 µm, 10 µm, or even 5 µm. In some implementations, the lateral alignment accuracy between the first and the second metasurface is better than 1 µm.

[0014] In some implementations, the method includes attaching a third substrate to the second substrate by additional adhesive, the third substrate having a third metasurface thereon, wherein the first, second and third metasurfaces are stacked one over the other. In some instances, the third substrate is attached to the second substrate such that the third metasurface faces the second substrate, with only the additional adhesive between them.

[0015] In some implementations, the method includes removing completely at least one of the first or second substrates. In some implementations, the method includes attaching a third substrate to the second metasurface by additional adhesive, the third substrate having a third metasurface thereon, wherein the first, second and third metasurfaces are stacked one over the other. In some instances, the third substrate is attached to the second substrate such that the third metasurface faces the second metasurface, with only the additional adhesive between them.

[0016] Some implementations include one or more of the following advantages. For example, in some implementations, a lens configuration in which two or more metasurfaces are stacked can achieve a relatively short total track length (TTL), low f-number, and/or improved overall imaging performance. In some cases, a first optical functionality can be implemented on one metasurface and another, different optical function can be implemented on the second metasurface. In some cases, the stacked metasurfaces can facilitate a wide range of optical functionalities by having a resonant interaction between the stacked metasurfaces. The stacked metasurfaces can, in some cases, facilitate integration of an image sensor or light source with the stack of metasurfaces, which may permit the sensor or light source to be positioned in relatively close proximity to the stack of metasurfaces. Such arrangements can, in some cases, achieve a highly compact (e.g., thin) optical device.

[0017] Other aspects, features and advantages will be readily apparent from the following detailed description, the accompanying drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 illustrates an example of a lens configuration including stacked metasurfaces.

[0019] FIGS. 2A, 2B, 2C, 2D, 2E, 2F illustrate various stages in a method of fabricating a lens configuration.

[0020] FIGS. 3A-3C illustrate various stages in a method of fabricating a lens configuration having more than two stacked metasurfaces.

[0021] FIGS. 4 and 5 illustrate examples of lens configurations having stacked metasurfaces and an optical aperture.

[0022] FIGS. 6A, 6B, 6C, 6D, 6E, 6F illustrate various stages in a method of fabricating a lens configuration.

[0023] FIG. 7 illustrates an example of an image sensor module including a lens configuration having stacked metasurfaces.

[0024] FIG. 8 illustrates an example of a light source module including a lens configuration having stacked metasurfaces.

DETAILED DESCRIPTION

[0025] The present disclosure describes apparatus that include a lens configuration having stacked metasurfaces, as well as methods for fabricating such a lens configuration. In some implementations, lens configurations in which two or more metasurfaces are stacked can achieve a relatively short total track length (TTL), low f-number, and/or improved overall imaging performance.

[0026] As shown in the example of FIG. 1, a lens arrangement 10 includes first and second substrates 12A, 12B attached (e.g., bonded) to one another. Each substrate 12A, 12B has a respective metasurface 14A, 14B on one side. Each metasurface 14A, 14B has carefully arranged “unit cells” or “meta-atoms” with sub-wavelength structures (e.g., nanostructures). The term “subwavelength” indicates that the nanostructures have at least one lateral dimension (parallel to the substrate on which they are disposed) that is less than a wavelength of light that is to be incident thereon. The meta-atoms can be composed, for example, of silicon. In general, the dimensions of the nanostructures scale with the shortest wavelength of interest. For example, in some implementations, the nanostructures can be in the form of nanoscale features having dimensions less than 1 micron. By adjusting the geometry of these unit cell elements, one can modify the phase above the elements in response to a plane wave. With the knowledge of the phase in terms of the geometry parameters, it is possible to create a metalens with an arbitrary phase profile by placing the meta-atoms at the necessary positions. In general, the derivative of the phase profile determines the ray bending. Each substrate together with its respective metasurface forms a metalens.

[0027] The substrates 12A, 12B, which may be composed, for example, of glass (e.g., borosilicate glass such as D 263® glass manufactured by Schott), can be attached (e.g., bonded) to one another by an adhesive 16A, such as a polymer glue, that is optically clear at the operating wavelength (e.g., infrared or visible). In some implementations, the adhesive is index matched to the glass substrates 12A, 12B. The substrates are attached to one another such that the metasurfaces 14A, 14B are adjacent one another. That is, the first metasurface 14A faces the second metasurface 14B, with only a thin layer of the adhesive 16A between them. In the illustrated example, there is no air gap present between the metasurfaces 14A, 14B. In some cases, the overall thickness (T) of the lens arrangement 10 is on the order of ten microns (μm), and in some cases may be even less. Incorporating a stack of metasurfaces into a lens arrangement as described in this disclosure can, in some instances, facilitate a wide range of optical functionalities by having a resonant interaction between the stacked metasurfaces. Such optical functionalities can include, for example, near-field interactions, filtering functions, and/or plasmonics.

