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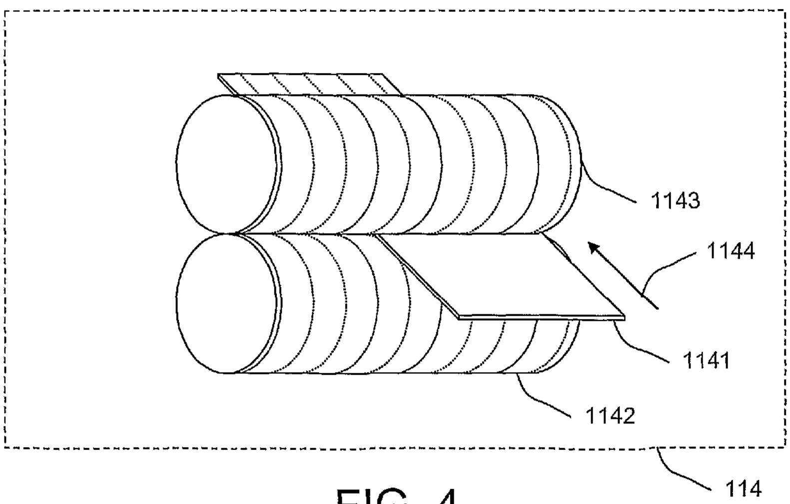

FIG. 4

(57) Abstract: The present invention provides apparatus for performing a processing operation on a web (114), the apparatus comprising: a processing apparatus having two substantially identical processing regions; and aligning means enabling the web to be aligned selectively with either the first or the second processing region; the arrangement being such that, in the event of a defect occurring in the processing apparatus- in one of the processing regions, the web can be realigned with the other processing region.

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WEB PROCESSING

The present invention relates to processing operations performed on a web. Such operations may be physical operations such as printing or embossing, or even arrangements for recording data on the web, such as by applying varying magnetic fields to a magnetic tape.

A problem which arises with such operations is that the device which performs the operations can become worn or damaged in use, and this has in the past required replacement of the device. This problem could be reduced by manufacturing the device from materials which are more robust, but these will tend to be more expensive. Alternatively, the mounting arrangements of the device could be simplified to permit the device to be replaced more readily. However, this would normally involve a complete redesign of the processing apparatus.

The present inventors have realised that these problems can be overcome in a particularly simple arrangement.

This, in accordance with a first aspect of the present invention there is provided apparatus for performing a processing operation on a web, the apparatus comprising: a processing apparatus having two substantially identical processing regions; and aligning means enabling the web to be aligned selectively with either the first or the second processing region; the arrangement being such that, in the event of a defect occurring in the processing apparatus in one of the processing regions, the web can be realigned with the other processing region.

With such an arrangement, it will be appreciated that, in the event of a fault developing within the processing region of the apparatus currently being used, it is merely a question of moving the web relative to the processing apparatus such that the other processing region is used to perform the processing operation on the web.

It is advantageous that the two processing regions do not overlap, since this arrangement would overcome the problem of a fault developing anywhere within a processing region. However, this feature is not essential, since, in some processing operations, only one edge of the processing region may be subject to damage, in which case the invention could be put into effect by providing two overlapping processing regions which are mirror images.

The two processing regions are preferably adjacent, since this results in a compact arrangement.

The processing operation may be is a physical operation which is performed by bringing the processing apparatus into contact with the web, in which case the processing apparatus may comprises one or more rollers.

A process where the present invention finds particular application is in the embossing of webs, such as those used in the manufacture of electrode assemblies for photovoltaic cell arrays. In this case, the embossing may be in the form of one or more indentations in the web, which act in the assembled array to provide an electrical connection between the two opposing electrodes.

The embossing is preferably in the form of a plurality of indentations in the web in a substantially regular array, and advantageously in the form of a plurality of lines of indentations, the separation of indentations within each line being substantially less than the spacing between adjacent lines.

Each of the two processing regions of the processing apparatus may comprise two respective complementary surfaces between which, in use, the web is caused to pass. This enables the operation to be performed in a more controlled manner, since the web can be held in position between the two surfaces.

By spacing the complementary surfaces from each other by a distance of between 0.01 mm and 0.10 mm, this enables a processing operation to be performed on a foil, such as that used in the formation of a photovoltaic cell array.

The processing operation is preferably arranged to take place by moving the web relative to the processing apparatus along a processing direction, in which case the aligning means is advantageously arranged to move the web relative to the processing apparatus along an alignment direction transverse, e.g. substantially perpendicular, to the processing direction.

The processing apparatus may comprise first and second complementary rollers between which, in use, the web is caused to pass so as to be in contact with the surface of both of the rollers, the first roller being formed with an array of projections, and the second roller being formed with a corresponding array of recesses, the arrangement being such that an array of indentations is caused to be formed on the web.

The present invention extends to apparatus for manufacturing an electrode for a photovoltaic cell comprising apparatus as defined above.

The present invention further extends to apparatus for manufacturing a photovoltaic cell comprising apparatus as defined above.

Preferred embodiments of the present invention will now be described with reference to the accompanying drawings wherein:

Figure 1 illustrates the overall process for manufacturing a photovoltaic cell;

Figure 2 illustrates the process for manufacturing a primary electrode array of the photovoltaic cell array;

Figure 3 illustrates the processes involved in embossing a pattern on the titanium web of the primary electrode array;

Figure 4 illustrates the path of the titanium web of the primary electrode through the embossing rollers;

Figure 5 illustrates the respective male (raised) and female (recessed) profile of the embossing rollers which produce the small near-spherical projections on the titanium web of the primary electrode array, when viewed along the axes of the rollers;

Figure 6 illustrates the process for cleaning the titanium web of the primary electrode array;

Figure 7 is a cross-sectional view of apparatus for cleaning the embossed titanium web;

Figure 8 illustrates the process for coating the titanium web with titanium dioxide;

Figure 9(a) is an exploded view of an extrusion head used for coating the titanium web with both titanium dioxide and a dyestuff;

Figure 9(b) is an exploded view of an alternative embodiment of an extrusion head having two supply holes;

Figure 10 illustrates the flow path of titanium dioxide paste or dyestuff as the titanium web is directed past the extruder;

Figure 11 illustrates an arrangement for applying pressure to an extrusion head;

Figure 12 illustrates the cleaning of a coated titanium web by a laser;

Figure 13 illustrates the process for coating the titanium dioxide layer on the titanium web with a ruthenium-based dye;

Figure 14 illustrates an arrangement for applying a layer of dye to the coated titanium web;

Figure 15 illustrates the final stages in the fabrication of the primary electrode array in accordance with an embodiment of the present invention;

Figure 16(a) and 16(b) illustrate first and second alternative types of dynamic tensioning device for use in the arrangement of Figure 15;

Figure 17 illustrates the final stages in the fabrication of the counter-electrode array in accordance with an embodiment of the present invention;

Figure 18 illustrates how the primary electrode array and the counter-electrode array are joined together in accordance with an embodiment of the present invention;

Figures 19(a) to 19(c) are cross-sectional views of the photovoltaic cell array in accordance with a preferred embodiment of the present invention, at different stages in the fabrication;

Figure 20 illustrates how the primary electrode array and the counter-electrode array are joined together in accordance with a further embodiment of the present invention;

Figure 21 is a cross-sectional view of the final lamination process;

Figure 22(a) illustrates how an external electrical connection is made to the photovoltaic cell array in accordance with a preferred embodiment of the present invention;

Figure 22(b) is a cross-sectional view on X-X of a portion of the electrical connection shown in Figure 22(a);

Figure 23(a) is an exploded cross-sectional view of a portion of two adjacent cells of the primary electrode and counter-electrode arrays before assembly;

Figure 23(b) is a cross-sectional view of a portion of two adjacent cells of the laminated assembled primary electrode and counter-electrode arrays;

Figure 24 is a cross-sectional view showing the dimensions of the components of an assembled photovoltaic cell array in accordance with a preferred embodiment of the present invention;

Figure 25 shows the overall appearance of the assembled photovoltaic cell array;

Figure 26(a) is a view of an alignment fine tuner for the position of a roller when viewed along the axis of the roller; and

Figure 26(b) is an isometric view of the roller with the alignment fine tuner.

Referring to Figure 1, a process for manufacturing an array of photovoltaic cells includes: a process 100 for forming an array of primary electrodes; a process 200 for forming a corresponding array of counter-electrodes; a process 300 for assembling the two electrode arrays with electrolyte therebetween; and a process 400 for sealing the edges of the assembled electrode arrays and laminating the sealed assembly.

In a preferred embodiment, the resulting sealed assembly comprises 11 functioning pairs of electrodes and one pair of dummy electrodes at the side edge of the array which is used for establishing external electrical contacts. Preferably, the electrolyte is not present between the pair of dummy electrodes.

Figure 2 illustrates in greater detail the process 100 for forming the primary electrode array. There are five separate stages to this process: embossing 110; cleaning 120; coating 130 with titanium dioxide (TiO_2); coating 140 with a ruthenium-based dye which acts as the light-absorbing material in the array of photovoltaic cells; and cutting 150 the resulting coated web into strips and attaching the strips to an insulating substrate.

The apparatus used in the embossing process is illustrated in greater detail in Figure 3. In this process a roll of titanium web having a thickness of 0.05 mm is unwound from an unwinding stage 111 comprising two separate unwinding units and supplied via an edge-guiding mechanism 112 to a welding stage 113 which is arranged to weld together the trailing edge of one roll of titanium web and the leading edge of a subsequent roll of titanium web. The titanium web is then supplied to an embossing stage 114 at which the web is embossed with a pattern of dimples, described in greater detail below, and then to a cutting stage 115 where the titanium web is cut at substantially the same position as the join previously formed at the welding stage 113. The embossed titanium web is then fed via a further edge-guiding mechanism 116 to a rewinding stage 117 which rewinds the embossed titanium web on to a cardboard former on one of two separate rewinding units.

The reason for providing two separate unwinding units, the welding stage 113, the cutting stage 115 and two separate rewinding units is to enable the embossing to take place on a continuous web of titanium without requiring each roll of titanium web to be fed manually through the embossing stage 114. Thus, the trailing edge of a first roll of titanium web is welded to the leading edge of a second roll of titanium web at the welding stage 113, and the web is cut at the same position when the welded join subsequently arrives at the cutting stage 115. A third roll of titanium web is then fitted on to the empty unwinding unit so that the leading edge can then be welded to the trailing edge of the second roll. In order to allow the titanium web to be supplied to the embossing stage at constant speed, even during the welding process, a buffer arrangement of rollers is arranged both upstream and downstream of the embossing stage 114. However, in an alternative arrangement, the buffer arrangements are eliminated and the speed of the embossing process allowed to vary.

The embossing stage 114 is shown in greater detail in Figure 4. The titanium web 1141 is fed into a nip defined by first and second embossing rollers 1142, 1143 along the direction shown by arrow 1144 and at a speed of around 20 m per minute (0.33 ms^{-1}). The size of the nip is chosen so as to engage the titanium web which has a thickness of 0.05 mm, and is therefore selected to be a value preferably within the range of 0.01 mm and 0.10 mm. The embossing rollers 1142, 1143 are formed with 48 lines of embossing patterns for forming corresponding parallel lines of dimples on the titanium web 1141, although only a few lines are illustrated in Figure 4 for the sake of clarity. As can be seen in Figure 4, the titanium web 1141 occupies only one half of the width of the embossing rollers 1142, 1143. The titanium web 1141 therefore engages with 24 of the 48 lines of embossing patterns. This advantageous feature enables the embossing rollers 1142, 1143 to continue to be used in the event of a defect occurring in the embossing pattern on one side of one or both of the rollers 1142, 1143. A means of aligning the titanium web (not shown) is therefore provided so that, in the event of such a defect, the web can simply be realigned with the other side of the embossing pattern, so that the embossing process can continue without a substantial interruption in the process.

The surfaces of the embossing rollers 1142, 1143 are shown in greater detail in Figure 5. The surface of the first embossing roller 1142 is formed with a raised (male) embossing pattern in the form of an array of near-spherical projections 1145 which are aligned with a recessed (female) embossing pattern in the form of a corresponding array of near-spherical recesses 1146. The scale of the embossing patterns shown in Figure 5 is exaggerated relative to that of the embossing rollers 1142, 1143, for the sake of clarity. By passing the titanium web 1141 between the first and second embossing rollers 1142, 1143, an array of dimples 1147 is formed on the titanium web 1141. The dimples 1147 are formed in a rectangular array in which the spacing between adjacent dimples along the direction of travel of the titanium web 1141 is substantially less than that along the width of the titanium web. The dimples 1147 are thus formed in a number of lines, in which the dimples are regularly spaced and typically separated by approximately 1 mm, and the lines are separated by 12.25 mm. The dimples 1147 serve as a means of establishing an electrical connection between the two electrodes of each photovoltaic cell within the assembled array.

Before the embossing process is started, a length of approximately 15 metres of stainless steel header web is welded to the leading edge of a first roll of titanium web and fed between the embossing rollers 1142, 1143, which at this stage are separated from each other, in order to create a continuous length of web downstream of the rollers 1142, 1143, thereby to prevent wastage of unembossed titanium web 1141 which would otherwise have to be present in this downstream position. The length of the stainless steel header web is governed by the physical arrangement of the overall embossing stage 114 which includes a bridge located downstream of the embossing rollers 1142, 1143 which provides space for the two separate rewinding units of the rewinding stage 117. In practice, the length of the header web is typically between 20 m and 30 m. As described above, when the first roll of titanium web is exhausted, the trailing edge of the web of the first roll is welded to the leading edge of the next roll of titanium web at the welding stage 113, so that, once started, the embossing process is continuous. In operation, the welding stage 113 punches a hole in the web at the position where the trailing end of the first roll of titanium web is welded to the leading edge of the next titanium web, and this hole is subsequently detected by a sensor at the cutting stage 115 which, in turn, causes the titanium web to be cut at this point and a stainless steel trailer portion to be welded to the trailing end of the titanium web. Thus, during the subsequent processing of the titanium web, there are attached to the web both leading and trailing stainless steel web portions.

However, it has been found that the subsequent heat treatment of the titanium web, described in greater detail below, can give rise to buckling of the web at the positions where the leading and trailing stainless steel web portions are welded to the titanium web, due to the different rates of thermal expansion of the two metals.

Therefore, in an alternative arrangement, in place of the stainless steel header and trailer web portions, header and trailer web portions of the titanium web itself are used. Although this might appear to be wasteful of expensive titanium, the header and trailer portions can of course be reused once they are removed from the main processed portion of each titanium roll of web at the end of the final processing stage. Furthermore, when the header and trailer portions are at the end of their useful life, they can be recycled, e.g. by melting and forming as a new web.

After the titanium web has been embossed, the embossed web is optionally passed to a cleaning stage 120, shown in greater detail in Figure 6. The cleaning stage serves to remove oil, residues and other contaminants and comprises, in sequence, an unwinder 121, an edge guide 122, a cleaning unit 123, a floatation drier 124, an edge guide 125 and a rewinder 126. In operation, the embossed titanium web is unwound and passed via the edge guide 122 into the cleaning unit 123. Referring to Figure 7, the cleaning unit 123 comprises a bath 1231 of liquid detergent such as that marketed under the brand name LiquiNox (RTM) and a rinsing chamber 1232. The bath 1231 and the rinsing chamber 1232 are both heated to 85°C. The embossed titanium web 1233 is guided through the detergent in the bath 1231 and over a separating wall 1234 into the rinsing chamber 1232. De-ionised water is then sprayed on to the web 1233 from spray nozzles 1235 and is collected at the base of the rinsing chamber 1232 via a drainage outlet 1236 for re-use. In some embodiments of the invention, the cleaning stage 120 is omitted.

To prevent cross-contamination, first and second rows of air knives 1237, 1238 are positioned respectively above and below the path of the web 1233 a short distance upstream of the wall 1234, and these serve to force any detergent residue on the web 1233 back into the bath 1231.

The rinsed titanium web 1233 is then immersed in a bath of ethanol (not shown) and fed to a floatation unit 124 (see Figure 6) which dries the web 1233. In the flotation unit 124 a supply of air heated to between 80°C and 120°C is directed above and below the web 1233 as it is held under tension between two rollers.

The dried titanium web is then fed via an edge guide 125 to a rewinding station 126.

Referring back to Figure 2, the embossed and cleaned titanium web is then supplied to a coating station 130 for depositing a layer of titanium dioxide (TiO_2) on the titanium web, and this is shown in greater detail in Figure 8. An unwinder 131 supplies the web via an edge guide 132 to an extrusion station 133, described in greater detail below. At the extrusion station 133, a water-based paste containing TiO_2 is extruded on to the web from a pressurised container and is deposited in the form of strips which extend between adjacent rows of embossed dimples.

