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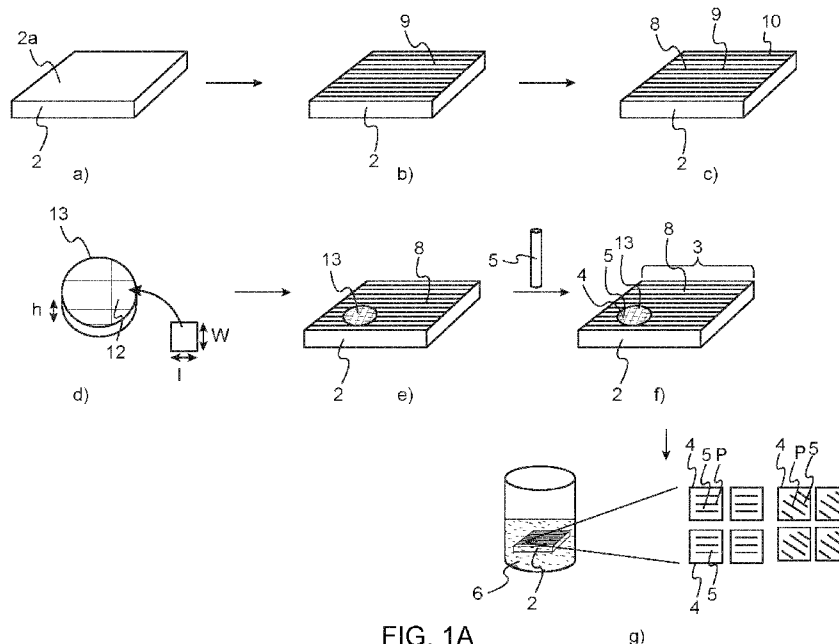


FIG. 1A

(57) Abstract: The invention concerns a method for processing an optoelectronic arrangement comprising the steps of providing a first carrier substrate with a top surface, providing an alignment structure on the top surface of the first carrier substrate, the alignment structure comprising a plurality of elements having a polarity caused by a self-aligned material of the plurality of elements, immersing the first carrier substrate with the alignment structure into an aqueous solution, and depositing a plurality of optoelectronic devices on the alignment structure immersed in the aqueous solution. The polarity of the plurality of elements thereby causes the optoelectronic devices to align with the alignment structure.

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METHOD FOR PROCESSING AN OPTOELECTRONIC ARRANGEMENT

The present invention claims priority from German application No. 10 2022 115 723.7 dated June 23, 2022, the disclosure of which is incorporated herein in its entirety.

The present invention concerns a method for processing an optoelectronic arrangement, and an optoelectronic arrangement.

BACKGROUND

Current miniaturization of optoelectronic devices such as light emitting diodes (LEDs) has led to the development of mini-LEDs and μ -LEDs. In particular μ -LEDs are thereby of great interest for consumer applications such as for example augmented reality or virtual reality applications where small displays with a high resolution and thus a high pixel density are required. However also for larger display applications such as smartphones, tablets, laptops and televisions, small LEDs are becoming more and more of a great interest to increase the resolution of the corresponding displays.

Due to its miniaturization μ -LED's prerequisites are significantly upgraded fabrication processes in work areas from class 100 to 10 to ensure trouble-free and, in particular, contamination-free production and processing of the μ -LEDs. One of the further prerequisites, in terms of number, is in particular the requirement of a high throughput of units per hour (UPH) placed onto a carrier substrate, as more units, in particular for large displays with a high resolution need to be placed on the carrier substrate. In order to remain efficient at the same time and not take too long to assemble such a display, a way must be found to apply more units per hour to the substrate. From traditional LEDs, mini-LEDs to μ -LEDs, a standard die bonder UPH requirement in case of LEDs hence develops to shift from 50K UPH, to half-million UPH for mini LEDs and ends at more than 100 millions UPH for μ -LEDs. Thus, the need to invest and to development new process technologies with particularly a high throughput under work areas from class 100 to 10 are self-understanding.

It is an objective of the present application to provide a method for processing an optoelectronic, which counteracts at least one of the aforementioned problems.

5 SUMMARY OF THE INVENTION

This and other objectives are addressed by the subject matter of the independent claims. Features and further aspects of the proposed principles are outlined in the dependent claims.

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The concept, the inventors' proposal, is to provide an alignment structure on a carrier substrate, the alignment structure comprising a plurality of elements each having a certain polarity, and to deposit a plurality of optoelectronic devices, in particular μ -LEDs on the alignment structure, wherein the polarity of the plurality of elements causes the optoelectronic devices to align with the alignment structure. The process is thereby carried out within an aqueous solution to reduce friction and to allow the optoelectronic devices to move easier on the alignment structure and to align with the alignment structure. By this, the optoelectronic devices are aligned on the alignment structure in an easy way and can be picked up by a pick-up tool to transfer them to a backplane. Thus, compared to a pick-and-place process, by means of which only one optoelectronic device or a few optoelectronic devices can be transferred and placed at a time, a large number of optoelectronic devices can be aligned and later placed on a backplane at once using said process.

In one aspect, a method for processing an optoelectronic arrangement comprises a step of providing a first carrier substrate with a top surface, a step of providing an alignment structure on the top surface of the first carrier substrate, the alignment structure comprising a plurality of elements having a polarity caused by a self-aligned material of the plurality of elements, a step of immersing the first carrier substrate with the alignment structure into an aqueous solution, and a step of depositing a plurality of optoelectronic devices on the alignment structure immersed in the aqueous solution.

The polarity of the plurality of elements thereby causes the optoelectronic devices to align with the alignment structure.

The polarity of the plurality of elements can thereby extend substantially parallel to each other, and in particular substantially parallel to the top surface of the first carrier substrate. This can in particular be advantageous if the optoelectronic devices each comprise contact pads on one surface of the optoelectronic devices resulting in current passage through the optoelectronic device along that surface of the optoelectronic device. The optoelectronic devices can align accordingly on the alignment structure such that their current passage aligns along the polarity of the plurality of elements substantially parallel to the top surface of the first carrier substrate. The polarity of the plurality of elements can however also extend substantially parallel to each other, and in particular substantially perpendicular to the top surface of the first carrier substrate. This can in particular be advantageous if the optoelectronic devices each comprise a contact pad on two opposing surfaces of the optoelectronic devices resulting in current passage directly through the optoelectronic device. The optoelectronic devices can align accordingly on the alignment structure such that their current passage aligns along the polarity of the plurality of elements substantially perpendicular to the top surface of the first carrier substrate.

In some aspects, the plurality of elements are arranged in rows and/or columns, and in particular in a matrix pattern. In particular, the arrangement of the elements of the plurality of elements may provide a pattern of how the optoelectronic devices are to be arranged on the alignment structure after they are aligned. Thereby, each one optoelectronic device can be aligned with the polarity of one of the plurality of elements, or two or more optoelectronic devices can be aligned with the polarity of one of the plurality of elements. Accordingly, there may be a one-to-one association between the optoelectronic devices and the elements of the plurality of elements, but it is also possible for two or more optoelectronic devices to be associated with an element of the plurality of elements.

In some aspects, the alignment structure comprises a polar base layer on the first carrier substrate, particularly on the top surface of the first carrier substrate. The polar base layer can in particular be provided on the first carrier substrate comprising a material, that tends to have an ordered structure on the first carrier substrate with a certain polarity, and by means of which the self-aligning material of the plurality of elements can align itself causing the polarity of the plurality of elements. Hence in some aspects, the self-aligned material of the plurality of elements aligns with the polar base layer causing the polarity of the plurality of elements.

The polar base layer can for example comprises a gold film and self-assembled monolayers (SAMs) on the gold film, in particular of hexadecanethiol (C16) or pentadecanethiol (C15) SAMs. The gold film can in particular have a thickness of less than 200 nm, less than 100 nm, less than 50 nm, and in particular around 20 nm. The gold film is obliquely deposited via a method such as electron beam evaporation onto the first carrier substrate, such as but not limited to, a glass substrate, at an angle of 45° (measured from the normal; the incident angle of metal gold flux onto the substrate is 45°). Multiple polydimethylsiloxane (PDMS) elastomeric strip-like stamps are inked with an ethanolic solution of hexadecanethiol (C16) or pentadecanethiol (C15). The C15 or C16 SAMs are thus further microcontact-printed onto an obliquely deposited gold film with PDMS stamps.

SAMs are in particular of organic molecules in form of molecular assemblies formed spontaneously on surfaces by adsorption and are organized into more or less large ordered domains. The molecules possess a "head group" that has a strong affinity to the gold film and anchors the molecule to it. The SAMs can for example be created by a chemisorption of "head groups" onto the gold film from either vapor or fluid phase followed by a slow organization of "tail groups". Initially, at small molecular density on the surface, adsorbate molecules form either a disordered mass of molecules or form an ordered two-dimensional "lying down phase", and at higher molecular coverage, over a period of minutes to hours, begin to form three-dimensional crystalline or semicrystalline structures on the gold film surface.

The "head groups" assemble together on the gold film, while the tail groups assemble far from the substrate. Areas of close-packed molecules nucleate and grow until the surface of the gold film is covered in a single monolayer. By this, a polar base layer is formed along which the self-aligned material of the plurality of elements aligns causing the polarity of the plurality of elements.

The polar base layer can for example however also comprises of an octyltrichlorosilane (OTS) coating of the first carrier substrate without a gold film underneath. The OTS coating can in particular comprise of organic molecules in form of molecular assemblies formed spontaneously on surfaces by adsorption and are organized into more or less large ordered domains. By this as well, a polar base layer is formed along which the self-aligned material of the plurality of elements aligns causing the polarity of the plurality of elements.

In some aspects, the self-aligned material of the plurality of elements contains fluid liquid crystals (LCs), in particular 4-pentyl-4'-cyanobiphenyl (5CB). The self-aligned material of the plurality of elements contains in particular LCs in a nematic phase. In a nematic phase, the LC, in particular in form of rod-shaped molecules, have no preferred positional order, but they self-align to have long-range directional order with their long axes roughly parallel. Thus, the molecules are free to flow and their center of mass positions are randomly distributed as in a fluid, but still maintain their long-range directional order. The LCs can be uniaxial nematics, meaning that they have one axis (called directrix) that is longer and preferred, with the other two being equivalent (can be approximated as cylinders or rods). The LCs can however also be biaxial nematics, meaning that in addition to orienting their long axis, they also orient along a secondary axis. Nematic LCs have fluidity similar to that of ordinary (isotropic) fluids but they can be easily aligned by an external magnetic or electric field or dipolar force. Aligned nematic LCs create a dipolar effect (topological dipole), resulting in the polarity of the elements of the plurality of elements. The LCs can also in particular align with the polarity and structure of the polar base layer, thus adapting LCs' azimuthal orientations accordingly and

causing the polarity of the plurality of elements. For example, obliquely deposited (45° measured from the normal) gold films, when functionalized with either SAMs of C16 or C15, will orient nematic LC 5CB parallel or perpendicular to the direction of the gold deposition, respectively, which both resulting in a defined long-range directional order (planar alignment/anchoring/orientation) of the LC 5CB, and a polarity of the plurality of elements, which is substantially parallel to the top surface of the first carrier substrate accordingly.

In some aspects, the elements of the plurality of elements are each formed by fluid liquid crystals arranged in a cavity of a frame material. The self-aligned material in form of LCs or comprising LCs can in particular be filled into a frame material comprising a plurality of cavities, wherein the self-aligned materials/LCs within a cavity of the frame material form one of the plurality of elements. The frame material can for example be a structured thin substrate, such as a glass substrate with for example a thickness of less than 100 μm , less than 50 μm or approximately 20 μm , or can for example be a Transmission Electron Microscopy (TEM) grid, such as a TEM grid gold specimen with for example a thickness of less than 100 μm , less than 50 μm or approximately 20 μm . The frame material can be structured in such that it comprises a plurality of cavities/holes through the frame material, wherein the cavities/holes can have a size/diameter substantially of the size of the optoelectronic devices or many times the size of the optoelectronic devices. The cavities/holes can have any geometry, such as cylindric holes, cuboidal holes, holes with a hexagonal or octagonal cross section, holes in form of grooves/stripes, holes with a cross section in form of letters, symbols, or the like, tapering or widening holes, or any other type of holes, but may particularly go through the whole frame material. In case of the holes extend in form of stripes/grooves through a thin substrate, such as a glass substrate, the width of the stripes/grooves can be at least the diagonal length of the optoelectronic devices, to allow them to rotate when arranged in the stripes/grooves.

In some aspects, the step of providing the alignment structure comprises a step of providing a spacer substrate arranged on the

plurality of elements, the spacer substrate being coated with a conductive coating, such as for example Indium Tin Oxide (ITO), on a surface facing away from the plurality of elements and in particular being coated with an octyltrichlorosilane (OTS) coating on surface facing the plurality of elements. The spacer substrate with the two coatings can in particular be arranged on the plurality of elements and the optoelectronic devices are deposited on the conductive coating of the spacer substrate. The spacer substrate can be provided in particular that the optoelectronic devices are not deposited directly on the plurality of elements but on the conductive layer of the spacer substrate.

The spacer substrate can in addition be provided to pre-align the optoelectronic devices on the conductive coating of the spacer substrate when applying an electric field to the conductive coating. In a preferred embodiment the optoelectronic devices are therefore deposited on the spacer substrate and an electric field is applied to the conductive coating of the spacer substrate before the spacer substrate is arranged on the plurality of elements. By applying the electric field to the conductive coating the optoelectronic devices are pre-aligned on the conductive coating along the shortest electric field lines by creating induced dipoles within the optoelectronic devices. After the pre-alignment, the spacer substrate is arranged on the plurality of elements, the polarity of the elements of the plurality of elements further aligning the optoelectronic devices with the alignment structure. The step of applying the electric field to the conductive coating can in particular be carried out before the spacer substrate is arranged on the plurality of elements to not counteract an alignment of the self-aligned materials (for example LCs) with for example a polar base layer below the plurality of elements.