[0028] FIGS. 2A, 2B, 2C, 2D, 2E, 2F illustrate various stages in a method of fabricating the device of FIG. 1. The method can be performed, in some cases, at the wafer-level. As shown in FIG. 2A, first and second glass substrates 12A, 12B are provided, each of which has a respective metasurface 14A, 14B on its surface. In some instances, the initial thickness of each substrate 12A, 12B may be on the order of several hundred μm (e.g., 500 μm) to provide mechanical and structural integrity and a relatively planar surface for processing. As shown in FIG. 2B, a thin layer of an optically clear adhesive (e.g., polymer glue) 16A is provided on the side of one (or both) of the substrates 12A, 12B on which the metasurface 14A, 14B is present. The adhesive 16A can be provided, for example, by spin-coating or jetting, or in some other manner to apply a controlled amount of adhesive on the substrate surface. Then, as shown in FIG. 2C, the two substrates 12A, 12B are brought into contact with one another such that their respective metasurfaces 14A, 14B face one another. In some implementations, the adhesive 16A between the substrates 12A, 12B may be cured thermally and/or by the application of UV radiation. In some implementations, as indicated by FIG. 2D, one or both of the substrates 12A, 12B can be thined from the backside of the substrate (i.e., the side opposite the metasurface) to reduce the overall thickness of the resulting device. The thinning can be accomplished, for example, by etching techniques, including, for example, dry (e.g., reactive ion etching (RIE)) and/or wet (e.g., hydrofluoric acid) etches. Other thinning techniques include mechanical grinding and/or polishing. In some cases, the thinning may be performed to reduce the overall thickness (T) of the device to 10 μm or less. If the foregoing steps are performed at a wafer-level, a dicing operation subsequently can be performed to separate the wafer into individual devices.

[0029] In some implementations, as indicated by FIGS. 2E and 2F, one or both of the substrates 12A, 12B can be completely removed by the etching or other thinning technique.

[0030] In some instances, the techniques described in this disclosure can help provide active control of the total thickness of the stack. In some cases, the techniques can improve yield and reduce manufacturing costs.

[0031] In some implementations, further processing can be performed to provide a lens configurations in which more than two metasurfaces are stacked in close proximity to one another. For example, as shown in FIG. 3A, at least one of the substrates of FIG. 2C (e.g., the second substrate 12B) can be thinned (e.g., etched) so as to leave only a thin layer of the substrate material over the metasurface 14B. If a highly selective etch is used, then the substrate 12B can be etched down to (or almost down to) the metasurface 14B. Next, as shown in FIG. 3B, a third substrate 12C, having a respective third metasurface 14C, is attached (e.g., bonded) to the second substrate by an adhesive 16B such as a polymer glue, that is optically clear at the operating wavelength (e.g., infrared or visible). In some implementations, the adhesive is index matched to the glass substrates 12B, 12C. The substrates are attached to one another such that the metasurfaces 14B, 14C are in close proximity to one another. That is, the third metasurface 14C faces the second metasurface 14B, with only a thin layer of adhesive 16B and the remaining material of the second substrate 12B (if any) between them.

[0032] In some implementations, one or both of the outer substrates (i.e., the first substrate 12A and/or the third substrate 12C) can be etched from the backside of the substrate (i.e., the side opposite the metasurface) to reduce the overall thickness of the resulting lens configuration. In some implementations, at least one of the substrates is completely removed by the etching or other thinning technique. The etching techniques may include, for example, dry (e.g., RIE) and/or wet (e.g., hydrofluoric acid) etches. FIG. 3C shows an example of a lens configuration 20 that includes three stacked metasurfaces, 14A, 14B, 14C after thinning (e.g., etching) the outer substrates 12A, 12C. In the resulting lens configuration 20, the substrates are attached (e.g., bonded) to one another such that the metasurfaces 14A, 14B, 14C form a stack and are adjacent, or in close proximity, to one another. That is, the first metasurface 14A faces the second metasurface 14B, with only a thin layer of adhesive 16A between them, and the third metasurface 14C faces the second metasurface 14B, with only a thin layer of adhesive 16B (and possibly also a thin layer of the material of the second substrate 12B) between them. In the illustrated example, there is no air gap present between the metasurfaces 14A, 14B, 14C.

[0033] In some implementations, further processing, similar to that described in connection with FIGS. 3A-3C, can be performed to provide additional metasurfaces for the stack. Providing more than two metasurfaces may be advantageous, for example, for implementations of an achromatic lens and, in general, may provide greater flexibility in the lens design.

[0034] In some implementations, as shown in the examples of FIGS. 4 and 5, an optical aperture or stop 18 may be provided on an exterior surface of one of the substrates (e.g., the first substrate 12A) to form an optical device 30, 40 that includes a lens configuration having a stack of two or more metasurfaces 14A, 14B. The aperture 18 may be composed, for example, of black chrome or a structured resist, and may be helpful, in some implementations, to block unwanted (e.g., stray) light. In some instances (as shown in FIG. 4), the aperture 18 may slightly overlap the positions of the metasurfaces laterally, whereas in other instances (as shown in FIG. 5), the aperture 18 may not overlap with the positions of the metasurfaces laterally. In some implementations the aperture is applied on one of the metasurfaces.