In a preferred embodiment, the paste contains: (a) hydroxypropylcellulose (HPC) as a thickening agent, which has the advantage of decomposing without leaving an undesirable residue on the web; a surfactant, for example as marketed under the reference TX-100, which reduces the surface tension of the paste thereby allowing the TiO_2 to pass more readily into the surface grooves in the titanium foil; and a biocide for killing the moulds and fungi which are often found in the presence of HPC. The thickness of the TiO_2 paste deposited on the web is dependent on the shape of the extrusion head (and in particular, the thickness of the extrusion comb, to be described below), the speed at which the web is moved past the extrusion head and the viscosity of the paste.

The TiO_2 paste is then dried in three stages 134, 135, 136. The first stage 134 comprises an infrared oven heated to approximately 60°C which dries the paste from the inside, thereby preventing adverse blistering on the surface of the coating. Optionally, the first stage 134 instead comprises a floatation drier such as described previously with reference to Figure 6. The second stage 135 comprises a flotation dryer oven in which the web is suspended and dried by infrared radiation and warm air at a temperature of around 180°C. The third stage 136 comprises an infrared sintering oven which causes the TiO_2 from the paste to bind on the surface of the underlying titanium web. The coated web then enters a cooling stage 137 before being fed via an edge guide 138 to a rewinder 139.

The components of the extrusion head of a first embodiment are shown in greater detail in Figure 9(a). The extrusion head 1331 comprises a stainless steel extruder body 1332, a stainless steel extruder comb 1333 and a stainless steel cover plate 1334. Attached to each end of the extruder body 1332 are respective stainless steel end plates 1335 which are provided with polytetrafluorethylene (PTFE) sealing gaskets 1336. The comb 1333 of the extrusion head is illustrated with only ten extrusion channels for the sake of clarity, although in practice there are 24 channels in the preferred embodiment. The distal end of each finger of the extruder comb 1333 is formed with a respective notch 1337, and these notches are aligned with corresponding grooves 1338 on one side of the extruder body 1332. These allow the embossed lines of dimples on the titanium web to pass over the extrusion head 1331 without fouling. They also aid the correct assembly of the extrusion head. A single central supply hole 1339 formed in the extruder body 1332 allows TiO_2 paste to pass into one of two supply channels 1340 formed in the extruder body 1332.

An alternative embodiment is illustrated in Figure 9(b). In this embodiment, the extruder comb 1333, also shown with only ten channels, although there are 24 in practice, is made from a flexible plastics material, such as PTFE, or polyethylene. This is formed into the desired shape using a high-pressure stream of water. This provides enhanced sealing qualities against leakage of the TiO_2 paste, since the resilient material used for the comb 1333 compensates for any slight imperfections in the extruder body 1332 and cover plate 1334.

In this embodiment, two or more supply holes 1339 are symmetrically positioned about a central region of the extruder body 1332, in place of the single supply hole 1339 in the embodiment of Figure 9(a). The provision of additional symmetrically placed supply holes reduces the pressure differences within the TiO_2 paste and therefore provides a greater degree of control of the thickness of the TiO_2 coating applied. It will be appreciated that this arrangement provides two separate advantages: (a) the pressure differences are reduced by virtue of the reduced distance travelled by the TiO_2 paste as compared with the arrangement with only a single supply hole, since with two holes, the paste is spread by only one half the width of the extrusion head, whereas with only one hole, the paste must spread over the entire width of the extrusion head; and (b) only one half of the amount of paste passes into each supply hole 1339, and so the rate of travel is halved and the pressure difference reduced.

Additionally, the PTFE gaskets 1336 of the first embodiment are replaced with rubberised cork gaskets 1336. Rubberised cork has been found to enhance the sealing quality of the gasket 1336 which may often be desirable in the event of the stainless steel extruder body 1332 and stainless steel end plates 1335 suffering plastic deformation during assembly.

Referring to Figure 10, the direction of movement of the titanium web 1341 across the extrusion head 1331 is indicated by arrow 1342. The flow direction of the TiO_2 paste within the extrusion head is indicated by arrow 1343, and arrow 1344 indicates the flow direction of the TiO_2 paste as the paste is transferred to the titanium web 1341.

In a preferred arrangement, pressure is applied to the extrusion head 1331 by means of an external clamp 1345, as illustrated schematically in Figure 11, and the degree of compression exerted on the extrusion head 1331 by the clamp 1345 is controlled by a precision screw arrangement in the form of a vernier screw 1346. By precisely controlling the pressure applied to the extrusion head 1331 it is possible, in turn, to control the thickness of the TiO_2 coating applied to the titanium foil: the greater the applied pressure, the thinner the coating.

In a preferred embodiment, the degree of pressure exerted by the clamp 1345 is controlled automatically in dependence on the sensed thickness of the coating at a position downstream of the extrusion head 1331. The thickness can be sensed optically, e.g. by sensing the position of a beam of radiation, such as light, after reflection at the surface of the coating.

It has been found that the process of sintering gives rise to an undesirable layer of oxide over the regions of the titanium foil between the tracks of titanium dioxide coating. Since these regions include the embossed dimples, it is not possible to remove the oxide layer by conventional abrasion techniques without the risk of damaging the dimples. However, it has been found that the undesirable oxide coating can effectively be removed by scanning a high-power laser beam across the surface of the regions where the oxide is to be removed. The precision which is afforded by such laser cleaning permits removal of the undesirable oxide layer without affecting the tracks of titanium dioxide coating. Furthermore, this method is clean since it leaves no residue on the surface of the titanium foil which would otherwise require removal. The laser can additionally be used to apply a mark to the rear surface of the titanium foil for quality control purposes.

This arrangement is illustrated in Figure 12. A laser 1391 is mounted above the path, indicated by arrow 1392, of the coated titanium web 1393. The web comprises tracks 1394 which have been coated with titanium dioxide and intervening tracks 1395 containing the embossed dimples which have undesirably been coated with a layer of titanium dioxide during the sintering process. The laser 1391 directs a beam of radiation along a scan line 1396, but such that only the intervening tracks 1395 containing the embossed dimples are irradiated. This is achieved either by scanning the laser beam across the entire width of the web, using either a scanning head or a beam-splitter, and modulating the intensity accordingly, or by directing the laser beam only at the intervening tracks 1395, such as by a fibre-optic arrangement. In either case, the power and frequency of the laser beam are selected and/or controlled such that the radiation is able to ablate the oxide layer from the surface of the titanium web 1393, and the resulting cleaned intervening tracks 1397 can be seen downstream of the laser beam in Figure 12.

In an alternative arrangement, the entire surface of the titanium foil is coated with titanium dioxide paste using a simple extrusion head and then dried using the same three stages as described above. The tracks are then defined by removal of the titanium dioxide from the regions between the tracks using a high-power laser. This arrangement has the advantage of not requiring an extrusion head with a complex structure, although it will be appreciated that a greater quantity of titanium dioxide paste would be required to coat the entire upper surface of the titanium foil. In a preferred embodiment, the width of each track of titanium dioxide coating is 9.0 mm, and the separation between each pair of adjacent tracks is 3.5 mm, so that the additional quantity of titanium paste in this embodiment would amount to about 40%.

Referring to Figure 13, a coating containing ruthenium dye is then applied to the TiO_2-coated Ti web. An unwinder 141 supplies the TiO_2-coated Ti web via an edge guide 142 to a dye-coating station 143. In one embodiment, the Ti web is then passed via two vacuum units 144, which dry the dye coating, to a first bath 145 which cleans the web ultrasonically and then to a second bath 146 containing a solvent cleaner. In another embodiment, the vacuum units 144, ultrasonic bath 145 and solvent bath 146 are eliminated. Instead, the Ti web is passed into an imbibe area where the dye is allowed to infiltrate or imbibe the TiO_2 coating, and then to an agitated rinse bath where excess dye is removed.

A flotation unit 147 then dries the web using the same principal described above with reference to the flotation drier 124 (see Figure 6). The dried coated foil is then fed via an edge guide 148 to a rewinder 149.

It would be possible to apply the coating to the TiO_2-coated Ti web using an extrusion head which is identical to that used to apply the TiO_2 paste to the Ti web, in which case the dye-coating station 143 would be substantially identical to the extrusion station 133.

However, in view of the danger presented by the explosive volatile solvents of the dye, it is preferred that the dye is applied using two linear arrays of precision-controlled dosing valves, as shown in Figure 14.

Referring to Figure 14, the titanium web 1431, which is coated with strips of titanium dioxide 1432, is caused to pass in the direction indicated by arrow 1433 past a dye-coating station 1434 which comprises a plurality of solenoid-controlled dosing valves 1435 arranged in two linear arrays 1436, 1437. In Figure 14, 24 dosing valves are shown, but in a preferred embodiment, 22 dosing valves are provided. A source of dye is supplied to each of the 22 valves 1435, which, in turn apply the dye to the central region of each of the titanium dioxide strips 1432. The dye is absorbed into the titanium dioxide and thereby spreads across the entire width of each titanium dioxide strip 1432, although it is possible to control the spread by adjusting the separation between the needle of the dosing valve and the coated web 1431.

The dosing valves 1435 may be diaphragm valves. The end of each valve 1435 comprises a needle which is cut at an angle – or "slash-cut" – and this is particularly advantageous in the present application. In order for all of the 22 valves 1435 to be located in two linear arrays across the coated titanium web 1431, the valves 1435 are arranged at an angle to the web 1431, with alternate valves in each of the two arrays, e.g. 1435(a) being oriented in a downstream direction and the intervening valves, e.g. 1435(b) oriented in an upstream direction. Furthermore, the angular cut of the end of the needle of each valve 1435 enables the aperture of each needle to be located substantially parallel to, and at a small distance above, the coated web 1431.

The rate at which the dye is caused to pass through each valve 1435 is controlled by (a) the pressure at which the dye is supplied to each valve 1435 and (b) a manual vernier adjustment made to the valves 1435. The rate can also be controlled by selecting the calibre of the needles used with each valve. The use of replaceable needles is particularly useful when using dyes of different viscosity.

As the web is guided through the coating processes, the web is held at a tension per unit width of the web of 346 Nm^{-1}. This is found to be adequate to control the movement of the web, yet not sufficient to cause the coating to crack. In typical applications, in which the width of the web is 0.306 m, the actual tension applied is 106 N.

The edge guide 142 (see Figure 13) which is located upstream of the dye coater 143 is a passive, purely mechanical guide in the form of a pair of guide wheels fixed on a roller which transports the web toward the dye coater 143. The lateral position of the roller is adjusted by means of a micrometer screw gauge.

The edge guides referred to above and below can take one of two forms: either a purely mechanical arrangement as described above, or an electrically powered servo-system in which any misalignment of one or both edges of the web is sensed, and the resulting signal is fed back to an electric motor which realigns the web.

The reason for providing a purely mechanical edge guide 142 upstream of the dye coater 143 is to eliminate the risk of fire and/or explosion which could arise if the edge guide 142 were electrically powered.

It will be appreciated that the laser cleaning process described above with reference to Figure 12 could be applied before or after the web has passed through the dye coating station.

The next stages in the fabrication of the primary electrode array are illustrated in Figure 15. The coated titanium web 151 is transported along a direction indicated by arrow 152 to a cutting head 153 which comprises a linear array of 23 rotary cutter blades arranged to cut the coated titanium web 151 into 24 strips 154 each having a width of 12.25 mm, which will form the primary electrodes in the resulting photovoltaic cell array. However, before the cutting process starts, 23 initial longitudinal slots are cut manually across the width of the coated titanium foil 151 at the desired 23 lateral positions using a punch tool. This has been found to overcome the tendency for the flexible cutting blades to drift away from their desired lateral position. The edges of each of the resulting 24 strips 154 consist of uncoated titanium, and each strip 154 has a respective line of embossed dimples running adjacent one of its two edges.

The strips 154 are then supplied to first and second cylindrical guide rollers 155, 156 each of which is profiled so as to define 24 spaced parallel channels to guide the respective 24 strips 154 of the coated titanium web. Although the spacing between each adjacent pair of channels is only 0.25 mm, it will be appreciated that this nevertheless gives rise to a difference in path length between the outermost strips and the innermost strips. To overcome this problem, a dynamic tensioning device 157 is provided between the first and second guide rollers 155, 156, and this serves the dual functions of: (a) defining a greater path length between the cutting head 153 and the second cylindrical guide roller 156 for those strips 154 which have been cut from the centre of the coated titanium foil than for those strips which have been cut from the edges; and (b) applying substantially the same tension to each of the 24 strips 154.

The dynamic tensioning device 157 can take one of two different forms. In the first arrangement, illustrated in Figure 16(a), the device 157 comprises a linear array of 24 independently controlled dancers 1571 supported below a frame 1572 and which are biased vertically downwards, i.e. in the direction indicted by the arrow 1573. Each dancer 1571 comprises a semicircularly cylindrical actuator 1574 made from PTFE, with the circular part facing downwards and therefore in a position to contact the upper surface of the strips 154 of coated titanium web. Each dancer 1571 further comprises a compression spring 1575, the biasing force of which is adjusted by means of first screw 1576. Furthermore, the stroke length of the dancer, i.e. the maximum vertical distance over which it can move, is adjusted by means of a second screw 1577, which attaches the dancer 1571 to the frame 1572. The height of the frame 1572 is controlled pneumatically, which enables the overall tension applied to the 24 strips 154 of coated titanium web to be adjusted.

In the second arrangement, illustrated in Figure 16(b), each of the 24 dancers 1571, described above with reference to Figure 16(a), has been replaced with a respective tensioning element 1578 comprising a plastics wheel 1579 supported for rotation below an arm 1580 which is itself arranged to pivot about a shaft 1581 which defines a pivot axis 1582. Tension is applied by means of a weight 1583 attached to the upper surface of the arm 1580 at its greatest perpendicular distance from the pivot axis 1582, so as to maximise the applied moment. With this arrangement, since the wheel 1579 is caused to rotate by the movement of one of the strips 154 of coated titanium web, there is minimal friction between the surface of the wheel 1579 and the strip 154, thereby reducing the likelihood of both (a) damage to the strip 154 and (b) wear to the surface of the wheel 1579. Furthermore, since the arm 1580 is free to pivot about a horizontal axis, there is unlikely to be any damage to the dynamic tensioning device 157 caused by the tendency of the moving strip 154 to apply a force to the device 157 along the direction of travel of the strip 154, since such force would merely cause the device 157 to pivot about the axis 1582.

Referring back to Figure 15, the cut coated titanium strips 154 are then transported, with the embossed dimples facing upwards, to a nip defined between two rollers 158, 159. A web 160 of polyethylene terephthalate (PET) from a roll 161 is also supplied to the nip at a position below the cut coated titanium strips 154, which will form the substrate of the primary electrode array. The PET web 160 is pre-formed with four rows of rounded elongate holes 162, 5 mm in width and 20 mm in length, and which are positioned along the width of the web such that they are in register with the 1^{st}, 12^{th}, 13^{th} and 24^{th} strips 154 of the coated titanium foil, so as to expose portions of these strips 154 in the final photovoltaic cell array which will permit a direct electrical connection to be established directly to the exposed titanium foil at each side edge of the finished photovoltaic cell array. The PET web 160 carries a layer of thermal adhesive, so that the strips 154 are pressed against the thermal adhesive by the rollers 158, 159. The rollers 158, 159 are heated so as to activate the thermal adhesive to adhere the strips 154 to the PET web 160. The strips 154 are thereby attached to the underlying PET web 160, with the spacing between adjacent pairs of strips 154 maintained at 0.25 mm which will form an insulating track in the primary electrode array which separates the respective primary electrodes within the array.

In an alternative arrangement, the channelled rollers described above with reference to Figure 15 are replaced with a roller which is formed with a convex surface when viewed along the direction perpendicular to the roller axis. In this arrangement, the surface profile of the roller causes the strips 154 of the coated titanium web to become spaced laterally from each other and also prevents differential tensions arising in the strips 154. The cut strips 154 are then fed to a guide roller which is formed with a series of vertical ridges of about 2 mm height which serve to retain the cut strips 154 in a desired lateral position before being deposited on the underlying PET substrate 160.

The resulting structure of the primary electrode array is illustrated in the lower half of Figure 23(a), to be described in greater detail below, in which each adjacent pair of strips of the coated titanium layer 501 is separated by an insulating gap 503 which is adjacent the lines of embossed dimples 502. As can be seen from Figure 23(b), which illustrates both the primary electrode array and the counter-electrode array assembled to form the photovoltaic cell array, the dimples serve the dual function of defining the separation between the primary electrodes and counter-electrodes and establishing an electrical connection between the electrodes in the assembled photovoltaic cell array.

The process for forming the counter-electrode array is illustrated in Figure 17. A web 201 of polyethylene naphthalate (PEN) which is coated with a conductive layer of, for example, indium tin oxide (ITO) is transported from a supply roll 202 and guided past a row of 24 scoring pins 203 which are made of tungsten and formed with tungsten carbide tips, and which are heated to 150°C. These pins 203 serve to score the surface of the coated PEN layer, so as to remove the ITO coating and thereby expose the underlying PEN substrate, along 24 parallel lines which are spaced apart by a distance of

12.50 mm, which is the width of each cell of the final photovoltaic cell array, such that there is a single line in the same position within each cell. These lines serve as insulating tracks, as indicated by the reference numeral 510 in Figures 23(a) and 23(b), to be described in greater detail below.