In some aspects, the step of depositing the optoelectronic devices on the alignment structure comprises a sonication/shaking of the alignment structure, in particular of the spacer substrate, to avoid a stacking of the optoelectronic devices on the alignment structure and ensure a desired distribution of the optoelectronic devices on the alignment structure.

In some aspects, the plurality of elements are each formed by a microcapsule containing the self-aligned material, the microcapsules being arranged between the first carrier substrate and a second carrier substrate. The microcapsules containing the self-aligned material can
5 for example be comparable to electrophoretic ink, often called as electronic ink (E Ink). The self-aligned material can comprise positively and negatively charged particles suspended in a fluid within the microcapsules. When a positive and/or negative electric field is applied to a portion of the surface of the microcapsules, corresponding
10 particles move in the direction of the portion of the surface of the microcapsule and remain there until a different electric field is applied or an electric field is applied to a different portion of the microcapsule.

15 By applying a corresponding electric field, the self-aligned material within the microcapsules can thus be aligned in a desired way, causing the polarity of the elements/microcapsules even though the electric field is switched off during an alignment of the optoelectronic devices with the alignment structure. To apply the electric field, the first
20 and the second carrier substrates can each comprise a plurality of electrodes. Depending on the position, size and number of the electrodes, and depending on the direction of the electric field applied, the self-aligned materials within the microcapsules can be aligned in a desired way, causing the polarity of the microcapsules.

25 The electric field can thereby be applied such that positively charged particles are located at the top of a microcapsule and negatively charged particles at the bottom of the microcapsule or vice versa resulting in a perpendicular polarity of the microcapsule. The electric
30 field can however also be applied such that positively charged particles and negatively charged particles are located next to each other at the top and optionally also at the bottom of a microcapsule, resulting in a horizontal polarity of the microcapsule. In case of a perpendicular polarity of the microcapsules one optoelectronic device
35 each can be aligned by means of two microcapsules with opposite polarity, whereas in the case of a horizontal polarity of the

microcapsules one optoelectronic device each can be aligned by means of one microcapsule.

The optoelectronic devices may for example be light emitting diodes with edge lengths of less than 100 μm , or less than 40 μm , and in particular less than 10 μm , while a height of the optoelectronic devices can for example be less than 25 μm , or less than 10 μm , and in particular less than 5 μm . The optoelectronic devices can thus for example be μ -LEDs or μ -LED-chips. In some aspects, the optoelectronic devices may for example be light emitting diodes with their respective contact pads on a side opposite to their main emission surface, also referred to as horizontal diodes. In some other aspects, the light emitting diodes are realized as vertical diodes, of which their respective contact pads are on two opposite sides of the diode.

In some aspects, the method further comprises a step of picking up the optoelectronic devices aligned with the alignment structure and transferring them to a third carrier substrate. The optoelectronic devices can in particular be aligned on the alignment structure in an easy way and can then be picked up by a pick-up tool to transfer them to a further carrier substrate. Compared to a pick-and-place process, by means of which only one optoelectronic device or a few optoelectronic devices can be transferred and placed at a time, a large number of optoelectronic devices can be aligned and placed on a further carrier substrate at once using said method.

The transfer can for example be performed using MEMS pick-up heads or elastomeric (PDMS) pick-up stamps approaching to the aligned optoelectronic devices on the alignment structure within the aqueous solution or at the surfaces of the plurality of elements. The optoelectronic devices can be picked up as they are aligned on the alignment structure or a number of the optoelectronic devices can be picked up, depending on the pixel pitch of the further carrier substrate on which the optoelectronic devices are transferred. The optoelectronic devices held by the transfer tool, can be subjected to water/dry air cleanings to ensure no residuals of the alignment structure remain at the optoelectronic devices. Once the cleaning procedures are performed

the optoelectronic devices can be transferred onto the further carrier substrate or directly onto a backplane.

In some aspects, the method further comprises a step of placing the optoelectronic devices aligned with the alignment structure each on a corresponding electric contact arranged on the third carrier substrate. The third carrier substrate may thereby be the final substrate on which the optoelectronic devices are placed, for example a backplane, or the third carrier substrate may be a testing structure, on which the optoelectronic devices are placed for testing their functionality. The method may thus further comprise a step of testing the optoelectronic devices placed on a corresponding electric contact for its functionality. In case of malfunctional optoelectronic devices these can be replaced by functional optoelectronic devices on the third carrier substrate, before the tested and all functional optoelectronic devices can be picked up again and transferred to a fourth carrier substrate, which may be the final substrate on which the optoelectronic devices are placed, for example a backplane.

In one aspect it is further provided a method for processing a plurality of optoelectronic devices, in particular in combination with at least one of the aspects of the proposed principle. The method comprises a step of counting and/or sorting the plurality of optoelectronic devices provided in a sheath fluid with regard to their quality, in particular to later deposit a desired plurality of optoelectronic devices with a desired quality on the alignment structure according to some aspects of the proposed principle. To allocate a known amount of known good optoelectronic devices (known good dies, KGD), onto the alignment structure it is in some aspects proposed to utilize a fluid reader, such as a flow cytometry to facilitate counting and/or sorting of the optoelectronic devices.

A flow cytometer is a relatively standard analytical instrument. It is a technique exploited to measure and detect physical and/or chemical characteristics of a population of cells or particles. For example, in clinical practice, analyses such as cell counting and sorting of fluid media (e.g., complete blood count (CBC) or only white blood cell (WBC)

count) can be easily facilitated by a flow cytometry. In a flow cytometer, a laser beam is directed onto a hydro-dynamically focused stream of fluid, which could include tens of thousands of cells or particles. Multiple detectors are aimed at the point where the stream passes through the laser beam, both in line with the laser beam (measuring forward scatter or FSC) and perpendicular to the laser beam (measuring side scatter or SSC). The sample of interest (e.g., clinical fluid media) is focused to ideally only allow one cell at a time to go through a laser beam, where the laser light scattered (FSC and SSC) is characteristic to the cells and their components (and thus the CBC and WBC diagnosis results can be obtained almost in 'real time', around many thousands of cells per second).

In some aspects, it is proposed to incorporate a flow cytometry, assisting to allocate a known amount of optoelectronic devices on the alignment structure for being aligned with the alignment structure and to allow only KGD optoelectronic devices to be deposited on the alignment structure. The counting and sorting steps, assisted via a flow cytometry, facilitate defect managements such as yield management and stop defect propagation along sequential process steps.

As described for the standard cytometer, a counting of the optoelectronic devices can be realized by allowing only one optoelectronic device provided in the sheath fluid at a time to go through a laser beam of the cytometer, where the laser light scattered (FSC and SSC) is characteristic to the optoelectronic devices and their components. The number of optoelectronic devices running through the cytometer can thus be obtained almost in 'real time' without damaging the optoelectronic devices, while many thousands of optoelectronic devices pass the laser per second.

In some aspects, the sorting is to sort out malfunctional optoelectronic devices, in particular by exciting the optoelectronic devices with an excitation light source and detecting a photoluminescence of the optoelectronic devices due to the excitation.

As a light-emitting optoelectronic devices comprises material with photoluminescence (PL) character, the PL of the optoelectronic devices and the sorting capability of a flow cytometry can be leveraged to differentiate functional and malfunctional optoelectronic devices, to prevent malfunctional optoelectronic devices to be deposited on the alignment structure.

In case of functional optoelectronic devices excess carriers (electrons and holes) are photo-excited by exposure to a sufficiently intense light source, and the luminescence emitted from the radiative recombination of these photo-excited carriers can be mapped to identify the functional optoelectronic device. PL mapping, a well-established process control step for frontend LED manufacturing combines conventional PL with a scanning stage. *In situ* information such as the corresponding peak wavelength uniformity and the intensity across the whole wafer can thus be acquired and used for process control evaluation of the optoelectronic devices.

In some aspects, the optoelectronic devices pass through a laser light beam in a flow cytometry, scatter the light both forward and to the side, and simultaneously (upon being shone with a sufficiently intense light source; the light source here must be tuned to excite the PL of the optoelectronic devices properly) emit PL. The scattered light and the extra emitted PL light can be detected by analysing the fluctuations in brightness and wavelength at different flow cytometer detectors. A malfunctional optoelectronic device results from epitaxy layer defect (e.g., epitaxy layer crack and/or chipping during optoelectronic device handling) and would thus not emit the extra PL light. The disqualified optoelectronic device could then be assorted/abandoned further by a flow cytometry sorter and thus not further being carried out in sequential processes. This sorting employment enables defect management and contributes to yield improvement, which also reduces overall repair/rework cost at further downstream processes.

To pass the optoelectronic devices through the flow cytometer, a sheath fluid can be introduced into a pipe at a laminar flow, where the optoelectronic devices are injected into the center of the stream, at

a slightly higher pressure. The sheath fluid enables the optoelectronic devices being loaded to the flow cytometry running under hydrodynamic focusing, namely the optoelectronic devices align and follow the direction of flow, thus the optoelectronic devices of interest can pass through the pipe in order.

In one aspect it is further provided a method for processing a plurality of optoelectronic devices, in particular in combination with at least one of the aspects of the proposed principle. The method comprises a step of pre-aligning optoelectronic devices provided in a sheath fluid. The optoelectronic devices in the sheath fluid are therefore introduced into a laminar flow of a first fluid and a second fluid in a pipe, the first and the second fluids having different viscosities. The step of pre-aligning optoelectronic devices provided in the sheath fluid is in particular carried out before the plurality of optoelectronic devices is deposited on the alignment structure according to some aspects of the proposed principle.

The sheath fluid can in particular be chosen to be immiscible with the first and the second fluids, while the first and the second fluids can also be chosen to be immiscible with each other. In addition the first and the second fluids can be carefully selected for their densities closely matched to the epitaxial material and the material of the contact pads of the optoelectronic devices.

The optoelectronic devices are in particular introduced into a laminar flow containing immiscible first and second fluids in a pipe. The filling portion (e.g., half-filled or more in the pipe), flow rate and viscosity of each fluid, in conjunction of pressure or temperature gradient along the pipe, contribute to the final velocity and momentum flux distribution of each fluid in the pipe. At the same time a plane of zero shear results from aforementioned aspects within the pipe. Once the optoelectronic devices are introduced through the sheath fluid into the immiscible fluids, upon a steady state is achieved, a favourable plane with respect to the positioning of optoelectronic devices in the fluid system reveals, where the optoelectronic devices position

themselves with a preferred orientation (either epitaxial material facing up or facing down). If not yet in this position the optoelectronic devices spin/turn/move while floating through the pipe until they are positioned with the preferred orientation.

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Subsequently, these pre-aligned optoelectronic devices can further be deposited via a dispenser onto the alignment structure according to some aspects of the proposed principle. In case of optoelectronic devices not following the preferred orientation, these can in a further
10 step for example be additionally/selectively removed before reaching the alignment structure, to ensure a high yield rate of the optoelectronic arrangement.

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In one aspect an optoelectronic arrangement is provided comprising a first carrier substrate with a top surface, an alignment structure on the top surface of the first carrier substrate, and a plurality of optoelectronic devices on the alignment structure being aligned with the alignment structure. The alignment structure comprises a plurality of elements having a polarity caused by a self-aligned material of the
20 plurality of elements.

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The polarity of the plurality of elements can for example extend substantially parallel to each other, and in particular substantially parallel to the top surface of the first carrier substrate. The polarity
25 of the plurality of elements can however also extend substantially parallel to each other, and in particular substantially perpendicular to the top surface of the first carrier substrate. The optoelectronic devices can be aligned on the alignment structure such that their current passage aligns along the polarity of the plurality of elements
30 substantially parallel or substantially perpendicular to the top surface of the first carrier substrate.

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In some aspects, the plurality of elements are arranged in rows and/or columns, and in particular in a matrix pattern. In particular, the
35 arrangement of the elements of the plurality of elements corresponds to a pattern of the optoelectronic devices arranged on and aligned with the alignment structure. Thereby, each one optoelectronic device can

be aligned with the polarity of one of the plurality of elements, or two or more optoelectronic devices can be aligned with the polarity of one of the plurality of elements. Accordingly, there may be a one-to-one association between the optoelectronic devices and the elements of the plurality of elements, but it is also possible for two or more optoelectronic devices to be associated with an element of the plurality of elements. Vice versa, it is also possible for one optoelectronic device to be associated with more than one self-aligning material within one element of the plurality of elements.

In some aspects, the alignment structure comprises a polar base layer on the first carrier substrate, particularly on the top surface of the first carrier substrate. The polar base layer can in particular be arranged on the first carrier substrate comprising a material, that tends to have an ordered structure on the first carrier substrate with a certain polarity, and by means of which the self-aligning material of the plurality of elements is aligned causing the polarity of the plurality of elements. Hence in some aspects, the self-aligned material of the plurality of elements is aligned with the polar base layer causing the polarity of the plurality of elements.

The polar base layer can for example comprises a gold film and self-assembled monolayers (SAMs) on the gold film, in particular of hexadecanethiol (C16) or pentadecanethiol (C15). The gold film can in particular have a thickness of less than 200 nm, less than 100 nm, less than 50 nm, and in particular around 20 nm. The gold film is obliquely deposited via a method such as electron beam evaporation onto the first carrier substrate, such as but not limited to, a glass substrate, at an angle of 45° (measured from the normal; the incident angle of metal gold flux onto the substrate is 45°). Multiple PDMS elastomeric strip-like stamps are inked with an ethanolic solution of hexadecanethiol (C16) or pentadecanethiol (C15). The C15 or C16 SAMs are thus further microcontact-printed onto an obliquely deposited gold film with PDMS stamps. By this, a polar base layer is formed along which the self-aligned material of the plurality of elements is aligned causing the polarity of the plurality of elements.

The polar base layer can for example however also comprises of an octyltrichlorosilane (OTS) coating of the first carrier substrate without a gold film underneath. The OTS coating can in particular comprise of organic molecules in form of molecular assemblies formed spontaneously on surfaces by adsorption and are organized into more or less large ordered domains. By this as well, a polar base layer is formed along which the self-aligned material of the plurality of elements is aligned causing the polarity of the plurality of elements.