[0035] FIGS. 6A, 6B, 6C, 6D, 6E, 6F illustrate various stages in an example method of fabricating a lens configuration that includes an optical aperture. The method can be performed, in some cases, at the wafer-level. As shown in FIG. 6A, first and second glass substrates 12A, 12B are provided, each of which has a respective metasurface 14A, 14B on its surface. In some instances, the initial thickness of each substrate 12A, 12B may be on the order of several hundred μm (e.g., 500 μm) to provide mechanical and structural integrity and a relatively planar surface for processing. Further, a thin layer 18 (e.g., of black chrome or a structured resist) is applied to the surface of one of the substrates 12A so that the layer 18 laterally surrounds the edges of the metasurface 14A. As shown in FIG. 6B, a thin layer of an optically clear adhesive (e.g., polymer glue) 16A is provided on the side of one (or both) of the substrates 12A, 12B on which the metasurface 14A, 14B is present. The adhesive 16A can be provided, for example, by spin-coating or jetting, or in some other manner to apply a controlled amount of adhesive on the substrate surface. Then, as shown in FIG. 6C, the two substrates 12A, 12B are brought into contact with one another such that their respective metasurfaces 14A, 14B face one another. In some implementations, the adhesive 16A between the substrates 12A, 12B may be cured thermally and/or by the application of UV radiation. In some implementations, as indicated by FIG. 6D, one or both of the substrates 12A, 12B can be thined from the backside of the substrate (i.e., the side opposite the metasurface) to reduce the overall thickness of the resulting device. The thinning can be accomplished, for example, by etching techniques, including, for example, dry (e.g., reactive ion etching (RIE)) and/or wet (e.g., hydrofluoric acid) etches. Other thinning techniques include mechanical grinding and/or polishing. In some cases, the thinning may be performed to reduce the overall thickness (T) of the device to 10 μm or less. If the foregoing steps are performed at a wafer-level, a dicing operation subsequently can be performed to separate the wafer into individual devices. In some implementations, as indicated by FIGS. 6E and 6F, one or both of the substrates 12A, 12B can be completely removed by the etching or other thinning technique. The result in each of FIGS. 6D, 6E and 6F is a lens arrangement that includes a stack of metasurfaces 14A, 14B and an optical aperture defined by the layer 18.

[0036] The various lens arrangements and optical devices described in this disclosure may be used in a range of applications, including optical imaging systems (e.g., cameras) and light projection systems. FIG. 7 shows an example of a lens arrangement 50 having a stack of metasurfaces 14A, 14B. An image sensor 52 is disposed along the optical axis of the stack and is positioned to receive rays of light 54 passing through the stack of metasurfaces 14A, 14B. The image sensor 52 can be, for example, a CMOS or CCS sensor. FIG. 8 shows an example of a lens arrangement 60 having a stack of metasurfaces 14A, 14B. A light source 62 is operable to emit light (e.g., infra-red or visible) 64 toward the stack such that at least some of the rays of light pass through the stack of metasurfaces 14A, 14B. In some impleentations, the lens arrangement may help collimate light from the light source

62, which can include, for example, a vertical cavity surface emitting laser (VCSEL) or light emitting diode (LED). Integrating the image sensor or light source with a stack of metasurfaces as described in this disclosure can permit the sensor or light source to be positioned in relative close proximity to the stack of metasurfaces, which in some cases can achieve a highly compact (e.g., thin) optical device.

[0037] Various modifications will be readily apparent from the foregoing detailed description. Accordingly, other implementations also are within the scope of the claims.

What is claimed is:

1. An apparatus comprising:

a lens arrangement including a first substrate having a first metasurface thereon, and a second substrate having a second metasurface thereon,

wherein the first and second metasurfaces are stacked and face one another, the first and second metasurfaces being separated from one another by an adhesive that attaches the first and second substrates to one another.

2. The apparatus of claim 1 wherein the first and second substrates are composed of a glass material, and wherein the adhesive is a polymer glue.

3. The apparatus of any one of claims 1-2 wherein the adhesive is optically clear to infra-red radiation.

4. The apparatus of any one of claims 1-3 wherein the first and second substrates are composed of a borosilicate glass.

5. The apparatus of any one of claims 1-4 wherein the first metasurface faces the second metasurface, with only the adhesive between them, and wherein there is no air gap present between the first and second metasurfaces.

6. The apparatus of any one of claims 1-5 wherein a total combined thickness of the lens arrangement including the first and second substrates, the first and second metasurfaces and the adhesive, is 10 microns or less.

7. The apparatus of any one of claims 1-5 wherein the lens arrangement further includes a third substrate having a third metasurface thereon, the third substrate being attached by additional adhesive to the second substrate.

8. The apparatus of claim 7 wherein the third metasurface faces the second substrate with only the additional adhesive between them.

9. The apparatus of any one of claims 1-8 including at least one optical aperture on one of the metasurfaces or on one of the substrates.

10. The apparatus of any one of claims 1-9 wherein lateral alignment accuracy between the first and the second metasurfaces is better than 50 µm.

11. The apparatus of any one of claims 1-9 wherein lateral alignment accuracy between the first and the second metasurfaces is better than 5 µm.

12. A method comprising:

applying adhesive over a surface of a first substrate having a metasuface thereon;

attaching the first substrate to a second substrate having a second metasurface thereon such that the first and second metasurfaces are stacked and face one another, the first and second substrates being attached to one another by the adhesive, and the first and second metasurfaces being separated from one another by the adhesive.

13. The method of claim 12 wherein the first and second substrates are composed of a glass material, and the adhesive is a polymer glue, wherein, after attaching the first and second substrates to one another, the first metasurface faces the second metasurface, with only the adhesive between them, and wherein there is no air gap present between the first and second metasurfaces.

14. The method of any one of claims 12-13 further including:

thinning or removing completely at least one of the first or second substrates.