Insulating fibres 204 are then deposited on the scored coated PEN substrate 201. The fibres 204 are supplied from a 4x12 array 205 of 48 bobbins 206, on each of which is wound a supply of insulating fibre 204. Each fibre 204 is preferably made from an aramid material, for example a para-aramid synthetic material, marketed under the brand name Kevlar (RTM), and coated with a resinous hot-melt thermoplastic polymer adhesive. The para-aramid core of each of the 48 fibres 204 constitutes a number of separate threads and has a diameter of 50 µm. The resin coating of 24 of the fibres 204 has a thickness of 100 µm, whereas the thickness of the coating of the remaining 24 fibres 204 is 50 µm, so that the resulting outer diameters of the two types of coated fibre 204 are 150 µm and 250 µm respectively.

The scored web 201 is supplied, together with the 48 insulating fibres 204, to a fibre alignment head 207 in which each of the 48 fibres 204 is aligned laterally between a respective pair of guide pins (not shown) at the appropriate lateral position for deposition on the underlying coated PEN substrate. The fibres 204 are deposited in pairs, the separation between the fibres 204 in each pair being substantially less than the spacing between adjacent pairs. Typically, the separation between the fibres 204 in each pair is approximately 1 mm, while the spacing between adjacent pairs is approximately 12.5 mm. The 24 coated fibres 204 having the smaller outer diameter are deposited directly over the 24 scored lines in the PEN substrate, and the 24 coated fibres 204 with the larger outer diameter are formed in parallel lines running closely adjacent the smaller fibres 204.

The aligned fibres 204 are then caused to pass below a row of four hot air knives 208 which direct air heated to between 80 and 150°C on to the fibres 204. The heated fibres 204 are then supplied to a nip defined between two heated rollers 209, 210 which melt the adhesive resin coating and thereby bind the fibres 204 to the coated PEN substrate. The function of the hot air knives 208 is to pre-heat the fibres 204, so that the adhesive resin can more readily be melted by the heated rollers 209, 210.

In an alternative embodiment, air nozzles are used instead of the air knives.

The fibres will form insulating spacers between the primary electrodes and counter-electrode arrays in the final photovoltaic cell array, as can be seen more clearly from Figures 23(a) and 23(b), to be described in greater detail below, in which the smaller diameter fibre 508 is shown in the position aligned with the scored insulating line 510 on the PEN insulating substrate 506, and the larger diameter fibre 509 runs parallel thereto. In the photovoltaic cell array, the two fibres within each pair run along either side of a respective line of the embossed dimples formed on the primary electrodes.

The coated PEN substrate with the attached fibres is then cut to the desired width by means of a selected one or more of a row of ten evenly spaced hydraulically operated cutting heads (not shown). The desired width represents the number of photovoltaic cells required in the final array. The finished counter-electrode array is then wound on to a roll at a rewinder station.

At this stage, the manufacture of the separate primary electrode and counter-electrode arrays is complete. The two electrode arrays are now joined together, and the resulting channels defined between the two electrode arrays are filled with electrolyte, as will now be described with reference to Figure 18.

In order to join together the two electrode arrays, the primary electrode array 301 and the counter-electrode array 302 are transported in the respective directions indicated by arrows 303, 304 to the top of a vertical path defined between three pairs of opposing rollers 305, 306 which are heated by feeding a supply of heated oil into a channel 307 within each of the rollers 305, 306. One of each pair of rollers 305, 306 has a resilient rubberised surface. At the same time a supply of liquid electrolyte is injected from a row of nozzles 308 into the channels defined between the respective pairs of fibres of the counter-electrode which are now between the primary electrode array 301 and the counter-electrode array 302. In one example, 22 nozzles are provided. It would be possible to supply all of the 22 nozzles with the electrolyte using a single peristaltic pump. However, such an arrangement does not permit the flow of electrolyte from each nozzle 308 into its respective channel to be controlled independently. The nozzles 308 are therefore formed from one or more rows of solenoid-controlled dosing valves similar to those used in the dye-coating station described above with reference to Figure 14.

The level of the electrolyte within the 22 channels is sensed using a row of 22 reflective optical sensors 309 located downstream of the dosing valves 308, and the output signal from the optical sensors 309 is used to control the rate of flow of the electrolyte into the channels. Control of the flow of the electrolyte into each channel is effected by independently controlling the amount of electrolyte released from each of the 22 dosing valves. However, the overall rate at which the channels are filled can also be controlled by adjusting the rate at which the two electrode arrays 301, 302 are transported between the three pairs of rollers 305, 306.

The surfaces of each pair of rollers 305, 306 are formed with opposing ridges which are positioned relative to the electrode webs 301, 302 such that the pairs of coated fibres are compressed between the opposing ridges thereby to cause the resin adhesive coating on the fibres to conform to the shape of the primary electrode structure, as can be seen more clearly from Figures 23(a) and 23(b).

In an alternative arrangement, the 48 coated insulating fibres are deposited on the primary electrode array, instead of the counter-electrode array. In this arrangement, the primary electrode array is supplied, together with the 48 fibres, to a nip defined between two heated rollers which melt the adhesive resin coating and bind the fibres to the titanium web at their respective positions along pairs of parallel lines running each side of the lines of embossed dimples. As with the arrangement described above in which the fibres are deposited on the counter-electrode array, a linear array of hot air knives is arranged to direct hot air on to the fibres immediately upstream of the nip and serves to pre-heat the fibres, so that the adhesive resin can more readily be melted by the heated rollers. The resulting structure of the primary electrode array 171 is illustrated in Figure 19(a), in which it can be seen that the coating of the insulating fibres 172, 173 has partly melted, so that the thinner of the two fibres 172 in each pair of fibres is firmly adhered to the underlying titanium web strip 174 and the thicker of the two fibres 173 runs along the insulating track 175 formed in the primary electrode 171 between the ends of the titanium strips 174, and is firmly adhered to both the end regions of the underlying adjacent titanium strips 174 and also to the PET substrate 176. Each adjacent pair of fibres 172, 173 is deposited in lines running either side of a respective line of embossed dimples 177.

With this arrangement, the electrolyte is deposited into the channels formed between alternate pairs of coated insulating fibres 172, 173 when the primary electrode is oriented horizontally, in a process illustrated in Figure 20. In this arrangement, the primary electrode array 171 is transported from a supply roll 178 to an electrolyte filling station 179 at which the electrolyte is deposited on to the primary electrode array 171 when in a horizontal orientation. The electrolyte is supplied from 22 solenoid-controlled dosing valves arranged in one or more linear arrays, similar to those described above with reference to Figure 14. Since the primary electrode array 171 is horizontal, the electrolyte will, under gravity, fill the channels between alternate pairs of coated fibres. During the filling process, the level of the electrolyte within the 22 channels is sensed using a row of 22 optical colorimetric sensors 180, located downstream of the electrolyte filling station 179 in the direction of transport of the primary electrode array 171. The sensors 180 are condition-responsive in that they are arranged to detect a colour change which occurs as soon as the dye-coated titanium dioxide layers within the primary electrode array are covered with the electrolyte. The control of the rate of electrolyte deposition is achieved by adjusting either or both of (a) the rate of flow of electrolyte and (b) the speed at which the primary electrode array is transported through the electrolyte filling station 179. The structure of the primary electrode array 171 immediately after filling with the electrolyte is illustrated in Figure 19(b), where it can be seen that the electrolyte 181 fills the channels defined between alternative pairs of the insulating fibres 172, 173.

The counter-electrode array 182 is formed from a web of polyethylene naphthalate (PEN) which is coated with a conductive layer of, for example, indium tin oxide (ITO), and this is transported from a supply roll 183 past a linear array 184 of 24 scoring pins identical to those in the arrangement described above, to create 24 parallel insulating tracks. The scored counter-electrode array 182 is then transported, together with the electrolyte-filled primary electrode array 171, to a nip defined between a first pair of heated rollers 1831, 1841, which causes the two electrode arrays 171, 182 to become sealed together. Alignment between the primary electrode array 171 and the counter-electrode array 182 is achieved using mechanical edge guides of the type described above. Although, in this case, the primary electrode array 171 is already formed with the coated fibres 172, 173, alignment between the two electrode arrays 171, 182 is still necessary in order to align the 24 insulating tracks 185 formed on the counter-electrode array 182 with the corresponding 24 thinner fibres 172 on the primary electrode array 171. This is achieved in this arrangement, by mounting the array of scoring pins 179 to a frame (not shown) to which the electrolyte filling station 179 is also attached, such that the relative alignment of the primary electrode array 171 and the counter-electrode array 182 is less critical. The sealed electrode arrays 171, 182 are then transported between a second pair of rollers 186, 187 which compresses the two electrode arrays 171, 182 together by an amount which gives rise to the desired spacing between the two electrode arrays 171, 182. Preferably, the two electrode arrays are positioned as close to one another as possible, but not so close as to cause short-circuiting between the electrode arrays 171, 182 across the electrolyte. The second pair of rollers 186, 187 serve also to force any excess electrolyte along the respective channels in the upstream direction of movement of the electrode arrays 171, 182. The final structure of the electrode assembly is illustrated in Figure 19(c), where it can be seen that the conductive ITO layer 188 of the counter-electrode array 182 is in direct electrical contact with one of the embossed dimples 177 of the primary electrode array 171, and the coated insulating fibres 172, 173 serve to retain the electrolyte within the pre-defined channels and therefore isolated from the region of the embossed dimples 177.

In a yet further arrangement, the thicker 24 of the 48 fibres are deposited directly on to the insulating tracks formed in the primary electrode array, and the thinner 24 of the 48 fibres are deposited directly on to the insulating tracks formed in the counter-electrode array. The method of deposition of the respective fibres is as described above. With this arrangement, the ease of alignment of all of the fibres is enhanced.

In a further embodiment, instead of using Kevlar fibres coated with hot-melt adhesive as insulating spacers, only the hot-melt adhesive is used, in which case, a supply of the hot-melt adhesive is pre-heated and then extruded directly on to the surface of either or both (a) the primary electrode array in parallel lines running adjacent the lines of embossed dimples or (b) the counter-electrode array, again in parallel lines at the corresponding positions. In this arrangement, only the embossed dimples serve to define the spacing between the primary electrode and counter-electrode arrays.

In a modification of this further embodiment, the hot-melt adhesive is supplied with 50 μm-diameter spherical beads of silicon dioxide glass which, when deposited on either the primary electrode array or the counter-electrode array, serve, in conjunction with the lines of embossed dimples, to define the spacing between the two electrode arrays in the assembled photovoltaic cell array.

In each of the above arrangements for forming the assembly of the two electrode arrays, the required length of the electrode assembly is then cut manually using a guillotine.

In order to prevent the electrolyte from escaping from the ends of the channels between the two electrode webs, both the leading and trailing edges of the cut length are sealed by placing the assembly on an edge-sealing table and applying a hot-melt adhesive, which is heated to 180°C, to each of the edges in turn.

After sealing the edges, the resulting sealed assembly is then laminated using the laminating station illustrated in Figure 21. The sealed assembly 401 is supplied to a nip defined between two rollers 402, 403, the surface of each of which is resilient. Two rolls of protective laminate 404 are provided, one above and one below the rollers 402, 403. The laminate 404 is supplied on reels with an outward-facing adhesive layer which is covered with a removable protective layer 405. The two layers of the laminate 404 are fed to the nip between the two rollers 402, 403 via stations which remove the protective layer 405. Each of the laminate layers 404 then travels past a respective radiant heater 406 with the adhesive surface facing the heater 406 so as to activate the adhesive. The sealed assembly is fed manually into the nip between the two rollers 402, 403, such that the laminate layers 404 are adhered to the upper and lower surfaces thereof. Once the resulting laminated assembly passes through the laminating station, the trailing edges of the laminate layer 404 are removed.

The resilience of the two rollers 402, 403 effectively eliminates air bubbles from forming below the laminate layers 404.

To set up the laminating station, the layers of laminate 404 are first caused to pass into the nip between the two rollers 402, 403 without removing the protector layer covering the adhesive. This is to permit alignment of the laminate layers, which would be hindered by the presence of exposed adhesive layers, and this also prevents adhesive from coming into contact with the rollers 402, 403.

The laminate layers act as a moisture barrier and protect the photovoltaic cell array from harmful ultraviolet radiation.

The final stage in the production of the flexible photovoltaic cell array is the connection of a respective electrical terminal to each side edge of the array, and this is achieved by removing selected areas of the laminate overlying the elongate slits in the PET substrate so as to expose the underlying titanium foil and attaching a suitable electrical connector to the exposed titanium surface. As described above, one or both of the two photovoltaic cells at the side edges are not active and serve merely as dummy cells to enable external electrical connection to be established.

In an alternative arrangement, illustrated in Figures 22(a) and (b), a crimped connection is achieved by forming a respective aperture 5011 in each of the first and last cells 5021 within the array and crimping an eyelet 5031 into both apertures 5011. External connections are effected, either by directly soldering a respective terminal 5041 to both of the crimped eyelets 5031 or by crimpling together each eyelet 5031 with its respective terminal 5041 together.

Figures 22(a) and (b) show a crimped connection formed in electrolyte-containing cells 5021. However, in a preferred embodiment (not shown), the dummy cells 5021 do not contain electrolyte or a dye coating. Furthermore, the line of dimples in the primary electrode array closest to the edge of the assembled array (shown on the right side of the array in Figures 22(a) and (b)) can be omitted, and only one coated fibre or, most preferably, a single line of hot-melt adhesive can be provided in this location in place of the two coated fibres shown in Figures 22(a) and (b).

Since there is preferably no electrolyte in the dummy cell 5021, there is no risk either of any undesirable leakage of the electrolyte or any corrosive attack of the electrical connection by the electrolyte. In this way, an external electrical connection can effectively be made to the internal strip of titanium web forming part of the dummy cell 5021. Furthermore, with this arrangement, it is not necessary for the PET substrate of the primary electrode array to be formed with elongate holes.

Figure 23(a) is an exploded cross-sectional view of a portion of two adjacent cells of a photovoltaic cell array before assembly, in an embodiment in which the coated insulating fibres are deposited on the counter-electrode array. The primary electrodes of the cells comprise strips of titanium web 501 each having an embossed line of dimples 502 along one edge thereof, the titanium strips being separated by an insulating gap 503. Each strip of the titanium web 501 is partially coated with a layer 504 of titanium dioxide and ruthenium dyestuff. The titanium strips 501 are formed on an underlying continuous PET substrate 505.

The counter-electrode array is formed from a continuous insulating substrate 506 made from PEN which is coated with a conductive layer 507 of ITO and having relatively thinly coated fibres 508 and relatively thickly coated fibres 509, the thinner fibres 508 being aligned with insulating tracks 510 formed in the conductive layer 507 of ITO.

Figure 23(b) is a cross-sectional view of a portion of two adjacent cells of the photovoltaic array after assembly and lamination, in which the outer surfaces of the two insulating substrates 505, 506 are each coated with a respective laminate layer 511.

Figure 24 illustrates the dimensions of the components of the finished photovoltaic cell array in accordance with a preferred embodiment of the present invention. The representation in the drawing is not to scale, and the vertical dimension is exaggerated for the sake of clarity.

Figure 25 illustrates the overall appearance of a finished array of 12 photovoltaic cells. In this case, external electrical connections 701 are made to the titanium web through two of the elongate apertures 702 formed along the side edges of the PET substrate of the primary electrode array. It will be appreciated that the finished array may comprise a different number of photovoltaic cells. In a preferred embodiment, for example, the finished array comprises 11 photovoltaic cells.

Certain rollers require alignment adjustment. Figures 26(a) and 26(b) illustrate how this is achieved. A fixed mounting block 601 is rigidly attached to a guide track 602 by means of mounting bolts 603. An adjustable mounting block 604 is slidably attached to the fixed mounting block 601 by means of upper and lower threaded bolts 605 which are received within respective clearance bores 606 in the fixed block 601 and with respective threaded bores 607 in the adjustable block 604. By rotating the threaded bolts 605 clockwise, the adjustable block 604 is caused to move toward the fixed block 601. A third threaded bolt 608 is received within a threaded bore 609 in the fixed mounting block 601 between the upper and lower threaded bolts 605 and extends from the fixed mounting block 601 toward the adjustable block 604. The third threaded bolt 608 has a hexagonal head 610 which acts as an end-stop by abutting a surface of the adjustable block 604. The third threaded bolt 608 is rotated by an amount such that the hexagonal head 610 defines a desired position of the adjustable block 604, and the upper and lower bolts 605 are tightened to draw the adjustable block 640 toward the fixed block 601 until it abuts the hexagonal head 610, at which point the adjustable block 604 is at the desired position. The adjustable block 604 can then be rigidly attached to the guide track 602 using fixing bolts 611.