In some aspects, the self-aligned material of the plurality of elements contains fluid liquid crystals (LCs), in particular 4-pentyl-4'-cyanobiphenyl (5CB). The self-aligned material of the plurality of elements contains in particular LCs in a nematic phase. The LCs can in particular be aligned with the polarity of the polar base layer causing the polarity of the plurality of elements.

In some aspects, the elements of the plurality of elements are each formed by fluid liquid crystals arranged in a cavity of a frame material. The self-aligned material in form of LCs or comprising LCs can in particular be filled into a frame material comprising a plurality of cavities, wherein the self-aligned materials/LCs within a cavity of the frame material form one of the plurality of elements. The frame material can for example be a structured thin substrate, such as a glass substrate with for example a thickness of less than 100 μm , less than 50 μm or approximately 20 μm , or can for example be a Transmission Electron Microscopy (TEM) grid, such as a TEM grid gold specimen with for example a thickness of less than 100 μm , less than 50 μm or approximately 20 μm . The frame material can be structured in such that it comprises a plurality of cavities/holes through the frame material, wherein the cavities/holes can have a size/diameter substantially of the size of the optoelectronic devices or many times the size of the optoelectronic devices. The cavities/holes can have any geometry, such as cylindric holes, cuboidal holes, holes with a hexagonal or octagonal cross section, holes in form of grooves/stripes, holes with a cross section in form of letters, symbols, or the like, tapering or widening holes, or any other type of holes, but may particularly go through the whole frame material. In case of the holes extending in form of

stripes/grooves through a thin substrate, such as a glass substrate, the width of the stripes/grooves can be at least the diagonal length of the optoelectronic devices, to allow them to rotate when arranged in the stripes/grooves.

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In some aspects, the alignment structure comprises a spacer substrate arranged on the plurality of elements, the spacer substrate being coated with a conductive coating, such as for example Indium Tin Oxide (ITO), on a surface facing away from the plurality of elements and in particular being coated with an octyltrichlorosilane (OTS) coating on surface facing the plurality of elements. The spacer substrate with the two coatings can in particular be arranged on the plurality of elements and the optoelectronic devices are deposited on the conductive coating of the spacer substrate. The spacer substrate can be provided in particular that the optoelectronic devices are not deposited directly on the plurality of elements but on the conductive layer of the spacer substrate.

In some aspects, the plurality of elements are each formed by a microcapsule containing the self-aligned material, the microcapsules being arranged between the first carrier substrate and a second carrier substrate. The microcapsules containing the self-aligned material can for example be comparable to electrophoretic ink, often called as electronic ink (E Ink). The self-aligned material can comprise positively and negatively charged particles suspended in a fluid within the microcapsules. When a positive and/or negative electric field is applied to a portion of the surface of the microcapsules, corresponding particles move in the direction of the portion of the surface of the microcapsule and remain there until a different electric field is applied or an electric field is applied to a different portion of the microcapsule.

To apply the electric field, the first and the second carrier substrates can each comprise a plurality of electrodes. Depending on the position, size and number of the electrodes, and depending on the direction of the electric field applied, the self-aligned material within the

microcapsules can be aligned in a desired way, causing the polarity of the microcapsules.

The optoelectronic devices may for example be light emitting diodes with edge lengths of less than 100 μm , or less than 40 μm , and in particular less than 10 μm , while a height of the optoelectronic devices can for example be less than 25 μm , or less than 10 μm , and in particular less than 5 μm . The optoelectronic devices can thus for example be μ -LEDs or μ -LED-chips.

SHORT DESCRIPTION OF THE DRAWINGS

Further aspects and embodiments in accordance with the proposed principle will become apparent in relation to the various embodiments and examples described in detail in connection with the accompanying drawings in which

Figures 1A and 1B show steps of a method for processing an optoelectronic arrangement in accordance with some aspects of the proposed principle;

Figure 2 illustrates steps of a further embodiment of a method for processing an optoelectronic arrangement in accordance with some aspects of the proposed principle;

Figures 3 to 6 show steps of further embodiments of a method for processing an optoelectronic arrangement in accordance with some aspects of the proposed principle;

Figures 7A to 8D illustrate steps of further embodiments of a method for processing an optoelectronic arrangement in accordance with some aspects of the proposed principle;

Figure 9 shows steps of a method for processing an optoelectronic device in accordance with some aspects of the proposed principle;

5 Figures 10A to 10C illustrate steps of another method for processing an optoelectronic device in accordance with some aspects of the proposed principle; and

10 Figure 10D shows a third carrier substrate with optoelectronic devices in accordance with some aspects of the proposed principle and a malfunctional optoelectronic device.

DETAILED DESCRIPTION

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The following embodiments and examples disclose various aspects and their combinations according to the proposed principle. The embodiments and examples are not always to scale. Likewise, different elements can be displayed enlarged or reduced in size to emphasize individual aspects. It goes without saying that the individual aspects of the
20 embodiments and examples shown in the figures can be combined with each other without further ado, without this contradicting the principle according to the invention. Some aspects show a regular structure or form. It should be noted that in practice slight differences and
25 deviations from the ideal form may occur without, however, contradicting the inventive idea.

In addition, the individual figures and aspects are not necessarily shown in the correct size, nor do the proportions between individual
30 elements have to be essentially correct. Some aspects are highlighted by showing them enlarged. However, terms such as "above", "over", "below", "under" "larger", "smaller" and the like are correctly represented with regard to the elements in the figures. So it is possible to deduce such relations between the elements based on the
35 figures.

Figure 1A and 1B and in particular subfigures a) to j) show steps of a method for processing an optoelectronic arrangement 1 in accordance with some aspects of the proposed principle. In a first step a first carrier substrate in form of a glass substrate 2 with a top surface 2a is provided. The top surface 2a is further processed in that a gold film 9, with for example a thickness of 20 nm is deposited on the top surface 2a. The gold film is obliquely deposited via a method such as electron beam evaporation onto the first carrier substrate 2, namely top surface 2a, at an angle of 45° (measured from the normal; the incident angle of metal gold flux onto the substrate is 45°).

On top of the gold film 9, as shown in subfigure c), self-assembled monolayers (SAMs) 10 of for example either pentadecanethiol (C15) or hexadecanethiol (C16) are microcontact-printed via PDMS elastomeric strip-like stamps. The gold film 9 together with the self-assembled monolayers (SAMs) 10 forms a polar base layer 8 arranged on the top surface 2a serving as an ordered structure on the glass substrate 2 with a certain polarity, by means of which nematic LCs, later deposited on the polar base layer, are aligned. The azimuthal orientation of the LCs is dictated by the chemically patterned surface of C15 or C16 SAMs.

On the polar base layer 8 a frame material 13 comprising a plurality of cavities/holes 12 is provided. The frame material 13 comprising the plurality of cavities/holes 12 is in the embodiment shown realized by a TEM gold grid, with for example a thickness h of 20 μm and square holes with a width w and length l of around 280 μm . The TEM gold grid, as shown in subfigure d) is placed on the polar base layer 8, as shown in subfigure e). Here exemplarily only one small TEM gold grid is placed on the polar base layer 8, it is however to be understood that several of such TEM gold grids can be placed on the polar base layer 8 or also one or several larger TEM gold grids can be placed on the polar base layer 8.

By use of a capillary tube, for example a capillary glass tube, a nematic fluid liquid crystal (self-aligning material) 5, for example 4-pentyl-4'-cyanobiphenyl (5CB), is filled into the holes 12 of the TEM gold grid, as shown from subfigure e) to subfigure f). The LCs 5 in

the holes 12 of the TEM gold grid align with the order of the polar base layer 8 resulting in an azimuthal orientation of the LCs 5. Each one hole 12 filled with the LC 5 forms an element 4 having a defined polarity P due to the azimuthal orientation and topological dipole/defect of the LCs 5. Each four of such elements 4 are shown in subfigure g) to demonstrate the SAMs-laden stripes 10 can be microcontact-printed onto the gold film 9, with the stripes parallel to or align at an arbitrary angle (for example 45°) to the top surface 2a. The SAMs 10, either C15 or C16, on the obliquely deposited gold film 9 will orient LCs 5 azimuthal orientation perpendicular or parallel to the direction of gold deposition, respectively, which both resulting in a defined long-range direction order (planar alignment/anchoring/orientation) of the LC 5CB. The resulting polarity of the plurality of elements 4, which is substantially parallel to the top surface 2a of the first carrier substrate 2, whereas its in-plane polarity direction is dedicated by the abovementioned SAMs-laden stripe/LC azimuthal direction accordingly.

The polar base layer 8 together with the TEM gold grid 13 and the LCs 5 form an alignment structure 3 comprising a plurality of elements 4 having a polarity P caused by the LCs 5. The alignment structure 3 serves to provide a structure on which later deposited optoelectronic devices align in a desired way, in particular in form of a power-free self-assembly along the azimuthal orientation of the LCs 5.

In a following step, as shown in subfigure g) the first carrier substrate 2 with the alignment structure 3 is immersed into an aqueous solution 6, such as for example water, resulting in an aqueous-LC interface. The aqueous solution 6 serves to allow optoelectronic devices 7, deposited onto the alignment structure 3 in a subsequent step, as shown in subfigure h), to move easier/frictionless on the alignment structure 3 and to align with the alignment structure 3. The optoelectronic devices 7 are deposited onto the alignment structure 3 via gravitation/sedimentation or through a laminar flow closely along the surface of the LCs 5, which further expedites the self-assembly and thus enhances the process UPH.

The optoelectronic devices 7 deposited onto the alignment structure 3, as shown in subfigure h), align with the alignment structure 3, and in particular with the polarity P of the plurality of elements 4 along the azimuthal orientation of the LCs 5. Subfigure i) shows a detail view of the first carrier substrate 2 with the alignment structure 3 being immersed into the aqueous solution 6, as well as a closer detail view of the azimuthal orientation of the LCs 5 of four elements 4 causing the polarity P of the four elements 4, along which the optoelectronic devices 7 align. Subfigure j) on the other hand shows the optoelectronic devices 7 being aligned with the polarity P of an element 4 on the LCs 5 of an element 4. As shown, several optoelectronic devices line up along the azimuthal orientation of the LCs 5 forming several lines on the LCs 5 of an element 4.

The optoelectronic devices 7 are in particular μ -LEDs, which were microscopically-diced into individual pieces after epitaxial growth of the same on a wafer.

The topological dipoles/defects of the LCs 5 resulting in the polarity P of the elements 4 dedicates the μ -LEDs 7 to chains with minimum distance between (head-to-tail) neighbouring μ -LEDs 7, and the dipolar symmetry orientates the P and/or N pads 18 of the μ -LEDs 7. Between parallel μ -LED chains, the repulsive or attractive dipole pairs, depending on the dipole force and the distance of the P and N pads 18 of the μ -LEDs, assigns the final assembly pattern of the μ -LEDs either as a two-dimensional-square-close-packing-like or as a two-dimensional-hexagonal-close-packing-like array (see subfigure j, upper right and lower right images). In either case, the well-aligned μ -LED arrays are ready for a following pick-and-place process. The term two-dimensional-square-close-packing-like array can in this regard be understood as an array in which the P and N pads 18 of each μ -LED 7 are well aligned in both X and Y axes, wherein for the two-dimensional-hexagonal-close-packing-like array parallel μ -LED chains are shifted to each other to accommodate the attractive/repulsive force between neighbouring P and N pads 18 of the μ -LEDs 7.

A following transfer of the μ -LEDs 7, either via MEMS pick-up heads or elastomeric (PDMS) pick-up stamps approaching to the aqueous-LC interface, can be done as it is or it is picked every-second chain, depending on a square-close-packing-like or a hexagonal-close-packing-like array is formed on the alignment structure 3.

Figure 2 illustrates steps of a further embodiment of a method for processing an optoelectronic arrangement. Fig. 2 in particular illustrates a further embodiment of the frame material 13 comprising the holes 12 and being arranged on the polar base layer 8. The frame material 13 shown in subfigure a) is formed by a thin glass substrate, with for example a height h of approximately 20 μm , processed by Laser Induced Deep Etching (LIDE) to generate several grooves/stripes 12 through the glass substrate 13. The structured glass substrate 13 is then applied to the polar base layer 8 together with the polar base layer 8 forming the alignment structure 3 as shown in subfigure b). The grooves/stripes 12 are in a subsequent step filled with the LCs 5, as shown in subfigure c), forming the elements 4 and depending on elements 4's polarity P direction, the optoelectronic devices 7 deposited on the elements 4 will align with the polarity accordingly.

Subfigures d) and e) each shows a detail view of one element 4 with optoelectronic devices 7 deposited on the same. The optoelectronic devices 7 deposited on the elements 4 are shown in subfigure d) as pre-aligned within the groove 12 but are with regard to the polarity P of the element 4 twisted. The polarity P of the self-aligned material LC 5 however causes the optoelectronic devices to align along with after time interval Δt , as shown in subfigure e). The groove 12 thereby in particular comprises a width w , which corresponds at least to the diagonal length of the optoelectronic devices or slightly larger, to allow them to twist/rotate when arranged in the groove 12, and thus allows the optoelectronic devices to interact with the dipolar symmetry of neighbouring optoelectronic devices. If desired, within a single groove/stripe, multiple μ -LED strings/chains, with P/N pad symmetry, can also be arranged via matching the groove/stripe and diagonal μ -LED widths.

Figure 3 shows a further embodiment in its subfigures a) to c), according to which the structured glass substrate 13 comprises holes with a complex geometry, where the letters "O" and "S" shown in the embodiment represent the complex geometry. This is to show that the holes 12 through the glass substrate 13 can be of any shape for example tailored via a LIDE-assisted glass confinement pattern, to align the optoelectronic devices on the alignment structure 3 in a desired way. This high geometry design freedom is especially applicable for matching the form factors of head mounted displays such as smart glasses, augmented reality headset (AR headset) and/or virtual reality headsets (VR headsets).