15. The method of claim 14 wherein the thinning or removing completely includes etching.

16. The method of any one of claims 14-15 including thinning at least one of the first or second substrates until a total combined thickness of the first and second substrates, the first and second metasurfaces and the adhesive, is 10 microns or less.

17. The method of any one of claims 12-16 further including:

attaching a third substrate to the second substrate by additional adhesive, the third substrate having a third metasurface thereon, wherein the first, second and third metasurfaces are stacked one over the other.

18. The method of claim 17 wherein, the third substrate is attached to the second substrate such that the third metasurface faces the second substrate with only the additional adhesive between them.

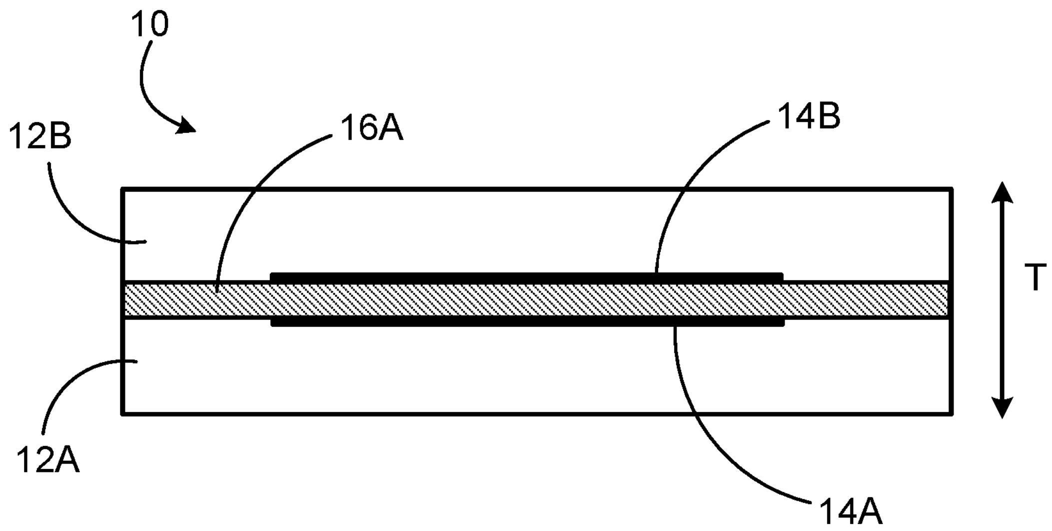