When used to adjust the position of the axis of a roller 612, respective pairs of fixed and adjustable mounting blocks 601, 604 are used, and the ends 613 of the roller 612 are mounted within respective recesses in the two adjustable blocks 604, as shown in Figure 16(b). It will be appreciated that, with such an arrangement, it is possible to align the axis of the roller 612 precisely in relation to fixed guide tracks 602.

It will be appreciated that the flexible arrays of photovoltaic cells manufactured in accordance with the above processes have wide-ranging applications, such as the following:

(a) generating electricity by floating the array on the surface of water and subjecting the array to a source of light;

(b) desalinating a body of seawater by floating the array on the water, subjecting the array to a source of light, such as sunlight or even moonlight, and using the resulting electricity generated by the array to power the desalination process using reverse osmosis;

(c) reducing evaporation from the surface of a body of water by floating the array of photovoltaic cells on the surface; and

(d) heating a swimming pool by floating the array of photovoltaic cells on the surface thereof and connecting the output of the array to an electrically powered heater.

CLAIMS:

1. Apparatus for performing a processing operation on a web, the apparatus comprising:

a processing apparatus having two substantially identical processing regions; and

aligning means enabling the web to be aligned selectively with either the first or the second processing region;

the arrangement being such that, in the event of a defect occurring in the processing apparatus in one of the processing regions, the web can be realigned with the other processing region.

2. Apparatus as claimed in claim 1, wherein the two substantially identical processing regions do not overlap.

3. Apparatus as claimed in claim 2, wherein the two substantially identical processing regions are mutually adjacent.

4. Apparatus as claimed in any preceding claim, wherein the processing operation is a physical operation which is performed by bringing the processing apparatus into contact with the web.

5. Apparatus as claimed in any preceding claim, wherein the processing apparatus comprises one or more rollers.

6. Apparatus as claimed in any preceding claim, wherein the processing operation comprises embossing the web.

7. Apparatus as claimed in any preceding claim, wherein the processing operation comprises forming one or more indentations in the web.

8. Apparatus as claimed in claim 7, wherein the processing operation comprises forming a plurality of indentations in the web in a substantially regular array.

9. Apparatus as claimed in claim 8, wherein the substantially regular array of indentations comprises a plurality of lines of indentations, the separation of indentations within each line being substantially less than the spacing between adjacent lines.

10. Apparatus as claimed in claim 9, wherein the separation of indentations within each line is substantially 1 mm.

11. Apparatus as claimed in claim 9 or claim 10, wherein the spacing between adjacent lines is within the range 10 mm to 15 mm.

12. Apparatus as claimed in claim 11, wherein the spacing is substantially 12.25 mm.

13. Apparatus as claimed in any one of claims 7 to 12, wherein the or each indentation extends over a substantially circular region having a diameter within the range 0.1 mm to 1.0 mm.

14. Apparatus as claimed in claim 13, wherein the diameter is approximately 0.5 mm.

15. Apparatus as claimed in claim 14, wherein the diameter is substantially 0.508 mm.

16. Apparatus as claimed in any one of claims 7 to 15, wherein the or each indentation extends to a height above the surface of the web within the range 100 to 150 μm.

17. Apparatus as claimed in claim 16, wherein the height is within the range 122 to 132 μm.

18. Apparatus as claimed in any preceding claim, wherein each of the two identical processing regions of the processing apparatus comprises two respective complementary surfaces between which, in use, the web is caused to pass.

19. Apparatus as claimed in claim 18, wherein the complementary surfaces are arranged, in use, to be spaced from each other by a distance of between 0.01 mm and 0.10 mm.

20. Apparatus as claimed in claim 19, wherein the distance is within the range 0.03 mm to 0.07 mm.

21. Apparatus as claimed in claim 20, wherein the distance is substantially 0.05 mm.

22. Apparatus as claimed in any preceding claim, wherein the processing operation is arranged to take place by moving the web relative to the processing apparatus along a processing direction.

23. Apparatus as claimed in claim 22, wherein the aligning means is arranged to move the web relative to the processing apparatus along an alignment direction transverse to the processing direction.

24. Apparatus as claimed in claim 23, wherein the alignment direction is substantially perpendicular to the processing direction.

25. Apparatus as claimed in any one of claims 1 to 4, wherein the processing apparatus comprises first and second complementary rollers between which, in use, the web is caused to pass so as to be in contact with the surface of both of the rollers, the first roller being formed with an array of projections, and the second roller being formed with a corresponding array of recesses, the arrangement being such that an array of indentations is caused to be formed on the web.

26. Apparatus for manufacturing an electrode for a photovoltaic cell comprising apparatus as claimed in any preceding claim.

27. Apparatus for manufacturing a photovoltaic cell comprising apparatus as claimed in any preceding claim.

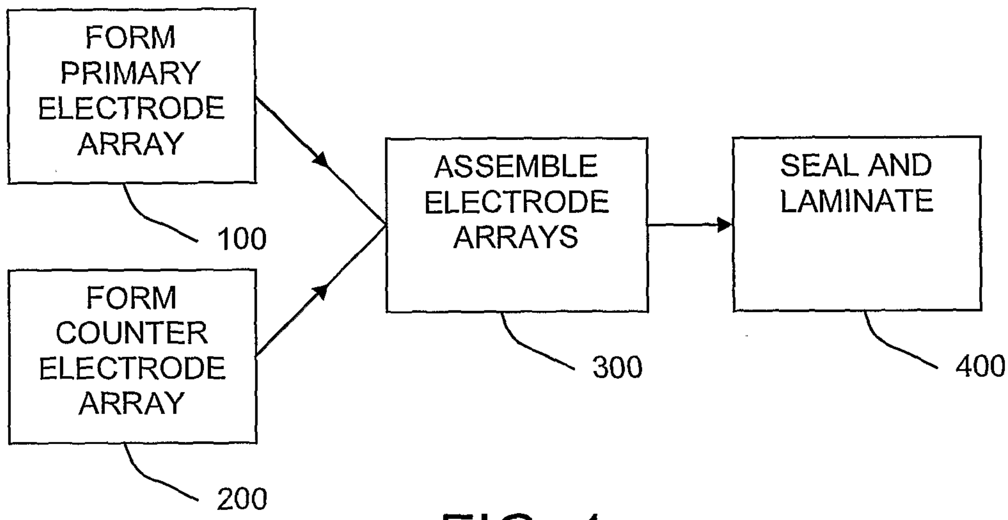
FORM PRIMARY ELECTRODE ARRAY
100
FORM COUNTER ELECTRODE ARRAY
200
ASSEMBLE ELECTRODE ARRAYS
300
SEAL AND LAMINATE
400

FIG. 1

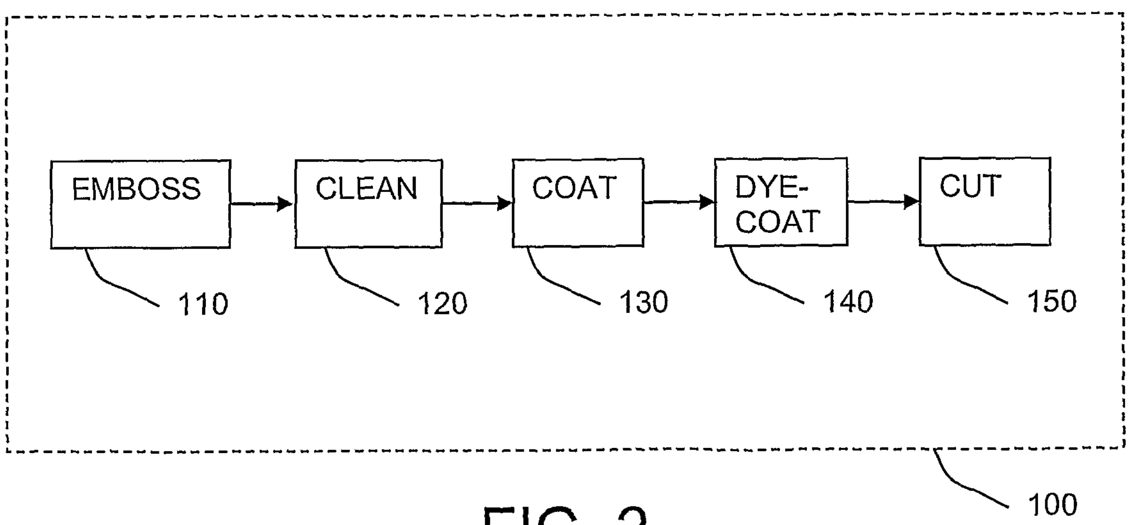
EMBOSS
110
CLEAN
120
COAT
130
DYE-COAT
140
CUT
150
100

FIG. 2

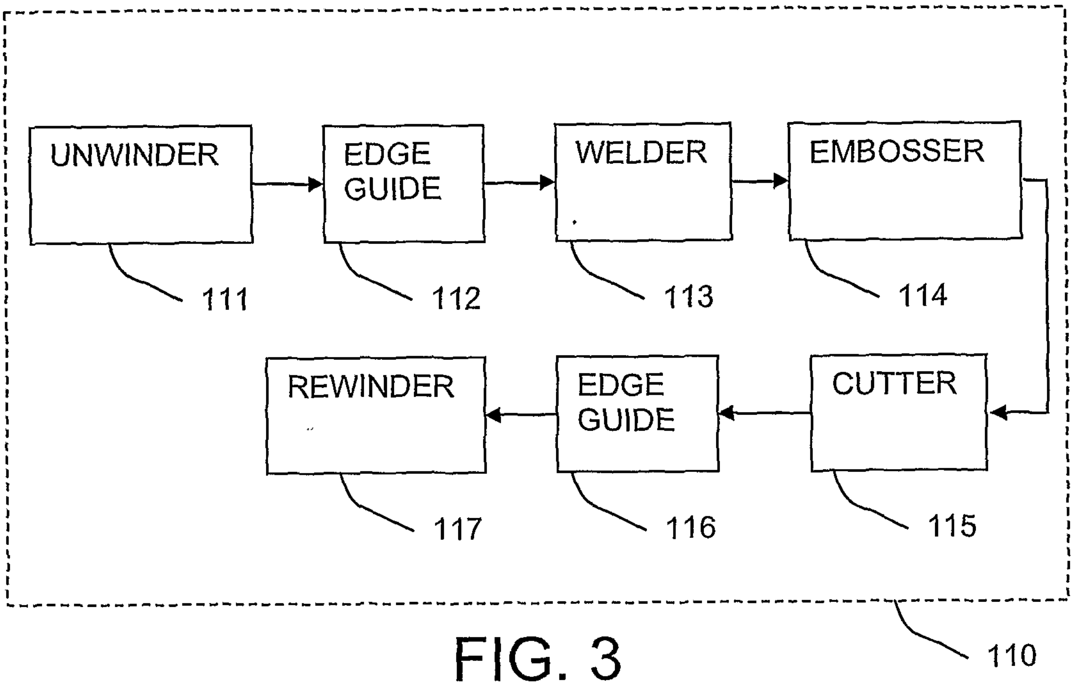
UNWINDER
EDGE GUIDE
WELDER
EMBOSSER
CUTTER
EDGE GUIDE
REWINDER
111
112
113
114
115
116
117
110

FIG. 3

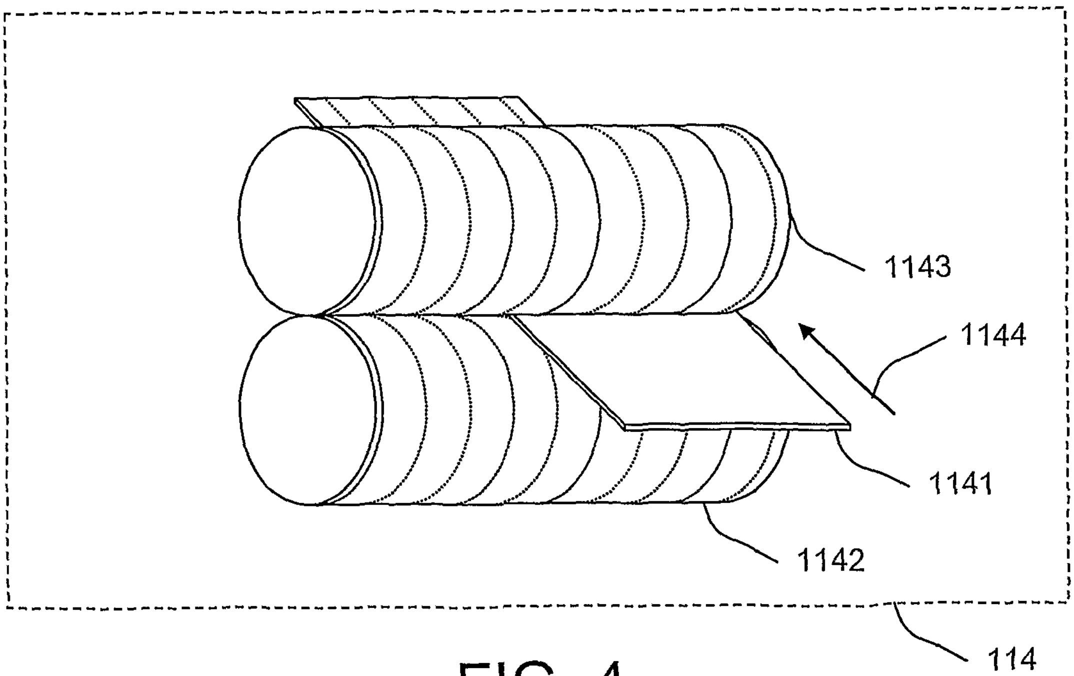
1143
1144
1141
1142
114

FIG. 4

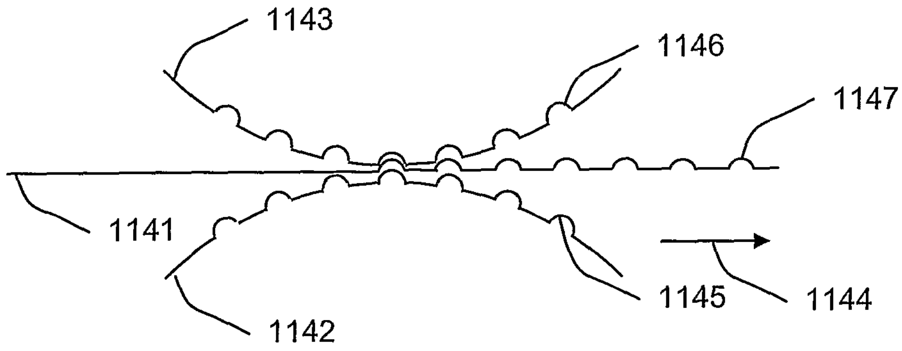
1143
1146
1147
1141
1145
1144
1142

FIG. 5

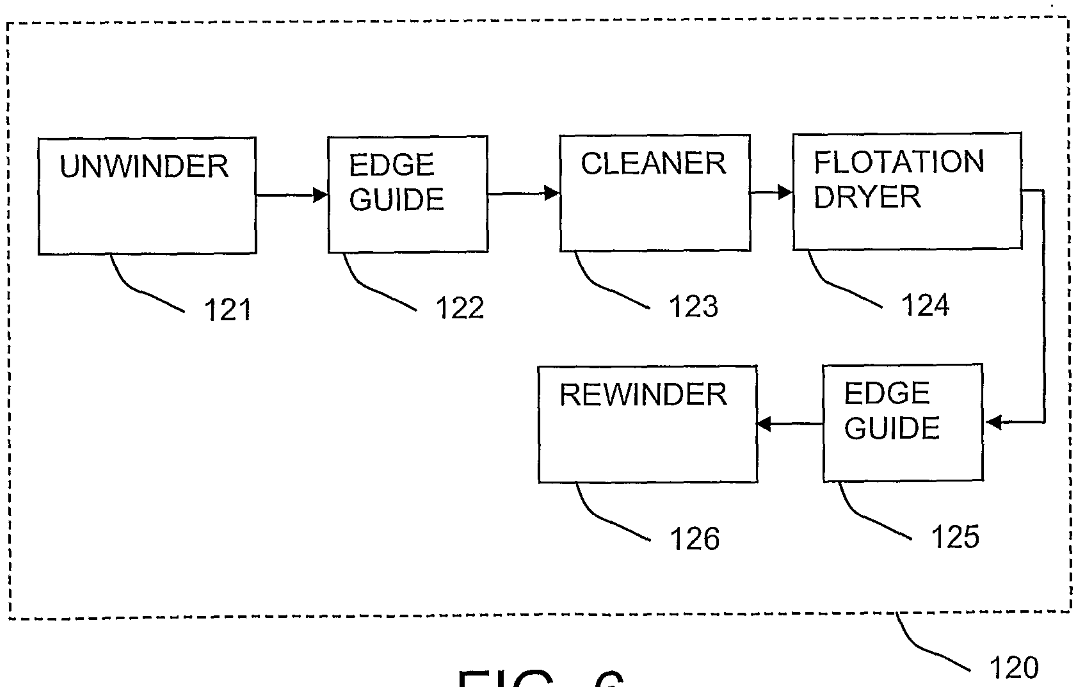
UNWINDER
EDGE GUIDE
CLEANER
FLOTATION DRYER
121
122
123
124
REWINDER
EDGE GUIDE
126
125
120