Figure 4 shows in its subfigures a) to j) a further embodiment of a method for processing an optoelectronic arrangement 1. The method shown provides an alternative of a μ -LED alignment to the methods shown in Figures 1 to 3. The topological defects of the LCs remain the driving force to dictate the μ -LED alignment during the alignment. Instead of assembling the μ -LEDs at an aqueous-LC interface, the alignment takes however place at an aqueous-glass interface to avoid later effort for removing LC residues at the P/N pad(s) of the μ -LEDs. Compared to the embodiment shown in Figures 1 to 3, the polar base layer 8 is an octyltrichlorosilane (OTS) coating 11 of the glass substrate 2 without gold film (see subfigure a)).

On top of the OTS coating 11, a thin glass substrate, with a height h of for example 20-100 μm , preferable close to 20 μm , is provided as the frame material 13 with a plurality of Through Glass Vias (TGV) 12, as shown in subfigure b). The holes comprise a minimum diameter that is slightly larger than a single μ -LED's diagonal length and are for example processed via LIDE. The holes 12 are filled with the LCs 5, each filled hole 12 forming an element 4, as shown in subfigure c).

The optoelectronic devices 7 are however not deposited directly onto the LCs 5 but a spacer substrate 14 is in addition provided on which the optoelectronic devices 7 are deposited and pre-aligned. The spacer substrate, as shown in subfigure d), comprises another OTS coating 11 on a first surface and a conductive coating 15 such as for example an

ITO layer, on an opposite second surface of the spacer substrate 14. The optoelectronic devices 7, shown in subfigure e) are for pre-alignment deposited on the conductive coating 15, as shown in subfigure f) and an electric field E is applied to the conductive coating 15 as shown in subfigure g). The electric field E causes the randomly distributed optoelectronic devices 7 on the conductive coating 15 to pre-aligned along the shortest electric field lines by creating induced dipoles within the optoelectronic devices 7.

The spacer substrate 14 with the pre-aligned optoelectronic devices 7 arranged on, is then, with its OTS coating 11 facing down, arranged on the LCs 5 as shown in subfigure h). The LCs 5 within the TGVs 12 are thus arranged between two OTS coatings 11, one on the first carrier substrate 2, and one on the spacer substrate 14 dictating the LC alignment causing the polarity P of the elements 4. The OTS coatings 11 from both substrates 2, 14 dictate the LC 5 azimuthal orientation perpendicular to both substrates 2, 14, resulting a homeotropic/perpendicular anchoring/orientation of the LCs, and a corresponding perpendicular polarity P of the element 4. The polarity P acts through the spacer substrate 14 to the pre-aligned optoelectronic devices 7 on the conductive coating 15 shown in subfigure i) and aligns the optoelectronic components each one with an element 4, as shown in subfigure j).

As the LCs 5, in addition to the pre-alignment, further define the position of the optoelectronic devices 7 in terms of centring each optoelectronic device 7 above a TGV 12 underneath the spacer substrate 14. With the pre-alignment via the previously temporary exposure to an electric field and the further interaction with the LCs 5, an alignment of the optoelectronic devices 7 can be achieved without the use of a continuous external applied electric field.

The interfacial dipolar forces present within the nematic LCs 5 to direct the ordering of optoelectronic devices 7 can be further tuned with the assistance of TGV distance or pattern, to reach a desired pixel density of the optoelectronic devices 7 or complex geometries with the optoelectronic devices 7, as shown in subfigures a) and b) of

Figure 5. The distance between adjacent (head-to-tail) optoelectronic devices 7 can in addition be customized via tuning the TGV distance A and B, as indicated in subfigures c) and d) of Figure 5. An optoelectronic device 7 chain can thus become a dot line/matrix pattern with defined distances A and B. This desired dot line/pattern can be freely tailored to match required pixel density and array pattern of the optoelectronic devices 7 on a final backplane.

Figure 6 shows in its subfigures a) to e) a further embodiment of a method for processing an optoelectronic arrangement 1 in which compared to aforementioned embodiment a spacer substrate is omitted and the alignment of the optoelectronic devices 7 takes place at a surfactant-laden aqueous-LC interface.

The OTS-coated glass substrate 2, the thin glass substrate 13 with the plurality of TGVs 12 and the LCs 5 within the TGVs remain in the setup as shown in subfigures a) to c). The setup is then immersed into a surfactant-containing aqueous solution, such as for example surfactant sodium dodecyl sulfate (SDS), with the surfactant concentration above a threshold to dictate the LCs at the aqueous-LC interface besides the effect of the OTS coating 11. By this an azimuthal orientation, a homeotropic/perpendicular anchoring of the LCs 5 supported by the OTS coating 11 and the surfactant SDS-laden aqueous-LC interface is achieved resulting in the perpendicular polarity P of the elements 4 relative to glass substrate 2.

Following the homeotropic anchoring preparation of the LCs 5 within the individual TGVs 12, the optoelectronic devices 7 are introduced onto the aqueous-LC interface via gravitation/sedimentation, or through a laminar flow closely onto the aqueous-LC interface, as shown in subfigure d). By the homeotropic anchoring of the LCs 5, resulting in a perpendicular polarity of the elements 4, the optoelectronic devices 7 can be centred or aligned above an element 4 as shown in subfigure e). Adjacent P/N pad(s) of the optoelectronic devices 7 are aligned in accordance with a dipolar symmetry across the whole alignment structure 3.

Figures 7A to 8D show yet other embodiments of a method for processing an optoelectronic arrangement 1. The self-aligned material in form of the LCs 5 causing the polarity of the elements 4 is in these embodiments exchanged with positively and negatively charged particles 5 within a plurality of microcapsules. Each microcapsule contains positively and negatively charged particles 5 forming one of the plurality of elements 4. The microcapsules 4 follow the principle of a mature commercial electronic paper (e-paper) display technology, namely electrophoretic ink, often called as electronic ink (E Ink) to serve as the mediator to dictate the alignment of the optoelectronic devices 7.

The microcapsules are as shown in Fig. 7A arranged between the first carrier substrate 2 and a second carrier substrate 16, each for example formed by a glass substrate. The microcapsules 4 in combination with the carrier substrates together form the alignment structure 3 by which optoelectronic devices 7 are aligned with the same.

When a positive and/or negative electric field is applied to a portion of the surface of the microcapsules via electrodes 17 in the first and second substrates, as shown in Figure 7A, corresponding particles move in the direction of the portion of the surface of the microcapsule and remain there (see Fig. 7B) until a different electric field is applied or an electric field is applied to a different portion of the microcapsule. By applying a corresponding electric field, the particles 5 within the microcapsules 4 can thus be aligned in a desired way, causing the polarity of the elements 4 even though the electric field is switched off during an alignment of optoelectronic devices 7 deposited on the alignment structure 3 with the alignment structure 3 (see Fig. 7C). The dipole-dipole interactions between the aligned particles in the microcapsules and the optoelectronic devices serve to align the optoelectronic devices 7 in a desired way. The desired density of the optoelectronic devices 7 can be pre-selected or tailored via the distances d and A between the microcapsules, as well as via the positive and negative charge distributions of the particles in the microcapsules (see Fig. 7D).

As shown in Figures 7A to 7D, the electric field can be applied such that positively charged particles 5 are located at the top of a microcapsule 4 and negatively charged particles 5 at the bottom of the microcapsule 4 and vice versa resulting in a perpendicular polarity of the microcapsules 4. The electric field can, as shown in Figures 8A to 8D, however also be applied such that positively charged particles 5 and negatively charged particles 5 are located next to each other at the top and also at the bottom of a microcapsule 4, resulting in a horizontal polarity of the microcapsules 4. By this, one optoelectronic device 7 can each be aligned by means of one microcapsule 4, wherein the distance d can be chosen to match the distance of the contact pads of the optoelectronic devices 7 and the distance A can be chosen to achieve a desired density of the optoelectronic devices 7 on the alignment structure 3.

It is further provided a method for processing a plurality of optoelectronic devices as shown in Fig. 9, in particular in combination with at least one of the aspects of the proposed principle. The method comprises a step of counting and sorting optoelectronic devices 7 provided in a sheath fluid 21 with regard to their quality. The step of counting and sorting optoelectronic devices 7 can be carried out in particular before a desired plurality of optoelectronic devices 7 with a desired quality is in a later step deposited on an alignment structure of an optoelectronic arrangement. To allocate a known amount of known good optoelectronic devices, onto the alignment structure it is proposed to utilize a fluid reader, such as a flow cytometry 22 to facilitate counting and sorting of the optoelectronic devices.

The counting of the optoelectronic devices 7 is realized by allowing only one optoelectronic device 7 provided in the sheath fluid 21 at a time to go through a laser beam 23 of the cytometer 22, where the laser light scattered by the optoelectronic device 7 is characteristic to the optoelectronic device 7 and their components/materials. The number of optoelectronic devices running through the cytometer can thereby be obtained almost in 'real time' without damaging the optoelectronic devices, by detecting the scattered light using the detectors 24 and 25.

In addition to scattering, the optoelectronic devices can also emit light due to photoluminescence when being excited by the laser light. By mapping the photoluminescence using the detectors 24 and 25 malfunctional optoelectronic devices 7 can be sorted out to prevent malfunctional optoelectronic devices to be deposited on the alignment structure.

It is further provided a method for processing a plurality of optoelectronic devices as shown in Figs. 10A to 10C, in particular in combination with at least one of the aspects of the proposed principle. The method comprises a step of pre-aligning optoelectronic devices 7 provided in a sheath fluid 21. The optoelectronic devices 7 in the sheath fluid 21 are therefore introduced into a laminar flow of a first fluid 26 and a second fluid 27 in a pipe 28, the first and the second fluids having different viscosities. The step of pre-aligning the optoelectronic devices is thereby in particular carried out before the optoelectronic devices are deposited on an alignment structure.

As shown in Fig. 10A, the optoelectronic devices 7 are introduced into a laminar flow containing immiscible first and second fluids 26, 27 in a pipe 28. The cross sectional filling portions a and b of the pipe with the first and second fluids (see Fig. 10C), the flow rate of the first and second fluids and the viscosities of the first and second fluids, in conjunction with a pressure and/or temperature gradient along the pipe 28, contribute to the final velocity v and momentum flux distribution of the first and second fluids in the pipe 28. At the same time a plane of zero shear 29 results from aforementioned aspects within the pipe 28 (see Fig. 10C) and can in particular be tuned by for example injecting further fluid(s) at different locations of the pipe, as shown in Fig. 10B.

Once the optoelectronic devices 7 are introduced through the sheath fluid 21 into the immiscible fluids 26, 27, upon a steady state is achieved, a favourable plane 29 with respect to the positioning of optoelectronic devices in the fluid system reveals, where the optoelectronic devices 7 position themselves with a preferred orientation (either epitaxial material facing up or facing down). If

not yet in this position the optoelectronic devices spin/turn/move while floating through the pipe 28 until they are positioned with the preferred orientation (see Figs. 10A and 10B).

5 Subsequently, these pre-aligned optoelectronic devices 7 can be deposited onto the alignment structure 3 according to some aspects of the proposed principle. In case of optoelectronic devices not following the preferred orientation, these can in a further step for example be additionally/selectively removed before reaching the alignment
10 structure 3, to ensure a high yield rate of the optoelectronic arrangement.

Fig. 10D shows a further step of a method according to some aspects of the proposed principle, according to which the optoelectronic devices
15 7 aligned with the alignment structure 3 are picked up and placed on electric contacts 20 arranged on a third carrier substrate 19. The third carrier substrate 19 can for example be a testing structure, on which the optoelectronic devices 7 are placed for testing their functionality. The third carrier substrate 19 can for example be
20 backplane with transparent indium tin oxide (ITO) stripes (in the range of 50-200nm thick), on which the optoelectronic devices 7 are placed for testing their functionality. These ITO stripe pattern matches the P/N pads' locations of the optoelectronic devices 7 aligned with the alignment structure 3 and can for example be in accordance with a
25 desired assembly pixel density of the optoelectronic devices 7.

The optoelectronic devices 7 on the third carrier substrate 19 can be powered, and an electroluminescence (EL) characterization of the optoelectronic devices 7 can be performed to identify malfunctional
30 optoelectronic devices 7a. Individual defect and/or unqualified optoelectronic devices can therefore be sorted out and rework can be followed in time before the tested and all functional optoelectronic devices 7 can be picked up again and transferred to a fourth carrier substrate, which may be a final substrate on which the optoelectronic
35 devices are placed with a desired assembly pixel density of the optoelectronic devices 7.

LIST OF REFERENCES

	1	optoelectronic arrangement
	2	first carrier substrate
5	2a	top surface
	3	alignment structure
	4	elements
	5	self-aligning material
	6	aqueous solution
10	7	optoelectronic device
	7a	malfunctional optoelectronic device
	8	polar base layer
	9	gold film
	10	SAMs
15	11	OTS coating
	12	cavity, hole
	13	frame material
	14	spacer substrate
	15	conductive coating
20	16	second carrier substate
	17	electrode
	18	contact pad
	19	third carrier substrate
	20	electric contact
25	21	sheath fluid
	22	flow cytometer
	23	laser
	24	detector
	25	detector
30	26	first fluid
	27	second fluid
	28	pipe
	29	plane
	h	thickness, height
35	w	width
	l	length
	d	distance

	t	time
	v	velocity
	τ	shear stress
	A, B	distance
5	P	polarity
	E	electric field

CLAIMS

1. Method for processing an optoelectronic arrangement (1) comprising the steps:

5 Providing a first carrier substrate (2) with a top surface (2a);

 Providing an alignment structure (3) on the top surface (2a) of the first carrier substrate (2), the alignment structure (3) comprising a plurality of elements (4) having a polarity (P) caused
10 by a self-aligned material (5) of the plurality of elements (4);

 Immersing the first carrier substrate (2) with the alignment structure (3) into an aqueous solution (6); and

 Depositing a plurality of optoelectronic devices (7) on the alignment structure (3) immersed in the aqueous solution (6);

15 wherein the polarity (P) of the plurality of elements (4) causes the optoelectronic devices (7) to align with the alignment structure (3).