FIG. 1

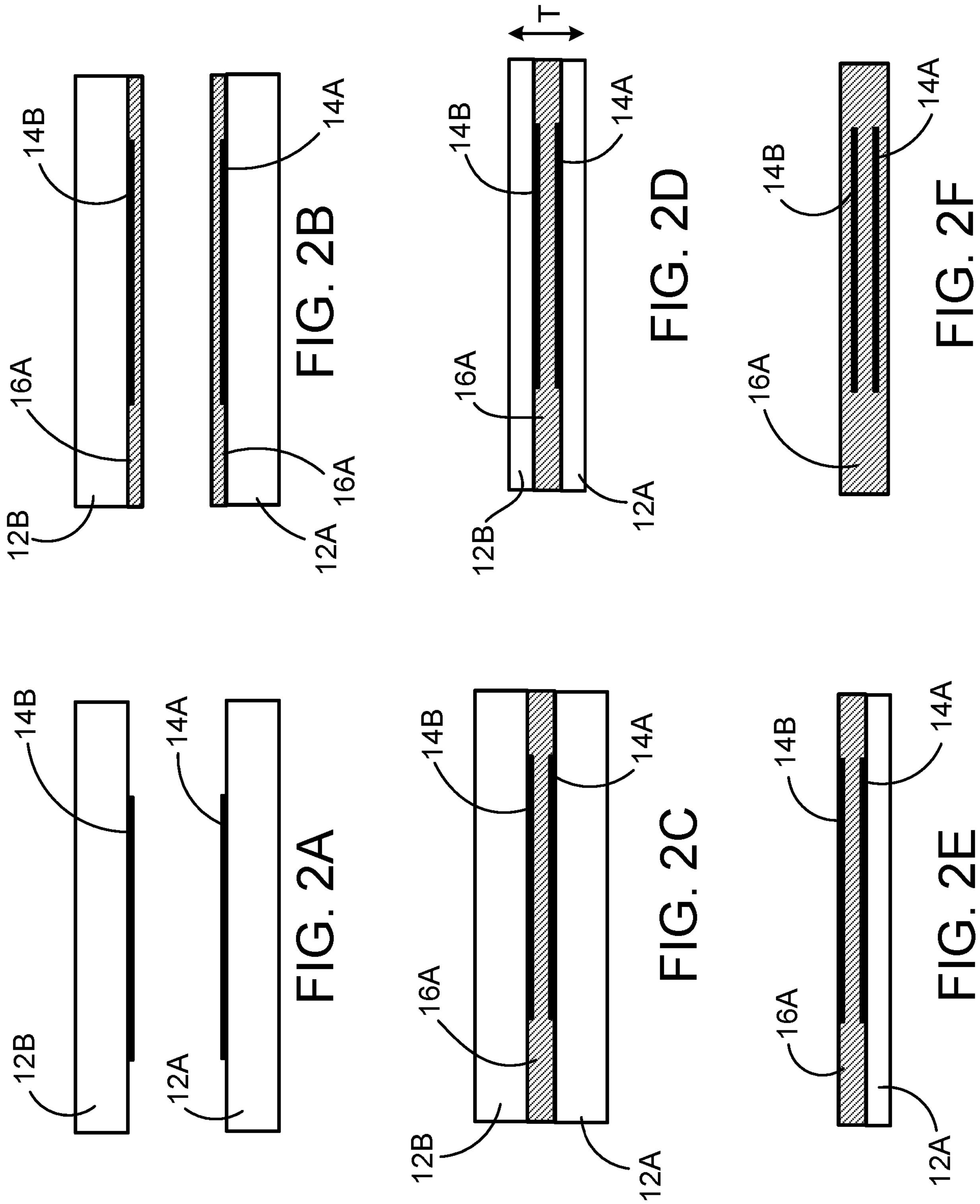

FIG. 2A

FIG. 2B

FIG. 2C

FIG. 2D

FIG. 2E

FIG. 2F

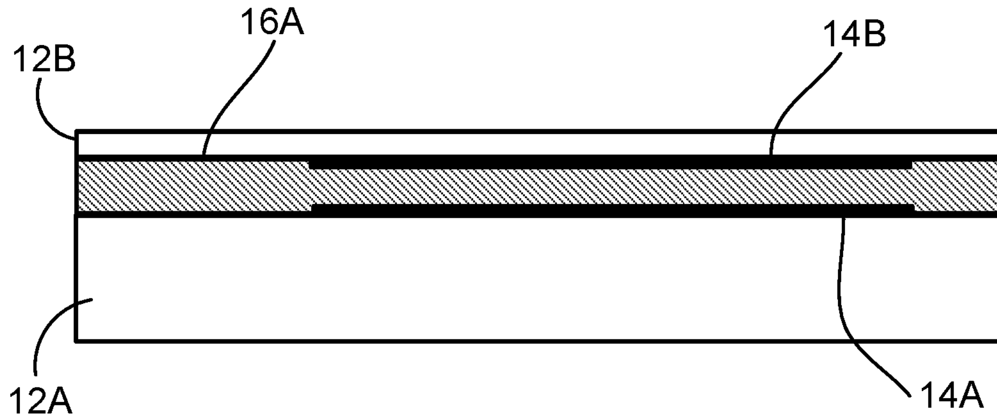

FIG. 3A

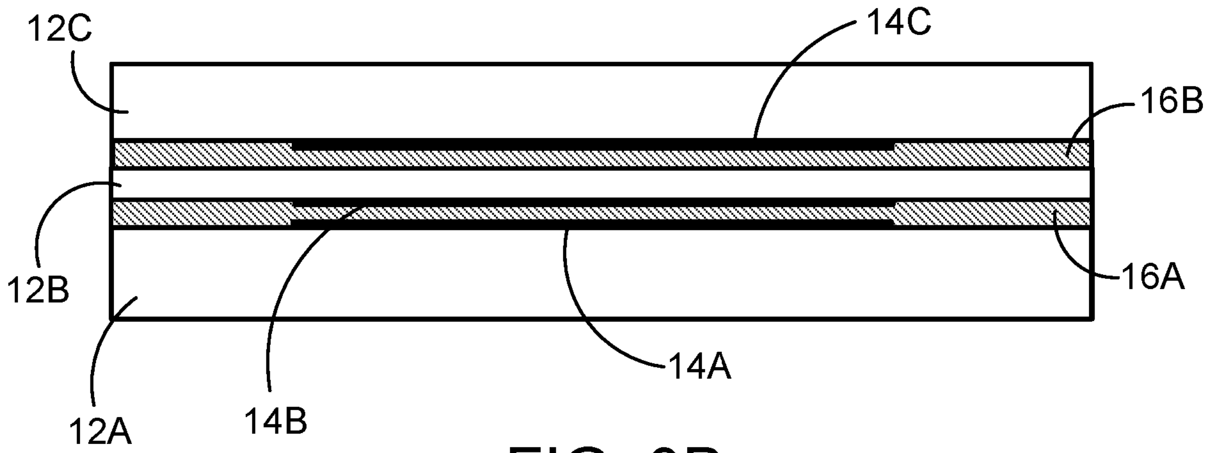

FIG. 3B

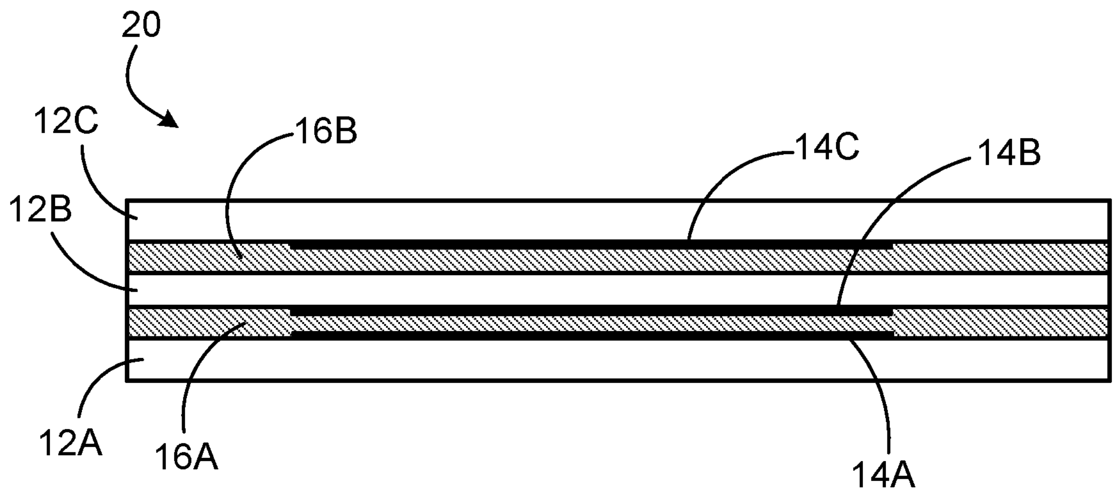

FIG. 3C

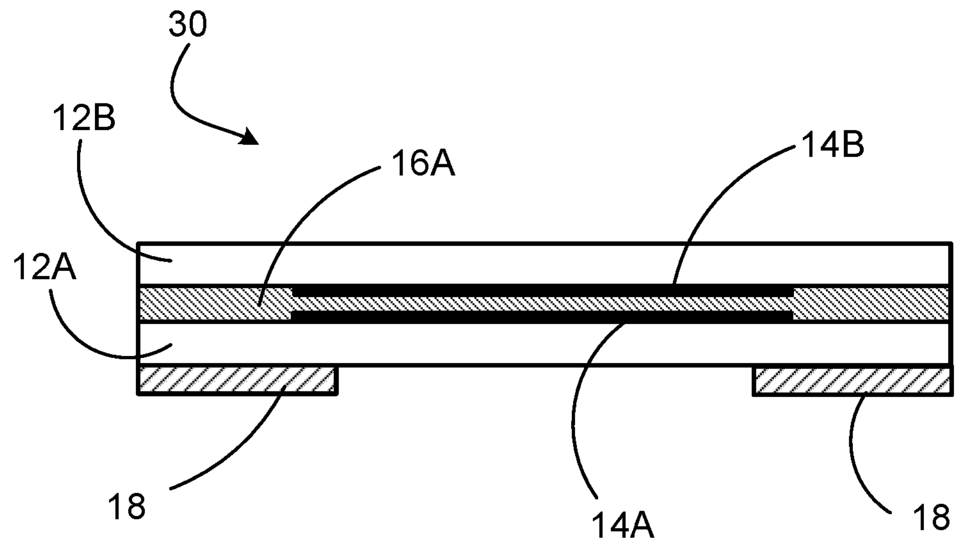
30
12B
16A
14B
12A
18
14A
18

FIG. 4

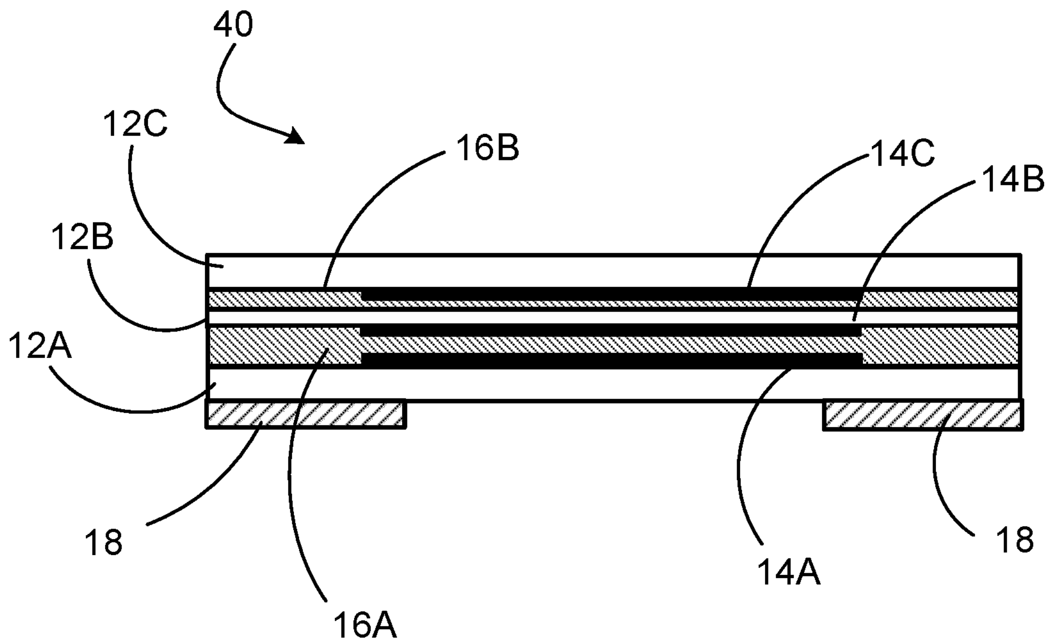
40
12C
16B
14C
14B
12B
12A
18
14A
18
16A