FIG. 6

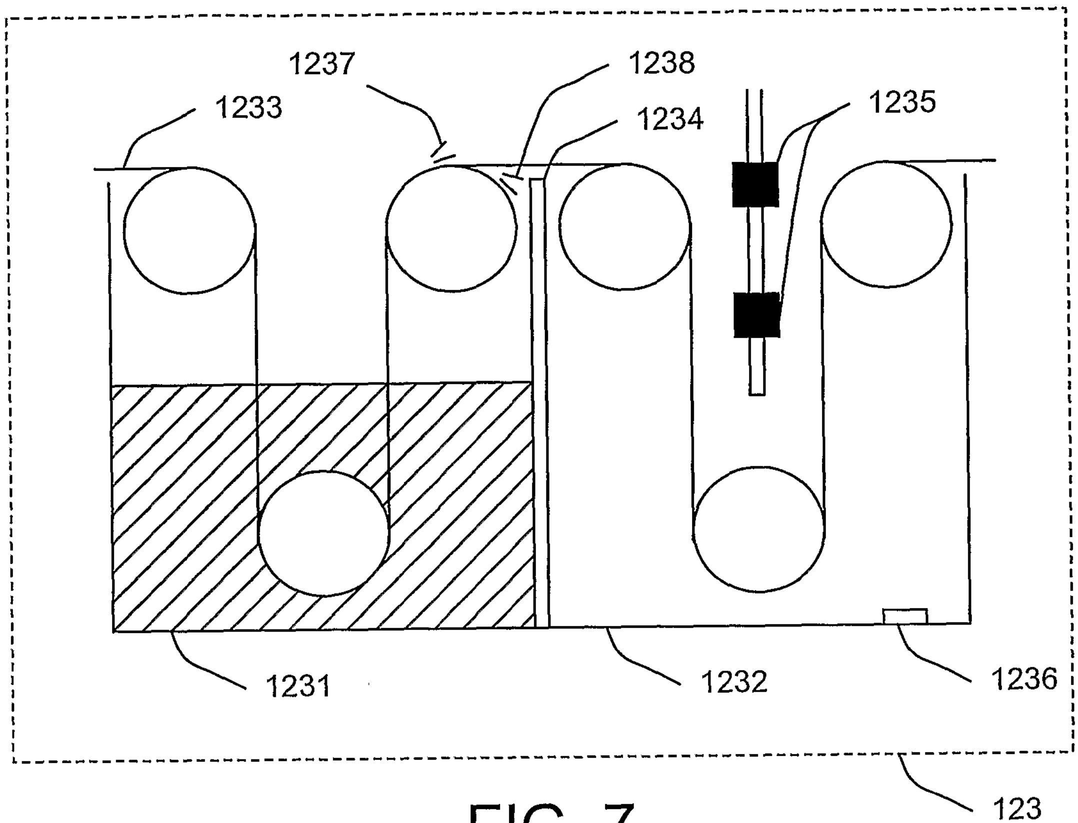
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FIG. 7

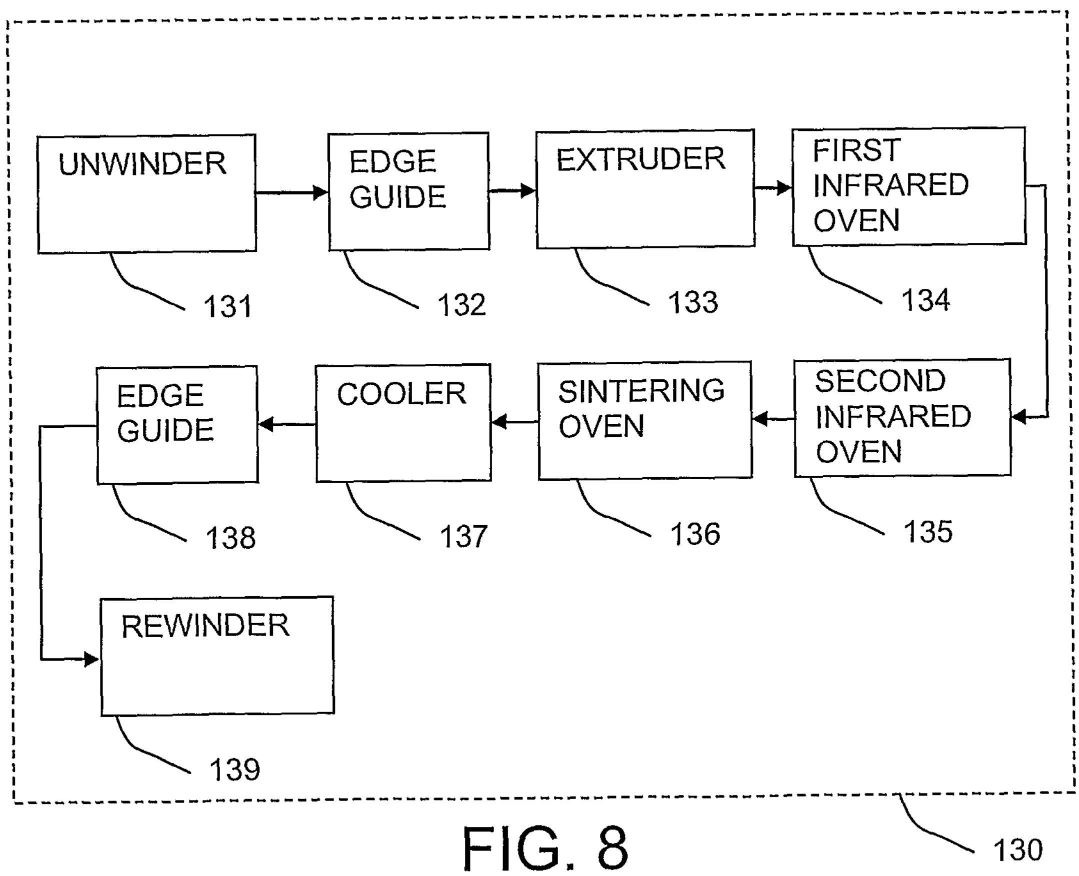
UNWINDER
EDGE GUIDE
EXTRUDER
FIRST INFRARED OVEN
131
132
133
134
EDGE GUIDE
COOLER
SINTERING OVEN
SECOND INFRARED OVEN
138
137
136
135
REWINDER
139
130

FIG. 8

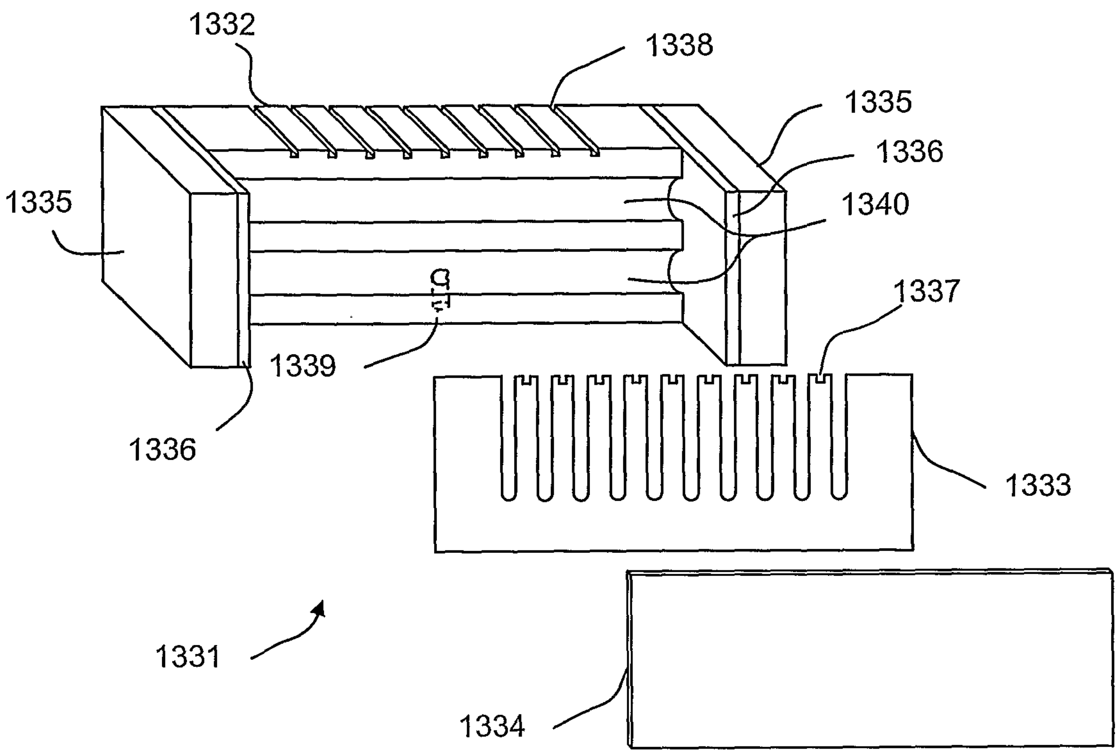
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FIG. 9(a)

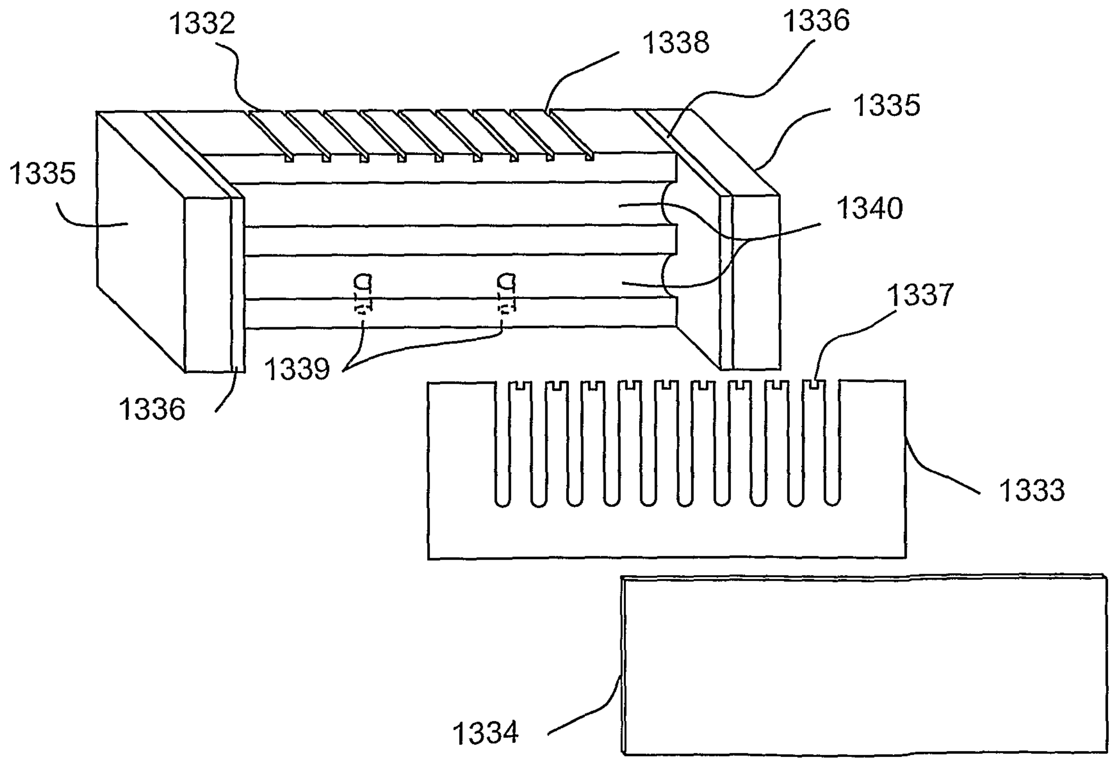
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FIG. 9(b)

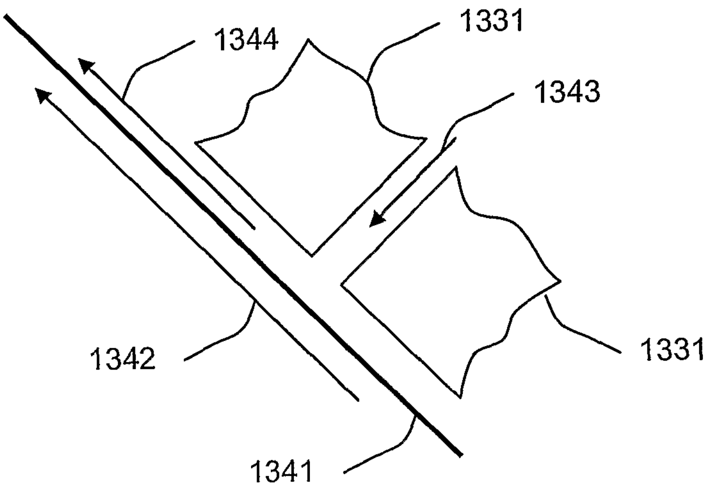

FIG. 10

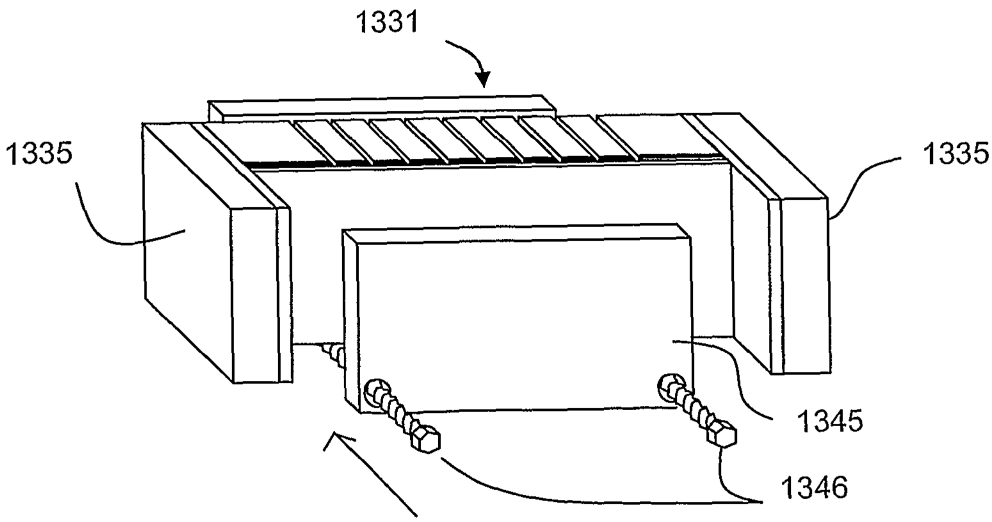

FIG. 11

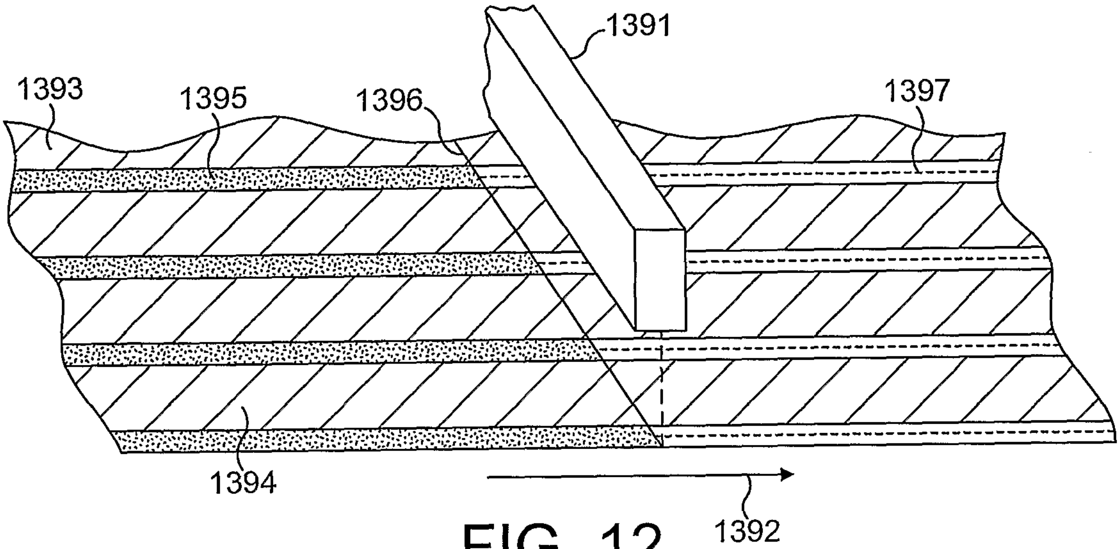
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FIG. 12