2. The method according to claim 1, wherein the polarity (P) of the
20 plurality of elements (4) extends substantially parallel or perpendicular to the top surface (2a) of the first carrier substrate (2).

3. The method according to claim 1 or 2, wherein the plurality of
25 elements (4) are arranged in rows and columns.

4. The method according to any one of claims 1 to 3, wherein the alignment structure comprises a polar base layer (8) on the first carrier substrate (2).
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5. The method according to claim 4, wherein the self-aligned material (5) of the plurality of elements (4) aligns with the polar base layer (8) causing the polarity (P) of the plurality of elements (4).
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6. The method according to claim 4 or 5, wherein the polar base layer (8) comprises a gold film (9) and self-assembled monolayers (10) on

the gold film (9), in particular of hexadecanethiol or pentadecanethiol.

7. The method according to claim 4 or 5, wherein the polar base layer (8) is an octyltrichlorosilane coating (11) of the first carrier substrate (2).

8. The method according to any one of the preceding claims, wherein the self-aligned material (5) of the plurality of elements (4) contains fluid liquid crystals.

9. The method according to claim 8, wherein the elements of the plurality of elements (4) are each formed by fluid liquid crystals arranged in a cavity (12) of a frame material (13).

10. The method according to any one of the preceding claims, wherein the step of providing the alignment structure (3) comprises a step of providing a spacer substrate (14) arranged on the plurality of elements (4), the spacer substrate (14) being coated with a conductive coating (15) on a surface facing away from the plurality of elements (4).

11. The method according to claim 10, further comprising a step of applying an electric field to the conductive coating (15) to pre-align optoelectronic devices (7) deposited on the conductive coating (15) with the alignment structure (3).

12. The method according to claim 10 or 11, wherein the spacer substrate (14) comprises an octyltrichlorosilane coating (11) on surface facing the plurality of elements (4).

13. The method according to any one of the preceding claims, wherein the plurality of elements (4) are each formed by a microcapsule containing the self-aligned material (5), the microcapsules being arranged between the first carrier substrate (2) and a second carrier substrate (16).

14. The method according to claim 13, wherein the first and the second carrier substrates (2, 16), each comprises a plurality of electrodes (17) to apply an electric field to the alignment structure.

15. The method according to claim 13 or 14, further comprising a step of applying an electric field to the plurality of electrodes (17) to align the self-aligned material (5) in the microcapsules (4) causing the polarity of the plurality of microcapsules (4).

16. The method according to any one of the preceding claims, wherein the optoelectronic devices (7) are μ -LEDs.

17. The method according to any one of the preceding claims, further comprising a step of picking up the optoelectronic devices (7) aligned with the alignment structure (3) and transferring them to a third carrier substrate (19).

18. The method according to claim 17, further comprising a step of placing the optoelectronic devices (7) aligned with the alignment structure (3) each on a corresponding electric contact (20) arranged on the third carrier substrate (19).

19. The method according to claim 18, further comprising a step of:

- testing the optoelectronic devices (7) placed on a corresponding electric contact (20) for its functionality;
- replacing malfunctional optoelectronic devices (7a); and
- picking up the tested optoelectronic devices and transferring them to a fourth carrier substrate.

20. A method for processing a plurality of optoelectronic devices (7), in particular according to any one of the preceding claims, the method comprising a step of counting and/or sorting the plurality of optoelectronic devices (7) provided in a sheath fluid (21) with regard to their quality, in particular to deposit a desired plurality of optoelectronic devices (7) with a desired quality on the alignment structure (3).

21. The method according to claim 20, wherein the step of counting and/or sorting is utilized by a flow cytometer (22).

22. The method according to claim 20 or 21, wherein the sorting is to sort out malfunctional optoelectronic devices, in particular by exciting the optoelectronic devices (7) with an excitation light source and detecting a photoluminescence of the optoelectronic devices due to the excitation.

23. A method for processing a plurality of optoelectronic devices, in particular according to any one of the preceding claims, the method comprising a step of pre-aligning optoelectronic devices (7) provided in a sheath fluid (21), in particular before depositing the plurality of optoelectronic devices (7) on the alignment structure (3), wherein the optoelectronic devices (7) in the sheath fluid (21) are introduced into a laminar flow of a first fluid (26) and a second fluid (27) in a pipe (28), the first and the second fluids having different viscosities.

24. The method according to claim 23, wherein due to the different viscosities and/or flow rates and/or filling amounts and/or temperatures of the first and the second fluids (26, 27), the first and the second fluids comprise different flow velocity distributions (v) between opposing inner surfaces of the pipe (28), causing the optoelectronic devices (7) to pre-align.

25. An optoelectronic arrangement (1) comprising:

a first carrier substrate (2) with a top surface (2a);

an alignment structure (3) on the top surface (2a) of the first carrier substrate (2), the alignment structure (3) comprising a plurality of elements (4) having a polarity (P) caused by a self-aligned material (5) of the plurality of elements (4); and

a plurality of optoelectronic devices (7) on the alignment structure (3) being aligned with the alignment structure (3).

26. The optoelectronic arrangement according to claim 25, wherein the polarity (P) of the plurality of elements (4) extends substantially

parallel or perpendicular to the top surface (2a) of the first carrier substrate (2).

27. The optoelectronic arrangement according to claim 25 or 26, wherein
5 the plurality of elements (4) are arranged in rows and columns.

28. The optoelectronic arrangement according to any one of claims 25 to
27, wherein the alignment structure (3) comprises a polar base layer
(8) on the first carrier substrate (2).

10 29. The optoelectronic arrangement according to claim 28, wherein the
self-aligned material (5) of the plurality of elements (4) is
aligned with the polar base layer (8) causing the polarity (P) of
the plurality of elements (4).

15 30. The optoelectronic arrangement according to claim 28 or 29, wherein
the polar base layer (8) comprises a gold film (9) and self-
assembled monolayers (10) on the gold film (9), in particular of
hexadecanethiol or pentadecanethiol.

20 31. The optoelectronic arrangement according to claim 28 or 29, wherein
the polar base layer (8) is an octyltrichlorosilane coating (11) of
the first carrier substrate (2).

25 32. The optoelectronic arrangement according to any one of claims 25 to
31, wherein the self-aligned material (5) of the plurality of
elements (4) contains fluid liquid crystals.

30 33. The optoelectronic arrangement according to claim 32, wherein the
elements of the plurality of elements (4) are each formed by fluid
liquid crystals arranged in a cavity (12) of a frame material (13).

35 34. The optoelectronic arrangement according to any one of claims 25 to
33, wherein the alignment structure (3) comprises a spacer substrate
(14) arranged on the plurality of elements (4), the spacer substrate
(14) being coated with a conductive coating (15) on a surface facing
away from the plurality of elements (4).

35. The optoelectronic arrangement according to claim 34, wherein the spacer substrate (14) comprises an octyltrichlorosilane coating (11) on surface facing the plurality of elements (4).

5 36. The optoelectronic arrangement according to any one of claims 25 to 35, wherein the plurality of elements (4) are each formed by a microcapsule containing the self-aligned material (5), the microcapsules being arranged between the first carrier substrate (2) and a second carrier substrate (16).

10 37. The optoelectronic arrangement according to claim 36, wherein the first and the second carrier substrates (2, 16) each comprises a plurality of electrodes (17) configured to apply an electric field to the alignment structure (3).

15 38. The optoelectronic arrangement according to any one of claims 25 to 37, wherein the optoelectronic devices (7) are μ -LEDs.