FIG. 5

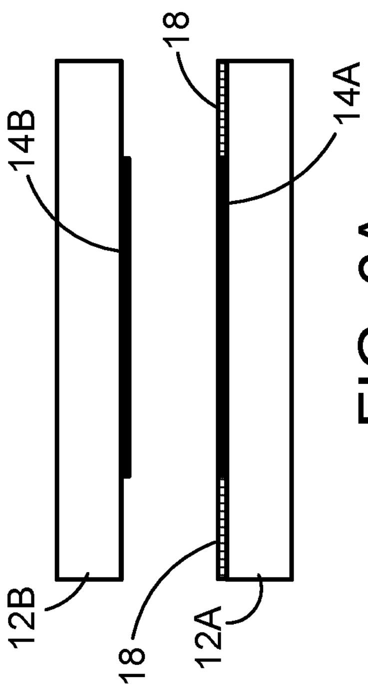

FIG. 6A

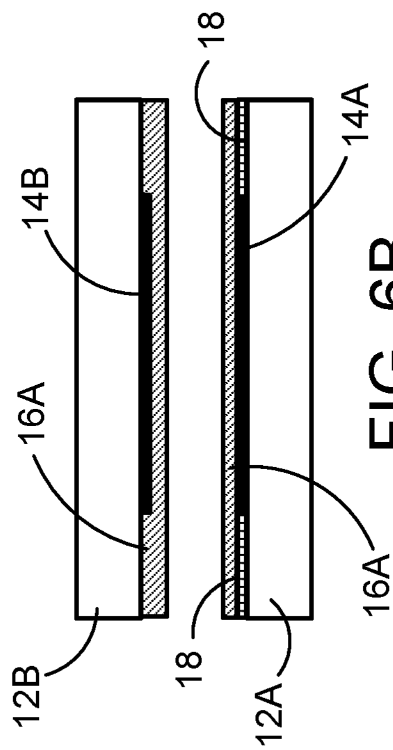

FIG. 6B

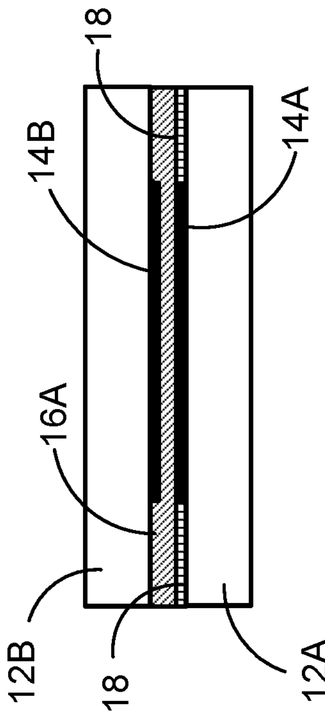

FIG. 6C

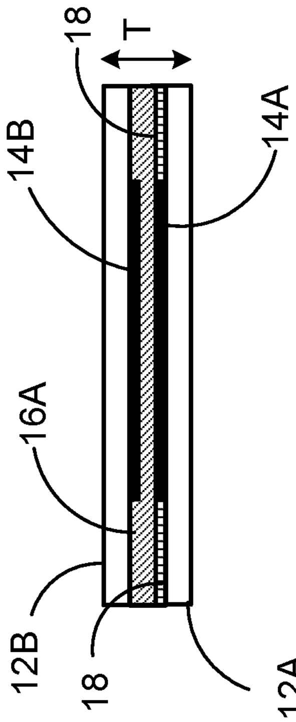

FIG. 6D

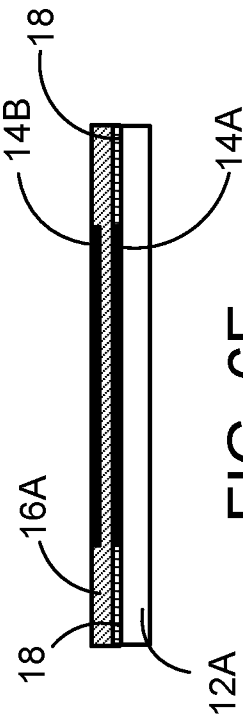

FIG. 6E

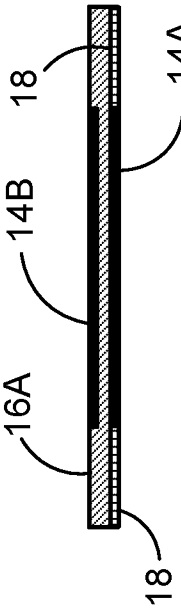

FIG. 6F

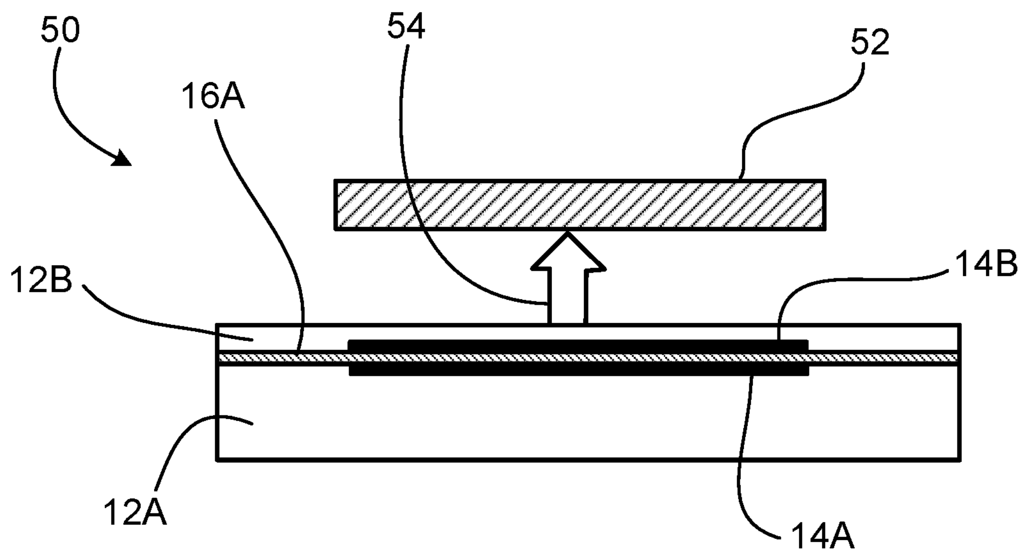

FIG. 7

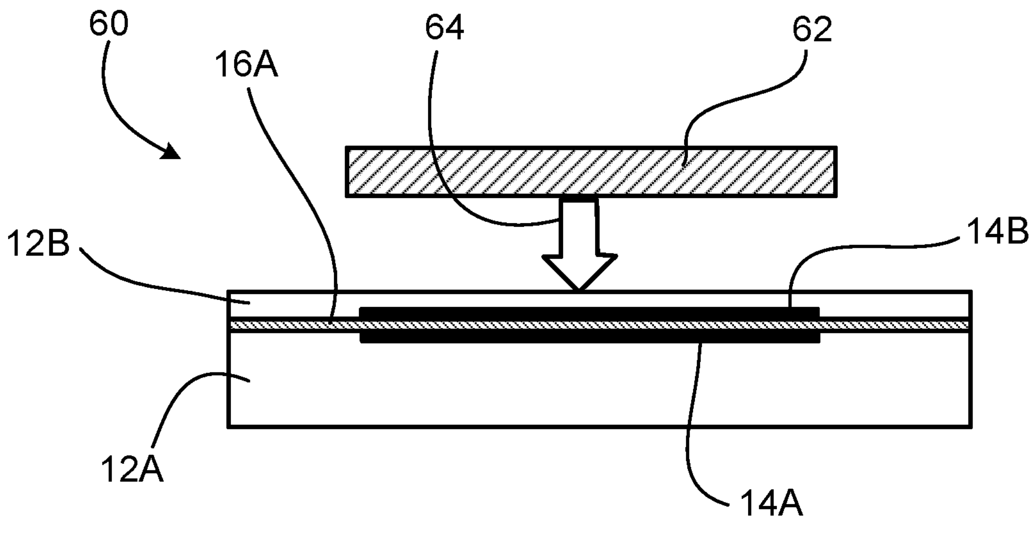

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/051750

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B1/00
ADD. G02B13/00

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	WO 2022/117458 A1 (NILT SWITZERLAND GMBH [CH]) 9 June 2022 (2022-06-09) abstract paragraph [0022] paragraphs [0033] - [0034] paragraphs [0042] - [0043] figures 2C, 2D, 4C, 4D -----	1-3,5, 10-13 4,7-9, 14,15, 17,18 6,16
Y	US 2019/064532 A1 (RILEY JR GILBERT N [US] ET AL) 28 February 2019 (2019-02-28) abstract paragraphs [0005] - [0011] ----- -/--	4

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 April 2024	06/05/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schenke, Cordt

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2022/336270 A1 (GODET LUDOVIC [US] ET AL) 20 October 2022 (2022-10-20) abstract paragraph [0003] paragraphs [0043] - [0053] paragraphs [0065] - [0072] paragraphs [0076] - [0079] figures 2, 7, 8, 11, 15 -----	7,8,14, 15,17,18 6,16