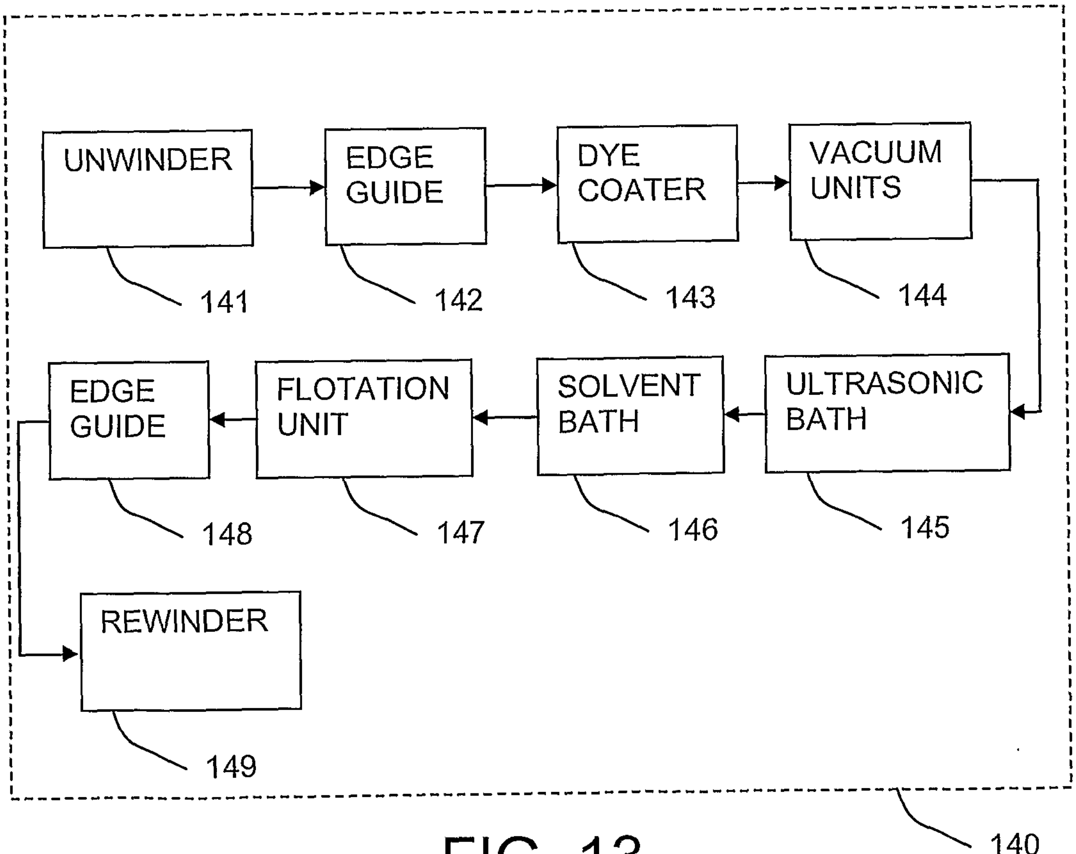

UNWINDER
141
EDGE GUIDE
142
DYE COATER
143
VACUUM UNITS
144
ULTRASONIC BATH
145
SOLVENT BATH
146
FLOTATION UNIT
147
EDGE GUIDE
148
REWINDER
149
140

FIG. 13

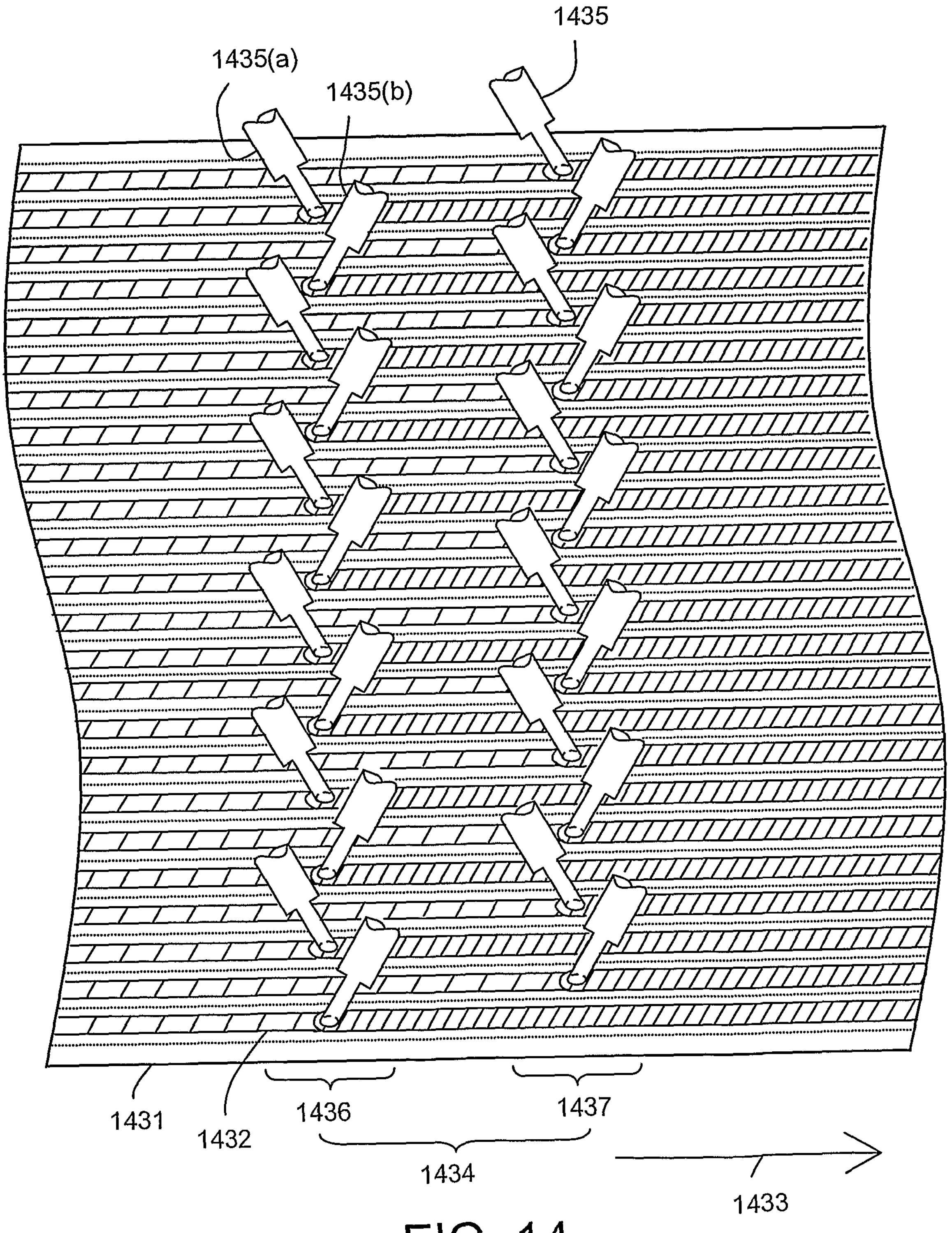


FIG. 14

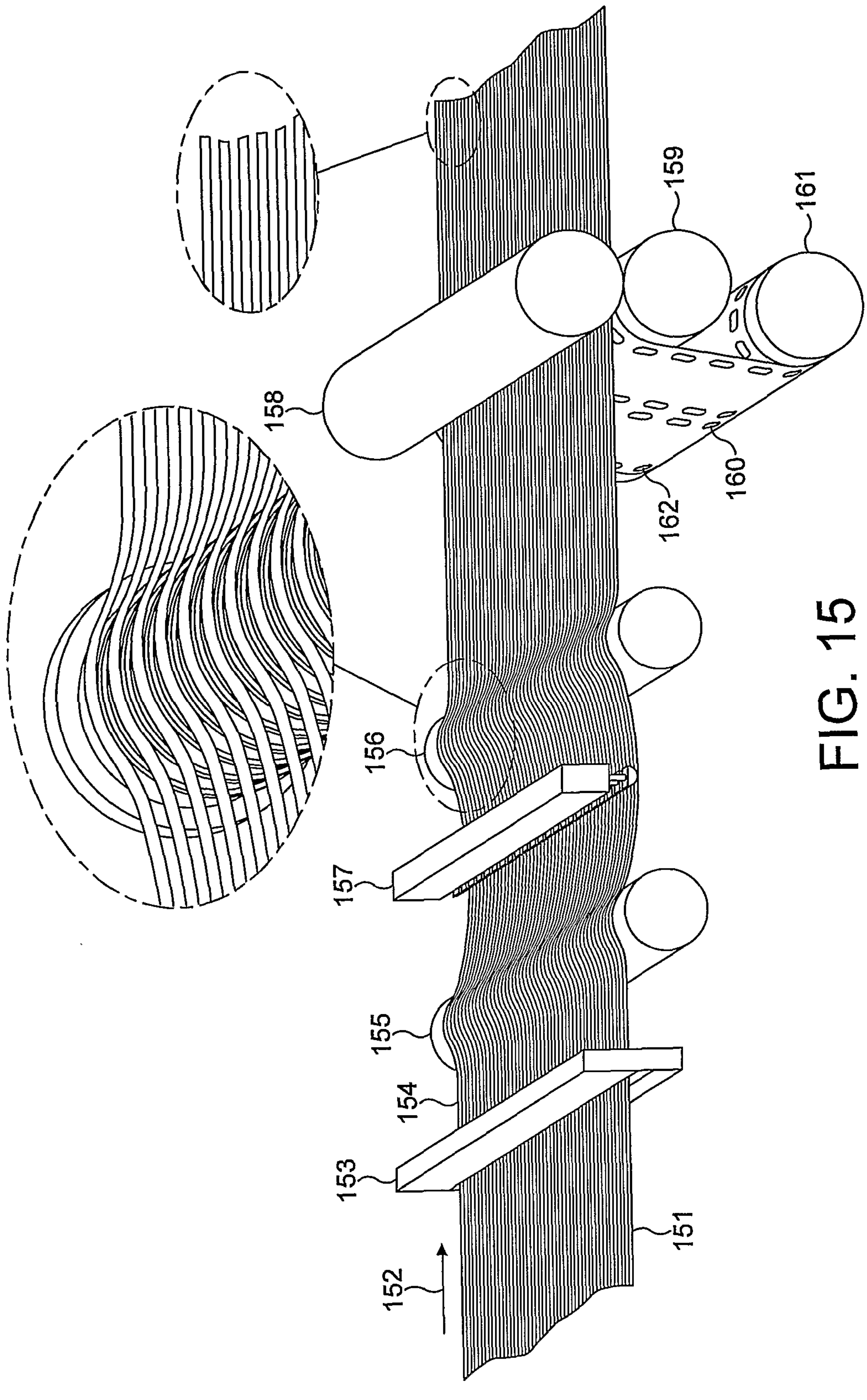


FIG. 15

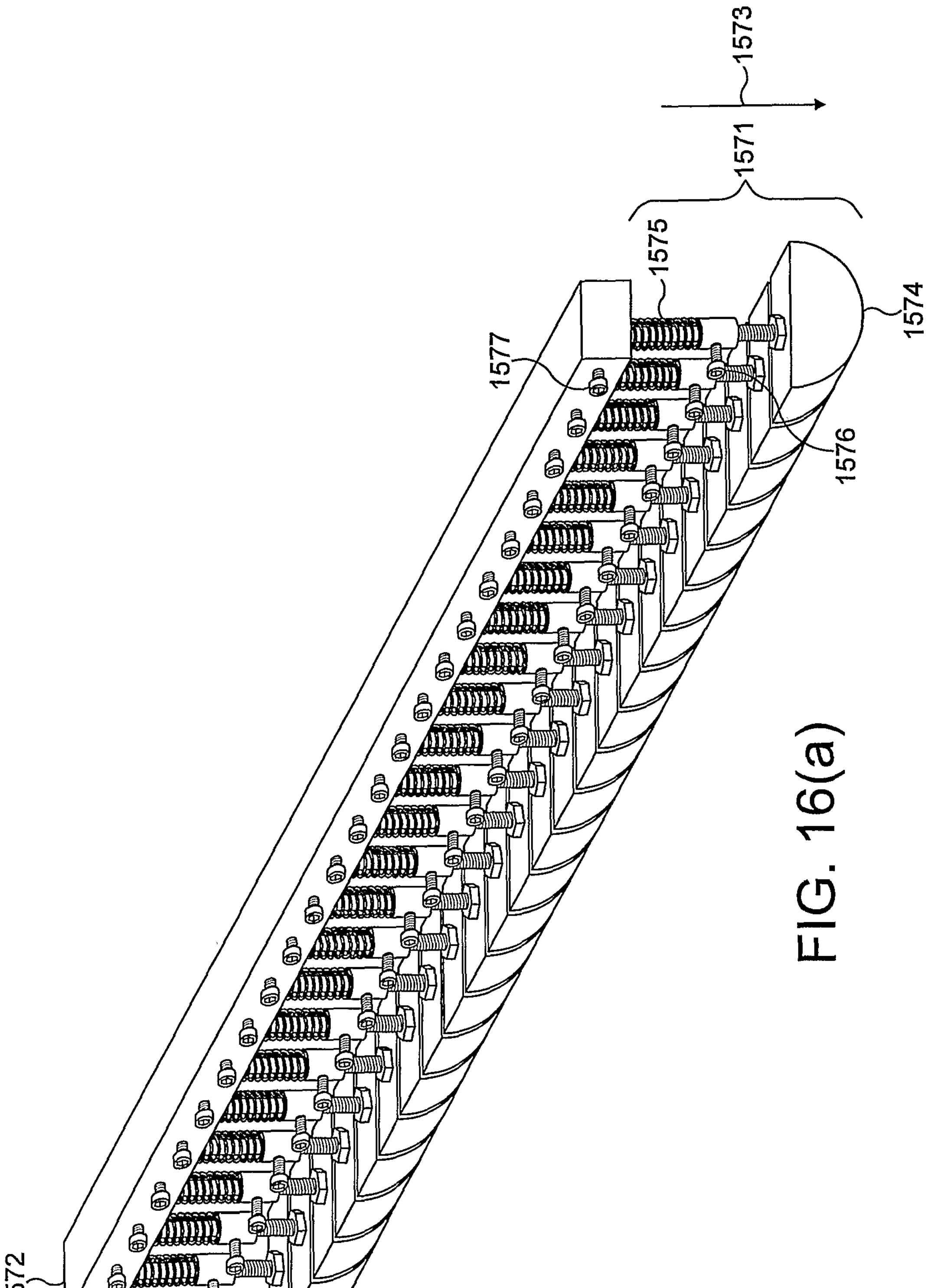


FIG. 16(a)

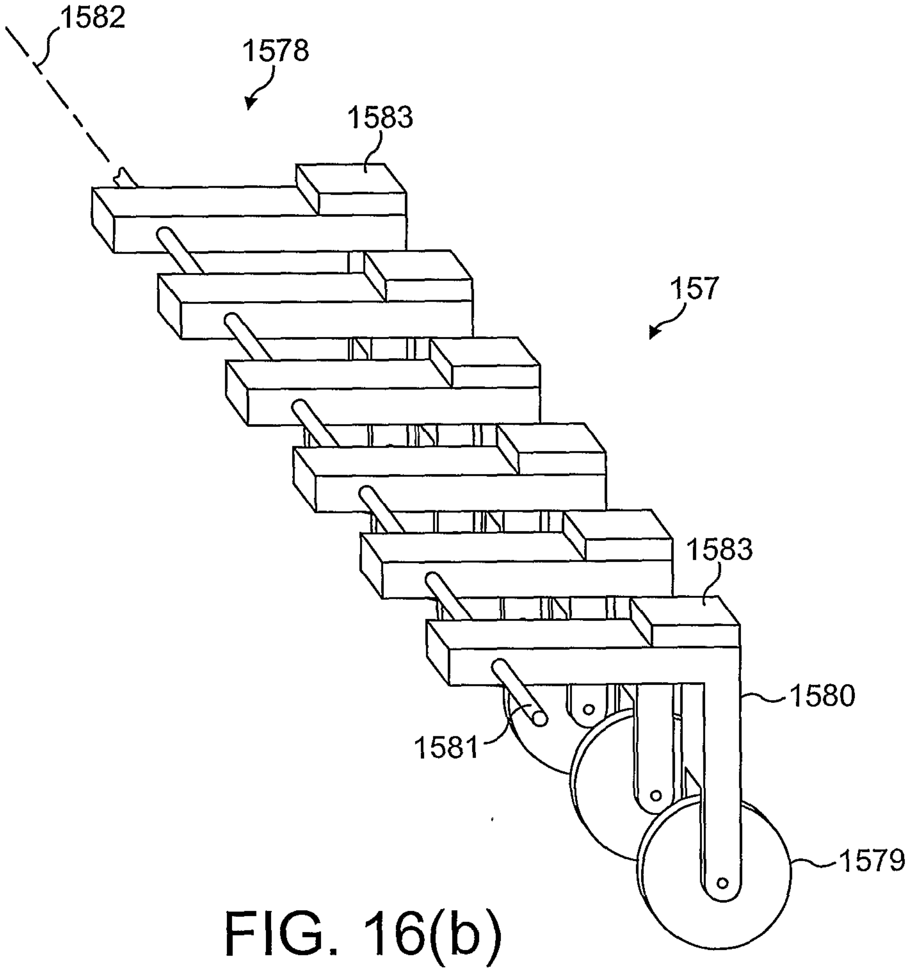


FIG. 16(b)