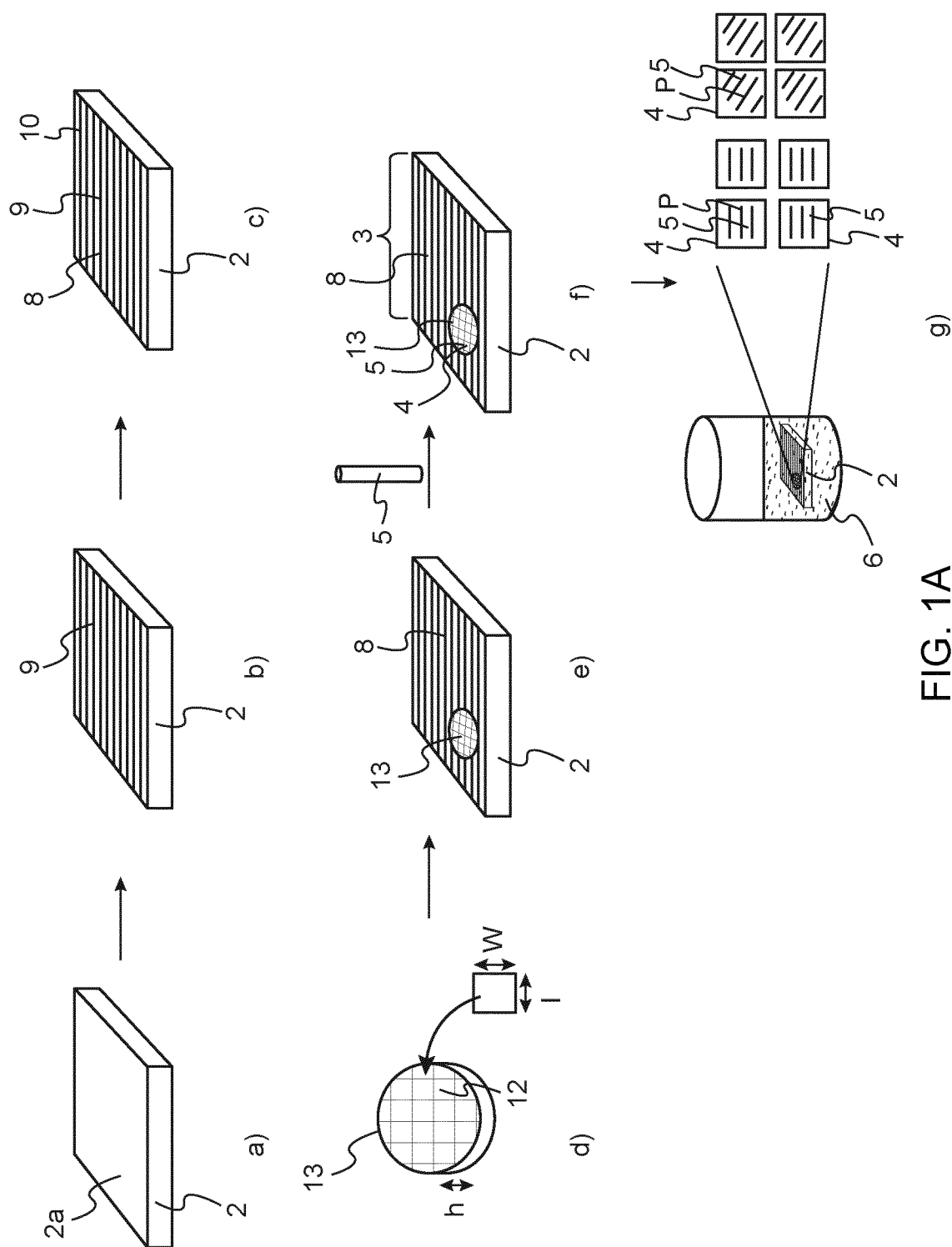


FIG. 1A

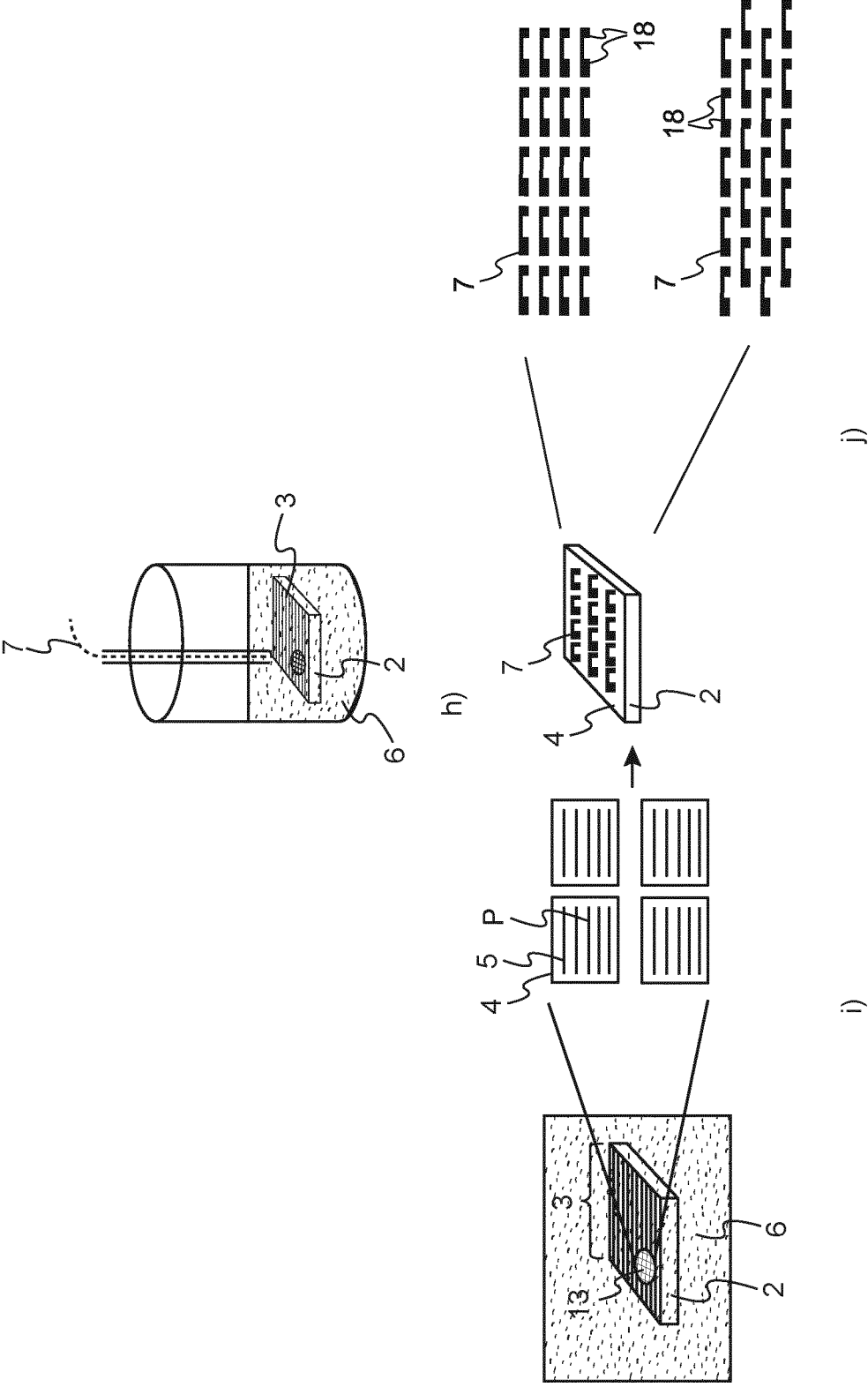


FIG. 1B

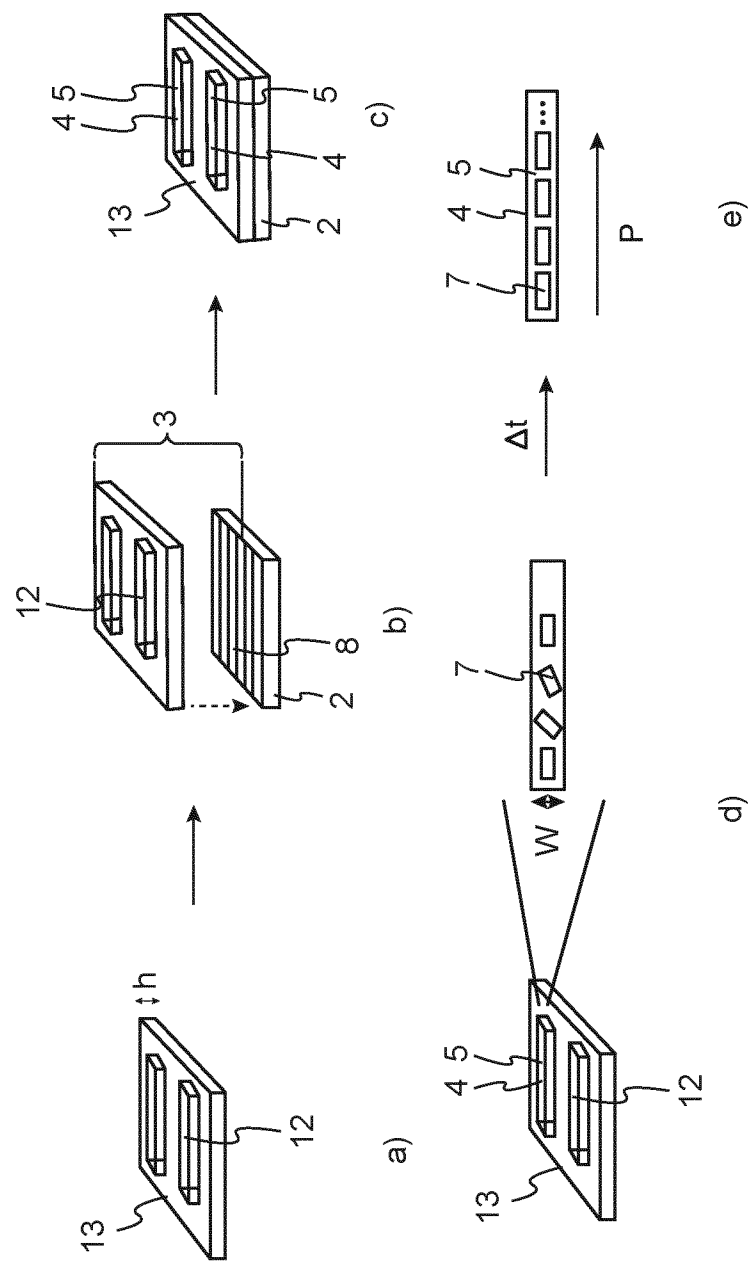


FIG. 2

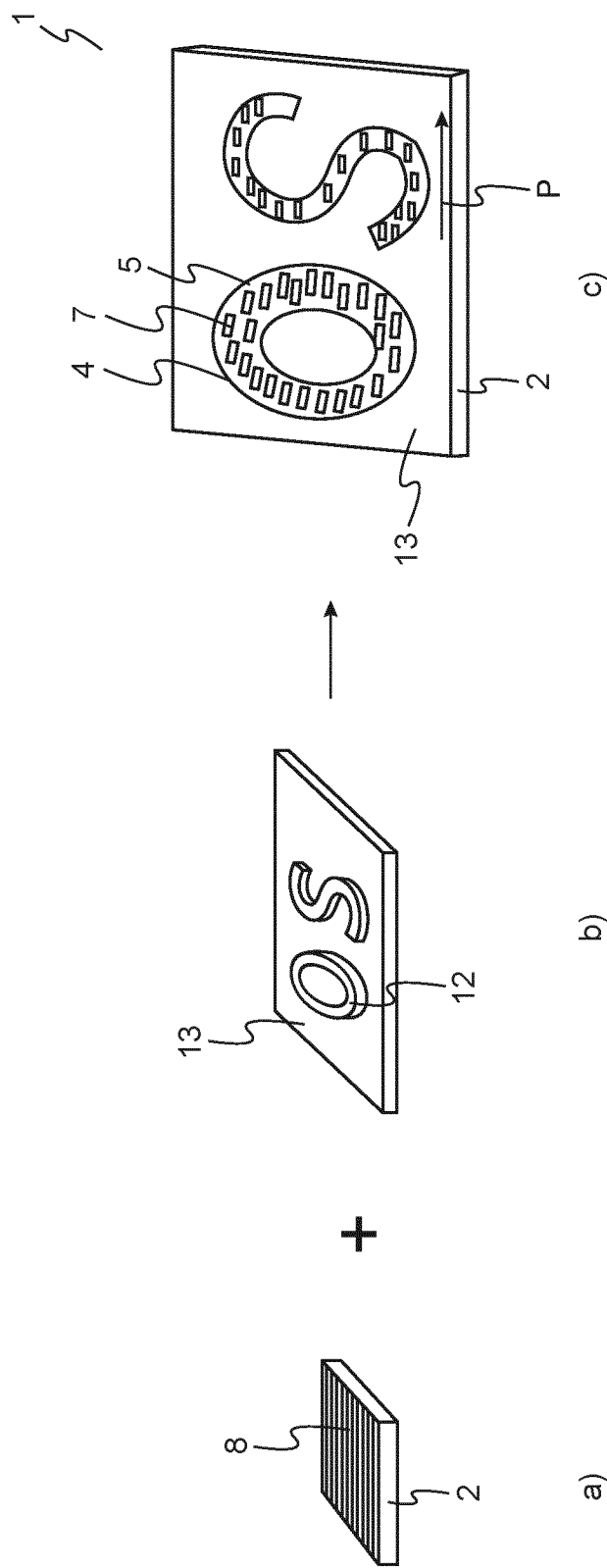


FIG. 3

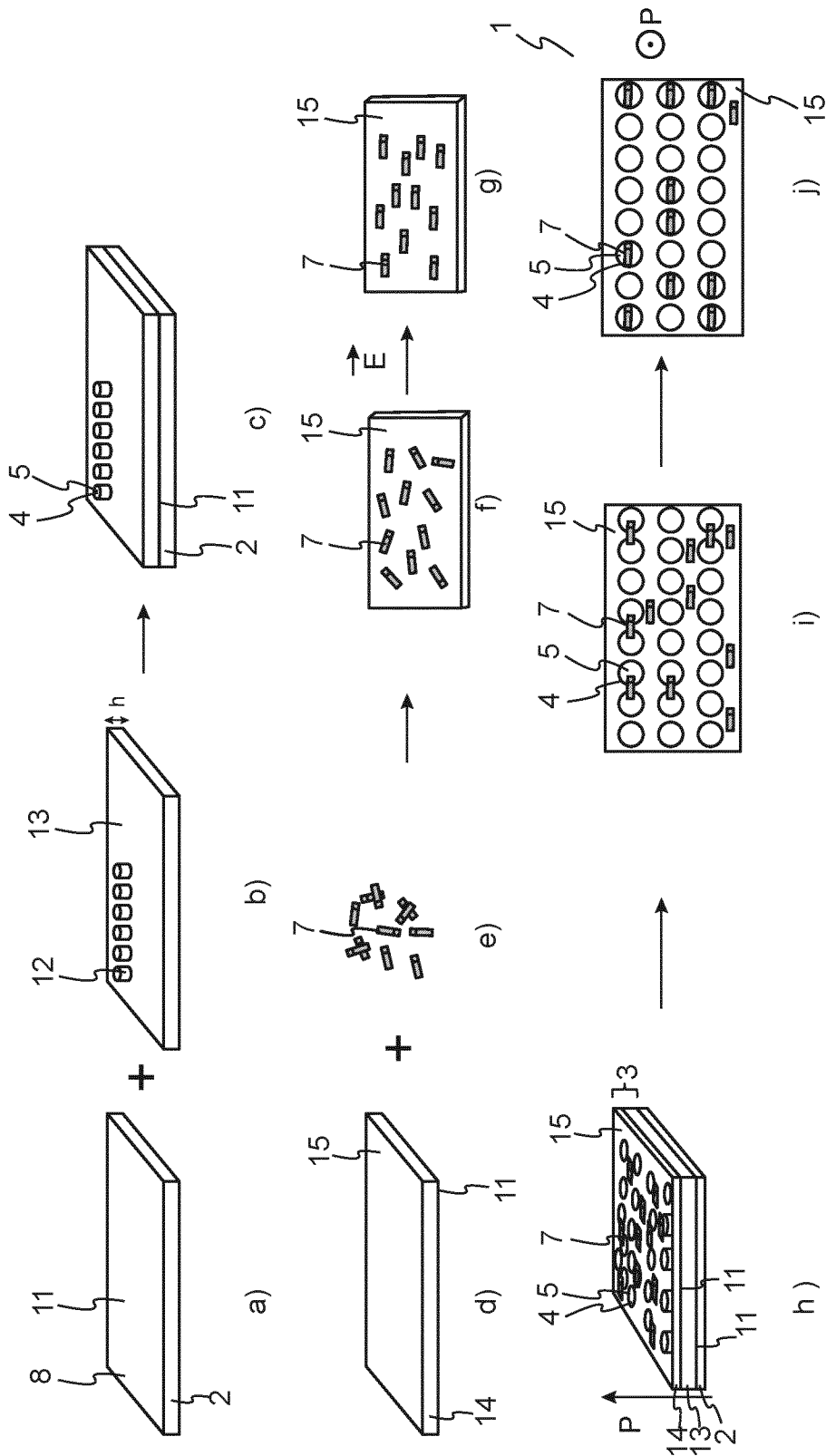


FIG. 4

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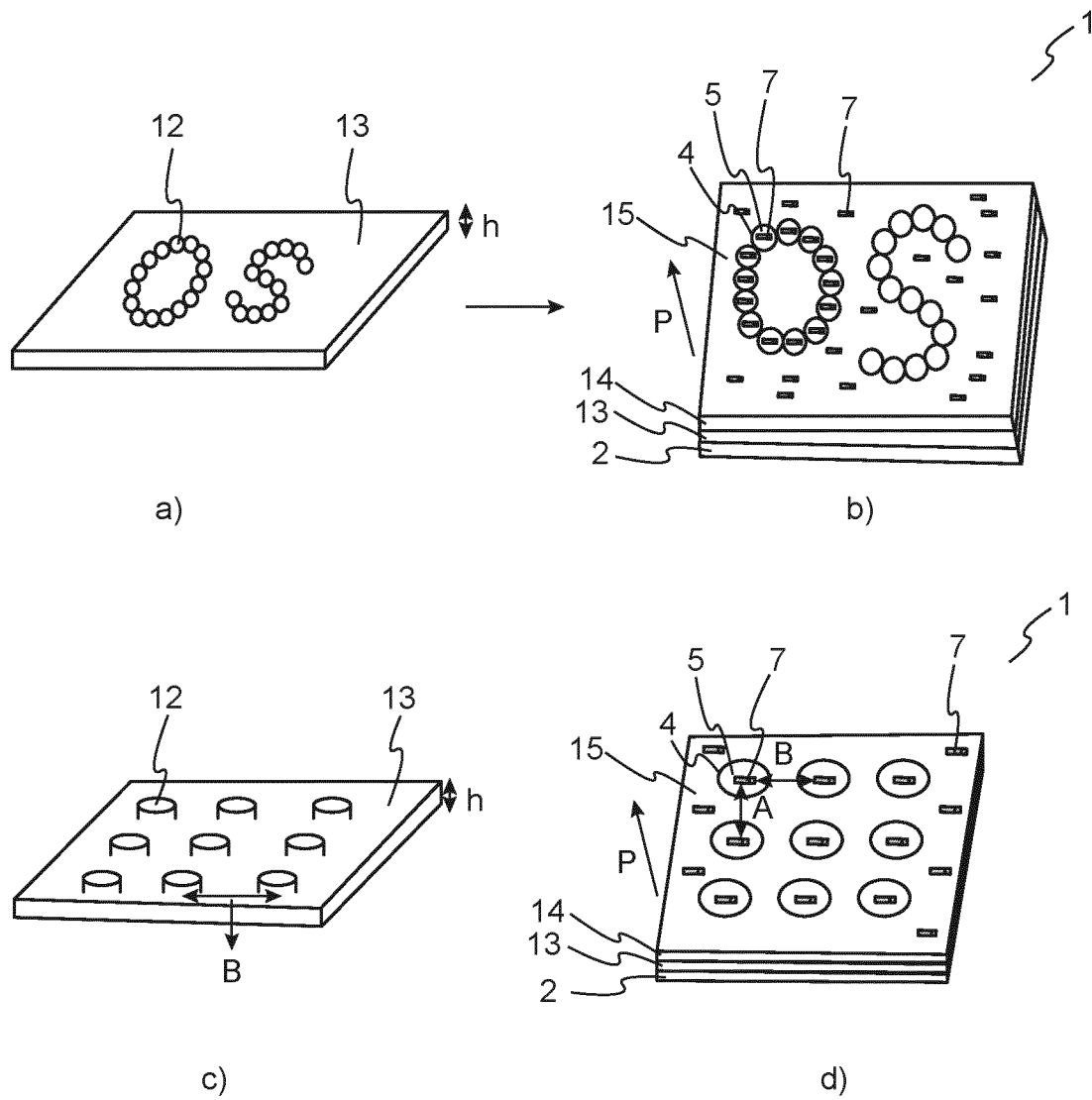