Y	US 2019/086579 A1 (KIM JAEKWAN [KR] ET AL) 21 March 2019 (2019-03-21) abstract paragraphs [0123] - [0125], [0135] - [0137] figures 16, 18 -----	9

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/051750

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2022117458 A1	09-06-2022	US 2024085589 A1	14-03-2024
		WO 2022117458 A1	09-06-2022
US 2019064532 A1	28-02-2019	CA 3074566 A1	07-03-2019
		CN 111656707 A	11-09-2020
		EP 3676973 A1	08-07-2020
		JP 7461294 B2	03-04-2024
		JP 2020537193 A	17-12-2020
		JP 2024045435 A	02-04-2024
		KR 20200047612 A	07-05-2020
		SG 11202001717V A	30-03-2020
		US 2019064532 A1	28-02-2019
		US 2020271941 A1	27-08-2020
		US 2022091428 A1	24-03-2022
		US 2023194883 A1	22-06-2023
		WO 2019046827 A1	07-03-2019
US 2022336270 A1	20-10-2022	CN 112020770 A	01-12-2020
		EP 3782190 A1	24-02-2021
		JP 7210608 B2	23-01-2023
		JP 2021521481 A	26-08-2021
		JP 2023055709 A	18-04-2023
		KR 20200130872 A	20-11-2020
		KR 20230074638 A	30-05-2023
		TW 202005046 A	16-01-2020
		TW 202125765 A	01-07-2021
		TW 202245001 A	16-11-2022
		US 2019318957 A1	17-10-2019
		US 2020286778 A1	10-09-2020
		US 2022336270 A1	20-10-2022
		WO 2019203926 A1	24-10-2019
US 2019086579 A1	21-03-2019	EP 3460535 A2	27-03-2019
		KR 20190033283 A	29-03-2019
		US 2019086579 A1	21-03-2019
		US 2022026605 A1	27-01-2022
		US 2024012178 A1	11-01-2024