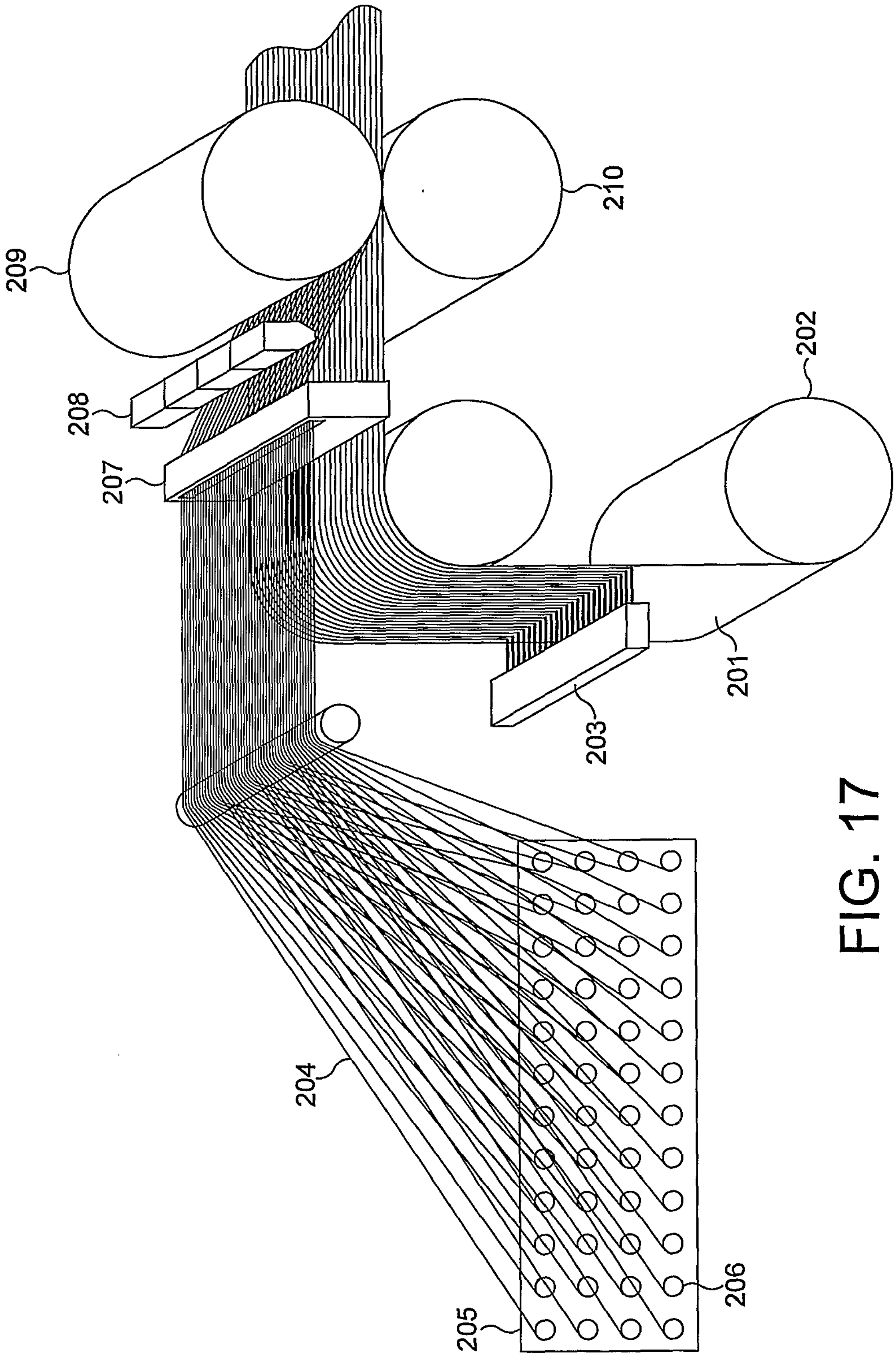


FIG. 17

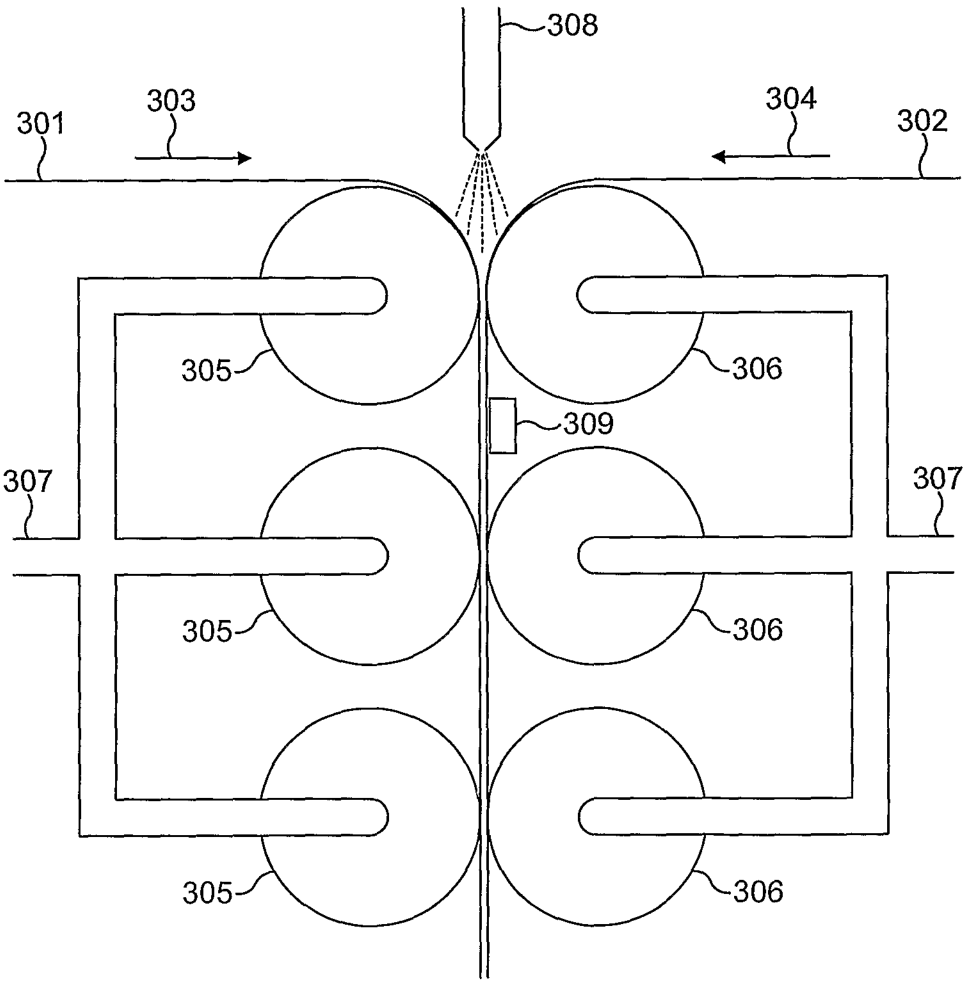


FIG. 18

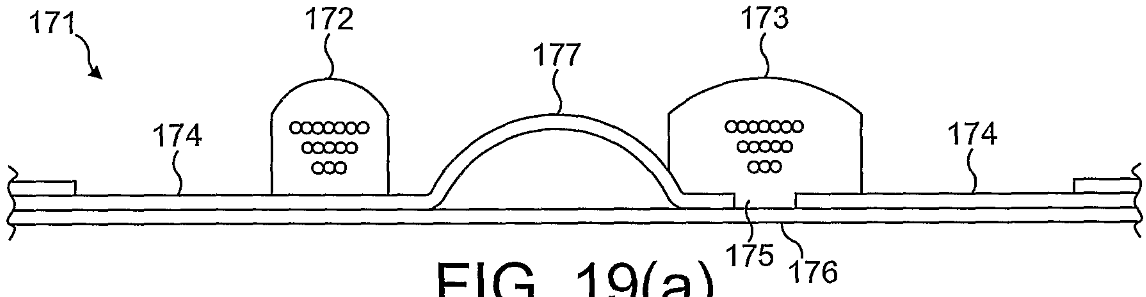


FIG. 19(a)

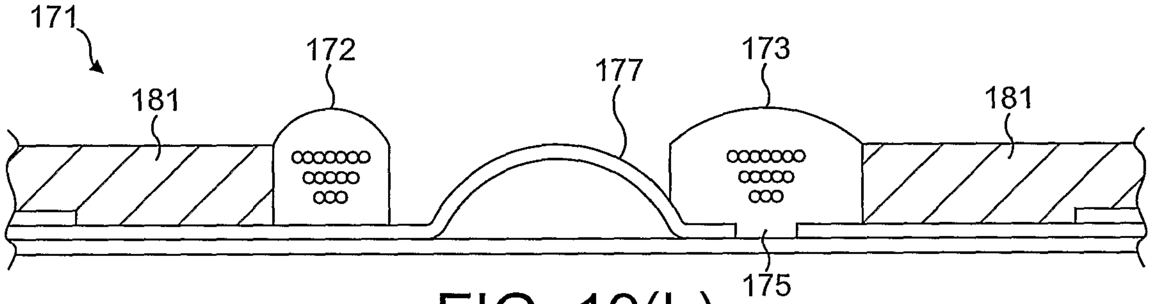


FIG. 19(b)

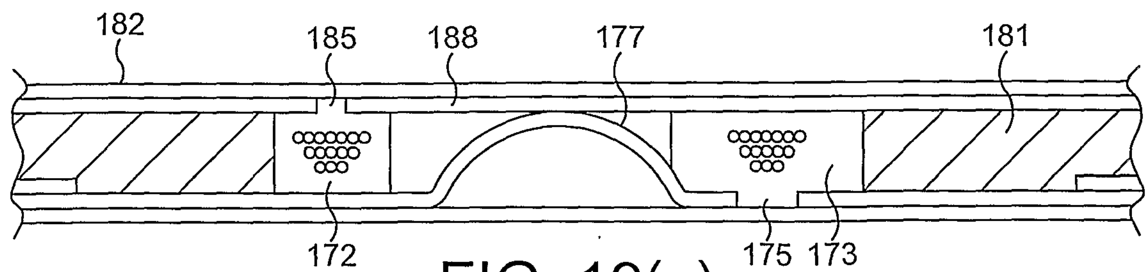


FIG. 19(c)

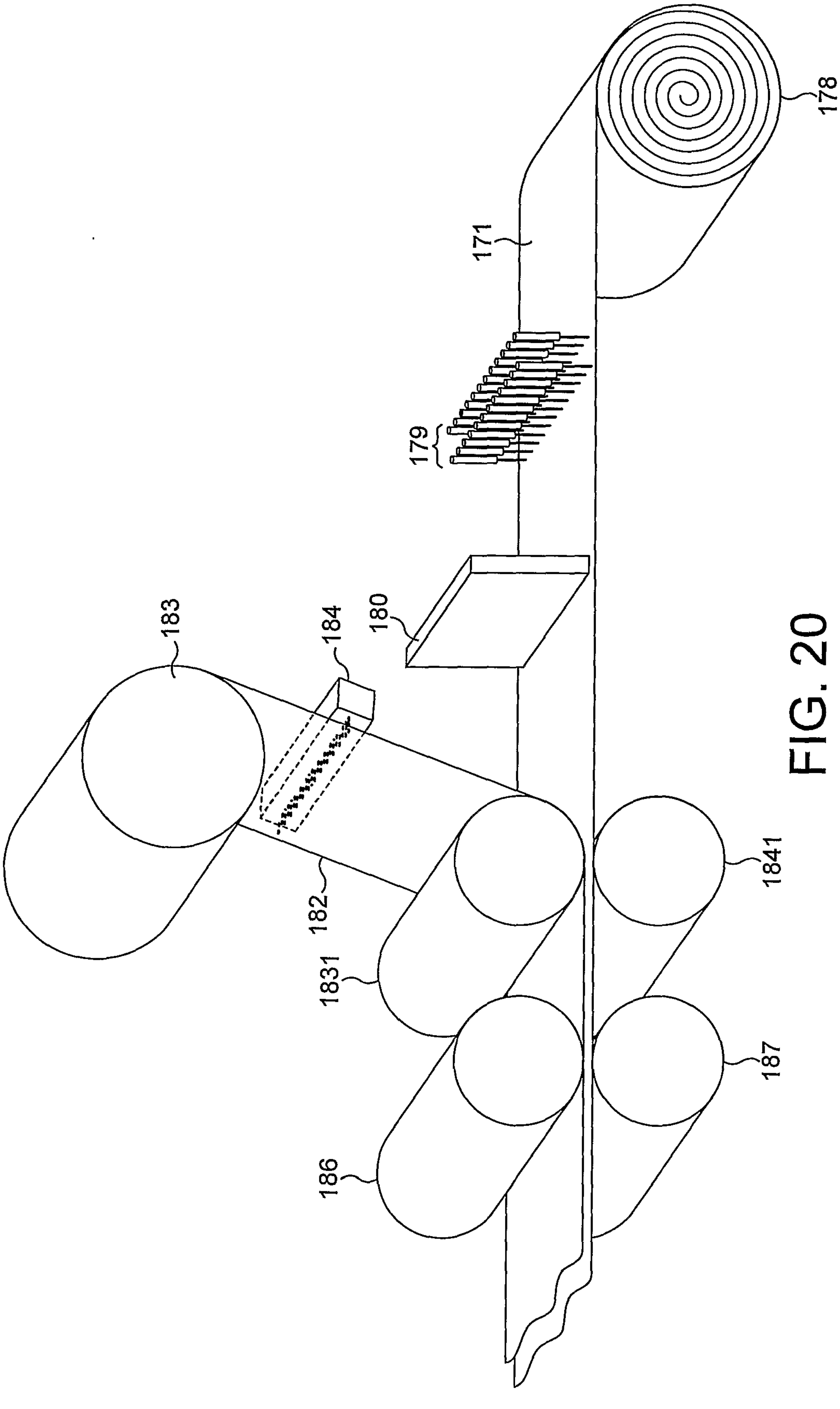


FIG. 20

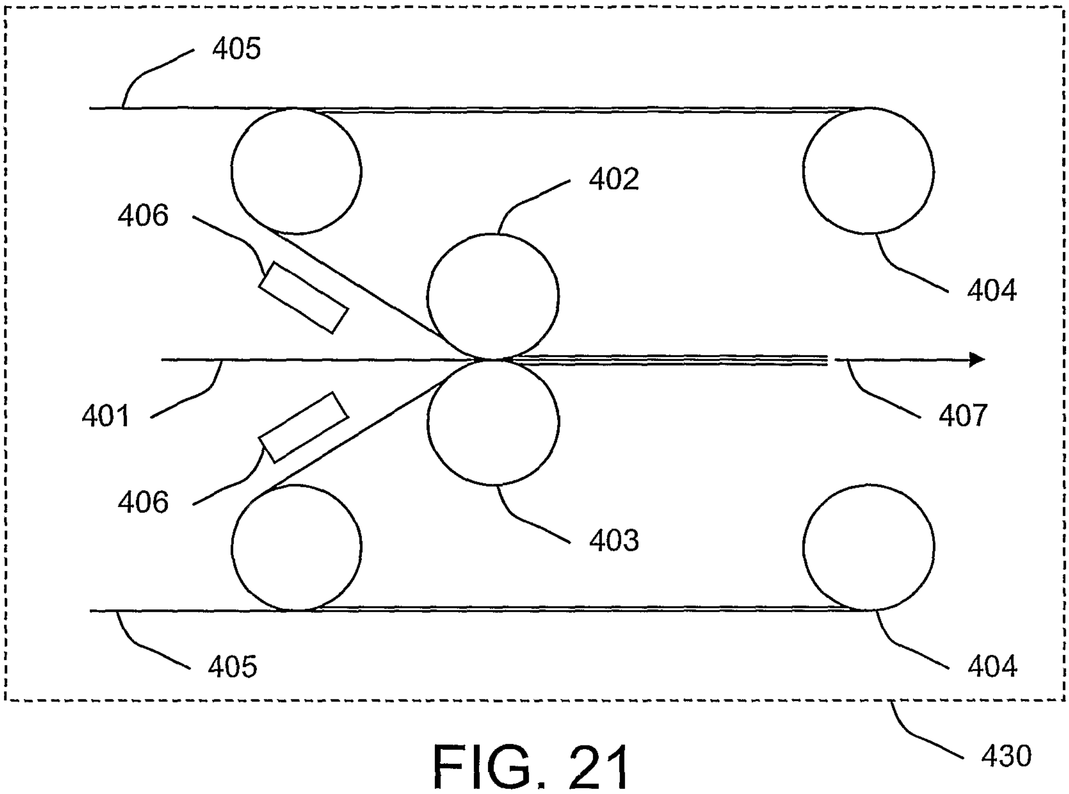


FIG. 21

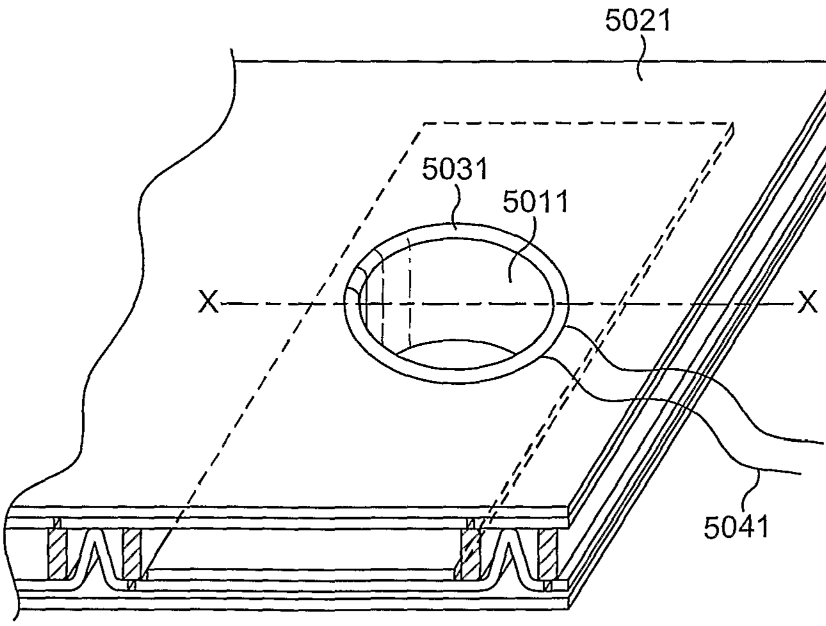


FIG. 22(a)