FIG. 5

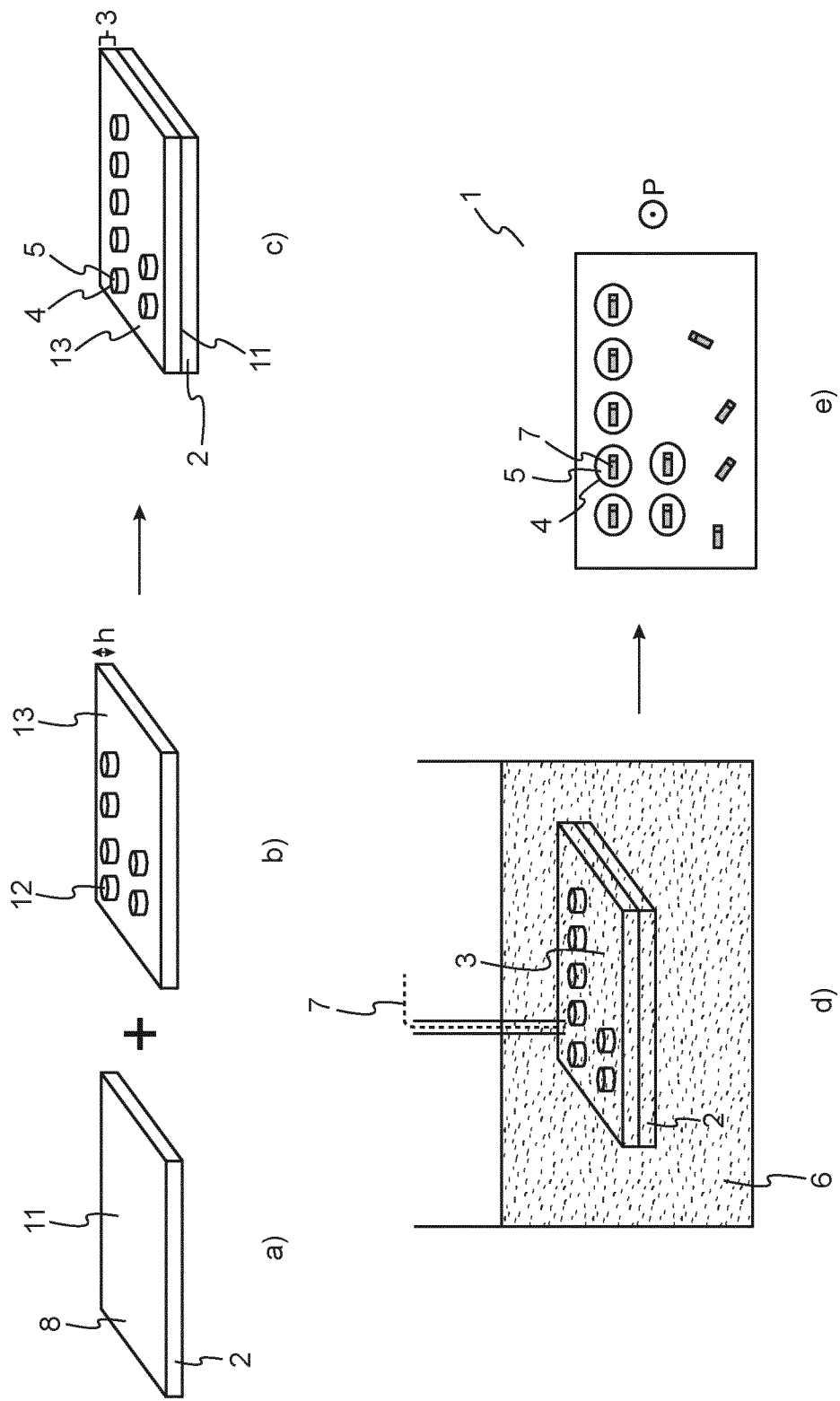


FIG. 6

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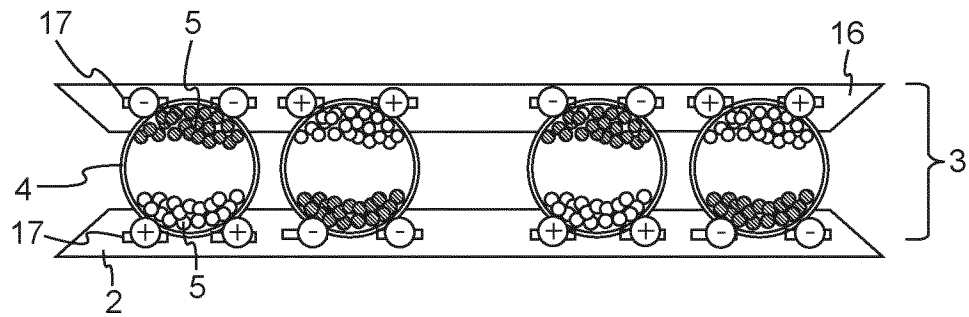


FIG. 7A

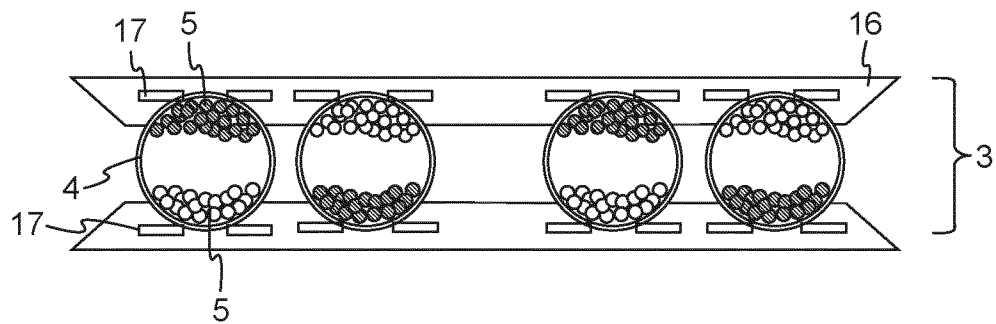


FIG. 7B

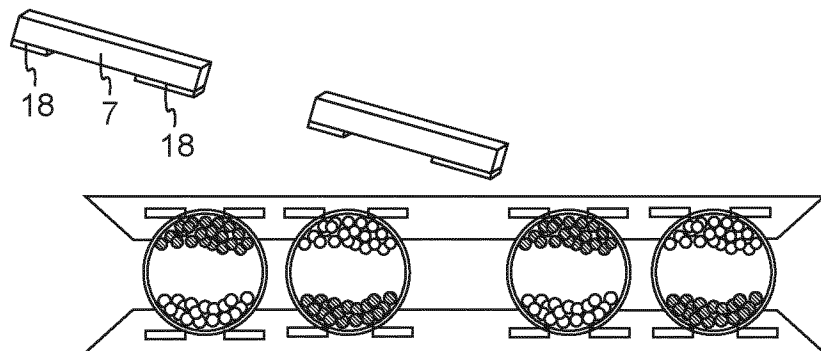


FIG. 7C

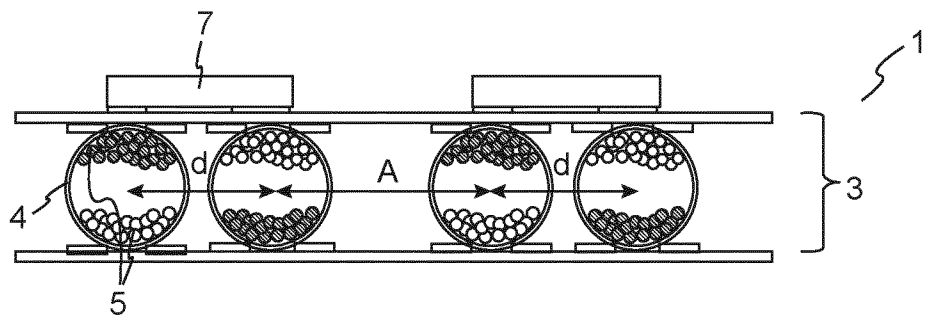


FIG. 7D

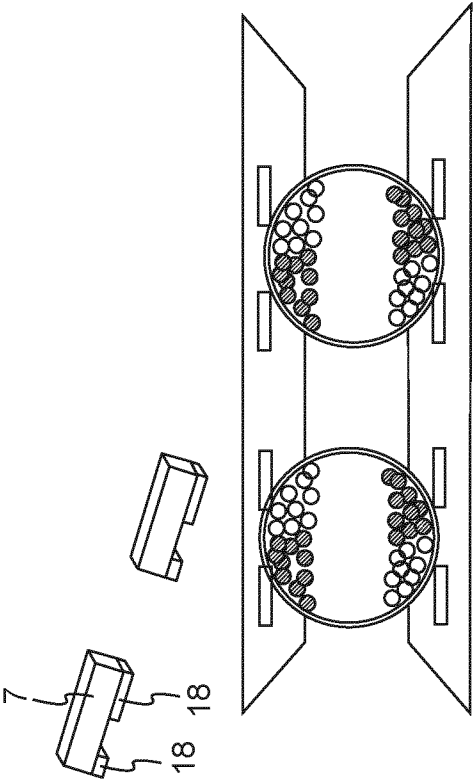


FIG. 8A

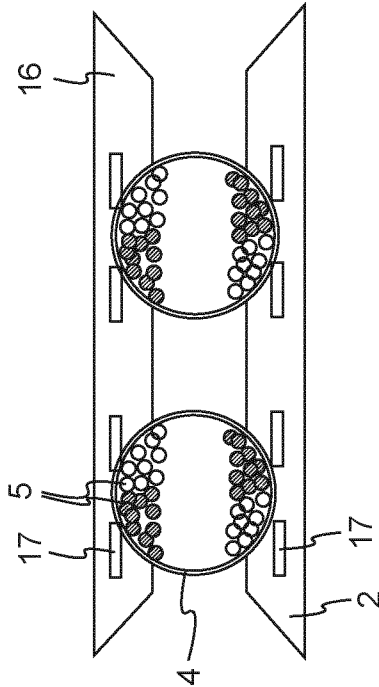


FIG. 8B

FIG. 8C

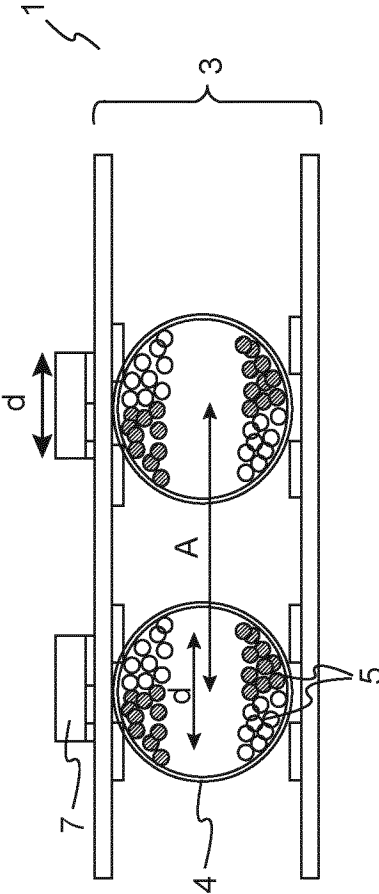
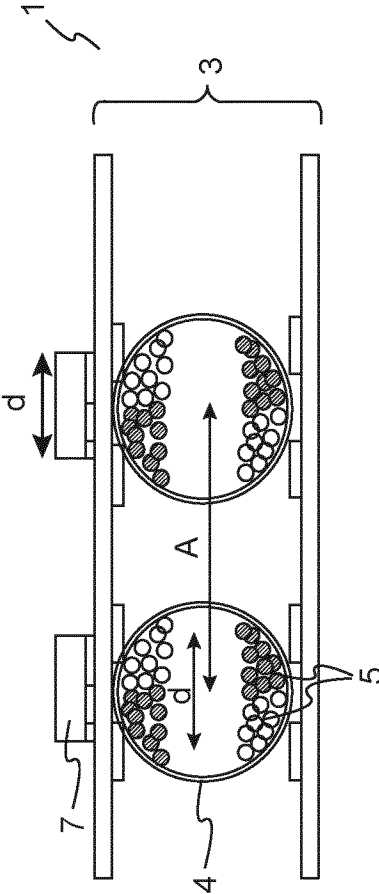


FIG. 8D



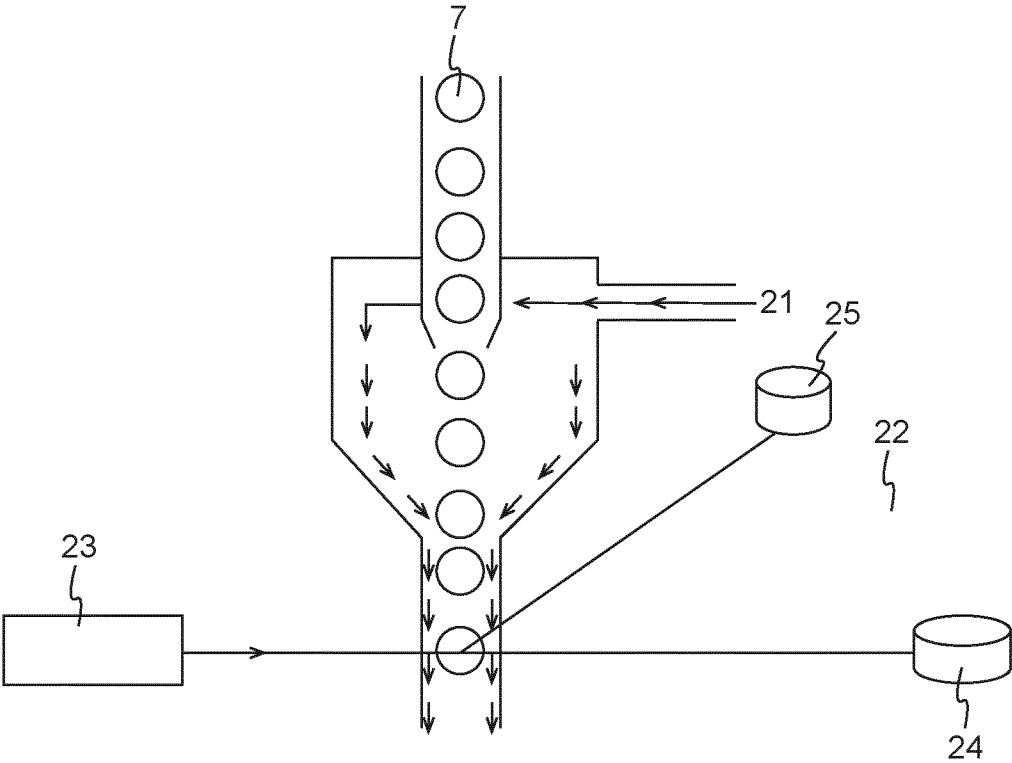


FIG. 9

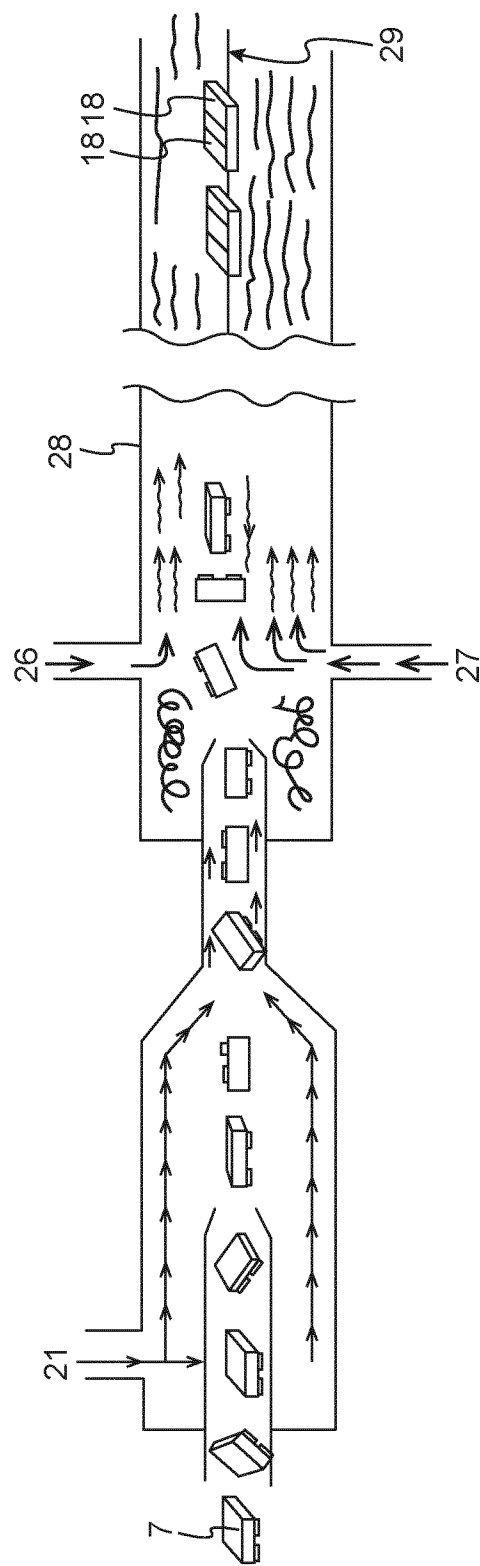


FIG. 10A

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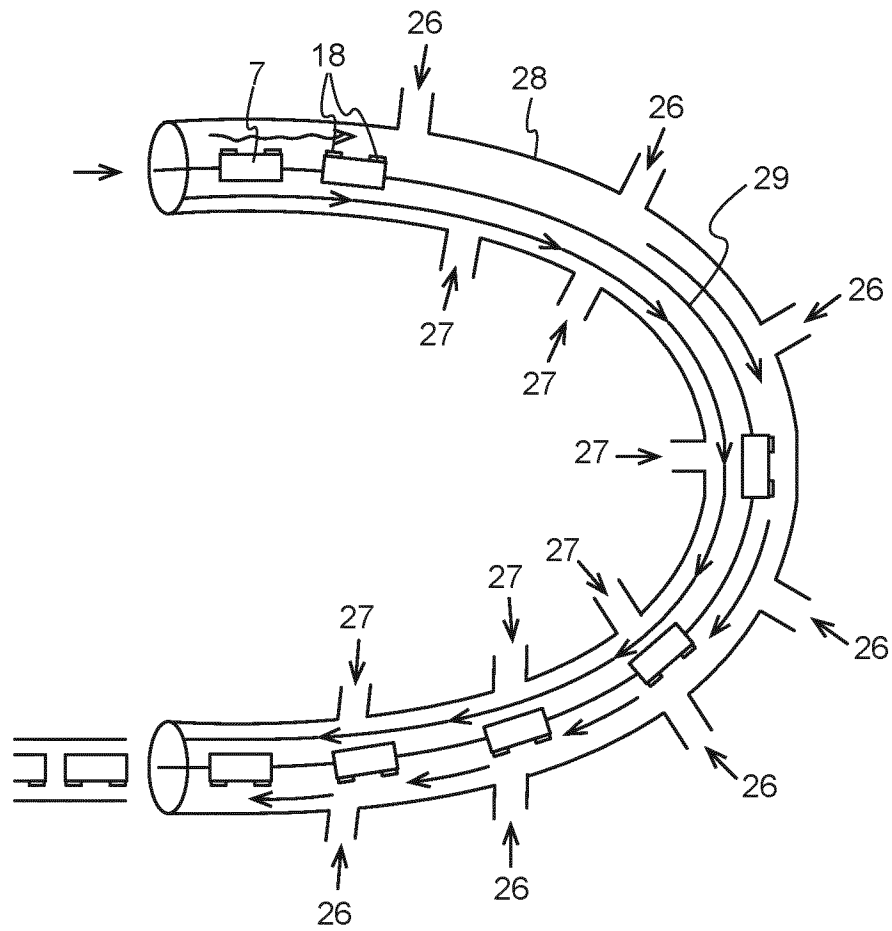


FIG. 10B

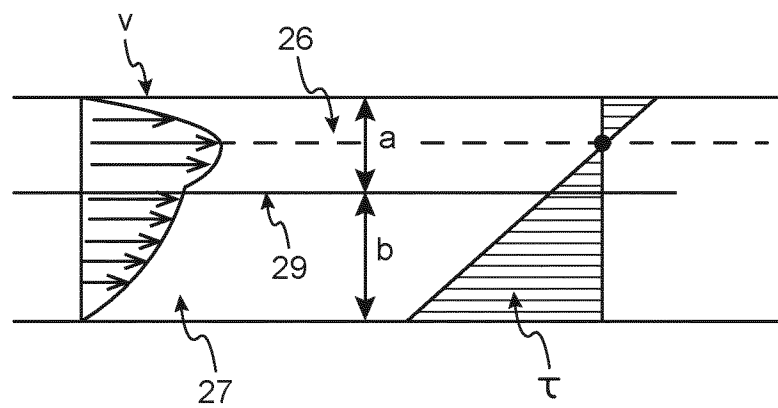


FIG. 10C

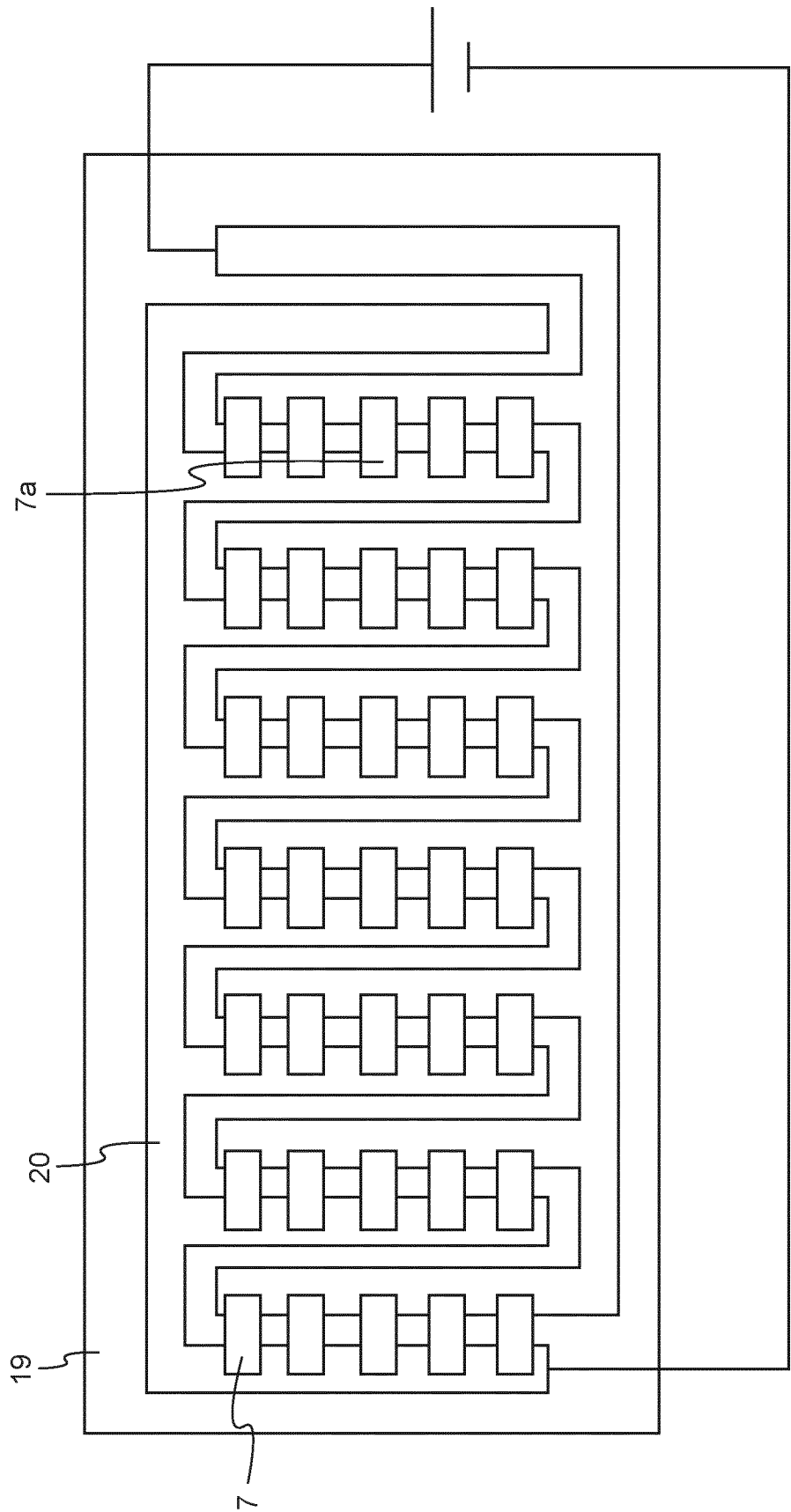


FIG. 10D

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/066365

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01L33/00 H01L23/00
 ADD. H01L21/67 H01L25/075

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)

H01L

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	US 2013/168708 A1 (SHIBATA AKIHIDE [JP] ET AL) 4 July 2013 (2013-07-04)	1-4, 16, 19, 25-29, 38
A	paragraphs [0355] - [0386]; figures 32-36	8-15, 20-24, 32-37
X	US 2010/170086 A1 (RAMADAN QASEM [SG] ET AL) 8 July 2010 (2010-07-08)	1-3, 16-19, 25-29, 38
	paragraphs [0081] - [0084]; figure 8	

	-/--	



Further documents are listed in the continuation of Box C.



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

29 September 2023

Date of mailing of the international search report

04/12/2023

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

Dehestru, Bastien

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/066365

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BALAKRISHNAN S ET AL: "Self Assembly of Microcomponents on Patterned Substrate Using Capillary Force", ELECTRONIC PACKAGING TECHNOLOGY CONFERENCE, 2005. EPTC 2005. PROCEEDINGS OF 7TH SINGAPORE 07-09 DEC. 2005, PISCATAWAY, NJ, USA, IEEE, vol. 1, 7 December 2005 (2005-12-07), pages 148-152, XP010905911, DOI: 10.1109/EPTC.2005.1614384 ISBN: 978-0-7803-9578-7 section "II. Experimental"; figure 1 -----	1-7, 25-31, 38
A	US 2017/200859 A1 (DO YOUNG RAG [KR] ET AL) 13 July 2017 (2017-07-13) paragraph [0077] -----	7, 31
A	US 8 133 680 B2 (ABBOTT NICHOLAS L [US]; TINGEY MATTHEW L [US] ET AL.) 13 March 2012 (2012-03-13) figure 1.1 -----	1, 25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2023/066365

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1-19, 25-38 (completely) ; 20-24 (partially)

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-19, 25-38 (completely); 20-24 (partially)

A method of aligning optoelectronic devices in a desired direction on a substrate, and a corresponding arrangement, using an alignment structure formed on a surface of the substrate.

2. claims: 20-22 (partially)

A method of increasing the yield of an optoelectronic arrangement manufacture by controlling the quality of optoelectronic devices before their transfer to a substrate.

3. claims: 23, 24 (partially)

A method of increasing the yield of the alignment of optoelectronic devices on a substrate, by pre-aligning the optoelectronic devices before their transfer.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/066365

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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