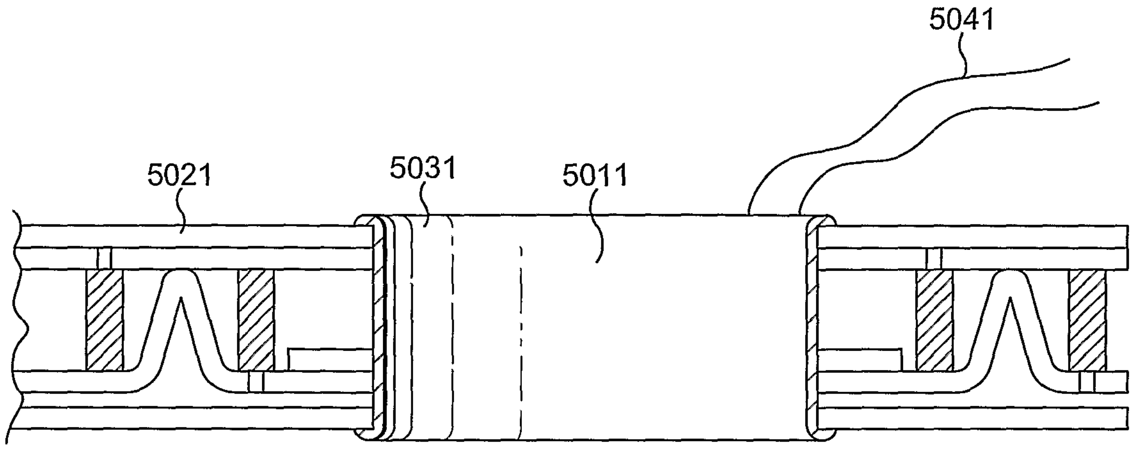


FIG. 22(b)

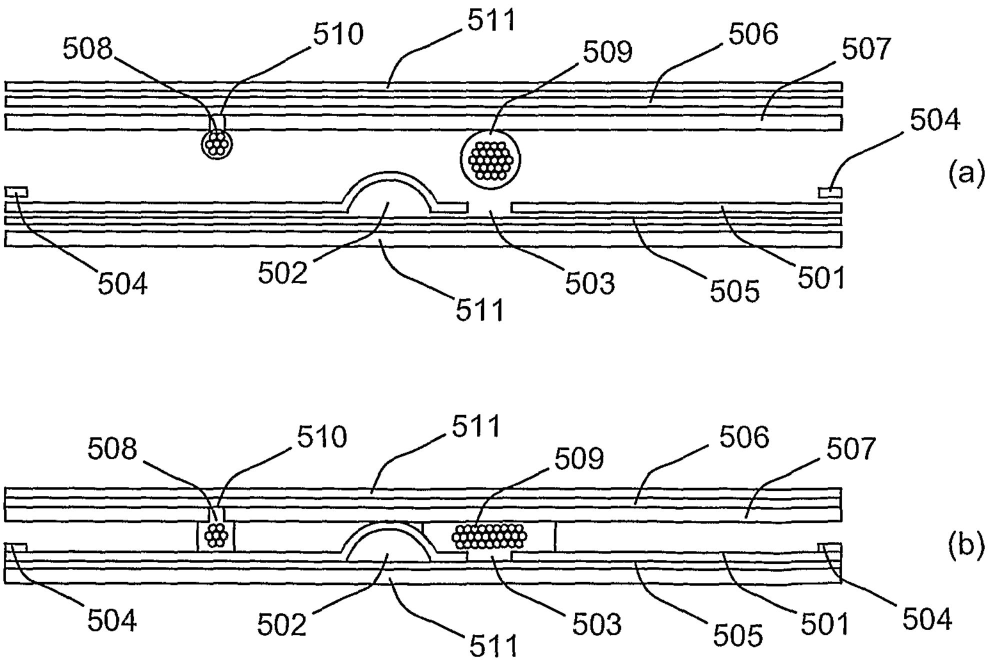
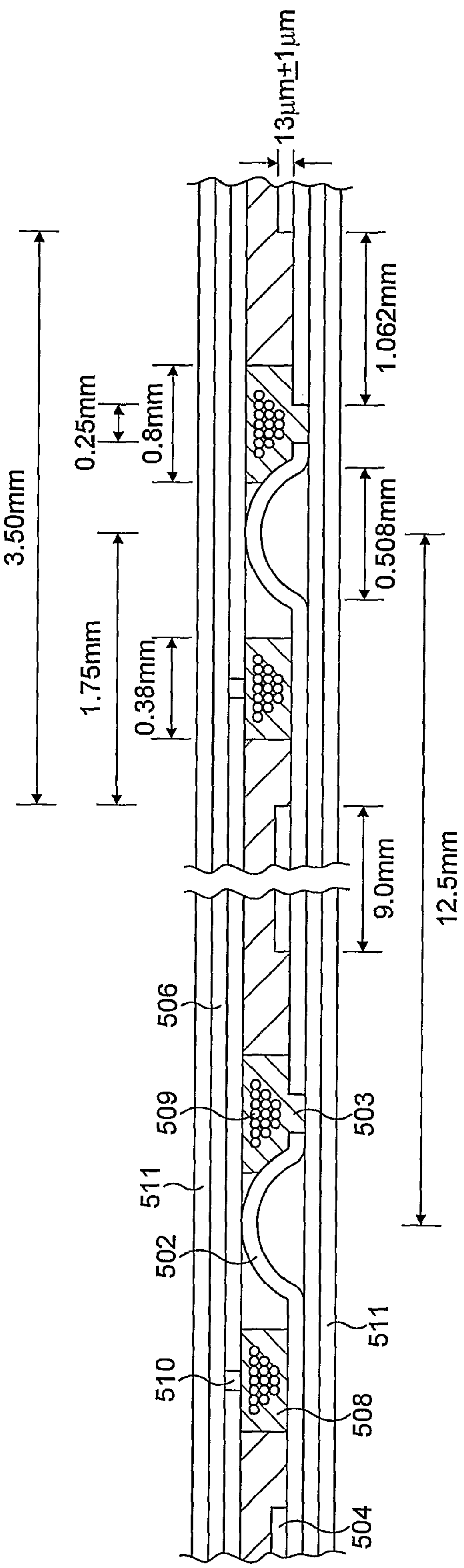


FIG. 23


13µm±1µm
1.062mm
0.25mm
0.8mm
3.50mm
0.508mm
1.75mm
0.38mm
9.0mm
12.5mm
506
509
503
511
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511
510
508
504

FIG. 24

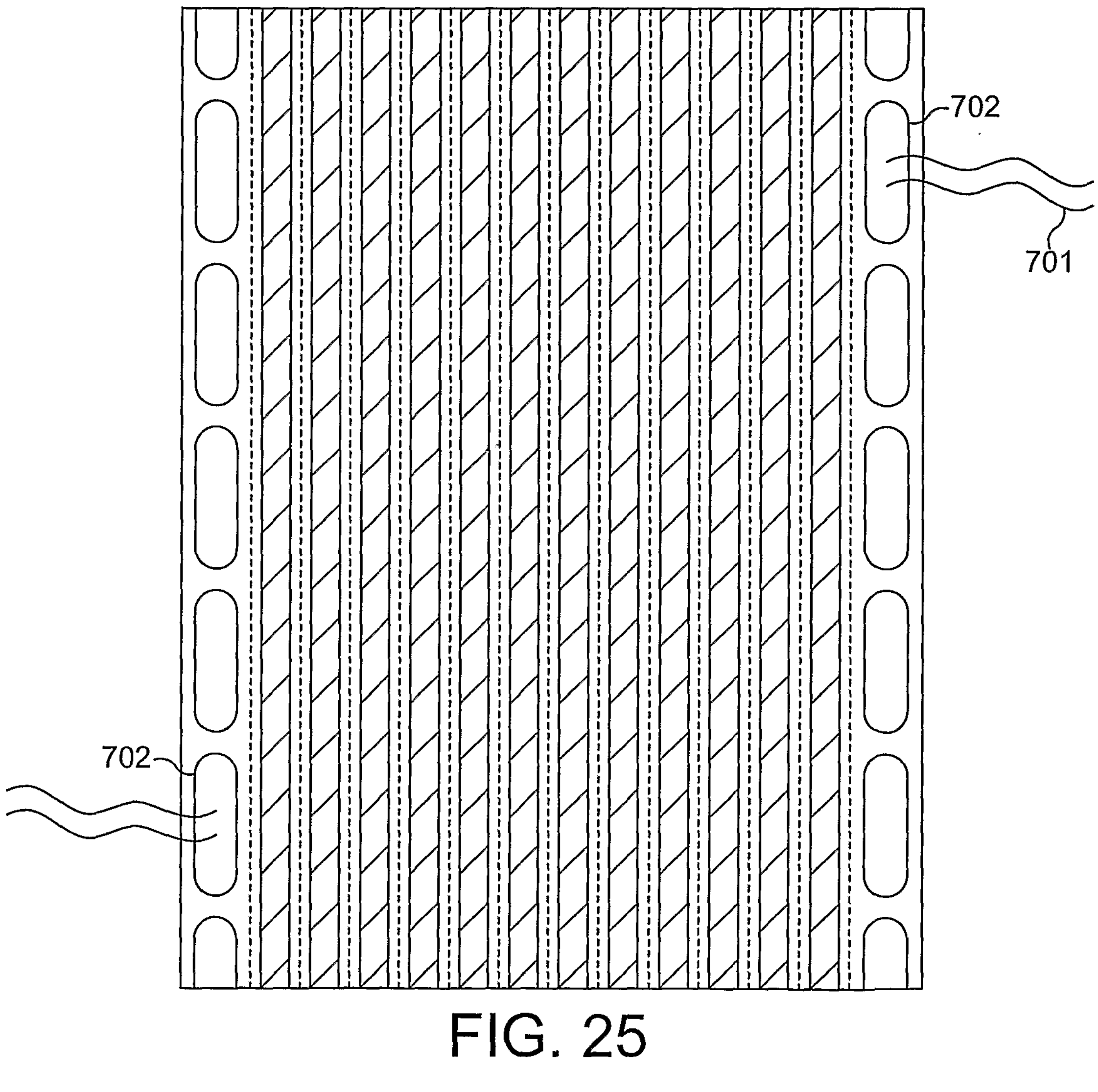

FIG. 25

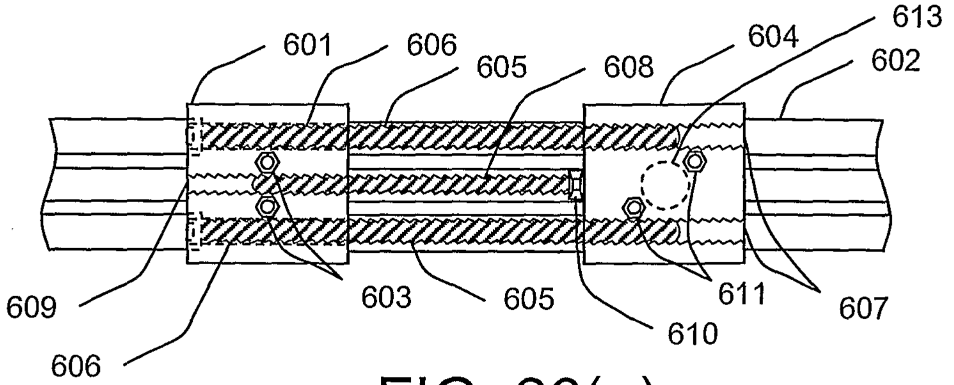

FIG. 26(a)

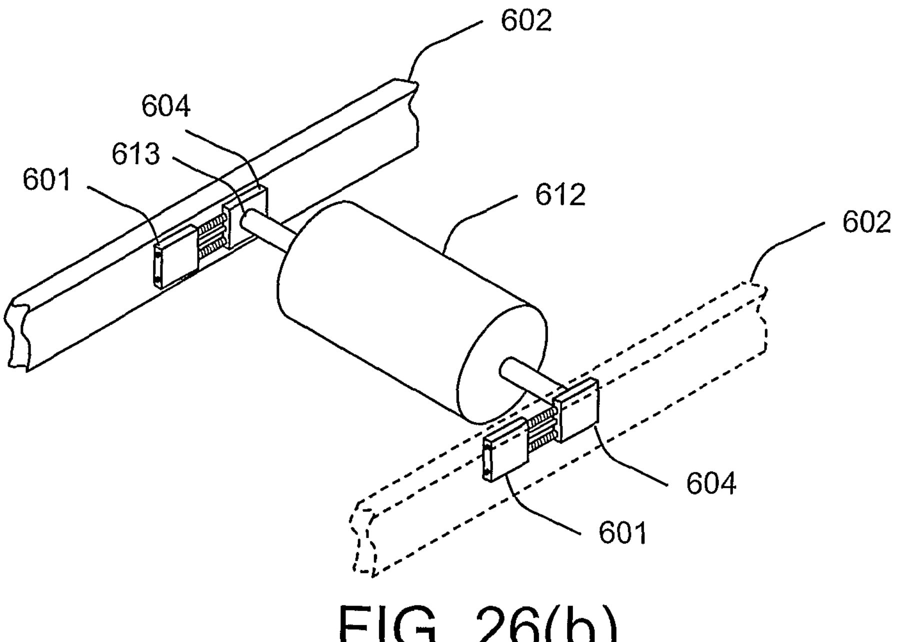

FIG. 26(b)

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/000370

A. CLASSIFICATION OF SUBJECT MATTER
INV. B65H26/00

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)
B65H

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 practical, 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 A	US 4 387 614 A (EVANS DONALD J) 14 June 1983 (1983-06-14) column 9, line 30 - column 10, line 32; figure 6	1,4,5, 26,27 2,3,6-25
X A	US 4 380 943 A (EVANS DONALD J) 26 April 1983 (1983-04-26) column 9, line 6 - column 10, line 8; figures	1,4,5, 26,27 2,3,6-25
X A	GB 2 397 793 A (MARQUIP LLC [US]) 4 August 2004 (2004-08-04) page 8, line 25 - page 11, line 8	1,4,5, 26,27 2,3,6-25
A	EP 0 893 382 A (HEIDELBERGER DRUCKMASCH AG [DE]) 27 January 1999 (1999-01-27)	
A	US 3 477 657 A (NORBISRATH MAX) 11 November 1969 (1969-11-11)	

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

☒ See patent family annex.

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"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

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"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
19 May 2008	27/05/2008

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, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Haaken, Willy

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2008/000370

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 4387614	A	14-06-1983	NONE			
US 4380943	A	26-04-1983	DE	3217703	A1	23-12-1982
			FR	2506207	A1	26-11-1982
			GB	2098752	A	24-11-1982
			JP	1330868	C	14-08-1986
			JP	57194899	A	30-11-1982
			JP	60052920	B	21-11-1985
GB 2397793	A	04-08-2004	DE	102004002210	A1	19-08-2004
			FR	2851950	A1	10-09-2004
			US	2004149378	A1	05-08-2004
EP 0893382	A	27-01-1999	DE	19825467	A1	28-01-1999
			DE	59807520	D1	24-04-2003
			FR	2766472	A1	29-01-1999
			JP	11077977	A	23-03-1999
			US	6065401	A	23-05-2000
US 3477657	A	11-11-1969	DE	1574428	B1	16-06-1971